Daily Body Mass Variability and Stability in Active Men Undergoing Exercise-Heat Stress

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The purpose of this study was to quantify the variability and stability of 1st morning body mass (BM) fluctuations during daily exercise in the heat while following traditional fluid intake guidance. Data from 65 men were examined retrospectively. BM fluctuations were monitored over 4 to 15 consecutive days. Group daily variation in BM was 0.51 ± 0.20 kg. Group coefficient of variation was 0.66 ± 0.24%, normally distributed, and not related to either absolute BM ($r = 0.04$) or number of measurements ($r = 0.34$). Three days resulted in a similar variability estimate compared to 6 or 9 d, although precision was improved with 9 d. In conclusion, 3 consecutive BM measurements provide an accurate assessment of daily BM variability, which is less than 1% for active men when replacing 100% of sweat losses during exercise. The data also suggest that daily BM is a sufficiently stable physiological parameter for potential daily fluid balance monitoring.

Key Words: hydration assessment, hypohydration, dehydration, fluid balance, body weight

Body mass (BM) is an often used, simple, and inexpensive measurement for the rapid assessment of athlete hydration changes in both laboratory and field environments. Changes in hydration are calculated as the difference between pre- and post-exercise body mass expressed as a percentage of pre-exercise body mass (i.e., $[\Delta BM/BM_{pre}] \times 100$). Though popular, the accuracy and reliability of this method remains controversial for assessing anything beyond acute changes in fluid balance. Part of this controversy surrounds the unknown magnitude of expected variability in baseline body mass (i.e., 1st morning measurement) which, though logically minimal when well hydrated (8), lacks empirical support data.

As with other hydration assessment techniques, body mass is limited by several assumptions. It is implicit that 1 g of lost mass is equivalent to 1 mL of lost fluid (sweat and respiratory water). This is because mass lost through carbon exchange, even during prolonged exercise, produces minimal error (9). Sweat retained in clothing, however, will artificially inflate mass and can significantly underestimate sweat losses, making semi-nude or nude measurements a key meth-
odological requirement (9). Day-to-day caloric balance is also an assumption that limits body mass for long-term hydration assessment (25), because gross changes cannot dissociate between alterations in fluid balance and body composition. The mass of fecal material in the large intestine will vary based on diet and gut motility, but this is a likely diurnal constant. Perhaps most importantly, it is assumed that baseline body mass will vary minimally when well hydrated (8). There is presently no empirical data to support this assumption, however. Instead, other measures of hydration, such as plasma or urine markers (3, 4, 20, 24), are usually required to affirm euhydration at the outset of exercise. Yet even these techniques might not allow detection of small, but important fluctuations in hydration (< 2% body mass) (6, 13, 14). In fact, all popular hydration assessment markers (plasma, urine, saliva, total body water) vary greatly in their sensitivity and circumstantial applicability based on various methodological limitations. More comprehensive reviews of this topic can be found elsewhere (17, 19, 22).

The regulation of daily water balance is estimated at ± 0.22 to 0.48% of daily body mass in moderate and hot environments, respectively (1, 2). Thus, given the constraints described above, small changes in body mass are interpreted to reflect a stable, euhydrated condition. This coincides with Greenleaf’s (15) description of euhydration as a normal fluctuation in daily body water, to which Casa et al., (8) add should not produce variations exceeding 1% of body mass. Although there are many studies examining daily or monthly regulation of body mass, the experimental focus is usually related to diet composition, food availability, menstrual cycle, or body composition influences (5, 7, 25). Grandjean et al. (13, 14), however, recently reported mean fluctuations in body mass of 0.3 to 0.7% over 2 d in free-living, sedentary men while controlling for fluid intake over the same duration, but the range of individual responses was large (-1.52 to +0.90%) (13) even when exertion and environmental exposure were restricted. Over longer measurement periods in free-living subjects, the difference between any 2 body mass measurements over 30 d also exceeds 1% (1.3 to 2.7%) (5, 7), which raises questions concerning the stability of daily body mass.

Acute body mass changes during exercise primarily reflect acute perturbations in fluid balance (9), but acute replacement of these losses (100%) does not result in full rehydration in the short term (hours) (23). Over days, ad libitum food and fluid intake in response to work in a hot environment and modest fluid losses (1.5 to 3% body mass) may (3) or may not (12) result in some degree of chronic hypohydration. If body mass is to be a useful measure for detecting low levels (< 2% body mass) of chronic hypohydration, the explicit study of daily body mass variability over multiple, consecutive days in active people requires characterization, as does the potential impact that exercise-heat stress and associated fluid flux might have on body mass variability.

To reliably quantify hydration changes that could occur with daily physical activity, especially in warm training environments and without the aid of additional hydration assessment measures, the variability and stability of daily baseline body mass fluctuations requires better elucidation. The purpose of this retrospective analysis was to examine the variability and stability of 1st morning body mass fluctuations in active men under conditions similar to free-living athletes training in the heat while adhering to American College of Sports Medicine (ACSM) and National Athletic Trainers’ Association (NATA) fluid replacement guidance (8,
We hypothesized that, so long as proper hydration practices were followed (i.e., match fluid intakes to fluid losses), daily variability in body mass would be minimal (< 1%) and sufficiently stable over days for potential fluid balance monitoring. For the purposes of this study, 1st morning body mass will be abbreviated always as BM.

Methods

Subjects

The subjects were 65 healthy men representing a cross section of U.S. Army personnel with the following characteristics (mean ± standard deviation and range): age 23 ± 6 (18 to 42) y, height 176 ± 6 (165 to 192) cm, weight 77.15 ± 10.80 (55.40 to 107.90) kg. Each subject gave his voluntary and written informed consent to participate, which received approval from the appropriate institutional review board. Investigators adhered to AR 70–25 and U.S. Army Research and Development Command Regulation 70–25 on Use of Volunteers in Research.

Procedures and Calculations

Fluctuations in BM were monitored using 4 to 15 consecutive daily measurements. These data were collected during heat acclimation studies and archived at the U.S. Army Research Institute of Environmental Medicine (USARIEM), Natick, MA between 1983 and 2003. The 4 to 15 d range in monitoring activity was based solely on differences in the heat acclimation outcome measures of interest (i.e., stabilization criteria for heart rate and core temperature responses). Only studies including the procedures outlined below were considered for analysis.

Subjects reported to the laboratory between 07:00 and 08:00 after an overnight fast. BM was measured nude or semi-nude (shorts only) with an electronic precision balance scale accurate to ± 50 g (Toledo ID1 Multirange, United Scale & Engineering Corp., New Berlin, WI) after the 1st morning urine void. If BM was not identical on the 1st 2 measurements, a 3rd was taken and the appropriate mean or mode used as representative of the day. Subjects then performed a standardized exercise regimen consisting of moderate intensity walking (~ 6 metabolic equivalents of oxygen consumption (METS)) in the heat (30 to 49 ºC, 20 to 50% relative humidity) for 2 to 3 h. During exercise, subjects drank ad libitum their choice of water or sports drink. Following exercise, subjects replaced any fluid deficit (generally < 1 L consumed in < 20 min) with the same beverage of choice until recovery to pre-exercise BM was confirmed. Subjects were instructed to eat and drink normally for the rest of the day and specifically encouraged to drink water before bed. Additional daily exercise was prohibited. Thus, these conditions were very similar to those expected for free-living athletes training daily in the heat when following traditional fluid intake guidance (8, 11).

A coefficient of variation (% CV) was calculated for each individual [(standard deviation for mean daily BM, kg/mean daily BM, kg) × 100] as the measure of daily BM variability. A grand mean and pooled standard deviation were then calculated for the group to characterize population data (n = 65). A subset of subjects (n = 44) with at least 9 consecutive daily BM measurements was further studied. Many regulatory agencies use 6 sampling determinations for assessing analytical
measurement precision (16). Thus, we examined the % CV for daily BM using 6 d and compared this to 50% fewer (3 d) or greater (9 d) days for the same subjects to ascertain the practical minimum number of daily measurements required to reliably estimate BM stability.

Statistical Analysis

Descriptive data are presented as mean ± standard deviation. Prior to analysis, data were examined for distribution normality and variance equality. A 1-way analysis of variance for repeated measures was calculated to compare the daily variability in BM (% CV) among the 44 subjects when averaged for 3, 6, and 9 consecutive measurement days. Tukey’s post hoc procedure was used following a significant F-test. Pearson product moment correlations were computed for the relationships between the BM (% CV) and absolute BM or number of daily measurements (DM). All data analyses were performed using GraphPad software (GraphPad Software, Inc., San Diego, CA). Statistical significance was set at $P < 0.05$.

Results

The smallest and largest of BM differences between any 2 DM was 0.10 and 3.0 kg, respectively. Figure 1 presents a scatter plot for individual daily BM variability across a range of BM for the 65 subjects tested. The pooled standard deviation for the group was 0.51 ± 0.20 kg (range = 0.05 to 1.1 kg). The grand mean for % CV was 0.66 ± 0.24% (range = 0.09 to 1.24%), which was normally distributed (Figure 2). BM and DM were also normally distributed (Table 1), however, neither variable was significantly correlated ($P > 0.05$) with the % CV in BM ($r = 0.04$, BM; $r = 0.34$, DM).

Table 1  Frequency Distributions for BM and DM Paradigms*

<table>
<thead>
<tr>
<th>BM (kg)</th>
<th>Subjects (#)</th>
<th>DM (days)</th>
<th>Subjects (#)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50.0 – 55.0</td>
<td>0</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>55.1 – 60.0</td>
<td>2</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>60.1 – 65.0</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>65.1 – 70.0</td>
<td>12</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>70.1 – 75.0</td>
<td>11</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>75.1 – 80.0</td>
<td>13</td>
<td>9</td>
<td>15</td>
</tr>
<tr>
<td>80.1 – 85.0</td>
<td>7</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>85.1 – 90.0</td>
<td>5</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>90.1 – 95.0</td>
<td>5</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>95.1 – 100.0</td>
<td>3</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>100.1 – 105.0</td>
<td>1</td>
<td>14</td>
<td>2</td>
</tr>
<tr>
<td>105.1 – 110.0</td>
<td>1</td>
<td>15</td>
<td>1</td>
</tr>
</tbody>
</table>

*Note.* Distributions (subject #s) for BM and DM are independent. BM, body mass; DM, daily measurements.
Data for a subset of 44 subjects is presented in Figure 3. The % CV was calculated for 3, 6, and 9 consecutive DM on the same subjects. A significant difference in % CV was observed between calculations based on 3 and 9 consecutive DM, but the absolute difference was only 0.1% (Figure 3). Nine DM also reduced the standard deviation for the mean % CV estimate by 40% ($P < 0.05$).
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**Discussion**

This study is the 1st to perform a detailed analysis of the daily variability and stability in BM over multiple days in a large number of subjects. The principal findings of this study were that: 1) daily BM variability in active men undergoing exercise-heat stress fluctuates by less than 1% when adhering to ACSM and NATA fluid replacement guidance (8, 11), and 2) the stability of daily BM allows for accurate BM variability assessment using 3 consecutive days of measurements, although the estimate is slightly improved using 9 d.

Daily variability in BM, defined as the % CV calculated for individuals over 4 to 15 d of consecutive measurements, was 0.66 ± 0.24%. Because this measure of variability was normally distributed (Figure 2) for a large sample of subjects under controlled, but simulated real world conditions, knowledge of the variability in this group makes it possible to calculate the amount by which the mean % CV would have to increase to estimate BM variability for a true population of similar subjects in similar circumstances. It can therefore be calculated, adding +2 standard deviation of the mean, that 98% of like individuals would experience a daily fluctuation in BM of 1.1% or less under similar circumstances. Although BM and DM data were also normally distributed, their poor correlations with % CV suggest they had little influence on the distribution of this calculation, thus supporting the application of these findings.

Small differences among daily BM variability measurements using 3, 6, or 9 consecutive days illustrate the stability of daily BM. The difference (0.1%) in

![Figure 3 — Comparison of daily variability in BM (% CV) calculated using 3, 6, and 9 DM of BM for the same subjects (n = 44). * P < 0.05 for 3 vs. 9 d (mean % CV). # P < 0.05 for 3 vs. 9 d (standard deviation of % CV).](image)
variability between calculations based on 3 or 9 d, though statistically significant, was well below the measurement error for the entire group (0.66%). The precision of the estimate (standard deviation of mean % CV) was, however, improved when using 9 d of measurements (Figure 3). The largest individual difference between any 2 measurements taken over multiple days varied greatly from 0.10 to 3.0 kg. This might be explained by parallel adjustments in ad libitum food intakes (25) and as a range encompasses values reported by others using similar methods (5, 7). Taken together, these observations support the use of at least 3 consecutive measurement days when assessing BM variability and stability.

This retrospective data analysis was limited by the absence of a corroborating hydration marker. Grandjean et al. (13, 14), however, reported very similar mean fluctuations in BM (~ 0.50 kg, 0.3 to 0.7% BM) over 2 d in sedentary men with no changes in plasma and urine markers of hydration. Under similar circumstances, small (< 1%) fluctuations in mean weekly BM are also associated with a stable body composition for as many as 30 d (5, 7). According to Adolph (1, 2), fluctuations in daily water balance, assessed using intake–output and metabolic exchange calculations, account for 0.22 to 0.48% of total euhydrated BM. It is therefore likely that the daily BM variability in this study (0.66%) includes primarily small alterations in fluid balance, with remaining variability owing to food intake and bowel habits.

It is possible that the heat acclimation regimen employed during the collection of these data could have also contributed to daily BM variability; however, research examining the effects of heat acclimation on total body water (TBW) is equivocal (21). Studies that do report changes calculate a 2 to 3 L (2 to 3 kg) increase in TBW that usually peaks by day 4 to 6 (21), but such large differences between any 2 measurement days occurred in only 1 of 65 subjects in this study. Because this outcome of heat acclimation would only increase the observed variability, it is possible that subjects were partially heat acclimated at the outset of testing, which would explain an absence of overt BM fluctuations that might otherwise occur with heat acclimation. It is therefore unlikely that heat acclimation had any measurable effect on BM variability in this study.

One practical application of this information is in establishing an acceptable limit for normal variability in daily BM, which has implications for hydration testing. Although there is no way of knowing if the baseline BM measurements recorded in this study reflected a true state of euhydration, other corroborating hydration markers (plasma/urine osmolality, urine specific gravity) would probably have been of little additional value unless chronic dehydration was in excess of 1% BM (6, 13, 14). Consolazio et al. (10) reported that hydration markers such as plasma osmolality, measured at the same time of day in 99 men consuming a regular diet for 14 d, had larger day-to-day baseline variability (% CV = 1.8 to 4.8) than the daily BM observed in this study. Similarly, a large range of acceptable “euhydrated” 24-h urine osmolalities have been reported cross culturally for epidemiological purposes (18). The results of this study therefore support the usefulness of daily BM measurements for detecting small (≥ 1%) fluctuations in hydration, especially when such changes might escape detection by other accepted techniques (6, 13, 14). In practice, changes in 1st morning BM in excess of 1% could be easily identified using a simple decimal displacement rule of thumb (i.e., 1% of 75 kg is 0.75 kg or 150 kg is 1.50 kg). Because there is a potential for larger
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body mass fluctuations (3 to 4%) (7) in women owing to menstrual cycle phase (7, 19) and other factors, the findings reported herein for men might not apply for women if the daily measurements extend between menstrual cycle phases. The results might not be representative of other specific populations (e.g., children or the elderly) as well.

In summary, our findings indicate that 3 consecutive measurements of BM provide an accurate assessment of daily variability in BM, which is less than 1% for active men in the heat when adhering to ACSM and NATA fluid replacement guidance. This study provides evidence that daily BM is a sufficiently stable physiological parameter for potential daily fluid balance monitoring (8). Limitations to these findings include application to long-term hydration assessment, which cannot account for alterations in body composition, and possibly short-term ovarian hormone or heat acclimation influences on fluid balance.

Acknowledgments

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References


