Hypohydration Does Not Alter Standing Balance


We examined the effect of body water deficits on standing balance and sought to determine if plasma hyperosmolality ($P_{\text{osm}}$) and/or volume reduction ($\% \Delta V_{\text{plasma}}$) exerted independent effects. Nine healthy volunteers completed three experimental trials which consisted of a euhydration (EUH) balance test, a water deficit session and a hypohydration (HYP) balance test. Hypohydration was achieved both by exercise-heat stress to 3% and 5% body mass loss (BML), and by a diuretic to 3% BML. Standing balance was assessed during quiet standing on a force platform with eyes open and closed. With eyes closed, hypohydration significantly decreased medial-lateral sway path and velocity by 13% (both $p < .040$). However, 95% confidence intervals for the mean difference between EUH and HYP were all within the coefficient of variation of EUH measures, indicating limited practical importance. Neither $V_{\text{plasma}}$ loss nor $P_{\text{osm}}$ increases were associated with changes in balance. We concluded that standing balance was not altered by hypohydration.

**Keywords:** dehydration; center of pressure; sway path; sway velocity; plasma volume; plasma osmolality.

Body water deficits (hypohydration) have been associated with loss of balance and occupational (Szinnai, Schachinger, Arnaud, Linder, & Keller, 2005; Wasterlund, Chaseling, & Burstrom, 2004) and military (Institute of Medicine, 2005; Kenefick & Sawka, 2007) accidents. The possible contribution of hypohydration to accidents could result from orthostatic intolerance or altered postural stability and balance control. Hypohydration degrades orthostatic tolerance (Adolph & Dill, 1938; Beetham & Buskirk, 1958; Carter, Cheuvront, Vernieuw, & Sawka, 2006) and is likely mediated through reduced blood volume (hypovolemia) altering baroreceptor responsiveness (Charkoudian, Eisenach, Joyner, Roberts, & Wick, 2005) and perhaps increased cerebral vascular resistance reducing brain blood flow (Carter et al., 2006).

The impact of hypohydration on postural stability is inconclusive. Derave et al. (1998) and Gauchard et al. (2002) both reported degraded standing balance following exercise-induced (sweat) hypohydration, defined by increased Center of
Pressure (COP) sway measures during quiet standing. Derave et al. (1998) measured standing balance before and 20 min after completing prolonged intense exercise (2h at ~60% VO\textsubscript{2max} in temperate conditions) in which subjects either did not consume fluids or consumed a carbohydrate-electrolyte beverage sufficient to replace sweat losses. Hypohydration (2.7% body mass loss, BML) was found to degrade postural stability. However, no difference in standing balance was found after sauna (85 °C) induced hypohydration (3% BML) followed by a cold shower and brief (30 min) rest. Gauchard et al. (2002) measured standing balance before and immediately after intense exercise (45 min at ~60% VO\textsubscript{2max} in temperate conditions) in which fluid was either replaced or not replaced. Balance was impaired in the fluid restriction trial, but the magnitude of hypohydration (not reported) was likely less than 2% BML given the reduced exercise duration as compared with Derave et al. (1998). It has been shown that prior physical exercise itself likely degrades standing balance for at least 15 min after exercise (Nardone, Tarantola, Giordano, & Schieppati, 1997). Since both studies included intense exercise bouts with little to no recovery time when hypohydrated, exercise effects may have contributed to degraded postural stability in addition to, or instead of hypohydration. Therefore, a need exists for a study that measures standing balance in euhydrated and hypohydrated subjects with adequate controls for prior exercise effects. In addition, no study has simultaneously tested both moderate (3% BML) and marked (5%BML) hypohydration.

In hypertonic hypovolemia induced by exercise-heat stress and water deprivation, which is common in occupational, sports and military settings (Lieberman et al., 2005; Manning & Wilson, 2007; Sawka et al., 2007), the loss of water is relatively larger than the loss of electrolytes. Blood becomes hypertonic but plasma volume ($V_{\text{plasma}}$) is reduced marginally. Alternatively, in isotonic hypovolemia, stressors such as cold (Greenleaf, 1992), high-altitude exposure (Institute of Medicine, 1996) and diarrhea (Brown et al., 2009; Hayajneh, Jdaitawi, Al Shurman, & Hayajneh, 2010) induce proportionate losses of water and electrolytes, and can be reproduced using a diuretic (O’Brien, Young, & Sawka, 1998). Blood tonicity does not change appreciably, but $V_{\text{plasma}}$ losses are twice as large for any given total body water deficit (Cheuvront, Kenefick, Montain, & Sawka, 2010). If hypohydration indeed impairs standing balance, the use of both hypertonic and isotonic hypohydration models may help elucidate the mechanism(s) involved (i.e., tonicity versus volume). Indeed, both hypovolemia and hyperosmolality have been shown to have independent effects on thermoregulation (Sawka et al., 1989; Sawka, Young, Francesconi, Muza, & Pandolf, 1985), thus both may provide different neurogenic feedback to balance centers.

The purpose of this study was to determine the effects of hypohydration (both hypertonic and isotonic) on standing balance. We examined the effect of hypohydration of magnitude sufficient to produce a variety of negative functional outcomes (Sawka et al., 2007). Due to the reporting of balance decrements attributed to hypohydration (Derave et al., 1998; Gauchard et al., 2002), we hypothesized that the magnitude of hypohydration would be related to COP measures (path excursion and velocity), where postural sway would increase with hypohydration, indicating decreased performance in standing balance. To reinforce these findings in the physiological realm, we also examined the relationships between balance parameters and changes in plasma osmolality ($P_{\text{osm}}$) and $V_{\text{plasma}}$. We hypothesized that increases in $P_{\text{osm}}$ and decreases in $V_{\text{plasma}}$ would correspond to increases in
COP, which would indicate a relationship between these physiological measures and balance performance.

**Methods**

**Participants**

Nine healthy, active volunteers completed this study (6M, 3F; mean ± SD: age, 22 ± 3 yr; body mass, 76.3 ± 13.6 kg; height, 174 ± 10 cm; body mass index, 25.3 ± 3.9). Appropriate institutional review boards approved this study. Before participation each volunteer attended briefings informing them of the purpose of the experiment and possible risks and completed a written informed consent document. Investigators adhered to policies for protection of human subjects as prescribed in Army Regulations 70–25 and US Army Medical Research and Materiel Command Regulation 70–25. The research was conducted in adherence with the provisions of 45 Code of Federal Regulations Part 46.

**Experimental Design**

**Study Overview.** During a preliminary week volunteers were familiarized with balance testing procedures and baseline measurements were established. Two baseline practice trials were completed to control for learning effects. The experimental trials were conducted over three consecutive weeks. During each week, volunteers were hypohydrated (HYP) to one of three specified levels: exercise-heat stress to 3% and 5% BML and by a diuretic to 3% BML. The order of HYP trials was not counter balanced. Instead, baseline balance measures were taken on the first morning while euhydrated (EUH) and 24 hr later once volunteers were dehydrated, thus affording ample recovery and minimizing any of the residual effects of exercise-heat stress suspected to impact balance testing (Cheuvront, Kenefick, et al., 2010).

During each week of testing, on the day before baseline measures, volunteers were given 3 L of fluid to consume over 24-hr in addition to ad libitum beverage consumption and habitual dietary practices to ensure a euhydrated state. On the afternoons after EUH baseline testing, volunteers underwent one of three hypohydration protocols to achieve the desired HYP state. The magnitude of hypohydration selected spanned a functionally important range of 2–5% BML (Greenleaf, 1992; Institute of Medicine, 2005; Sawka et al., 2007), which is a typical hypohydration range reported in military operations (Lieberman et al., 2005), sporting events (Byrne, Lee, Chew, Lim, & Tan, 2006), and previous research on hypohydration and standing balance (Derave et al., 1998; Gauchard et al., 2002). This magnitude of water deficit is associated with functional outcomes of degraded aerobic exercise performance and orthostatic intolerance (Institute of Medicine, 2005; Sawka et al., 2007).

After all hypohydration procedures, volunteers were provided with a small, standardized meal (450 kcal; 57% carbohydrate, 30% fat, 13% protein, 450 mg Na+) and 200 ml of water or apple juice. No additional food or water was permitted. Volunteers stayed in supervised housing where lights out was no later than 2300 hr. At 0630 hr the next morning, while in a HYP state, physiological and balance
measures were repeated. The decision to adopt this particular study design, which we have used previously (Cheuvront, Ely, Kenefick, & Sawka, 2010), was based on the primary aim of improving recovery from the potential residual effects of prolonged exercise-heat exposure on standing balance. Each HYP trial was separated by four to six days to provide adequate recovery from hypohydration itself.

**Hypohydration Protocol.** The hypohydration protocols during weeks one and two involved exercise-heat stress to induce hypertonic hypohydration corresponding with approximately 3% and 5% BML, and the week 3 hypohydration procedure involved diuretic administration to induce isotonic hypohydration to approximately 3% BML. During the exercise-heat exposure, volunteers performed work/rest cycles (50 min work, 10 min rest) of treadmill (1.56 m/s, 4–7% grade) and/or cycle ergometer exercise (100–120 W) inside an environmental chamber set to 40 °C, 20% relative humidity with 1 m•sec⁻¹ laminar wind flow for up to 5 hr (target sweat loss of 5% BML) and up to 3 hr (target sweat loss of 3% BML). The purpose of exercise-heat stress was to provide sufficient sweating to reach water deficit goals. Two modes of exercise were offered to reduce the risk of overuse injuries (blisters, sore muscles) and ample recovery time was given (>12 hr). For the diuretic exposure, volunteers were given 40 mg of Furosemide under directions of a physician to stimulate increased urinary losses while resting in a temperate environment. Six hours after administration, volunteers were weighed and those who had lost less than 2% BML were given an additional 20–40 mg of Furosemide, with the goal of inducing a total BML of 3% by the following morning (3% Diuretic).

**Blood Measures.** EUH and HYP baseline and balance testing began at 0630 each morning after an overnight fast. Nude body mass (Metler Toledo IDI, Toledo, OH) was obtained, then volunteers remained seated for 20 min before having a blood sample drawn. Blood was analyzed for hemoglobin and hematocrit, then separated and analyzed for plasma osmolality ($P_{\text{osm}}$) by freezing-point depression (Fiske Micro-Osmometer, Norwood MA). Hemoglobin and hematocrit values were used to calculate percent change in plasma volume ($V_{\text{plasma}}$) during hypohydration (Dill & Costill, 1974) by comparing the EUH baseline and the following day’s HYP blood samples within each week of testing. Balance measures were made following both the EUH and HYP blood measures.

**Balance Testing.** Balance sway parameters were measured while standing on a Force Platform (type OR6–7, AMTI, Watertown, MA, USA). During testing before and after all hydration manipulations, volunteers were instructed to stand as still as possible for 30 s in the following conditions: two feet with eyes open and two feet with eyes closed. Shoes and socks were removed, and foot position was standardized (Gauchard et al., 2002) so that the medial aspect of the heel and the second toe were centered on two lines that were taped onto the force platform. During the eyes open condition, volunteers were instructed to focus on a target 2 m away at eye level. Conditions were identical during all practice, EUH, and HYP conditions. Volunteers were given breaks between eyes open and eyes closed conditions. COP data were collected from the fifth to the twenty-fifth second of a thirty second measuring period (Derave et al., 1998). If a volunteer took a step or opened their eyes before the measuring period had transpired, they were asked to briefly step off of the platform, and another trial was collected.
One complete trial was collected in each balance condition and used in analysis. Data were collected and processed using custom LabView software (version 6i, National Instruments Corporation, Austin, TX, USA). Data processing included calculations of COP total path length (cm) and velocity (cm/s), as well as anterior-posterior and medial-lateral components (Gauchard et al., 2002).

**Statistical Analysis**

Two-way repeated-measures ANOVA were conducted to compare among hypohydration methods (3% BML Diuretic, 3% BML Sweat, 5% BML Sweat) and hydration status (EUH vs. HYP) for all variables examined in each balance condition (eyes open and eyes closed). A significant F-value was investigated using Tukey’s HSD post hoc analysis. Sample size was calculated for standing balance measures using a desired effect size > 1.0. Signal variability was estimated from the typical within-subjects coefficient of variation for a specified measurement [(SD/mean)*100] during the first two practice trials, but ultimately determined from 5 measurements (2 training plus 3 EUH trials) for final analytical interpretations. Conventional α = .05 and β = 0.20 values were applied and 8 subjects were determined to provide sufficient power to detect a 12% difference from EUH for both main effects and interactions (Potvin & Schutz, 2000).

To supplement the interpretation of statistical results, the practical importance of hypohydration on standing balance was further examined by using the mean and 95% confidence limits of the true effect for the percentage change in balance performance relative to hydration status, to include comparison against the coefficient of variation (CV), or trivial effect (Batterham & Hopkins, 2006; Cheuvront, Carter, Castellani, & Sawka, 2005). This procedure is similar to conventional significance testing, but provides additional insight into the magnitude and uncertainty of the true population effect (Hopkins, Marshall, Batterham, & Hanin, 2009; Nakagawa & Cuthill, 2007; Reichardt & Gollob, 1997). It is also similar to equivalence testing as it allows an evaluation of performance against an evidentiary standard other than zero (Batterham & Hopkins, 2006; Ebbutt & Frith, 1998). Briefly, when the 95% confidence interval for the percentage change does not cross zero, this is a corollary for \( p < .05 \). However, the importance of the effect is independent of \( p < .05 \) and considered meaningful only when the mean and majority of the 95% confidence interval fall outside the CV. In addition, associations between \( P_{\text{osm}} \) or \( V_{\text{plasma}} \) changes and balance performance outcomes during HYP were examined using Pearson’s Correlation Test (GraphPad Prism 5). All data are presented as mean ± SD except where indicated.

**Results**

The coefficient of variation for sway path and sway velocity for the two feet, eyes open condition were 2.16 cm (14.6%) and 0.055 cm/sec (12.8%), respectively. There was no significant difference among EUH trials (\( p = .604 \)), suggesting no concerns over an order effect, and confirming findings from the literature that minimal practice is required to achieve the desired learning effect in similar balance tests (Thyssen, Brynskov, Jansen, & Münster-Swendsen, 1982). Table 1 summarizes descriptive trial data, including BML, \( P_{\text{osm}} \), change in \( P_{\text{osm}} \) from EUH to HYP, and percent change
in plasma volume. Due to individual sweat rates, body masses, and tolerance, a range of BML were achieved in each condition with a mean at the desired level. As expected, Posm increased most in the 5% sweat trial (+16 mmol/kg), and Vplasma decreased most with the 3% diuretic administration (~16% Vplasma loss). However, Posm increased and Vplasma decreased by modest to large amounts in all three trials, providing a range of Posm increases and Vplasma decreases for correlation analysis with balance measures.

Postural sway variables were organized by hypohydration method and status for the eyes open and eyes closed balance conditions in Table 2. Neither hypohydration method nor status affected COP sway path or velocity (Table 2). There were also no significant interactions between hypohydration method and hydration status for the eyes closed balance condition. There was a significant main effect of the hydration status on medial-lateral sway path (p = .039) and sway velocity (p = .040), indicating COP excursion and velocity decreased when hypohydrated, regardless of method (Table 2). There was no significant change in COP values due to hypohydration method during the eyes open condition.

Because we observed significant differences during the eyes closed balance condition, we assessed the practical changes within this condition. Figure 1 represents the change in sway path and sway velocity measured between EUH and HYP for all three methods, and averaged across all methods during the eyes closed balance condition. Changes due to hypohydration method were not different, nor were they different when averaged across methods (‘ALL HYP’). In Figure 1, panels C and D demonstrate that although there was a statistically significant main effect for hydration status in the medial-lateral component of sway path and velocity (Table 2) these changes were not of practical importance, as it can be observed that none of the mean values fall outside the zone of indifference (Batterham & Hopkins, 2006; Cheuvront et al., 2005), which is indicated by the gray band.

Posm values during HYP were examined relative to changes in medial-lateral sway path parameters during the eyes closed condition (Figure 2). No relationship was found for either medial-lateral sway path or velocity (r = .28 for both; Figure 2, top panels). Similarly, % Vplasma change was correlated to change in medial-lateral sway path and velocity (r = .16 for both; Figure 2, bottom panels), and no relationships were apparent in either case. The slope of each best-fit line was not significantly different from zero in any case, and remained within the CV of each parameter through a range of mild to severe changes in Posm (-4 to +32 mmol/kg) and decreases in Vplasma (0–23% Vplasma loss).

Table 1: Summary of Mass Loss, Plasma Volume (PV) Change, and Plasma Osmolality (Δ O\text{plasma}) in HYP Trials.

<table>
<thead>
<tr>
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<th>5% Sweat</th>
<th>3% Sweat</th>
<th>3% Diuretic</th>
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<tr>
<td>Mass loss (%)</td>
<td>5.0 ± 1.4</td>
<td>3.1 ± 0.8</td>
<td>3.1 ± 0.7</td>
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<tr>
<td>Δ V\text{plasma} (%)</td>
<td>13.5 ± 4.6</td>
<td>7.6 ± 2.4</td>
<td>15.6 ± 4.6</td>
</tr>
<tr>
<td>EUH O\text{plasma} (mmol/kg)</td>
<td>292 ± 5</td>
<td>290 ± 3</td>
<td>291 ± 4</td>
</tr>
<tr>
<td>HYP O\text{plasma} (mmol/kg)</td>
<td>307 ± 5</td>
<td>300 ± 4</td>
<td>293 ± 3</td>
</tr>
<tr>
<td>Δ O\text{plasma} (mmol/kg)</td>
<td>16 ± 10</td>
<td>10 ± 5</td>
<td>2 ± 4</td>
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</table>
Table 2  Mean ± SD for COP Sway Path and Sway Velocity for Hypohydration Trial During Eyes Open and Eyes Closed Balance Conditions. M-L, Medial-Lateral Component; A-P, Anterior-Posterior Component. * main effect for hydration status (p < 0.05).

<table>
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<tr>
<th></th>
<th>5% Sweat</th>
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<th>3% Diuretic</th>
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<tr>
<td></td>
<td>EUH</td>
<td>HYP</td>
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<td>Eyes Open</td>
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<tr>
<td>Sway Path (cm)</td>
<td>14.42 ± 4.34</td>
<td>15.98 ± 3.62</td>
<td>14.67 ± 4.10</td>
<td>15.37 ± 4.70</td>
<td>16.02 ± 5.07</td>
<td>15.58 ± 3.41</td>
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<td>M-L (cm)</td>
<td>11.72 ± 3.92</td>
<td>12.69 ± 3.12</td>
<td>11.88 ± 3.85</td>
<td>12.07 ± 3.74</td>
<td>12.89 ± 4.27</td>
<td>12.46 ± 3.54</td>
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<td>A-P (cm)</td>
<td>6.14 ± 1.75</td>
<td>7.13 ± 1.62</td>
<td>6.29 ± 1.61</td>
<td>7.16 ± 2.94</td>
<td>6.97 ± 2.58</td>
<td>6.79 ± 1.52</td>
</tr>
<tr>
<td>Sway Velocity</td>
<td>0.44 ± 0.14</td>
<td>0.49 ± 0.11</td>
<td>0.45 ± 0.13</td>
<td>0.47 ± 0.15</td>
<td>0.49 ± 0.16</td>
<td>0.48 ± 0.11</td>
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<tr>
<td>(cm/s)</td>
<td>0.39 ± 0.13</td>
<td>0.42 ± 0.10</td>
<td>0.40 ± 0.13</td>
<td>0.40 ± 0.12</td>
<td>0.43 ± 0.14</td>
<td>0.42 ± 0.12</td>
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<tr>
<td>M-L (cm/s)</td>
<td>0.20 ± 0.06</td>
<td>0.24 ± 0.05</td>
<td>0.21 ± 0.05</td>
<td>0.24 ± 0.10</td>
<td>0.23 ± 0.09</td>
<td>0.23 ± 0.05</td>
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<td>A-P (cm/s)</td>
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<td>Eyes Closed</td>
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<tr>
<td>Sway Path (cm)</td>
<td>19.95 ± 8.99</td>
<td>19.34 ± 6.06</td>
<td>19.71 ± 8.21</td>
<td>17.51 ± 6.75</td>
<td>20.15 ± 9.72</td>
<td>16.45 ± 6.24</td>
</tr>
<tr>
<td>M-L (cm)</td>
<td>17.65 ± 8.49</td>
<td>16.59 ± 5.95</td>
<td>17.52 ± 7.93</td>
<td>15.02 ± 6.40</td>
<td>17.61 ± 9.49</td>
<td>14.22 ± 6.37</td>
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<tr>
<td>A-P (cm)</td>
<td>6.34 ± 2.53</td>
<td>7.06 ± 1.86</td>
<td>6.07 ± 2.09</td>
<td>6.29 ± 1.94</td>
<td>6.70 ± 1.94</td>
<td>5.75 ± 1.62</td>
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<tr>
<td>Sway Velocity</td>
<td>0.63 ± 0.29</td>
<td>0.60 ± 0.20</td>
<td>0.62 ± 0.26</td>
<td>0.55 ± 0.22</td>
<td>0.63 ± 0.31</td>
<td>0.52 ± 0.21</td>
</tr>
<tr>
<td>(cm/s)</td>
<td>0.59 ± 0.28</td>
<td>0.55 ± 0.20</td>
<td>0.58 ± 0.26</td>
<td>0.50 ± 0.21</td>
<td>0.59 ± 0.32</td>
<td>0.47 ± 0.21</td>
</tr>
<tr>
<td>M-L (cm/s)</td>
<td>0.21 ± 0.08</td>
<td>0.24 ± 0.06</td>
<td>0.20 ± 0.07</td>
<td>0.21 ± 0.06</td>
<td>0.22 ± 0.06</td>
<td>0.19 ± 0.05</td>
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<tr>
<td>A-P (cm/s)</td>
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The purpose of this study was to determine the effects of hypohydration (both hypertonic and isotonic hypohydration) on standing balance. Our primary hypothesis was supported statistically, with a main effect for hypohydration status, which manifested as significant decreases in medial-lateral COP sway path length and velocity after hypohydration when collapsed across all hypohydration methods. However, despite statistical significance, the differences were small and considered of no practical consequence for postural sway measures for either balance condition at relevant levels of hypohydration (Byrne et al., 2006; Lieberman et al., 2005). Consistent with this interpretation, the two primary physiological changes

**Discussion**

The purpose of this study was to determine the effects of hypohydration (both hypertonic and isotonic hypohydration) on standing balance. Our primary hypothesis was supported statistically, with a main effect for hypohydration status, which manifested as significant decreases in medial-lateral COP sway path length and velocity after hypohydration when collapsed across all hypohydration methods. However, despite statistical significance, the differences were small and considered of no practical consequence for postural sway measures for either balance condition at relevant levels of hypohydration (Byrne et al., 2006; Lieberman et al., 2005). Consistent with this interpretation, the two primary physiological changes
observed in HYP (increased $P_{\text{osm}}$, decreased $V_{\text{plasma}}$) were examined in an attempt to elucidate a mechanism for potential balance impairment, and no relationships were observed between $P_{\text{osm}}$ or $V_{\text{plasma}}$ change and balance parameters. While the levels of hypohydration studied matched or exceeded levels in the literature (Derave et al., 1998; Gauchard et al., 2002), we were able to control for two key aspects of testing that may have confounded results from similar literature. Specifically, the familiarization sessions before experimental testing ensured volunteers were well-trained on balance testing procedures, thus eliminating any training or learning effects during experimental testing (Thyssen et al., 1982). In addition, the potential for muscular fatigue to confound outcomes was minimized by a recovery period greater than 12-hr following hypohydration procedures, and by standardizing food and fluid intake for all trials.

Changes in standing balance were reported in the current study after hypohydration during the eyes closed balance condition, however our attempts to control for the effects of exercise resulted in a change that was opposite in direction to those reported in similar studies. Specifically, we observed that COP sway path and velocity decreased after hypohydration in the eyes closed condition. A previous study

Figure 2 — Changes in $P_{\text{osm}}$ (top two panels, mmol/kg) and $V_{\text{plasma}}$ (bottom panels, percent change) by sweating and diuretic-induced hypohydration plotted against change in sway path in cm (HYP SP—EUH SP) during the eyes closed balance condition. Gray bands denote CV from practice and EUH testing. The %CV was multiplied by the mean for each baseline measure to allow CV to be displayed in units (cm, cm/sec).

(Gauchard et al., 2002) reported similar findings in the lateral excursion, but not in the total sway path or anterior-posterior excursion. Despite statistically different findings \((p \leq .04)\) for medial-lateral sway path and velocity, total sway path and velocity were not different \((p > .05)\). This difference in medial-lateral sway path and velocity should be considered unimportant since these differences were well within the coefficient of variation (Figure 1), and thus of no practical relevance. In fact, our findings were more consistent with data from Derave’s (1998) sauna condition, which indicates that the longer recovery time between the exercise bout and the HYP balance measurement was truly effective in controlling for the effects of exercise. In this regard, our findings appear to support Derave’s contention that decreased postural stability 20 min after exercise-induced hypohydration by cycle ergometry (Derave et al., 1998; Gauchard et al., 2002) may have resulted from local fatigue in the muscles around the ankle (Lundin, Feuerbach, & Grabiner, 1993), not from hypohydration alone.

The findings of this study have direct implications for understanding the physiological mechanisms by which hypohydration may mediate accidents related to balance and/or posture changes. While no meaningful changes in balance performance were apparent (Figure 1), osmotic stress (increased \(P_{\text{osm}}\)) and volume depletion (decreased \(V_{\text{plasma}}\)) were explored as an a priori means of trying to understand how hypohydration might impact standing balance (Figure 2). Orthostatic intolerance (Cox, Admani, Agarwal, & Abel, 1973; Davis & Fortney, 1997) is a well-established effect of hypohydration, and the observed reduction in cerebral blood flow velocity during an orthostatic challenge (Carter et al., 2006) may be related to \(V_{\text{plasma}}\) depletion. Similarly, while small increases in osmolality (~3 mmol/kg) have a low potential to impact orthostatic intolerance via alterations in baroreflex or muscle sympathetic nerve function (Charkoudian et al., 2005), larger changes in osmolality (~13 mmol/kg) may have deleterious effects (Bealer, 2003). In addition, increased \(P_{\text{osm}}\) could potentially affect vestibular function through altering blood-brain barrier permeability (Rapoport, 2000). However, neither hypertonicity (increased \(P_{\text{osm}}\)) nor hypovolemia (\(V_{\text{plasma}}\) loss) were associated with changes in balance performance across a large and relevant range of body mass losses and blood parameters representative of those experienced in athletic, military or occupational settings.

Neither the type (hypertonic vs. isotonic) nor level (3–5% BML) of hypohydration affected the postural stability measures in the current study, nor were there any practical differences, as evidenced by Figure 1. These findings have important implications when using standing balance testing as a functional screening tool, as athletes and service members may become hypohydrated (Lieberman et al., 2005; Manning & Wilson, 2007; Sawka et al., 2007) in conjunction with events that immediately precede test and evaluation, such as head injury during the final minutes of a practice or game for athletes, or following blast exposure for deployed warfighters (Guskiewicz, 2001; 2010). For example, current guidelines prescribe systematic balance assessment, in combination with neurocognitive testing, to assess the degree to which a patient has been affected by a traumatic injury to the head (Guskiewicz, 2001; 2010). Both soldiers and athletes are at a high risk for head injury, from a blast trauma in combat or from direct head contact in sports such as football or hockey. In military populations, soldiers are generally exposed to a blast while out on patrol, and upon return to the operating base are usually hypohydrated (Manning & Wilson, 2007), sleep deprived, and emotionally stressed
Similarly, athletes in competition may be suffering from hypohydration and muscle fatigue from strenuous activity. Our findings indicate that hypohydration alone does not have an effect on the standing balance measures used in the current study, and would therefore not be a confounding factor to consider if the tests used in this study are used to screen for balance-related effects of blast trauma or concussion. It is possible that more challenging postural manipulations tested while hypohydrated may reveal alterations in standing balance. However, variation within standing balance may still be an issue when attempting to observe these changes, and should be taken into account for future studies. Our findings also indicate that regardless of postural challenges that may be used for future research, recent physical activity and other factors must still be considered.

**Conclusion**

Standing balance was not impaired by either method of hypohydration (i.e., sweating v. diuretic) nor increased magnitude of hypohydration (5% BML). In addition, no relationships were apparent between physiological changes due to hypohydration ($V_{\text{plasma}}$ decreases or $P_{\text{osm}}$ increases) and balance performance. Previous findings indicating an effect of exercise-induced hypohydration on standing balance may be the result of incomplete recovery from exercise. Results of the current study indicate that hypohydration to physiologically relevant levels alone would not affect balance testing during quiet standing.

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**References**


