Effects of Dehydration on Balance as Measured by the Balance Error Scoring System

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Abstract: The purpose of this study was to identify the effects of active dehydration on balance in euthermic individuals employing the Balance Error Scoring System (BESS). The results indicate that dehydration significantly negatively affects balance.

The effect of dehydration on balance, performance, and proprioception is an important topic in athletic training and sports. Understanding the physiology of the body and the compensatory mechanisms offset by dehydration is essential to certified athletic trainers, team physicians, and emergency medical technicians. Dehydration may have serious effects on balance, greatly diminishing athletic performance and predisposing an athlete to injury.

Barr (1999) demonstrated that dehydration can cause increased heart rate, elevated core body temperature (hyperthermia) and increased oxygen consumption. All of these factors can inevitably lead to decreased performance during sport activity, even when the level of dehydration is as modest as 1-2% (Casa et al., 2000; Convertino et al., 1996; Neave et al., 2001). Fatigue caused by exercise and dehydration may lead to decreased postural stability due to a lowered muscle efficiency and decreased proprioceptive sensitivity. Decreased postural stability can affect an athlete's abilities during activity, leading to injury. Rehydration to replace water lost through sweat during exercise helps to maintain good postural stability. Good postural stability was described as a low sway path when assessing body sway (Gauchard, Gangloff, Vouriot, Mallie, & Perrin, 2002). Dehydration also negatively affects performance (Burge, Carey, & Payne, 1993; Devlin, Fraser, Barras, & Hawley, 2001).

This study examined the effects of exercise-induced dehydration on balance using the Balance Error Scoring System (BESS). The BESS is an instrument commonly used to evaluate postural stability on the field after mild head injury (Reimann, Guskiewicz, & Shields, 1999). The BESS tests three stances (double-leg, tandem, single-leg) which are each performed on both stable (firm) and unstable (foam) surfaces. Each stance is performed for 20 seconds. The instrument scores participant errors counted during stances.

Methods

Research Design and Procedures

The research design consisted of a test-retest design with three within-subjects factors. The three independent variables were: hydration status (euhydrated, dehydrated), stance (double-leg, tandem, single-leg) and surface (stable, unstable). The dependent variables were total balance error scores (TBES) and stance errors scores (SES) as measured by the BESS.

Familiarization session. Potential participants reported to the Sports Science Research Laboratory at Florida International University (FIU) for a familiarization session, during which the health and injury questionnaire was completed and the informed consent form was read and signed. The investigator distributed the CorTemp™ Ingestible Core Body Temperature Sensor (HT150002, HQInc., Palmetto, FL) along with a participant letter explaining expectations, a description of the sensor, and instructions for its ingestion. Demographic information, baseline nude body mass (model BWB-800S digital medical platform scale, Tanita Inc., Brooklyn, NY), and waist circumference were recorded. The BESS was demonstrated to the participants and standard instructions were provided verbally. Previous research has differed on whether repeated administration of the BESS elicits a “practice effect” (Riemann et al., 1999; Riemann & Guskiewicz, 2000; Valovich, Perrin, & Gansneder, 2003), however, research on other balance assessment systems has determined that two or more test trials ensures negated practice effects (Lephart, Pincivero, & Henry, 1995). Therefore, participants practiced the BESS protocol two times in order to avoid a “practice effect” during testing. To perform the test, the participants must stand with their hands on the iliac crests, eyes closed, feet fully on the surface, with the exception of single-leg stance, where the participant stands in 20^{o} of hip flexion and 40^{o} of knee flexion. Errors in stance are: (a) lifting hands off hips; (b) opening eyes; (c) stumbling or falling; (d) moving the hip into more than 30^{o} of flexion or to the side; (e) lifting front of foot or heel; (f) and remaining out of testing position for more than 5s. Each error is scored as one error point and performance is based on the total number of error points. The maximum number of errors per trial is 10, therefore the maximum number of errors per BESS test is 60 (Riemann et al., 1999; Riemann & Guskiewicz, 2000). Participants were instructed to return to the laboratory the following day wearing mesh shorts, a cotton t-shirt, sweat socks, running shoes and a sports bra or athletic supporter and to refrain from eating or drinking after 12 am the night before testing. Participants were also instructed not to ingest alcohol, caffeine, or non-prescription medication, or to engage in dehydrating behaviors (sauna, diuretics, sweat suits, etc.) for the duration of the study.

Heat stress exercise protocol. A heat stress exercise protocol was performed in order to cause active dehydration in participants. Prior to the protocol, participants completely voided urine (urine specimen was collected) and measurements of urine volume, urine color (urine color chart, Human Kinetics, Champaign, IL), and urine specific gravity (urine refractometer, model 300CL, Atago, Inc., Japan) were recorded. Participants were weighed and were required to have a nude body mass within $\pm$1% (or 0.4 kg) of baseline nude body mass to continue, which ensured that the participant began the protocol fully hydrated (euhydrated). Participants performed the BESS protocol and euhydrated scores were recorded. The heat stress exercise protocol consisted of the participants exercising outdoors on a motor driven treadmill (Proform, ICON Health & Fitness, Logan, UT) in a warm, humid environment. The participant warmed up at 40% maximum heart rate for 5 min and then increased speed to maintain 60 – 75% maximum heart rate until a criterion 3% loss of euhydrated body mass was reached. Maximum heart rate was determined by subtracting the participant’s age from 220 and percentage of maximum heart rate was determined by the Karvonen method. The heat stress exercise protocol varied in time from approximately 75-120 min depending on participant sweat rate and fitness and acclimatization levels. Participants were allowed water if absolutely necessary but were discouraged from drinking. During the heat stress exercise protocol, core body temperature and heart rate were measured every 5 minutes; blood pressure and rating of perceived exertion (RPE) were recorded every 15 min as precautionary measures. Core body temperature was measured by a CorTemp™ Ingestible Core Body Temperature Sensor (HT150002, HQInc., Palmetto, FL) that was ingested and tracked with a CorTemp™ Miniaturized Ambulatory Data Recorder (HT150016, HQInc., Palmetto, FL). Heart rate was measured using a Polar® heart rate monitor (Polar Electro Inc., Woodbury, NY). Blood pressure was assessed using a stethoscope and sphygmomanometer (American Diagnostics, West Babylon, NY). Rating of perceived exertion (RPE) was measured every 15 min during exercise using the Borg Scale (Borg, 1998).

Recovery period. The recovery period consisted of participants resting indoors in a thermoneutral environment where core body temperature was recorded until it returned to baseline (euthermic). Research has determined that balance (measured by BESS) decreases after fatigue (Wilkins, Valovich McLeod, Perrin, & Gansneder, 2004) but effectively recovers within 20 min after exertion (Susco et al., 2004). Thus, the prolonged recovery period ensured euthermia and diminished fatigue, ruling out hyperthermia and leg fatigue as confounding factors. No fluids were given during this period. Following recovery, participants removed all clothing, toweled dry, voided all urine (urine specimen was taken), and criterion body mass loss was confirmed. Measurements of urine volume, urine color, and urine specific gravity were recorded. Postural stability of the participants in a dehydrated state was then assessed by the BESS protocol and data were recorded. At the end of the data collection session, participants were required to orally re-hydrate with cool water until they returned to within 2% of their euhydrated body mass.

Participants. A random sample of 19 healthy volunteers were recruited from the university student body and surrounding community, however only 10 (7 men, 3 women; mean $\pm$SD: age = 25.2 $\pm$ 4.7 years; height = 177.9 $\pm$ 18.2 cm; body mass = 83.4 $\pm$ 14.8 kg) achieved the criterion body mass loss (mean body mass loss = 3.03 $\pm$ 0.34 %). Potential participants were screened by completing the health and injury history questionnaire to ensure they met the following conditions: no history of heat-induced illness, no chronic health problems, no orthopedic limitations, and no history of cardiovascular, metabolic, or respiratory disease within the past year. Participants read and signed the informed consent form for the study which was approved by the FIU Institutional Review Board.

Statistical analysis. TBES were compared with a 2 (condition) x 2 (surface) repeated-measures analysis of variance (ANOVA) and SES were compared using a 2 (condition) x 3 (stance) x 2 (surface) repeated-measures ANOVA. Descriptive statistics were calculated for measures of hydration, environmental monitoring, and thermoregulatory and cardiovascular monitoring. Data were analyzed using the SPSS 11.0 for Windows Statistical Package (SPSS, Chicago, IL). Significance was set at $P \leq .05$ for all statistical analyses.

Results

Significant dehydration ($t_9 = 13.388$, $p \leq .001$) was revealed between conditions based upon two of three hydration status measures (mean body mass loss = -2.6 $\pm$ 0.6 kg; urine color $t_9 = -6.082$, $p \leq .001$, -2.05 $\pm$ 1.06 shades; and urine specific gravity ($t_9 = -1.940$, $p = .084$). No significant differences were identified between euhydrated (37.3 $\pm$ 0.37 ^{o}C) and dehydrated (37.6 $\pm$ 0.13 ^{o}C) core body temperature measurements after a prolonged period of recovery (44.00 $\pm$ 13.70 min) which ensured euthermia and diminished fatigue.

Main effects for TBES (Table 1 and Figure 1) revealed a significant 21.5% increase in errors in the dehydrated condition ($F_{1,18} = 16.639$, $p = .001$) and a significant 57.5% increase in errors on the unstable surface ($F_{1,18} = 90.064$, $p \leq .001$). Main effects for SES (Table 2 and Figure 2) revealed significant interactions between condition and stance ($F_{2,18} = 14.082$, $p \leq .001$) and between stance and surface ($F_{2,18} = 3.644$, $p = .047$). A significant 56.0% increase was found in the dehydrated condition ($F_{1,9} = 33.502$, $p \leq .001$), a significant increase in errors was found for each stance ($F_{2,18} = 110.042$, $p \leq .001$), and a significant 23.3% increase in errors was found for the unstable surface ($F_{1,9} = 9.767$, $p = .012$).

Discussion

While there is a large amount of research on the effects of dehydration on cognition, endurance, and exercise performance, there is scant research about the effects of dehydration on balance. The research protocol utilized in this study was most similar to Derave, De Clercq, Bouckaert, and Pannier (1998) in that participants were tested on balance apparatus both before and after performing a prolonged exercise session without fluid. While participants in the Derave et al. study performed a 2 hr cycle ergometer exercise session, the participants in this study performed a 1.25-2 hr treadmill exercise session in order to more effectively mimic sports-specific posture and activity. While this investigation dealt only with active dehydration, Derave et al. also tested postural stability and found no effect after exercise with fluid replacement and after thermal dehydration produced by repeated sauna exposure.

Our study had no significant difference between baseline and post-recovery core body temperatures which ensured that participants were euthermic while performing the dehydrated BESS, and eliminated hyperthermia as a confounding factor. Research has determined that balance (measured by BESS) decreases after fatigue (Wilkins, Valovich McLeod, Perrin, & Gansneder, 2004) but effectively recovers within 20 min after exertion (Susco, Valovich McLeod, Gansneder, & Shultz, 2004). This allows us to conclude that the prolonged recovery period (44.00 $\pm$13.70 min) in this study diminished leg fatigue and ruled it out as a confounding factor.

Our primary finding was that dehydration adversely affected balance, as measured by the BESS. Although others have found that dehydration adversely affects balance (Derave et al., 1998; Gauchard et al., 2002), the BESS was not used as the balance measuring tool. The most likely explanation for our results follows a theory introduced in previous research (Gauchard et al., 2002). This research determined that dehydration can lead to body fatigue which reduces muscle efficiency and can influence an athlete to alter their normal posture. Proprioceptive muscle receptors are therefore affected and function with reduced sensitivity. Reduced proprioceptive sensitivity leads to a decrease in balance.

Limitations to the study include the relatively small sample size; thus future replications of this study should use a larger sample size to increase external validity of the results. Participant fitness and acclimatization were not tested. Therefore, one volunteer may have been more fit or acclimatized than another, causing differences in the length of time until dehydration or fatigue. Future studies may select participants based on a certain fitness or acclimatization level to more effectively mimic sport specificity.

Clinical Implications

This investigation determined that dehydration negatively affects balance. Balance deficits may result in diminished athletic performance and predispose an athlete to injury. The findings identify significant deficits in balance that likely result from decreased proprioceptive sensitivity and altered posture secondary to dehydration (Gauchard et al., 2002). Clinicians working with athletic populations must expect and recognize the effects of dehydration and act accordingly. Further research identifying the effects of dehydration on balance should incorporate a larger sample size and criteria for participant fitness and acclimatization should be more strictly monitored.

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(n= 10)	Condition*	Marginal Means	
Surface*	Euhydrated (TBES $\pm$sd)	Dehydrated (TBES $\pm$sd)	
Stable	3.9 $\pm$ 3.4	6.3 $\pm$ 3.9	2.4 $\pm$ 0.3
Unstable	10.6 $\pm$ 2.6	12.6 $\pm$ 1.3	3.2 $\pm$ 0.2
Marginal Means	1.7 + 0.4	3.9 $\pm$ 0.2	

Table 1. Total balance errors scores (mean $\pm$ SD) for euhydrated and dehydrated conditions. *****Significant differences were revealed between conditions ($F_{1,18} = 16.639$, $p = .001$) and between surfaces ($F_{1,18} = 90.064$, $p \leq .001$).

(n= 10)		Stance x Surface	Condition	
Stance	Surface	(SES $\pm$sd)	Euhydrated (SES $\pm$sd)	Dehydrated (SES $\pm$sd)
Double	stable	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0
	unstable	0.2 $\pm$ 0.1	0.0 $\pm$ 0.0	0.4 $\pm$ 0.3
Tandem	stable	2.5 $\pm$ 0.5	0.9 $\pm$ 0.6	4.1 $\pm$ 0.6
	unstable	3.4 $\pm$ 0.5	2.0 $\pm$ 0.6	4.8 $\pm$ 0.3
Single	stable	4.8 $\pm$ 0.4	3.0 $\pm$ 0.6	6.5 $\pm$ 0.4
	unstable	5.9 $\pm$ 0.4	4.3 $\pm$ 0.7	7.4 $\pm$ 0.3
	Total Means		1.7 + 0.4	3.9 $\pm$ 0.2

Table 2. Stance error scores (mean $\pm$ SD) for euhydrated and dehydrated conditions. *Significant interactions between condition and stance ($F_{2,18} = 14.082$, $p \leq .001$) and stance and surface ($F_{2,18} = 3.644$, $p = .047$) and main effects for condition ($F_{1,9} = 33.502$, $p \leq .001$), stance ($F_{2,18} = 110.042$, $p \leq .001$), and surface ($F_{1,9} = 9.767$, $p = .012$).

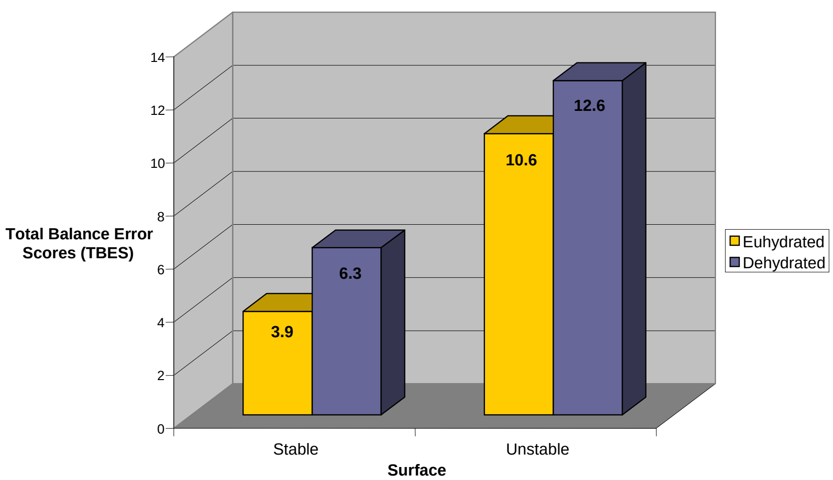

Figure 1. Total Balance Error Scores. ***Significant differences were revealed between conditions (euhydrated and dehydrated and between surfaces (stable and unstable).

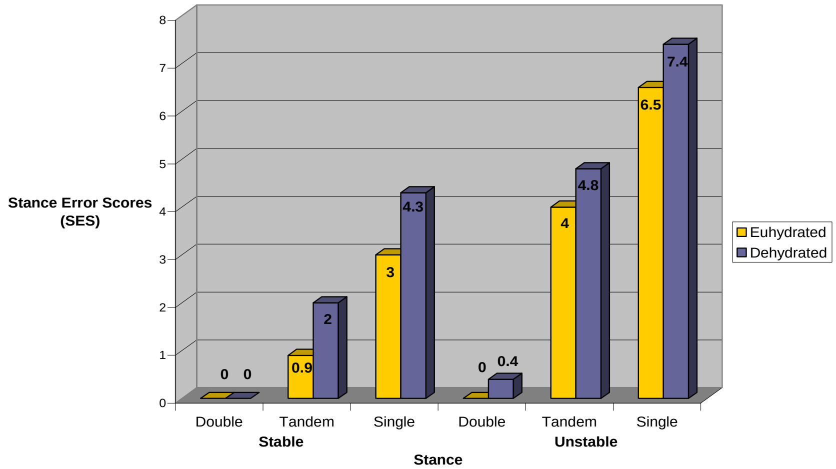

Figure 2. Stance Error Scores. *Significant differences were revealed for condition, stance, and surface with additional interactions between condition and stance and stance and surface.