Effects of Active Dehydration on Balance in Normothermic Participants

Lindsey E. Eberman, Michelle A. Cleary
Monique Butcher-Mokha, and Jennifer L. McKinney

Abstract: The purpose of this investigation was to identify balance deficits as a result of dehydration in a warm humid environment. Our investigation employed a clinical balance testing system in an upright stance to better mimic sport specific activity.

Exercise in hot, humid environments has led to an aggressive investigation of the physiological effects of performance implications of heat and hydration. Dehydration has been demonstrated to reduce physical performance (Barr, 1999; Casa, 1999; Hedley, Climstein, & Hansen, 2002; Sawka, Montain, & Latzka, 2001; Terrados, & Maughan 1995; Yoshida, Takanishi, Nakai, Yorimoto, & Morimoto, 2002). The physiological effects of dehydration on exercise performance are becoming well understood; however, the literature lacks comprehensive conclusions and clinical implications concerning the effects of dehydration on components of physical performance.

Performance has been described as an all inclusive term concerning agility, balance, coordination, speed, strength, and endurance (Barr, 1999; Casa, 1999; Hedley et al., 2002; Sawka et al., 2001; Terrados et al., 1995; Yoshida et al., 2002). Performance can best be described as a combination of high-level sensory input and motor output and is a highly cognitive and neurological function that incorporates balance by utilizing the sensorimotor system.

Balance is an integral aspect of performance and requires the use of muscular force after the input of visual and kinesthetic information to maintain the position of the body over its center of support (Irrang, Whitney, & Cox, 1994). Balance is a measure of the reaction forces produced by the body's center of gravity moving around a fixed axis of support (Guskiewicz, Riemann, Perrin, & Nasher, 1997; Guskiewicz, Ross, & Marshall, 2001; Riemann, & Lephart, 2002). Balance allows the body to self-evaluate joint position, movement, direction and speed based on a combination of somatosensory, visual, and vestibular input to the central nervous system (Riemann, Myers, & Lephart, 2002; Vuillerme, Danion, Forestier, & Nougier, 2002). Therefore, balance is a complex function of the nervous system and is a necessary component in order to achieve quality performance. The purpose of this investigation was to identify balance deficits as a result of dehydration in a warm, humid environment. Our investigation employed a clinical balance testing system and an upright stance to better mimic sport specific activity.

Methods

Experimental design and procedures. The research design consisted of a test-retest design with one within-subjects experimental group. The dependent variable was balance and was measured using a computerized clinical balance testing system (Biodex Balance System™, Biodex Medical Systems, Inc., Shirley, NY). The Biodex Balance System displays output for overall stability index (OSI), anterior/posterior stability index (APSI), medial/lateral stability index (MLSI), and percent time in zone. The OSI represents the variance of foot platform displacement in degrees in all directions; a high score is indicative of decreased stability. The APSI represents the variance of foot platform displacement in degrees for motion in the sagittal plane (parallel to the body's midline). The MLSI represents the variance of foot platform displacement in degrees for motion in the frontal plane (perpendicular to the sagittal plane).

Percent time in zone scores represent the percentage of the 30-s trial in which the participant's center of gravity remained within 0-5^{o} (zone A), 6-10^{o} (zone B), 11-15^{o} (zone C), and 16-20^{o} (zone D) of deflection. Measures of the dependent variable were obtained in euhydrated (prior to the heat stress trial) and in dehydrated conditions (after the heat stress trial).

Familiarization session. A familiarization session was conducted at the Florida International University Sport Science Research Laboratory 24-hours prior to the investigation. Informed consent, approved by Florida International University's Institutional Review Board, was obtained and demographic information was amassed prior to the collection of baseline data. Participants completed a health history questionnaire prior to participation and were excluded if they had experienced any of the following: heat-induced illness, chronic health problems, orthopedic limitations, cardiovascular disease, metabolic disease, or respiratory disease within the last year. Balance assessment was practiced during six separate trials (30-s each) to reduce the learning effect of balance testing (Cachupe, Shifflett, Kahonov, & Wughalter, 2001). Participants were instructed to return to the laboratory the following day.

Data collection session. Upon arrival at the laboratory, participants were instructed to completely void urine, and nude body mass, urine color, and urine specific gravity data were recorded. Body mass was measured using a digital medical platform scale (model BWB-800S, Tanita Inc., Brooklyn, NY). A urine color chart (Human Kinetics, Champaign, IL) was used to determine urine concentration with the closest shade on the chart recorded. Urine specific gravity was measured using a clinical refractometer (model 300CL Atago Inc., Japan). Euhydrated body mass was measured within $\pm$1% of baseline body mass (Convertino et al., 1996). Participants performed the heat stress trial (mean ambient temperature = 27.9 $\pm$0.7 ^{o}C, relative humidity = 50.0 $\pm$8.8%) until a criterion 3.0% body mass loss (Convertino et al., 1996) was achieved. As a preventative measure, heart rate, core body temperature, blood pressure, and rating of perceived exertion were monitored at intervals throughout the heat stress trial. No participant was permitted to continue if core body temperature exceeded 40.0 ^{o}C. Heart rate was measured using a Polar heart rate monitor (Polar Electro Inc., Woodbury, NY). Core body temperature was measured via ingestion of a CorTemp Ingestible Core Body Temperature Sensor (HT15002, HQInc., Palmetto, FL) tracked throughout the heat stress trial and recovery period with the CorTemp Miniaturized Ambulatory Data Recorder (HT150016, HQInc., Palmetto, FL). Every 15 min of the heat stress trial, blood pressure was assessed using a stethoscope and sphygmomanometer (American Diagnostics, West Babylon, NY). Rating of perceived exertion was measured with a Borg scale (Borg, 1998).

Recovery period. At the conclusion of the trial, participants were instructed to dismount the treadmill, remove clothing, and towel dry. Participants voided urine and criterion percent body mass loss was confirmed. Urine color was determined and specific gravity data were recorded. The recovery period was designed to eliminate the effects of hyperthermia and allowed participants to rest in a thermoneutral environment (26.7 $\pm$0.9 ^{o}C; 39.9 $\pm$ 5.1 % relative humidity). Following the return to baseline core temperature, balance testing was repeated. At the end of the data collection session, dehydrated participants were required to orally rehydrate with cool water.

Participants. A random sample of 19 healthy, active volunteers yielded 10 participants (seven men and three women; age = 25.2 $\pm$4.7 y; ht = 177.9 $\pm$8.2 cm; and body mass = 83.4 $\pm$14.8 kg) achieving a mean of -3.03 $\pm$.35% body mass loss. Participants were instructed to avoid alcohol, caffeine, and non-prescription medication ingestion, as well as partaking in dehydrating behaviors (i.e., sauna, diuretics, sweat suits, etc.). In addition, participants were instructed to cease eating and drinking at 12:00AM midnight the night before to aid in inducing dehydration during the subsequent heat stress trial.

Statistical analysis. Hydration status in the euhydrated and dehydrated condition were compared using dependent t-tests. Descriptive statistics were used to report cardiovascular measures, thermoregulatory data, and environmental conditions, and percent time in zone. A 2 (condition) x 3 (balance stability index) ANOVA with repeated measures was used to identify significant differences on the balance index scores. Data were analyzed using the SPSS series 11.0 Statistical Package for Windows (SPSS Inc., Chicago, IL) with significance set at $P \leq 0.05$ for all analyses.

Results

Participants were significantly dehydrated following the heat stress trial based on two of three appropriate criteria (see Table 1): body mass loss ($t_9 = 13.388$, $p \leq .001$, mean = -2.6 $\pm$0.6 kg) and urine color ($t_9 = -6.082$, $p \leq .001$; mean=-2.05 $\pm$ 1.07 shades) but not urine specific gravity ($t_9 = -1.940$, $p = .084$). Core body temperature prior to exercise in the euhydrated condition and following recovery (mean recovery= 44.0 $\pm$13.7 min) in the dehydrated testing condition were not significantly different between euhydrated (37.31 $\pm$0.37 ^{o}C) and dehydrated (37.56 $\pm$0.13 ^{o}C) conditions (see Table 2).

No significant differences between the euhydrated and dehydrated conditions on OSI, APSI, and MLSI were found. However, a trend toward increased stability scores in the dehydrated condition for OSI and APSI were revealed and are displayed in Figure 1. A visual comparison (see Figure 2) of euhydrated and dehydrated percentage time in zones revealed decreased percent time in zone A (closest to center).

Discussion

The current research surrounding the effects of dehydration on balance is limited. Comparisons of posturagraphic data from participants performing a two hour cycle ergometer exercise trial (Derave, DeClerQ, Bouckaert, & Pannier, 1998) concluded that dehydrated participants were significantly more unstable than euhydrated participants. A period of rest followed exercise, decreasing the confounding factors of hyperthermia and fatigue; however the change in sensory conditions (seated to standing) may have influenced the outcome of the study. Derave, et al. also studied the effects of a passive dehydration method, concurrent sauna sessions, on balance, and reported no significant effect on balance. Decrements in balance have been demonstrated when fatigue was induced through exercise and worsened in the dehydrated condition (Gauchard, Gangloff, Vouriot, Mallie, & Perrin, 2002). Hydration status was measured through fluid consumption or non-consumption, and was therefore not congruent with similar hydration investigations. In addition, the posturographic tests were performed immediately following the exercise trials indicating that balance deficits may be influenced by fatigue and hyperthermia.

Prior to the heat stress trial our participants were confirmed to be euhydrated and normothermic. Following the heat stress trial the participants became significantly dehydrated and had returned to the normothermic condition. The level of dehydration achieved in our investigation was moderate (-3.03 $\pm$.35%) compared to mild (-2.7 $\pm$0.4%) achieved by Derave et al. (1998), yet Derave found greater balance deficits. The force platform utilized by Derave et al., measured sway and velocity of center of foot pressure, which may be poorly associated to the calculated stability indices and degree of deflection measured within the Biodex Balance System^{TM}.

Compared to a previous investigation (Susco, Valovich McLeod, Gansneder, & Schultz, 2004), the recovery period in the current study was sufficient to decrease fatigue. Our research design was similar to that of Derave et al. (1998), with the exception of exercising in upright stance which we believed would better mimic sport specific activity by using a treadmill exercise heat stress trial. In addition, Derave et al. employed a static balance assessment which is appropriate for afflicted or aged participants but may not best evaluate physically active participants (Hinman, 2000). Hinman suggested that static balance tests do not incorporate all the domains of balance that are necessary for dynamic functional activities and therefore suggested the use of dynamic balance testing with the Biodex Balance System™. The Biodex Balance System™ dynamic stability testing employs movement of both center of pressure and the base of support incorporating somatosensory, visual, and vestibular input.

Researchers have found increased motion in the anterior/posterior plane, sway from heel to toe, in any condition (Derave et al., 1998; Gauchard et al., 2002). We also suggest that the ankle strategy within the anterior/posterior plane is affected by dehydration greater than that of the medial/lateral ankle strategy. Furthermore, the findings for percent time in zone suggest a trend toward decreased stability (see Figure 2). In the dehydrated condition, the participants demonstrated less time spent in zone A, which is closest to the center and greater time spent in the other three zones, suggesting greater deflection from center.

Clinical Implications and Suggestions for Further Research

The purpose of this investigation was to identify the effects of active dehydration on balance. Our research design provided a normothermic and minimized fatigue environment for dehydrated testing. We were unable to find significant differences between the euhydrated and dehydrated condition. Still, we were able to demonstrate a trend toward deficient balance in the dehydrated condition. This trend implies altered performance in an athletic setting, ultimately leading to poor performance and potential injury. Significant findings may have been limited by an insufficient number of participants, Biodex Balance System™ sensitivity, and severity of dehydration level. We suggest further investigation is necessary and should retain more participants and test at higher levels of dehydration.

References

Barr, S. L. (1999). Effects of dehydration on exercise performance. *Canadian Journal of Applied Physiology*, *24*, 164-172.

Borg, G. (1998). *Borg's perceived exertion and pain scales*. Champaign, IL: Human Kinetics.

Cachupe, W. J., Shifflett, B., Kahonov, L., & Wughalter, E. H. (2001). Reliability of Biodex Balance System Measures. *Measurement in Physical Education and Exercise Science, 5*, 97-108.

Casa, D. J. (1999). Exercise in the heat. I. Fundamentals of thermal physiology, performance implications, and dehydration. *Journal of Athletic Training, 34,* 246-252.

Convertino, V., Armstrong, L., Coyle, E., Mack, G., Sawka, M., Senay, L. C. et al. (1996). American College of Sports Medicine Position stand: Exercise and fluid replacement. *Medicine and Science in Sport and Exercise, 28,* i-vii.

Derave, W., De ClercQ, D., Bouckaert, J., & Pannier, J. L. (1998) .The influence of exercise and dehydration on postural stability. *Ergonomics, 41,* 782-789.

Gauchard, G. C., Gangloff, P., Vouriot, A., Mallie, J. P., & Perrin, P. P. (2002). Effects of exercise-induced fatigue with and without hydration on static postural control in adult human subjects. *International Journal of Neuroscience, 112,* 1191-1206.

Guskiewicz, K. M., Riemann, B. L., Perrin, D. H., & Nashner, L. M. (1997). Alternative approaches to the assessment of mild head injury in athletes. *Medicine and Science in Sport and Exercise*, *29*, S213-S221.
Guskiewicz, K. M., Ross, S. E., & Marshall, S. W. (2001). Postural stability and neuropsychological deficits after concussion in collegiate athletes. *Journal of Athletic Training*, *36*, 263-273.
Hedley, A. M., Climstein, M., & Hansen, R. (2002). The effects of acute heat exposure on muscular strength, muscular endurance, and muscular power in the euhydrated athlete. *Journal of Strength and Conditioning Research, 16,* 353-358.
Hinman, M. R. (2000). Factors affecting reliability of the Biodex Balance System: A summary of four studies. *Journal of Sport Rehabilitation, 9,* 24-252.
Irrgang, J., Whitney, S., & Cox, E. (1994). Balance and proprioceptive training for rehabilitation of the lower extremity. *Journal of Sport Rehabilitation, 3,* 68.
Riemann, B. L., & Lephart, S. M. (2002). The sensorimotor system, Part II: The role of proprioception in motor control and functional joint stability. *Journal of Athletic Training, 37,* 80-84.
Riemann, B. L., Myers, J. B., & Lephart, S. M. (2002). Sensorimotor system measurement techniques. *Journal of Athletic Training, 37,* 85-98.
Sawka, M. N., Montain, S. J., & Latzka, W. A. (2001). Hydration effects on thermoregulation and performance in the heat. *Comparative Biochemistry and Physiology Part A, 128,* 67-690.
Susco T. M, Valovich McLeod T. C., Gansneder B. M., & Schultz S. J. (2004). Balance recovers within 20 minutes after exertion as measured by the balance error scoring system. *Journal of Athletic Training*, *39,* 241-246.
Terrados, N., & Maughan, R. J. (1995). Exercise in the heat: Strategies to minimize the adverse effects on performance. *Journal of Sports Sciences, 13,* S55-S62.
Vuillerme, N., Danion, F., Forestier, N., & Nougier, V. (2002). Postural sway under muscle vibration and muscle fatigue in humans. *Neuroscience Letters*, *333,* 131-135.
Yoshida, T., Takanishi, T., Nakai, S., Yorimoto, A., & Morimoto, T. (2002). The critical level of water deficit causing a decrease in human exercise performance: A practical field study. *European Journal of Applied Physiology*, *87*, 529-534.

Nude Body Mass*		Urine Color*		Urine Specific Gravity	
Euhydrated (kg ± sd)	Dehydrated (kg ± sd)	Euhydrated (mean ± sd)	Dehydrated (mean ± sd)	Euhydrated (mean ± sd)	Dehydrated (mean ± sd)
83.4 ±14.8	80.8 ±14.3	3.9 ±1.0	6.0 ±0.9	1.021 ±.005	1.024 ±.004

Table 1.*Euhydrated and Dehydrated Nude Body Mass, Urine Color, and Urine Specific Gravity Measurements**Participants (n= 10) were significantly dehydrated based on body mass loss (t_9 = 13.388, $p \leq .001$, mean = -2.6 ±0.6 kg) and urine color (t_9 = -6.082, $p \leq .001$; mean= -2.05 ± 1.07 shades) but not urine specific gravity (t_9 = -1.940, p = .084).

Group (n = 10)	Euhydrated ($^oC \pm$ sd)	Dehydrated ($^oC \pm$ sd)
Core Body Temperature	37.31 $\pm$0.37	37.56 $\pm$0.13

Table 2. Euhydrated and Dehydrated Core Body Temperature

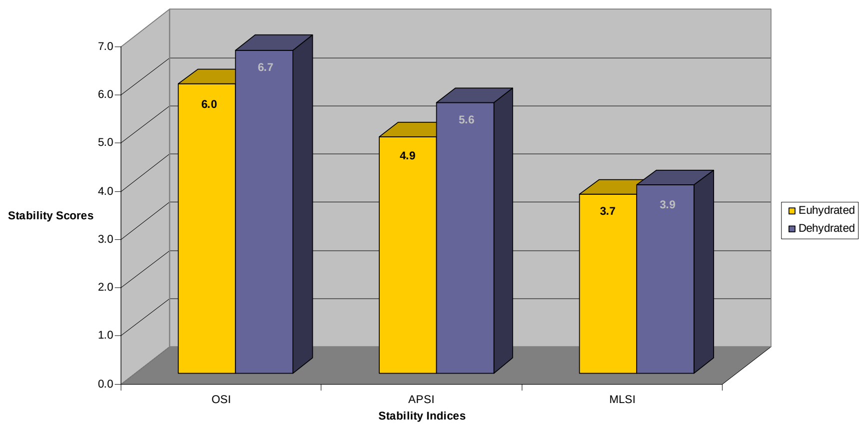

Figure 1. Mean Stability Index Scores. Mean stability index scores comparing the euhydrated and dehydrated conditions.

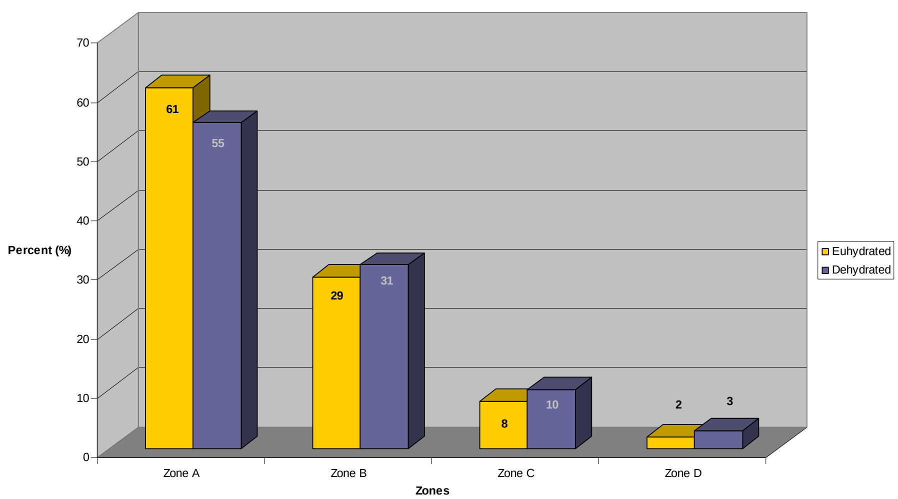

Figure 2. Percent Time in Zone. Percent time in zone values comparing the euhydrated and dehydrated conditions.