

5-7-2011

# Individual and Combined Effects of Dehydration, Hyperthermia, and Fatigue on Movement Patterns and Cognition

Rachel M. Karslo

University of Connecticut - Storrs, [rachel.karslo@uconn.edu](mailto:rachel.karslo@uconn.edu)

---

## Recommended Citation

Karslo, Rachel M., "Individual and Combined Effects of Dehydration, Hyperthermia, and Fatigue on Movement Patterns and Cognition" (2011). *Master's Theses*. 51.  
[https://opencommons.uconn.edu/gs\\_theses/51](https://opencommons.uconn.edu/gs_theses/51)

This work is brought to you for free and open access by the University of Connecticut Graduate School at OpenCommons@UConn. It has been accepted for inclusion in Master's Theses by an authorized administrator of OpenCommons@UConn. For more information, please contact [opencommons@uconn.edu](mailto:opencommons@uconn.edu).

# Individual and Combined Effects of Dehydration, Hyperthermia, and Fatigue on Movement Patterns and Cognition

Rachel M. Karslo

B.S., West Chester University of Pennsylvania, 2009

A Thesis

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Arts

At the

University of Connecticut

2011

APPROVAL PAGE

Master of Arts Thesis

Individual and Combined Effects of Dehydration, Hyperthermia, and Fatigue on  
Movement Patterns and Cognition

Presented by  
Rachel M. Karslo, B.S.

Major Advisor \_\_\_\_\_  
Douglas J. Casa, PhD, ATC, FACSM, FNATA

Associate Advisor \_\_\_\_\_  
Lindsay J. DiStefano, PhD, ATC

Associate Advisor \_\_\_\_\_  
Carl M. Maresh, PhD, FACSM

Associate Advisor \_\_\_\_\_  
Lawrence E. Armstrong, PhD, FACSM

University of Connecticut

2011

## TABLE OF CONTENTS

I.	Review of Literature.....	6
	Dehydration: Physiological Effects.....	7
	Thermoregulation.....	8
	Dehydration Effects on Performance.....	10
	Dehydration: Fluid Balance and Sweat Rate.....	15
	Cognitive Testing.....	17
	Balance and Movement Testing.....	21
	Fatigue Studies.....	23
	Conclusion.....	37
	References.....	38
II.	Introduction.....	41
III.	Methods.....	45
IV.	Results.....	56
V.	Discussion.....	67

## ABSTRACT

### Individual and Combined Effects of Dehydration, Hyperthermia, and Fatigue on Movement Patterns and Cognition

Rachel M. Karslo, University of Connecticut

**Purpose:** The purpose of the study was to examine the individual and combined of effects of dehydration, hyperthermia, and fatigue on movement patterns and cognition. Secondly, we wanted to see if the effects of dehydration, hyperthermia, and fatigue lead to a combined increase in injury risk.

**Methods:** 12 males completed a within-subject repeated measures design to study the effects of hyperthermia, dehydration and fatigue on movement and cognition. Subjects completed 4 randomized test sessions in different conditions: hydrated normothermic, dehydrated normothermic, hydrated hyperthermic, and dehydrated hyperthermic.

Movement and cognitive testing were performed three times during each test session: pre-exercise, post-exercise, and after a 60 minute recovery session (in which water perfused suits were worn to maintain body temperature). Subjects completed a 90 minute exercise protocol walking on a treadmill (5% incline, 3-4.0 mph) with a 50 lb. military backpack on. The Landing Error Scoring System (LESS) was used to assess movement patterns, and the psychomotor vigilance test and profile of mood state (POMS) was used to assess cognitive function.

**Results:** Rectal temperature, heart rate, and RPE increased from the beginning to the end of exercise, and decreased during the recovery session. The dehydrated hyperthermic condition resulted in higher LESS scores compared to the other three conditions. We observed a significant difference between condition for the change from pos-test to pre-test score ( $F_{(3, 33)}=6.17$ ,  $p = 0.002$ ). We observed no significant difference between condition for the change from post-test to recovery-test score ( $F_{(3, 33)}=2.70$ ,  $p = 0.06$ ). We

observed a significant difference between condition for the change from recovery-test to pre-test score (  $F_{(3, 33)}=7.28$ ,  $p = 0.001$ ). We observed a significant main effect for time with the psychomotor vigilance testing. The time of testing produced a significant effect, including an increase in mean reaction time during post testing ( $p= 0.13$ ). No difference was found with number of errors or non valid responses ( $p>0.05$ ). Significant changes for POMS from pre to post testing included: *total mood disorder* ( $F_{(3,33)}=13.38$ ,  $p<0.001$ ), *dejection-depression* ( $F_{(3,33)}=5.32$ ,  $p=0.004$ ), *vigor-activity* ( $F_{(1,63,17,93)}=2.95$ ,  $p=0.09$ ), *fatigue* ( $F_{(1,49,16,40)}= 7.52$ ,  $p=0.008$ ), and *confusion-bewilderment* ( $F_{(3,33)}=8.22$ ,  $p<0.001$ ).. Significant changes were also found for POMS from pre to recovery testing included: *total mood disorder* ( $F_{(3,33)}=5.28$ ,  $p=0.004$ ), *fatigue* ( $F_{(3,33)}=11.26$ ,  $p<0.001$ ), and *confusion-bewilderment* ( $F_{(2,07,22,77)}=2.94$ ,  $p=0.07$ ).

**Conclusions:** We found that dehydration and hyperthermia combined can cause a significant increase in LESS scores. The hyperthermic, dehydrated and fatiguing trial demonstrated the highest average LESS scores. We can conclude that an individual may be at a higher risk for injury when they are dehydrated, hyperthermic, and fatigued. We also found an increase in reaction time during post testing and changes in several mood states. Most significant changes were also in the dehydrated-hyperthermic condition. Decreases in cognitive testing may be the cause of increased LESS scores during this condition.

## **Review of Literature**

During exercise in the heat, it is known that hydration has a significant role on the functions in the body. An overwhelming majority of laboratory studies conclude that dehydration has a negative influence on the body's physiology.<sup>1-7</sup> A few studies, however, conclude that fluid replacement should not be a main concern, and that it does not significantly affect athletic performance.<sup>8</sup>

In many laboratory and field studies, it is difficult to isolate certain variables that affect physiology, therefore leading to conclusions in research that may be lacking in strength. For example, a person may exercise in the heat to cause fatigue, but this will also result in hyperthermia. This may be a reason that is responsible for some of the discrepancies that are seen throughout the literature. Arguments on proper hydration and fluid replacement have led to more research. While much is known about dehydration and its affects on the body, there are many other factors that couple with hydration that are still unknown. Hydration alone has been shown to have an effect on performance, cognition, and balance.<sup>9-17</sup>

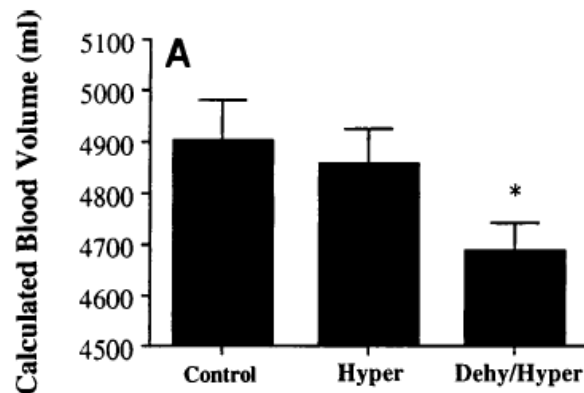
Also, there is minimal research performed on the effects of dehydration on movement patterns. Research has shown that poor movement patterns can cause an increase in an individual's risk of injury.<sup>18</sup> If fatigue is added as a factor, it is theorized that a higher level of dehydration would subsequently increase fatigue. Since there is little knowledge about the effects of dehydration coupled with this factor, research needs to be conducted to further investigate this topic. If identifiable factors leading to injury can be prevented, this will be an important addition to the literature.

## Dehydration: Physiological Effects

There are several physiological factors affected by dehydration. Heart rate, stroke volume, cardiac output, and core temperature are all factors significantly altered by dehydration. Literature shows that a body water deficit greater than 2% affects physiologic function and performance.<sup>1-3, 5, 6, 19</sup> Body water loss is primarily done through sweating, however small amounts are lost through respiration, urine, and insensible water loss.<sup>1</sup>

## Cardiovascular: Stroke Volume and Cardiac Output

Gonzalez-Alonso et al. studied the effects of hyperthermia and dehydration on cardiovascular strain both individually and combined. They showed that dehydration and hyperthermia individually decreased stroke volume by 7-8%. As a combined effect, these two factors decreased stroke volume by  $20 \pm 1\%$  and cardiac output by  $13 \pm 2\%$ .<sup>2</sup> (See Figure 1)



**Figure 1.** Blood volume responses during 30 minutes of exercise when euhydrated, hyperthermic, and hyperthermic + dehydrated.

\*Adapted from Gonzalez-Alonso et al.<sup>2</sup>



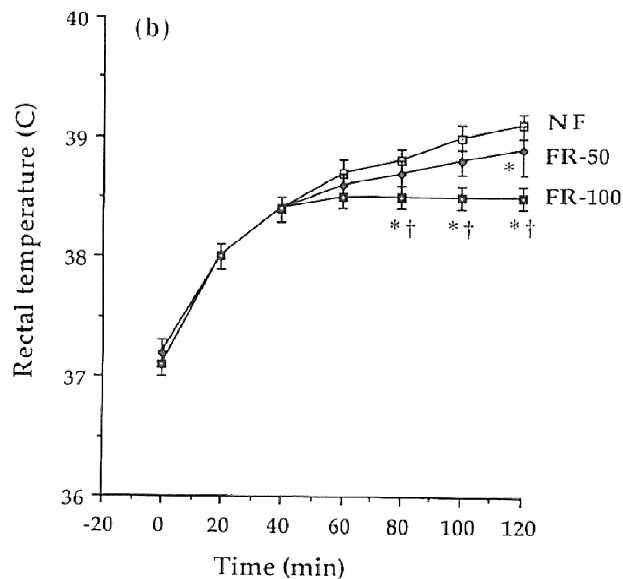
Research by Gaino also showed similar cardiovascular responses to Gonzalez-Alonso. The authors found that stroke volume decreased significantly when subject's exercised in the heat for 120 minutes with no fluid. Montain et al. also examined values of graded dehydration ( $1.1 \pm 0.1$ ,  $2.3 \pm 0.1$ ,  $3.4 \pm 0.1$ ,  $4.2 \pm 0.1\%$ ). Results showed a linear relationship between increased dehydration with increasing heart rate and decreasing stroke volume. Again, stroke volume was seen to decrease. However, Montain found that stroke volume decreased as much as 27% during exercise for the subjects with the highest grade of dehydration.<sup>6</sup>

Sawka et al. examined the physiologic effects of graded dehydration levels. The authors looked at the values of 3, 5, and 7% dehydration as compared to body weight. They found that core temperature and heart rate response increased with higher levels of dehydration. Results showed an increase in heart rate of about four beats per minute for each percent decrease in body weight.<sup>20</sup>

### **Thermoregulation**

Multiple studies show that core temperature can increase from  $0.1^{\circ}\text{C}$  to  $0.49^{\circ}\text{C}$  for each percent of body mass lost.<sup>6, 20-22</sup> As early as 1970, Ekblom showed that a 1% decrease in body weight after exercise increased a subject's rectal temperature of an average of  $0.3\text{-}0.4^{\circ}\text{C}$  when compared to when they were hydrated during the exercise task.<sup>21</sup> Gisolfi completed a similar study, and found that temperature increased between  $0.15^{\circ}$  and  $0.49^{\circ}\text{C}$  for every 1% increase in weight loss.<sup>22</sup> Sawka et al. examined the effects of graded hypohydration levels and found rectal temperature to increase an average of  $0.15^{\circ}\text{C}$  for each percent decrease in body weight.<sup>20</sup> McConell et al. examined

the effect on heart rate and rectal temperature with different fluid regiments. Subjects either received no fluid (NF), a volume to prevent body weight loss (FR-100), or 50% of this volume (FR-50). Results showed no significant difference in heart rate and rectal temperature during the first hour of exercise. However, both heart rate and rectal temperature increased and were highest in the NF group and intermediate in FR-50 when compared to the FR-100 group (see Figure 2).<sup>23</sup>



**Figure 2:** Rectal temperature before and during 2 h of exercise at  $69 \pm 1\%$   $\text{VO}_2$  peak with (FR-50 and FR-100) and without (NF) fluid ingestion. Values are means  $\pm$  SE.

\*Denotes different from NF,  $p < 0.05$ . †Denotes different from FR-50,  $p \leq 0.05$ .

\*Adapted from McConell<sup>23</sup>

The majority of these studies have shown the negative physiological effects caused by dehydration. Stroke volume has been shown to decrease by as much as 27%, while heart rate and rectal temperature have been shown to linearly increase with the increasing grade of dehydration. Heart rate can increase by 10 beats per minute for each percentage decrease in body mass loss. While these numbers may seem insignificant, the

changes can have significant effects on the body, and affect overall performance. This is why proper hydration is so vital to the success of athletes.

Reference	Heart Rate	Stroke Volume	Temperature	Cardiac Output
Gonzalez-Alonso <sup>2</sup>	$\uparrow 9 \pm 1\%$ bpm	Dehydration, hyperthermia = $\downarrow 7-8\%$ ; combined = $\downarrow 20 \pm 1\%$	N/A	$\downarrow 13 \pm 2\%$ .
Casa <sup>24</sup>	$\uparrow 10$ beats/min at 10 minutes postexercise for each 1% of body mass loss	N/A	$\uparrow T_{re} 0.226^{\circ}\text{C}$ for each 1% of body mass loss	N/A
Montain <sup>6</sup>	Progressive $\uparrow$	$\downarrow$ as much as 27%	Progressive $\uparrow$	Progressive $\downarrow$
Sawka <sup>20</sup>	$\uparrow 4$ bpm for each % of body mass loss	N/A	$\uparrow 0.15^{\circ}\text{C}$ for each % body mass loss	N/A
Gisolfi <sup>22</sup>	N/A	N/A	$0.15-0.49^{\circ}\text{C}$ for each % body mass loss	N/A

**Table 1.** Summary of effects of dehydration on physiology.

### Dehydration Effects on Performance

Throughout the literature, there is a large variety of publications on the effects of hydration and muscular performance. However, it is rather difficult to synthesize the research due to the fact that many factors are different throughout the studies. Judelson et al. performed a critical review of the literature on this topic, looking at results from numerous studies of hydration on muscle strength, power, and endurance.<sup>25</sup>

#### A. Muscle Strength

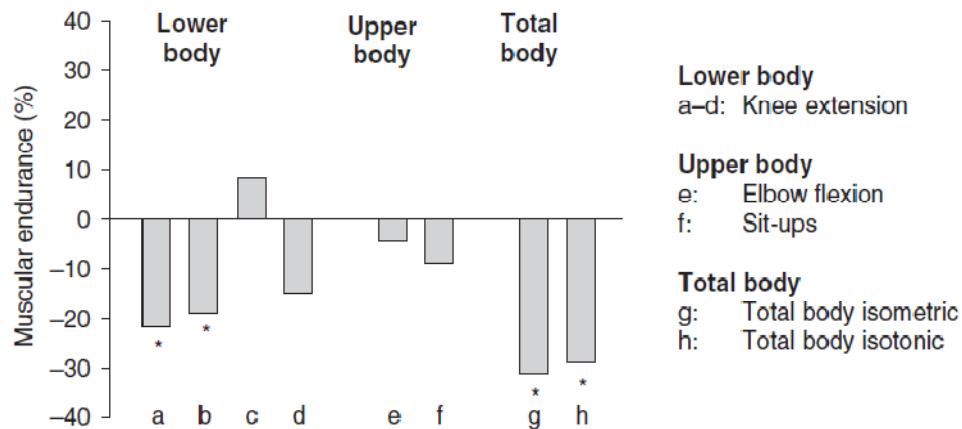
In review of this literature, numerous studies have been conducted regarding the effect of dehydration on muscular strength. In this article, muscle strength was usually measured in a single maximal effort (isometric, isotonic, isokinetic). The authors note that some of the studies have external factors that may have affected outcomes. Of these total studies, 15/70 (21%) showed significant performance reductions with dehydration. They hypothesized that the small percentage of performance reduction may be due to small sample sizes, or instrumentation that was not properly sensitive. Of the studies that were uninfluenced by external factors, over two-thirds of the studies showed reductions in performance with dehydration. The authors concluded that a 3-4% increase in dehydration will result in a 2% strength reduction.<sup>25</sup>

#### B. Muscle Power

Of the studies that examined muscular power changes with hydration, 9/47 (19%) showed significant results. The authors concluded that 3-4% dehydration resulted in a decrease in muscle power by 3%. Many of the studies used power measures during maximal intensity cycling and maximal knee extension.<sup>25</sup>

#### C. Muscle Endurance

Research in muscular endurance is limited, as the authors from Judelson were only able to include 27 studies. 7/27 (26%) studies showed a decrease in muscular endurance. A 3-4% decrease in dehydration resulted in a decrease in muscular endurance by 10%<sup>25</sup>. As seen in Figure 3, the lines extending below zero show negative performance for muscle endurance.

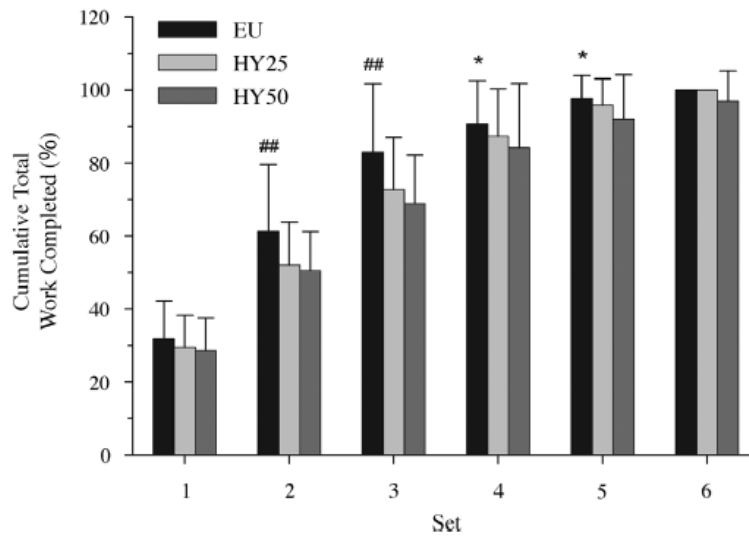


**Figure 3.** Non-confounded effects of hypohydration on high-intensity muscular endurance (activities lasting >30 seconds but <120 seconds). Data are presented as mean percentage change from baseline. \*  $p < 0.05$

\*Adapted from Judelson et al.<sup>25</sup>

### Overall Performance:

As described above, dehydration has multiple effects on the body that may lead to altered performance. A decrease in 2% of body weight has been shown to cause a decrease in performance.<sup>1</sup> An additional study by Judelson examined the effect of hydration state on strength, power, and resistance exercise performance. Seven subjects completed three resistance exercise bouts while either euhydrated (EU), hypohydrated by 2.5% body mass (HY25), or hypohydrated by 5.0% body mass (HY50). Results show no significant differences among trials while completing vertical, peak lower-body power (jump squat), or peak lower-body force (isometric back squat). However, hypohydration was seen to decrease total work performance when subjects had to perform a six-set back squat protocol.<sup>10</sup> (See Figure 4)



**Figure 4.** Cumulative total work completed (mean total standard deviation) after each set during the REC. EU, euhydrated; HY25, hypohydrated by approximately 2.5%; HY50, hypohydrated by approximately 5.0%. ##Significant difference between EU and both hypohydrated trials; \* significant difference between EU and HY50. Adapted from Judelson et al.<sup>9</sup>

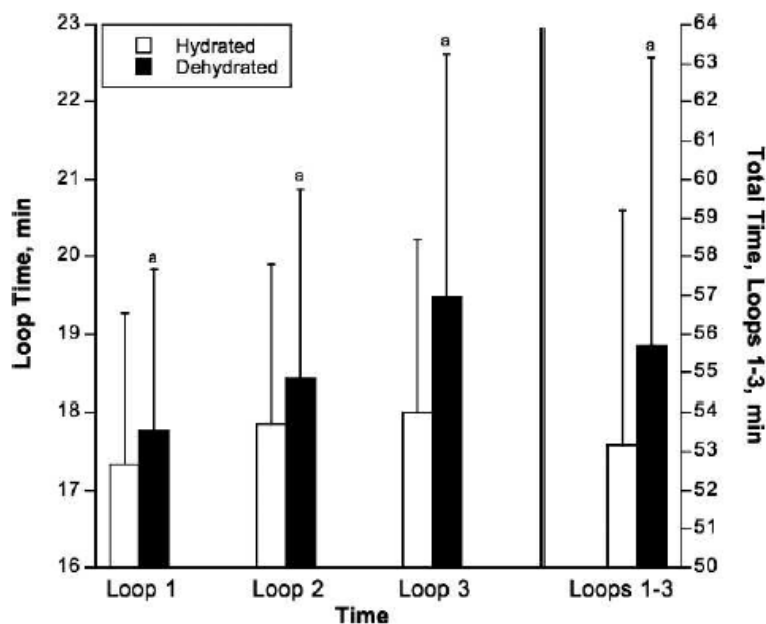
Mudambo et al. also examined the effects of hydration on performance and found similar results to Judelson. However, the authors used different types of fluid ingested for soldiers completing a running/walking exercise in the heat, and did not necessarily control for hydration levels. All subjects who received fluids finished the task, while six of the eighteen soldiers who did not receive any fluid were not able to finish. All the subjects who received fluid were able to complete the task and had lower ratings of perceived exertion compared to the no fluid group<sup>11</sup>. This further strengthens the results from Judelson, as the soldiers who were more hydrated performed better.

Baker et al. examined the effects of graded dehydration on basketball performance. Subjects completed a three hour walking interval exercise on a treadmill. There were six randomized trials completed: euhydrated and carbohydrate-electrolyte

solution (EUHC), euhydrated control (EUH), and 1, 2, 3, and 4% dehydration (DEH).

Like Judelson, Baker controlled his subject's hydration levels. After exercise, a seventy minute recovery period was instilled. A series of tasks were then performed relating to basketball. Results showed that performance progressively decreased when percent dehydration increased. 2-4% DEH showed a statistically significant change in performance.<sup>26</sup>

Casa et al. recently published a field study examining the effects hydration on physiology and performance. Subjects completed four trail runs (12 km) at their own pace in the heat. beginning with different levels of hydration (dehydrated and euhydrated). Similar to Judelson and Baker, subjects began at different levels of hydration. However, Baker's subjects also ingested different solutions, whereas Casa's subjects drank only water. Results showed that subjects who were hydrated ran faster ( $57.7 \pm 7.45$  minutes and  $53.15 \pm 6.05$  minutes, respectively).<sup>24</sup> (See Figure 5)



**Figure 5.** Race trial performance times (mean  $\pm$  SD) <sup>a</sup>  $P \leq .05$  for the same time point between hydration states.

\*Adapted from Casa et al. <sup>24</sup>

As seen from these studies, as little as 2% dehydration can significantly decrease performance. This clearly demonstrates the relationship of these two factors. When subjects were given fluid during exercise compared to those who did not receive fluid, performance was not only better but the activity was able to be completed. These factors are very important concerning an athlete's performance. It demonstrates the importance of keeping athlete's dehydration levels above 2%. It is interesting to note that of the studies assessing muscle strength, power, and endurance, very few used women as subjects. Also, many studies did not account for body mass changes. This may affect results, as it is easier to move a lighter load. This may also provide a foundation for further research.

### **Dehydration: Fluid Balance and Sweat Rate**

Several governing bodies of health care professions have position statements regarding fluid replacement and hydration. The National Athletic Trainers' Association (NATA) recommends that athletes drink 500 to 600 mL of fluid 2 to 3 hours prior to exercise to ensure exercise is started in a euhydrated state<sup>27</sup>. They also recommend drinking 200 to 300 mL of fluid every 10 to 20 minutes of exercise. The calculation of an individual's sweat rate can aid in planning a rehydration protocol. The NATA additionally recommends calculating the sweat rate over a variety of environmental conditions and practice intensities.<sup>7</sup> While the optimal fluid replacement method is to



replace the same amount fluid lost through sweat and urine, every individual is different and may not be able to handle high volumes of water during exercise. This creates a necessity for athletes to find a custom rehydration protocol to see which would work best for them. The American College of Sports Medicine position stand on fluid replacement also emphasizes beginning activity in a euhydrated state, similar to the NATA. Due to the fact that athlete's have such varying sweat rates from exercise, environment, and individual effects, they suggest specifically for marathon runners to drink *ad libitum*, when fluid is readily accessible, from 0.4 to 0.8 L·h<sup>-1</sup> (pending they are beginning exercise euhydrated). It is also recommended by both organizations that athletes monitor body weight changes in order to estimate sweat loss, in order to prevent >2% dehydration.<sup>19</sup> The NATA suggests using the wet-bulb globe temperature (WBGT) in conjunction with assessing a proper hydration program, whereas the ACSM seeks to include the environment in a more general sense.

There are some researchers that believe athletes should solely rely on *ad libitum* drinking as a means for fluid replacement. Researchers believe that drinking large amounts of water can irritate athlete's stomach and intestines, especially if the fluid is being consumed rapidly during exercise. Noakes suggests that elite marathon runners should ingest only 200 mL/h during marathon races, since the race is self paced. He has interviewed elite athletes and runners, who state that they drink smaller amounts of fluid, because it is difficult to drink large amounts during prolonged exercise.<sup>8, 28</sup>

For marathon runners, this includes individuals that are extremely trained and have a great understanding of his or her body. However, for the "normal" athlete, *ad libitum* drinking can possibly lead to dangerous consequences. *Ad libitum* fluid

consumption can lead to dehydration, as a normal person may not know how much is needed to replace their water loss. Over drinking is also a concern, as it can lead to hyponatremia. Calculating an individual sweat rate is not a difficult task, and it a great starting point in order to form a rehydration protocol specific to the athlete.

## Cognitive Testing

Hydration is important not only for performance, but also for maintaining proper brain fuction. There have been many studies examing the effects of dehydration on cognitive function. There are such a large variety of cognitive tests available, that is difficult to compare research studies. Professionals who study cognitive functioning also argue as to which tests are most effective in assessing certain fuctions. Gopinathan examined different levels of dehydration and its effect on cognitive performance in mild to moderate heat. The study consisted of subjects exercising in the heat at 1, 2, 3, or 4 % dehydration, which were chosen randomly on different days. Subjects began by participating in an eight-day heat acclimation exercise (45 °C, 35% humidity). Dehydration during the trial was induced through exercise in the laboratory. Results showed a decrease in cognitive function beginning at 2%<sup>+</sup> dehydration.<sup>14</sup> (See Figure 6)

Table 2.—Mean $\pm$ SEM Scores for Tests and Least Significant Difference (LSD) for Different Levels of Significance									
Test	Thermo-neutral	Body dehydration					LSD at		
		0%	1%	2%	3%	4%	5%	1%	0.1%
Serial addition test (% of correct response)	83.2 $\pm 4.3$	85.7 $\pm 4.2$	79.9 $\pm 4.7$	76.5 $\pm 4.6$	69.8 $\pm 5.2$	66.3 $\pm 5.0$	5.1529	6.8740	8.9846
Trail-marking test (mean speed in sec)	1.37 $\pm 0.07$	1.37 $\pm 0.07$	1.46 $\pm 0.05$	1.56 $\pm 0.06$	1.65 $\pm 0.06$	1.71 $\pm 0.05$	0.0985	0.1314	0.1718
Word recognition test (% correct words recalled)	73.7 $\pm 5.0$	74.9 $\pm 4.6$	68.4 $\pm 4.4$	65.4 $\pm 5.3$	59.8 $\pm 4.6$	58.2 $\pm 5.0$	4.879	6.508	8.506

**Figure 6.** Mean SEM Scores for Test and Least Significant Differences (LSD) for Different Levels of Significance.

\*Adapted from Gopinathan et. al <sup>14</sup>

Grego et. al studied the cognitive performance of eight trained male cyclists.

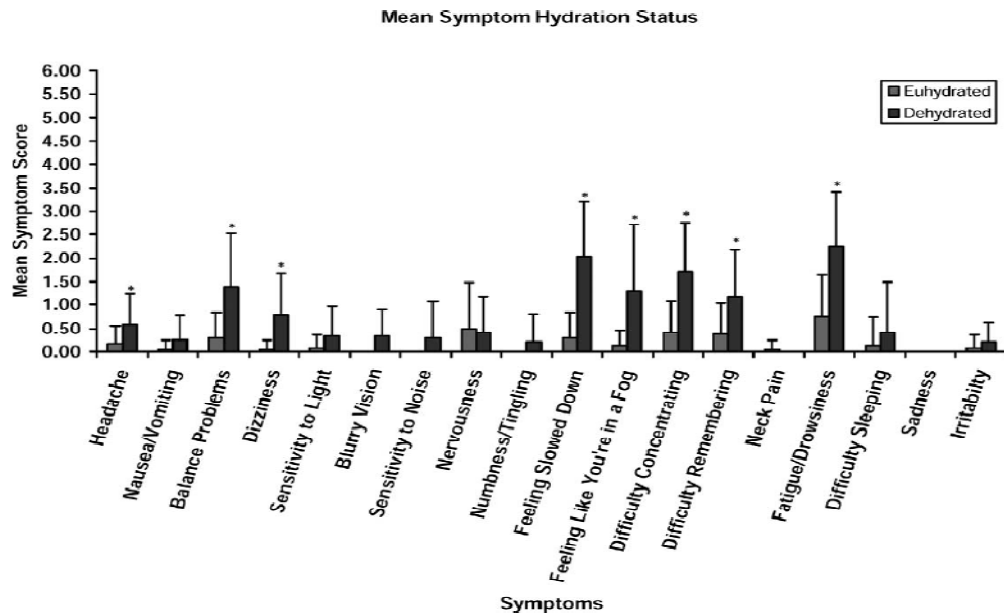
There was also a control group, and this included men who had “regular” physical training. The cyclist performed the following three exercises: first, cycling was done to determine VO<sub>2</sub>max; the second and third session consisted of three hours of cycling in a heat chamber (20-21 °C, 50 ± 5% humidity) corresponding to 60% of VO<sub>2</sub>max, either with fluid (F) or without fluid (NF). Even though a group was given fluid, unlike Gopinathan’s study the subjects were not controlled by percent dehydration. The cognitive testing was given at the following times: at rest, at each data collection point (every twenty minutes), and five minutes post exercise. Results showed no difference between the F and NF group, but cognitive function was decreased compared to the control group. <sup>29</sup>

Lieberman et. al examined cognitive function in thirty-one military volunteers. The testing took place over a five day span, activity consisting of military “duties” and exercises. This activity consisted of three phases: an in-garrison preparation phase (pre-field), a field exercise, and a concluding garrison phase (postfield). Measurements were taken once during each phase. During the field exercise, ambient temperature reached a maximum of 31 °C and a low of 19 °C. Morning humidity was approximately 86% , and afternoon humidity was about 56%. Unlike other studies, water was available to the subjects *ad libitum* . Dehydration was assessed through body mass changes. Results showed a significant difference of impaired cognitive function comparing the pre-test to

the field, and from the field test to the post test. Vigilance, reaction time, attention, memory and reasoning time were impaired ( $p < .001$ ).<sup>12</sup>

Another study was performed by Patel et al. Subjects were either euhydrated or dehydrated (<5% of body mass) and completed cycling exercise assignments. As shown with Gopinathan and Lieberman, similar performance results were found. The authors found decreased cognitive function in the matching-to-sample test, and the graded symptoms checklist only. The authors concluded that dehydration resulted in a decrease of visual memory and an increase in the self-reporting of fatigue<sup>13</sup>. (See Figure 7)

These studies show that dehydrated individuals do have a decrease in cognitive function. Most cognitive changes were seen when athletes were dehydrated to 2% or greater. The only significant factor is that these studies controlled for different variables, making true synthesis more of a challenge. However, there is a universal theme, and that is cognitive function is compromised when athletes are dehydrated  $\geq 2\%$ . The more dehydrated an athlete is, the more severe the cognitive impairments. This, again, supports how hydration is very important for athletics. At this point in time it is difficult to quantify how greatly cognition is affected by dehydration. The cognitive tests can show a decrement in function, but we have limited ways to be able to quantify those results.



**Figure 7.** Mean Graded Symptoms Checklist scores and hydration status. \* Significant difference between the dehydrated and euhydrated test conditions. \*\*Adapted from Patel et. al <sup>13</sup>

Cognitive Function	Reference	Condition	Results
Short term memory, visual motor tracking, attention, arithmetic efficiency	Gopinathan et al, 1988 <sup>14</sup>	1,2,3,4% dehydrated by exercising in heat	Impaired function $\geq 2\%$ dehydration
Perception of fatigue, perceived discrimination, short term memory, long term memory	Cian et al, 2000 <sup>30</sup>	2.8% dehydration by exercising in heat	Increased fatigue rating; discrimination, short-term and long term memory impaired
RPE, perceptual response, response speed	Grego et al, 2005 <sup>29</sup>	Group with fluid (F) given 400 ml of mineral water or no fluid (NF), plus control group	No difference between F and NF groups, but decrease in cognitive function compared to control group
Reaction time, vigilance, attention, pattern recognition, memory, reasoning	Lieberman et al, 2005 <sup>12</sup>	5 days consisting of military duties and activity	Impaired cognitive function from pre-test to field test, and from field test to post-test
Reaction time, mental speed/efficiency, visual memory, working memory, fatigue	Patel et al, 2007 <sup>13</sup>	Euhydrated and dehydrated (<5%) during exercise	Decreased function in matching-to-sample test and graded symptoms checklist only.

**Table 2.** Summary of Relevant Cognition Studies

## **Balance and Movement Testing**

For years, researchers have used expensive laboratory based motion analysis systems for investigating biomechanical risk to assess balance and movement. However, a study done in 2009 by Padua et al. showed that the Landing Error Scoring System (LESS) is a valid and reliable tool for identifying potentially high-risk movement patterns during a jump-landing task when comparing to the “gold standard”. The LESS utilizes two video camcorders and a force plate. The cameras are placed in a frontal and sagittal view. The ICC2,k and SEM values for interrater reliability were 0.84 and 0.71, respectively. These findings indicate that the LESS has good interrater reliability. Intrarater reliability for the LESS was excellent, as ICC2,1 and SEM values were 0.91 and 0.42, respectively.<sup>18</sup>

The LESS is a much more cost effective tool when compared to laboratory motion testing. LESS testing is also more convenient than laboratory motion testing. Force plates are able to be moved with some ease, making the LESS testing relevant in the clinical setting.

Another method to assess balance and movement is the Balance Error Scoring System (BESS). Riemann et al. recognized that force platforms are not available in many sports medicine settings, so the authors investigated the relationship between clinical (BESS) and force plate measures of postural stability. In this study, authors evaluated balance performance by using the BESS simultaneously with the force platform. Significant correlations ( $p \leq .05$ ) between the error scores from BESS and target sway measures from the force platform were found for all of the stances except for the double-leg stance on a firm surface, because subjects performed no errors on this

stance. The errors scores also had intertester reliability.<sup>31</sup> Therefore, the BESS can be used as a reliable measure for postural stability. However, the BESS has been shown to elicit a practice effect when frequently administered, therefore potentially creating a problem when it is repeatedly used to track recovery of athletes.



**Figure 8.** Demonstration of LESS jump-landing task.



**Figure 9.** Demonstration of BESS test. Firm surface; double leg, single leg, tandem. Foam surface; double leg, single leg, tandem.

Test	Equipment	Protocol	Practice Test	Scoring
LESS	Forceplate, video recorders (2), 30 cm tall box	Jump from a 30-cm high box to a distance of 50% of subject's height away from the box, down to a force platform, and immediately rebounded for a maximal vertical jump on landing	Yes	↑LESS score = poor technique in landing from a jump; ↓LESS score = better jump-landing technique. 17 scored items, use video recorder to assess landing
BESS	Foam pad, stop watch	Balance on floor and foam pad during stances: double leg, single leg, tandem	No	# of errors calculated; errors = hands lifted off iliac crest, opening eyes, step, stumble, or fall, moving hip into > 30 degrees abduction, lifting forefoot or heel, remaining out of test position >5 sec

**Table 3.** Comparison of Landing Error Scoring System (LESS) and Balance Error Scoring System (BESS).

### Fatigue Studies

Numerous studies have looked at the effects on fatigue on balance and posture. While not much research has been completed in the past using the LESS, the BESS test is commonly used. The method of achieving fatigue is variable for each study. A study completed by Nardone et al. assessed the body sway of thirteen young subjects by using a

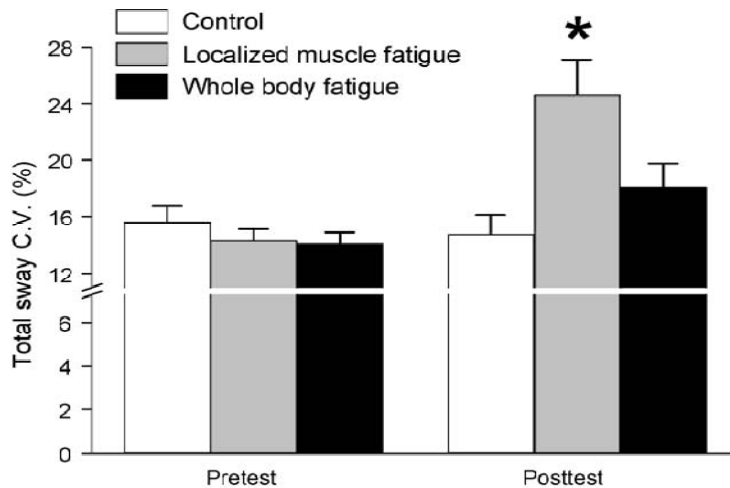


dynamometric platform. Body sway was measured with eyes open and eyes closed. The authors achieved fatigue by two methods, performed to volatile exhaustion: a treadmill exercise and cycle ergometer. There was a control group who did no exercise, and rested between the testing. The authors found a significant increase in body sway for both visual conditions in the treadmill exercise. However, they did not find any significant differences (only mild differences) in body sway during the ergometer exercises. They concluded that body sway increased after strenuous physical exercise, but was not significantly affected by non-fatiguing and cycling exercises. Results also showed that the effects on increased sway only lasted about 15 minutes.<sup>32</sup> Lepers et al. also examined the effects of body sway after exercise using a dynamic posturography. They found very similar results compared to Nardone; posture ability decreased after exercise. Again, a more significant difference was found with running as compared to cycling.<sup>33</sup>

Wilkins et al. performed a study in 2004 looking at the effects of whole body fatigue on performance of the BESS test. Fatigue was induced by a twenty minute fatigue protocol consisting of a circuit design (seven stations), or a rest period for the control group. Results showed a significant difference in BESS scores from pre testing to post testing in the fatigue group ( $14.36 \pm 4.73$  vs.  $16.93 \pm 4.32$ ).<sup>34</sup>

Two recent studies also showed similar results to Wilkins. Springer et al. and Fox et al. examined the effects of fatigue on balance. Springer examined local versus whole body fatigue, while Fox concentrated on whole body fatigue. Springer assessed balance with a force plate platform (assessing 10 repetitions of a 10 second single leg balance) while Fox used the BESS test. Results from Springer showed a significant increase in medial/lateral (M/L) and total body sway (TS). He also found that TS was higher after

localized fatigue as compared to whole body fatigue.<sup>35</sup> (See Figure 10) Fox found that subjects had less postural control after the exercise protocol, with both aerobic and anaerobic exercise. Results showed that measurements returned to baseline within 13 minutes after exercise.<sup>36</sup>



**Figure 10.** Total sway coefficient of variation (CV) mean ( $\pm$  SEM) prior to, and following, the localized muscle, and whole-body, and control protocols in healthy young adult men and women.

\*Adapted from Springer et al.<sup>35</sup>

These studies all demonstrate that fatigue does significantly affect balance and posture. An increase in errors and results are found with more strenuous exercise, compared to moderate exercise or no activity. While the longest duration for these effects to remain was only 15 minutes, it is still an important factor. This should be a key factor when assessing balance in a clinical setting. It would also be effective to repeat these studies including hydration elements, to assess the effects of these studies when coupled with dehydration. More research should also be completed utilizing the LESS test, as it is a valid and reliable measurement tool.

Reference	Subjects	Exercise	Method of Balance Assessment	Results	What This Means
Nardone et al. <sup>32</sup>	13, young healthy (6 males, 7 females 18-39 years)	Treadmill: Graded increase theoretical max heart rate reached Cycling: Same as above, but with a cycle ergometer Control: Maintained heart rate on treadmill to less than 60% max heart rate	Dynamometric Kistler Platform  Measured with eyes open and eyes closed	↑ in body sway under both visual conditions for treadmill  Ergometer showed mild postural changes, but no SD  Returned to baseline within 15 minutes	More exertional exercise affects balance/posture more than a lighter exercise
Lepers et. al <sup>33</sup>	Nine well trained subjects, including 5 triathletes	25 km run, plus 5 triathletes completed additional ergometer exercise (equal to run)	Instrumented platform system  (Sensory Organization Test)	↑ in posture change after exercise  Results showed a ↑ SD for posture with running (not cycling)	More exertional exercise affects balance/posture more than a lighter exercise
Wilkins et al. <sup>34</sup>	14 subjects (fatigue), 13 control	7 stations (circuit training)	BESS test	↑ in total errors in BESS from pre to post test for fatigue group, SD shown between groups	Balance/posture affected by circuit training exercise
Springer et al. <sup>35</sup>	20 healthy subjects (10 men, 10 women)	Fatigue: Single leg heel raises on raised platform, cycle ergometer to failure Control: Seated for 5 minutes	Single Force Platform	↑ in M/L and TS (postural stability)  Total sway variability ↑ with localized body fatigue	Balance/posture affected when fatigue it localized in a muscle compared to overall fatigue
Fox et al. <sup>36</sup>	36 college athletes (18 men, 18 women)	Indoor aerobic and anaerobic exercise (exertion measured by heart rate)	BESS test	↓ in postural control after exercise  Returned to baseline within 13 minutes	Both anaerobic and aerobic exercise affected balance/posture

**Table 4.** Summary of current studies: effects of fatigue on balance. SD = significant difference

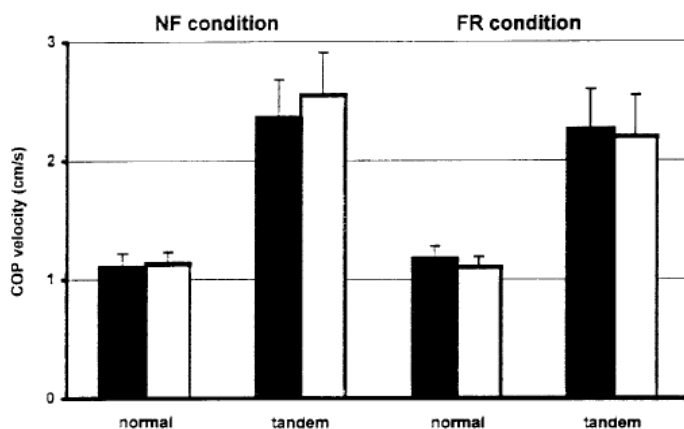
## **Balance and Movement Studies**

### Derave et al.

A study by Derave et al. had eight male subjects perform two cycling trials for two hours with either no fluid (NF) or with fluid replacement (FR, carbohydrate-electrolyte solution). To begin, subjects performed a graded exercise test to determine the workload during the experimental trials. Each experimental trial consisted of a two hour cycle exercise test at a workload at 60%  $\text{VO}_2\text{max}$  for the first hour. It was then decreased to 55%  $\text{VO}_2\text{max}$  for the second hour. If NF trial was first, subjects drank a fluid volume determined from body mass loss from the NF trial. If the FR trial was first, subjects drank 1.9 liters of a 6% carbohydrate-electrolyte solution.

Postural sway was measured by posturography before and 20 minutes after exercise. A Kistler force platform was used to measure posturography. Mean velocity of the center of pressure (COP) was used to determine postural sway. Eight other subjects also completed a sauna protocol to determine the effects of thermal dehydration on postural stability. In this protocol, subjects performed alternating periods of sitting in a sauna for 15 minutes and then 10 minutes of sitting in a thermo-neutral environment. After each time in the sauna, subjects were allowed to take a cold shower, but not allowed to drink during the trial. Posturography was measured after 30 minutes of rest at room temperature. Subjects were instructed to stand as still as possible for 30 seconds in two different stances. One position was designated as normal, with feet parallel to one another. The other was designated as tandem, which consisted of one foot in front of the other, heel to toe. Both positions were completed with the eyes open. Subjects in the sauna protocol only measured posture in the normal stance, but performed the test with eyes open and eyes closed.

Subjects receiving fluid replacement only lost  $0.5 \pm 0.5\%$  of body mass while those receiving no fluid lost up to  $2.7 \pm 0.4\%$  of body mass. The subjects who were in the sauna had a mean body mass loss of  $3.0 \pm 0.6\%$ . Rating of perceived exertion and heart rate were higher in the NF trials when compared to the FR trial. Posturography results show that the tandem had the biggest effect on stability. As seen in Figure 11, postural sway (as denoted on graph as COP velocity) was larger while subjects were in the tandem stance when compared to the normal stance ( $p < 0.05$ ). Also, postural sway was higher after exercise for the NF condition when compared to the FR condition ( $p < 0.05$ ). In the sauna experiment, no effect was seen from the hydration level, but there was a difference between eyes open and eyes closed.<sup>15</sup>



**Figure 11:** Mean velocities (n=8, SD) of COP excursion in normal and tandem foot positions before (filled bars) and after (empty bars) 2-h cycling exercise without (NF condition) and with (FR condition) fluid ingestion.

\* Adapted from Derave et al.<sup>15</sup>

The authors have shown that fluid intake affects postural stability after exercise. Subjects had increased postural stability in the fluid replacement trial when compared to the no fluid trial. Results showed that subjects who had no fluid replacement while standing in the tandem stance had the biggest decrease in postural stability (16% difference). The authors also looked at the balance effects of dehydration from a sauna

and found no significant decreases in postural stability. Because of the results from the sauna trial and NF trial, the authors hypothesize that drinking to prevent fatigue is more important than simple fluid replacement.<sup>15</sup>

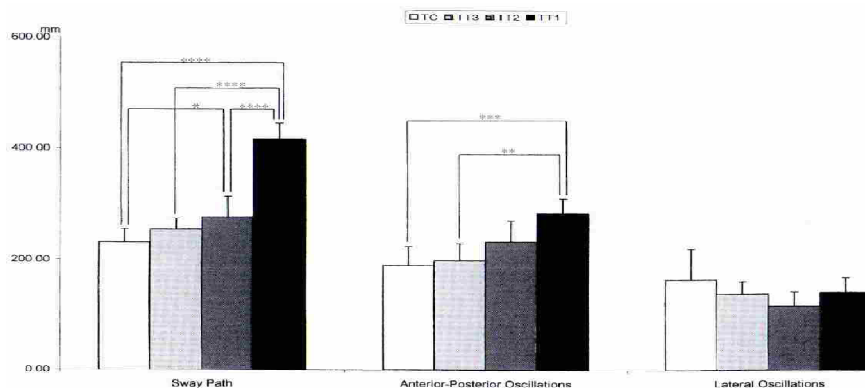
#### Gauchard et al.

Gauchard et al. used ten male subjects in this study. The participants regularly participated in physical and sport activities, and performed three cycling trials for the testing on a cycle ergometer. The first trial (T1) measured  $\text{VO}_2\text{max}$  by increasing the intensity 20 watts every minute until the subject was exhausted (about an average of 15 minutes). The second and third trial consisted of 45 minutes of cycling with either no hydration (T2) or hydration (T3 – 20 mL of water every 5 minutes). Subjects cycled at approximately 60% of their individual  $\text{VO}_2\text{max}$ . Subjects performed six, static posturographic tests before and immediately after each exercise trial. A vertical force platform measured the displacement of the center of foot pressure to describe body sway. Subjects were instructed to remain as stable as possible with their feet 30° apart while their eyes were open and again when they were closed.

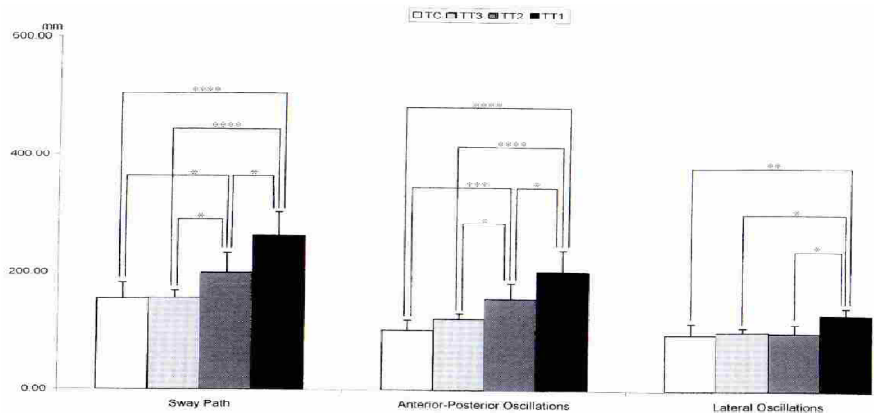
As seen in Figures 12 and 13, significant differences occurred between pre-exercise values and both T1 and T2. Significant differences were also seen between each of the trials. Anterior-posterior (AP) oscillations had greater differences during post-exercise tests when compared to lateral oscillations. Subjects also had higher posturographic values while standing with their eyes closed compared to having their eyes open.

The authors found that hydration level has a significant effect on postural control. The authors used fluid restriction and exercise to induce dehydration and measure

posturographic changes post-exercise. However, the authors did not report changes in body mass loss. The best results from the trial were found in the control group. Hydrated, dehydrated, and  $VO_{2\max}$  were the remaining order, showing that  $VO_{2\max}$  showed the worst postural control. The authors conclude that since dehydration is known to impair muscle function during exercise, this is the cause of the differences seen between the fluid replacement and no fluid group. The results show that balance is affected by both dehydration and exercise. The results also show that balance can be influenced by fatigue alone, as seen in the increased postural sway following exercise in the hydrated group, although it was not a significant increase.



**Figure 12:** Mean posturographic results, topped by SD, of sway path, A-P and lateral oscillations, eyes closed; before ergocycle test (**Tc – white bars**), after  $VO_{2\max}$  (**T<sub>T1</sub> – black bars**), no hydration (**T<sub>T2</sub> – dark gray bars**), and hydration (**T<sub>T3</sub> – light gray bars**). \* $p \leq 0.05$ , \*\* $p \leq 0.01$ , \*\*\* $p \leq 0.001$ , \*\*\*\* $p \leq 0.0001$ .



**Figure 13:** Mean posturographic results, topped by SD, of sway path, A-P and lateral oscillations, eyes open; before ergocycle test (**Tc – white bars**), after  $VO_{2max}$  (**T<sub>T1</sub> – black bars**), no hydration (**T<sub>T2</sub> – dark gray bars**), and hydration (**T<sub>T3</sub> – light gray bars**). \* $p \leq 0.05$ , \*\* $p \leq 0.01$ , \*\*\* $p \leq 0.001$ , \*\*\*\* $p \leq 0.0001$ .

\* Both adapted from Gauchard et al.<sup>16</sup>

### Patel et al.

Patel et al. also investigated the effects of dehydration on postural stability by having twenty-four male recreational athletes participate in this study. This study included a euhydrated and a dehydrated (passive and active) trial. During the dehydrated trial, subjects were restricted from ingesting fluids 15 hours prior to the beginning of the trial. Subjects performed a 45 minute cycling task at 65-70% of their maximal heart rate (Karvonen). After exercise, subjects rested for 25 minutes. During the rest, they also



were weighed and gave a urine sample to assess hydration level. Subjects had a mean negative body mass change of  $2.50 \pm 0.63\%$  and a mean urine specific gravity of  $1.025 \pm 0.0004$ . Subjects in the euhydrated trial did not perform the same exercise protocol as the dehydrated trials. After the rest period for the dehydrated group and after the euhydrated group arrived for testing, subjects' postural stability was measured using the BESS and the NeuroCom Sensory Organization Test (SOT). The SOT uses dual force plates and uses 18 trials under six conditions to measure postural stability in relation to the visual, somatosensory, and vestibular domains. An additional aspect of the study also had subjects perform tests related to side-line concussion evaluation.

Results show no significant impairment on the SOT for those in the dehydrated condition. However, dehydrated subjects had a statistically significant increase in performance on the somatosensory condition when compared to the euhydrated condition. The authors also report no significant impairment of the BESS total scores or between stances or surfaces for those subjects in the dehydrated trial (See Table 5).

	Mean	SD	<i>t</i>	<i>P</i>
Total error score				
Euhydrated	8.29	4.07		
Dehydrated	8.83	4.31	-0.805	.429
Firm surface				
Double-leg stance				
Euhydrated	0.00	0.00		
Dehydrated	0.00	0.00		
Single-leg stance				
Euhydrated	1.25	1.62		
Dehydrated	1.25	1.29	0.000	1.000
Tandem stance				
Euhydrated	0.33	0.76		
Dehydrated	0.58	0.83	-1.446	.162
Foam surface				
Double-leg stance				
Euhydrated	0.00	0.00		
Dehydrated	0.00	0.00		
Single-leg stance				
Euhydrated	4.50	1.87		
Dehydrated	4.46	1.41	0.132	.896
Tandem stance				
Euhydrated	2.21	1.38		
Dehydrated	2.54	2.11	-0.891	.382

**Table 5:** Balance Error Scoring System Means and Standard Deviations (n = 24).

\* Adapted from Patel et al.<sup>13</sup>

In this study, the authors have found no differences between the euhydrated and dehydrated trials for the SOT or BESS. However, the table above does show slight decreases in performance on the tandem stance on the BESS, but it is not statistically significant. The lack of significant differences may have occurred because of the 25 minute rest period after performing the exercise task because, as noted above, balance normally returns to baseline levels after 15 minutes.<sup>13</sup>

#### McKinney et al.

McKinney et al. also examined the effects of dehydration during exercise performed in a hot and humid environment. Ten subjects, including seven men and three women, performed a heat stress exercise session which resulted in a  $3.03 \pm 0.34\%$  mean body mass loss. Subjects performed the double-leg, single-leg, and tandem stances on stable and unstable surfaces for the BESS before (euhydrated condition) and after (dehydrated condition) performing the exercise task. However, repeated balance assessment allowed core temperature to return to baseline levels due to the recovery period, which lasted a mean of  $44.00 \pm 13.70$  minutes. The BESS was used to determine total balance errors scores (TBES) and stance error scores (SES).

The authors found a significant increase in errors in the subjects that were dehydrated. TBES increased 21.5% in the dehydrated condition, while TBES increased 57.5% while subjects were on the unstable surface compared to the stable surface. SES showed a significant increase in errors during the dehydrated-unstable surface condition

and the single-leg-unstable surface condition. The authors suggested that the increase in errors was due to decreased proprioceptive sensitivity and a change in posture from dehydration.<sup>37</sup>

#### Eberman et al.

Eberman et al. examined the effects of active dehydration on ten healthy, active subjects. The exercise task involved a treadmill exercise at a moderate intensity in a warm, humid environment. The exercise task aimed to induce a mean body mass loss of  $3.03 \pm 0.35\%$ . Subjects then performed the balance task by standing on the dominant leg using the Biodex Balance System. Pre-exercise values were considered the euhydrated trial, while post-exercise values were the dehydrated trial. Stability index (OSI), anterior/posterior stability index (APSI), and medial/lateral stability index (MLSI) were taken to measure balance.

The authors found no significant differences between the subjects who were dehydrated or euhydrated for OSI, APSI, and MLSI. However, they found that OSI and APSI were higher in the dehydrated condition.<sup>17</sup>

While there is a noticeable trend towards the concept that dehydration negatively affecting balance, not every study shows similar results. The research by Derave, Gauchard, and McKinney all found significant decreases in balance when comparing the hydrated conditions to the dehydrated conditions. However, Patel and Eberman were not able to find significant differences in balance between the hydrated and dehydrated trials.

These contradictory findings may have occurred simply because the methodologies of the trials were not similar.

Fatigue is known to have a significant effect on balance, as described earlier. A few of the studies utilized strenuous activity, while others used moderate activity. This may have a significant role on the differences outcomes that were found. Also, recovery period may be a factor as well. While Patel found no significant difference in balance deficit without a recovery period, Derave and McKinney included recovery periods and still saw no significant difference.

In addition, while these studies assess balance and postural stability in relation to dehydration, there is relatively little information about the effect of dehydration on movement (as measured by the LESS). Further research is needed to investigate this concept.

Reference	Subjects	Exercise Task	Fluid Replacement	Body Mass Change	Balance Test	Effect on Balance Ability?
Derave et al. <sup>15</sup>	8 healthy, males for exercise task – age = 19-24 yrs; 8 males for sauna sessions – age = 19-22 yrs	2-hour cycling at 57-63% VO <sub>2max</sub> ; seven 15-min sauna (85°C, 50% RH) sessions alternated with 10-min recovery in thermo-neutral environment	Performed exercise with NF or with FR (6% carbohydrate-electrolyte solution); sauna sessions had no FR	NF = 2.7 ± 0.4% FR = 0.5 ± 0.5% Sauna = 3.0 ± 0.6%	Measured velocity (cm/s) of COP on force platform before and 20-min after exercise - normal stance (both feet parallel) and tandem stance (one foot in front of other – heel to toe) 30-min after sauna session – normal stance, eyes open and closed	↑ in velocity of COP after exercise in NF compared to FR No effect after sauna sessions ↑ in velocity in tandem stance compared to normal stance
Gauchard et al. <sup>16</sup>	10 males; regularly practice physical and sporting activities; age = 24.5 ± 2.8 yrs	VO <sub>2max</sub> measurement to exhaustion (average 15-min), 45-min at 60% VO <sub>2max</sub> – all cycling	Subjects performed 45-min cycling task in both hydration and no hydration trials	Not reported	Posturographic tests on vertical force platform – measuring CFP – before and immediately after exercise Normal stance	↑ body sway after exercise, especially when dehydrated Best to worst: control (pre-exercise), hydrated, dehydrated, VO <sub>2max</sub>
Patel et al. <sup>13</sup>	24 male, recreational athletes; age = 21.92 ± 2.95 yrs	Dehydrated - 45-min cycling at 65-70% max HR Euhydrated – no exercise task	Subjects in dehydrated condition restricted from fluids for 15 hours prior to trial; no fluid consumed during exercise or while performing balance testing measures	Dehydrated – 2.5 ± 0.63%	BESS (double-leg, single-leg, and tandem on firm and foam surfaces); SOT – both were measured 25-min after exercise task for dehydrated trial	No statistically significant effects; slight decrease in performance during tandem stance of BESS
McKinney et al. <sup>37</sup>	10 (7 men, 3 women) – age = 25.2 ± 4.7 yrs	Heat stress exercise session in warm, humid environment (27.9 ± 0.7°C, RH = 50.0 ± 8.8%)	No fluid given during exercise	3.03 ± 0.34%	Balance measured before (euhydrated) and after a recovery period (dehydrated) following exercise using BESS	↑ in total errors in dehydrated condition ↑ in errors on foam surface
Eberman et al. <sup>17</sup>	10 active volunteers (7 men, 3 women) – age = 25.2 ± 4.7 yrs	Moderate intensity treadmill exercise in warm, humid environment (27.9 ± 0.7°C, RH = 50.0 ± 8.8%)	No fluid given during exercise	3.03 ± 0.35%	Balance measured before (euhydrated) and after (dehydrated) exercise on Biodex Balance System measuring OSI, APSI, MLSI	No significant differences between euhydrated and dehydrated on OSI, APSI, and MLSI Trend toward ↓ OSI as a result of ↓ control in A/P direction

**Table 6:** Summary of current balance/dehydration studies. VO<sub>2max</sub> = maximal oxygen uptake, RH = relative humidity, NF = no fluid, FR = fluid replacement, COP = center of pressure, OSI = overall stability index, APSI = anterior/posterior stability index, MLSI = medial/lateral stability index, CFP = center of foot pressure, BESS = Balance Error Scoring System, HR = heart rate, SOT = Sensory Organization Test \*Adapted from Jensen et al.

**Figure 14. Theoretical Figure for the Influence of Dehydration and Fatigue on Balance, Cognition, and Injury Risk**

<b>Factors That Affect</b>	<b>Movement</b>	<b>Cognition</b>
Hyperthermia	?	↑
Dehydration	↑	↑↑
Fatigue	↑↑	↑



<b>Factors That May Affect Injury Risk:</b>	
Hyperthermia	?
Dehydration	?
Fatigue	↑↑
Dehydration + fatigue	?

**Key:**

↑↑ = strong evidence

↑ = evidence indicates, but research not as strong

? = do not know

**Conclusion**

The purpose of this literature review is to examine the effects of dehydration and fatigue on movement, balance, and cognition. Decreased balance has been linked to an increase in injury risk. In most of the the studies where dehydration leads to a decrease in balance, it is usually paired with the component of fatigue. This being true, there is still uncertainty if dehydration alone can affect balance, movement, and cognition. There is also still a gap in the literature regarding cognitive testing, as results of many different studies with unsimilar settings and controls. In the future, it would be beneficial to be able to understand if dehydration and fatigue are factors for an increased risk of injury. Further research still needs to be completed to fully understand these concepts and the contributing factors.

1. Casa DJ, Clarkson PM, Roberts WO. American college of sports medicine roundtable on hydration and physical activity: Consensus statements. *Curr Sports Med Rep*. 2005;4:115-127.
2. Gonzalez-Alonso J, Mora-Rodriguez R, Below PR, Coyle EF. Dehydration markedly impairs cardiovascular function in hyperthermic endurance athletes during exercise. *J Appl Physiol*. 1997;82:1229-1236.
3. Sawka MN, Montain SJ, Latzka WA. Hydration effects on thermoregulation and performance in the heat. *Comp Biochem Physiol A Mol Integr Physiol*. 2001;128:679-690.
4. Sawka MN. Fluid balance and replacement in the heat. (abstract). In: *In International Paralympic Committee, Pushing the Limits: Congress Program and Abstract Book, [Sydney], [International Paralympic Committee], 2000, p.52*. Australia: ; 2000.
5. Murray B. Hydration and physical performance. *J Am Coll Nutr*. 2007;26:542S-548S.
6. Montain SJ, Coyle EF. Influence of graded dehydration on hyperthermia and cardiovascular drift during exercise. *J Appl Physiol*. 1992;73:1340-1350.
7. National athletic trainers' association: Position statement - fluid replacement for athletes. A summary of practical applications. *Texas Coach*. 2003;48:30-31.
8. Noakes TD, Adams BA, Myburgh KH, Greeff C, Lotz T, Nathan M. The danger of an inadequate water intake during prolonged exercise. A novel concept re-visited. *Eur J Appl Physiol Occup Physiol*. 1988;57:210-219.
9. Judelson DA, Maresh CM, Anderson JM, et al. Hydration and muscular performance: Does fluid balance affect strength, power and high-intensity endurance? *Sports Med*. 2007;37:907-921.
10. Judelson DA, Maresh CM, Farrell MJ, et al. Effect of hydration state on strength, power, and resistance exercise performance. *Med Sci Sports Exerc*. 2007;39:1817-1824.
11. Mudambo KS, Leese GP, Rennie MJ. Dehydration in soldiers during walking/running exercise in the heat and the effects of fluid ingestion during and after exercise. *Eur J Appl Physiol Occup Physiol*. 1997;76:517-524.
12. Lieberman HR, Bathalon GP, Falco CM, Kramer FM, Morgan CA, 3rd, Niro P. Severe decrements in cognition function and mood induced by sleep loss, heat, dehydration, and undernutrition during simulated combat. *Biol Psychiatry*. 2005;57:422-429.

13. Patel AV, Mihalik JP, Notebaert AJ, Guskiewicz KM, Prentice WE. Neuropsychological performance, postural stability, and symptoms after dehydration. *J Athl Train*. 2007;42:66-75.
14. Gopinathan PM, Pichan G, Sharma VM. Role of dehydration in heat stress-induced variations in mental performance. *Arch Environ Health*. 1988;43:15-17.
15. DERAIVE W, DE CLERCQ ,D., BOUCKAERT J, PANNIER JL. The influence of exercise and dehydration on postural stability (influence de l'exercice et de la deshydratation sur la stabilite posturale). *Ergonomics*. 1998;41:782-789.
16. Gauchard GC, Gangloff P, Vouriot A, Mallie JP, Perrin PP. Effects of exercise-induced fatigue with and without hydration on static postural control in adult human subjects. *Int J Neurosci*. 2002;112:1191-1206.
17. Eberman LE, Cleary MA, Butcher-Mokha M, McKinney J. Effects of active dehydration on balance in normothermic participants. (abstract). *Journal of Athletic Training*. 2005;40:S-14.
18. Padua DA, Marshall SW, Boling MC, Thigpen CA, Garrett WE,Jr, Beutler AI. The landing error scoring system (LESS) is a valid and reliable clinical assessment tool of jump-landing biomechanics: The JUMP-ACL study. *Am J Sports Med*. 2009;37:1996-2002.
19. American College of Sports Medicine, Sawka MN, Burke LM, et al. American college of sports medicine position stand. exercise and fluid replacement. *Med Sci Sports Exerc*. 2007;39:377-390.
20. Sawka MN, Young AJ, Francesconi RP, Muza SR, Pandolf KB. Thermoregulatory and blood responses during exercise at graded hypohydration levels. *J Appl Physiol*. 1985;59:1394-1401.
21. Ekblom B, Greenleaf CJ, Greenleaf JE, Hermansen L. Temperature regulation during exercise dehydration in man. *Acta Physiol Scand*. 1970;79:475-483.
22. Gisolfi CV, Copping JR. Thermal effects of prolonged treadmill exercise in the heat. *Medicine & Science in Sports*. 1974;6:108-113.
23. McConell GK, Burge CM, Skinner SL, Hargreaves M. Influence of ingested fluid volume on physiological responses during prolonged exercise. *Acta Physiol Scand*. 1997;160:149-156.
24. Casa DJ, Stearns RL, Lopez RM, et al. Influence of hydration on physiological function and performance during trail running in the heat. *J Athl Train*. 2010;45:147-156.



25. Judelson DA, Maresh CM, Anderson JM, et al. Hydration and muscular performance: Does fluid balance affect strength, power and high-intensity endurance? *Sports Medicine*. 2007;37:907-921.
26. Baker LB, Dougherty KA, Chow M, Kenney WL. Progressive dehydration causes a progressive decline in basketball skill performance. *Med Sci Sports Exerc*. 2007;39:1114-1123.
27. Casa DJ, Armstrong LE, Hillman SK, et al. National athletic trainers' association position statement: Fluid replacement for athletes. *J Athl Train*. 2000;35:212-224.
28. Noakes TD. Food and fluid intake and disturbances in gastrointestinal and mental function during an ultramarathon. *Int J Sport Nutr Exerc Metab*. 2004;14:249-52; author reply 252-4.
29. Grego F, Vallier JM, Collardeau M, Rousseu C, Cremieux J, Brisswalter J. Influence of exercise duration and hydration status on cognitive function during prolonged cycling exercise. *Int J Sports Med*. 2005;26:27-33.
30. Cian C, Koulmann N, Barraud PA, Raphel C, Jimenez C, Melin B. Influences of variations in body hydration on cognitive function: Effect of hyperhydration, heat stress, and exercise-induced dehydration. *Journal of Psychophysiology*. 2000;14:29-36.
31. Riemann BL, Guskiewicz KM, Shields EW. Relationship between clinical and forceplate measures of postural stability. *J Sport Rehab*. 1999;8:71-82.
32. Nardone A, Tarantola J, Giordano A, Schieppati M. Fatigue effects on body balance. *Electroencephalogr Clin Neurophysiol*. 1997;105:309-320.
33. Lepers R, Bigard AX, Diard JP, Gouteyron JF, Guezennec CY. Posture control after prolonged exercise. *Eur J Appl Physiol Occup Physiol*. 1997;76:55-61.
34. Wilkins JC, Valovich McLeod TC, Perrin DH, Gansneder BM. Performance on the balance error scoring system decreases after fatigue. *J Athl Train*. 2004;39:156-161.
35. Springer BK, Pincivero DM. The effects of localized muscle and whole-body fatigue on single-leg balance between healthy men and women. *Gait Posture*. 2009;30:50-54.
36. Fox ZG, Mihalik JP, Blackburn JT, Battaglini CL, Guskiewicz KM. Return of postural control to baseline after anaerobic and aerobic exercise protocols. *J Athl Train*. 2008;43:456-463.
37. McKinney JL, Eberman LE, Cleary MA, Lopez R. Effects of dehydration on balance as measured by the balance error scoring system. (abstract). *Journal of Athletic Training*. 2005;40:S-14-s-15.

## Introduction

During exercise in the heat, it is known that hydration, body temperature, and fatigue have significant roles on the functions in the body. An overwhelming majority of laboratory studies conclude that dehydration, hyperthermia, and fatigue have a negative influence on the body's physiology.<sup>1-7</sup> Hydration and fatigue separately have been shown to have an effect on performance, cognition, and balance.<sup>8-13</sup> As little as 2% dehydration can have a significant impact on the body's function and performance. Thermoregulatory research studies have also shown that hyperthermia imposes a thermoregulatory stress on the body, decreasing performance, muscle metabolism, and cognitive ability. Core body temperature has been shown as the strongest limiting factor of performance in the heat. In untrained subjects, core temperature at exhaustion from heat strain alone has been clearly shown to occur over 38°C.<sup>14</sup>

In many laboratory and field studies, it is difficult to isolate certain variables that affect physiology, therefore leading to conclusions in research that may be lacking in strength. For example, a researcher may have a subject exercise in the heat to cause fatigue, but this will also subsequently result in hyperthermia. This may be a reason that is responsible for some of the discrepancies that are seen throughout the literature. While much is known about dehydration, hyperthermia, and fatigue and their effects on the body, there are very few studies, if any, that have directly looked at these three factors together.

Additionally, there is no research to date performed on the effects of dehydration or hyperthermia on movement patterns. Fatigue has been shown to alter stop-jump tasks and therefore increase risk for noncontact Anterior Cruciate Ligament injuries.<sup>15</sup>

Additional research has also shown that poor movement patterns can cause an increase in an individual's risk of injury.<sup>16</sup> If it is known that dehydration, hyperthermia, and fatigue individually decrease performance, cognition, and balance, would the combined effect be enough to alter movement patterns and put an individual at an even higher risk for injury? Since there is little knowledge about the effects of dehydration, hyperthermia, and/or fatigue and their effects on movement patterns, research needs to be conducted to further investigate this topic. If identifiable factors leading to injury can be prevented, this will be an important addition to the literature.

### **Purpose**

The purpose of the study is to look at the individual and combined effects of dehydration, hyperthermia, and fatigue on movement patterns and cognition. Secondly, do the effects of dehydration, hyperthermia, and fatigue lead to a combined increase in injury risk? This study is unique because we are truly able to isolate factors such as dehydration, hyperthermia, and fatigue. We will also be able to answer questions on the additive effects of these factors on movement, and cognition. The theoretical graph below clearly illustrated the need for this study, as the question marks indicate areas of research that is still unknown.

### **Dependent Variables**

Landing Error Scoring System Score (movement pattern)

Psychomotor Vigilance Testing and Profile of Mood State Score (cognition)

## **Independent Variables**

Hydration

Hyperthermia

Fatigue

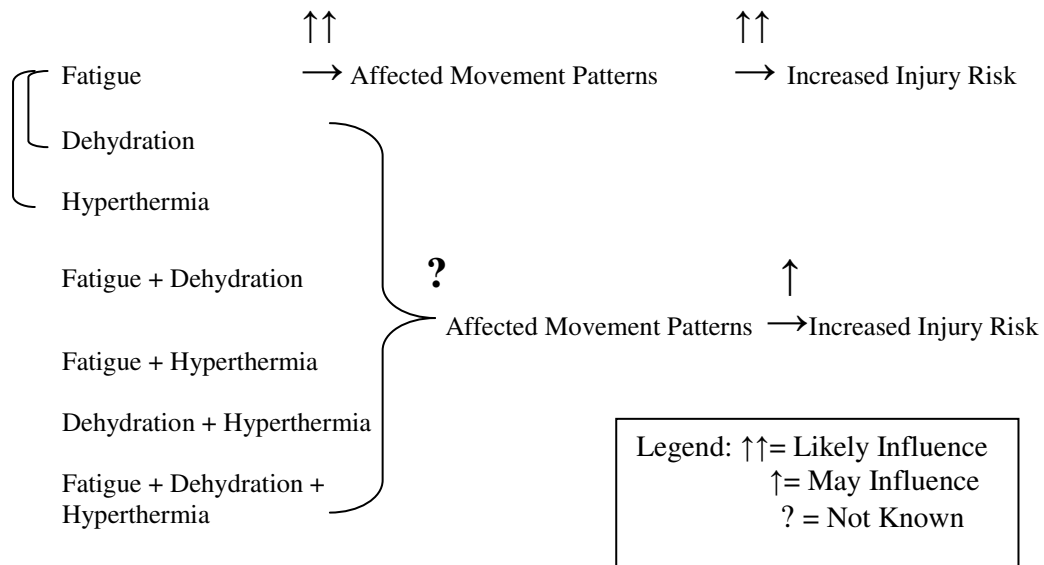
Time of Testing (Pre, Post, Recovery)

## **Research Questions:**

- Do the effects of dehydration, hyperthermia, and fatigue affect movement and cognition more so than each component individually?
- Is time of testing a factor for movement patterns?
- What are the effects of these variables on cognitive testing?
- Does cognitive testing have an influence on movement patterns?
- Does hyperthermia affect injury risk? Does hydration status affect injury risk? Does fatigue affect injury risk?

**Hypothesis:** I believe that dehydration, hyperthermia, and fatigue will lead to a decrease in performance of movement and cognition testing. As a combined effect of the three variables, I believe we will see an even greater decrement in performance of these tasks. Ultimately, hyperthermia, dehydration and fatigue will lead to an increase in injury risk.

**Figure 1. Theoretical Framework for the Influence of Dehydration, Hyperthermia, & Fatigue on Movement Patterns & Injury Risk**



## Methods

### Experimental Design

We used a within-subject repeated measures design to study the effects of hyperthermia, dehydration and fatigue on movement and cognition. Subjects performed a 90-minute standardized exercise protocol and assessment battery for movement and cognitive measures in four conditions in a randomized order. The four test conditions are listed in Table 1. Movement and cognitive testing were performed three times during each test session: pre-exercise (pre-test), post-exercise (post-test), and after a 60 minute recovery session (recovery). The pre-test and post-test assessments occurred within ten minutes of beginning and ending the exercise protocol, respectively. This study took place in the Human Performance Laboratory (HPL) at the University of Connecticut, which contains a thermal physiology laboratory complete with a climatic chamber (Model 2000, Minus Eleven, Inc., Malden, MA).

**Table 1. Hydration and Thermal Conditions of Exercise Protocol**

<b>Condition</b>	<b>Abbreviation</b>
Hydrated, Normothermic	HyN
Dehydrated, Normothermic	DehyN
Hydrated, Hyperthermic	HyHot
Dehydrated, Hyperthermic	DehyHot

### Subjects

Twelve healthy un-acclimatized adults (18-39 years) from the local university and community volunteered for this study. All subjects participated in minimal exercise/activity at least 6 hours per week at a moderate intensity (beyond walking pace). Individuals were included in the study if they had no chronic health problems, no history of cardiovascular, metabolic, or respiratory disease, fever or other current illness at the

time. Subjects needed to have a  $\text{VO}_{2\text{max}}$  of at least 50ml/kg/min. Subjects were asked to be English language speakers due to some of the cognitive tests performed. Also the age range of 18-39 years was utilized due to the desired practical applications of the elite athletic field and military settings of which the majority those subjects fall. Activity level and  $\text{VO}_2$  max were specified because we wanted individuals that would be able to handle the intense physical strains of this experiment.

Exclusion criteria included: previously experienced exertional heatstroke or heat exhaustion within the past 3 years, current use the drugs ibuprofen or Aleve, had a musculoskeletal injury at the time of testing, had a chronic disease or eating disorder, were on a diet (restricted calories) at time of study, previous knee/ankle surgery which could potentially interfere with movement patterns. We excluded women due to their natural hormonal fluctuations, which could have affected our hydration measures and possibly core body temperature. All subjects completed informed consent forms, which were approved by the Institutional Review Board at the University of Connecticut prior to completing any test or familiarization sessions.

### **Test Procedures**

Subjects attended six sessions which included two familiarization days and four test sessions that differed based on the test condition of the participant. The four test sessions were separated by at least two days, which allowed the subjects complete recovery from the previous session.

### *Familiarization Sessions:*

The familiarization trials included instruction on the use and insertion of a rectal thermometer, fitting a heart rate monitor, and walking on the treadmill at a standard speed (3.0 mph-4.0 mph) and incline (5%) for 15 minutes while carrying a standard 45lb pack. This pack was used to replicate the standard pack commonly issued in military scenarios. It was packed with materials similar to what a soldier in the military would use: flashlights, radio, clothing, first aid kit, clothes, and such items. Subjects were weighed prior to the familiarization session (using a calibrated scale to the 0.1kg) and also post exercise to determine sweat rate via body mass change. To ensure euhydration prior to familiarization sessions, subjects were asked to consume 500ml of fluid before going to sleep the night before and upon waking. Hydration status was measured upon arrival to the HPL via urine specific gravity ( $U_{sg} \leq 1.020$ ) and/or urine color ( $U_{color} \leq 4$ ). Subjects were then instructed on the correct procedures for the movement assessment portion of the trial and asked to perform two correct attempts. Subjects also had a demonstration of the cognitive testing procedures and instruction on the correct protocol for completion of these tests. Subjects were instructed on the use of the thirst, thermal sensation, and rating of perceived exertion (RPE) scales. During the first familiarization trial subjects were asked to perform a  $VO_2$ max test in order to ensure sufficient physical fitness ( $VO_2$  max must be  $\geq 50$  mL/kg/min). During these familiarization sessions, percent body fat was calculated using skin fold calipers.

### *Testing Sessions:*

Several physiologic measures were collected and recorded during each of the four



sessions: baseline mass, height, urine specific gravity, urine color, rectal temperature, heart rate (HR) and a perceptual scale (rating of perceived exertion, RPE) prior to the exercise protocol. The exercise protocol consisted of 90-minutes of walking on a treadmill at 3.0-4.0 mph at a 5% incline. Speed was determined during the familiarizations, according to what speed felt comfortable for each subject. This same speed was used for all four sessions. During exercise, subjects wore the described 45 pound military pack. During this time perceptual scale, heart rate, rectal temperature assessment were measured every 15 minutes. Post-exercise measures included: movement assessments and a cognitive testing session. For a flow chart of the testing sessions, see Figure 2.

#### *Temperature Assessment*

All subjects were instructed on insertion of a rectal thermometer for the purposes of attaining rectal temperature assessment throughout the exercise sessions. The thermistor was inserted 10cm into the anal sphincter to ensure that it stay in place the entire trial and correctly measure body temperature.

#### *Ratings of Perceived Exertion (RPE)*

Subjects were asked every fifteen minutes of exercise their perceived exertion level by asking the question, “How hard are you working right now?”. A sheet was held in front of them with numbers 6-20 along with word descriptions from “not hard at all” to “Extremely hard”. Subjects were asked to point or speak a number, to rate their level of

exertion, which was repeated back to them by the researcher to ensure correct data collection.

#### *Heart Rate (HR)*

Subjects were fitted with a chest strap Polar heart rate monitor before each testing session, and it remained on them until the entire session was complete and they were dismissed from the HPL. Every fifteen minutes the researcher used a Polar wrist watch receiver that read the subject's heart rate and recorded that number.

#### *Urine Osmolality*

Hydration status was confirmed by using urine osmolality. The sample was taken from the subject before and after the exercise sessions. Urine osmolality was determined via freezing-point depression using an osmometer.

#### *Body Mass Change*

Body mass change was assessed at the beginning and end of each session. After subjects gave a urine sample, they were dressed with a rectal thermometer and had their heart rate monitor on, they removed socks, shoes and shirt for a pre-exercise weight. Once the subjects completed the entire session, they again removed their socks, shoes and shirts and were weighed again (with all equipment on). This was done before the final urine sample.

Sixty minutes after the completion of the exercise bout subjects were asked to

repeat the movement assessment and the cognitive testing session for a third time. This rest period allowed the potential confounding influence of fatigue to be removed. Subject wore a water-perfused suit during this time to maintain a rectal temperature (based on thermal condition). All subjects completed the four test sessions in four counterbalanced conditions. During the hydrated conditions, subjects consumed fluids every 15 minutes in equal boluses during exercise according to the calculated sweat rate and were restricted from fluid during the 60 minute recovery period.

Chamber conditions for each trial depended on if the subject is participating in a hyperthermic or normothermic condition and were performed as follows, as well as estimated finishing temperature:

<b>Trial</b>	<b>Temperature</b>	<b>Humidity</b>	<b>Core Body Temp Range</b>
Normothermic	65°F	50%	100-102.5°F
Hyperthermic	95°F	50%	102.5-104°F

### **Dehydration Protocol**

Subjects in the dehydrated condition were fluid restricted starting 20-22 hours on the day before the dehydrated trials (DehyN, DehyHot). The goal of this guideline was that subjects would start the trial at about 1-2% dehydration as measured by body weight changes. Subjects were instructed to perform 60 minutes of exercise on either an elliptical, bike or treadmill the day before the trial. Whichever exercise method was chosen by the subject, the same exercise protocol was to be repeated the evening before every test day. The exercise should be completed between 2pm and 6pm the previous day. If using a treadmill, running was to be avoided. A suggested pace of 3.0 -4.0mph

along with an incline at 5% should be done. Subjects were instructed to consume the same dinner the night before the trial, and the same breakfast and snack before the four testing days.

### **Movement Assessment**

The movement assessment required subjects to perform a jump-landing task, which was videotaped. Video cameras were attached to the heat chamber walls directly in front and to the side of the landing platform. Subjects stood on a 30-cm high box while they wore the 45 lbs. military pack on, jumped forward from the box, landed in a target area placed a quarter of the subjects' body height away from the box, and immediately jumped for maximal vertical height. Each subject performed 3 jump-landing tasks. If subjects did not land in the target area or performed the task incorrectly, an additional jump was performed. If needed, each subject was allowed 2 practice jumps. The Landing Error Scoring System (LESS) was used to analyze the videos for potentially high-risk movement patterns. The LESS is a valid and reliable clinical movement assessment tool to identify risk factors for ACL and other lower extremity injuries.<sup>16</sup> The LESS has been validated in the military academy population<sup>16</sup> and correlates with subsequent injury risk in high school soccer players.<sup>17</sup> A higher value for the LESS score indicates a greater number of landing errors performed, and therefore indicates a “poor” jump-landing technique.

The following table demonstrates factors that are analyzed during the jump in order to score the LESS.

<b>Frontal View</b>	<b>Sagittal View</b>
Knee Valgus Angle at Initial Contact	Knee Flexion >30° at Initial Contact
Lateral Trunk Flexion at Initial Contact	Hip Flexion at Initial Contact
Knee Valgus Displacement	Trunk Flexion at Initial Contact
Internal Rotation Foot Position	Knee Flexion Displacement
External Rotation Foot Position	Hip Flexion at Maximum Knee Flexion
Stance Width > Shoulder Width	Trunk Flexion at Maximum Knee Flexion
Stance Width < Shoulder Width	Joint Displacement*
Initial Foot Contact: Symmetric	Overall Impression*
Ankle Plantarflexion Angle (Toe to Heel Landing)	

All items scored either (1) for error or (0) for no error. \* Denotes scoring of 0 (soft/excellent), 1 (average), or 2 (stiff/poor)

### **Cognitive and Mood Testing**

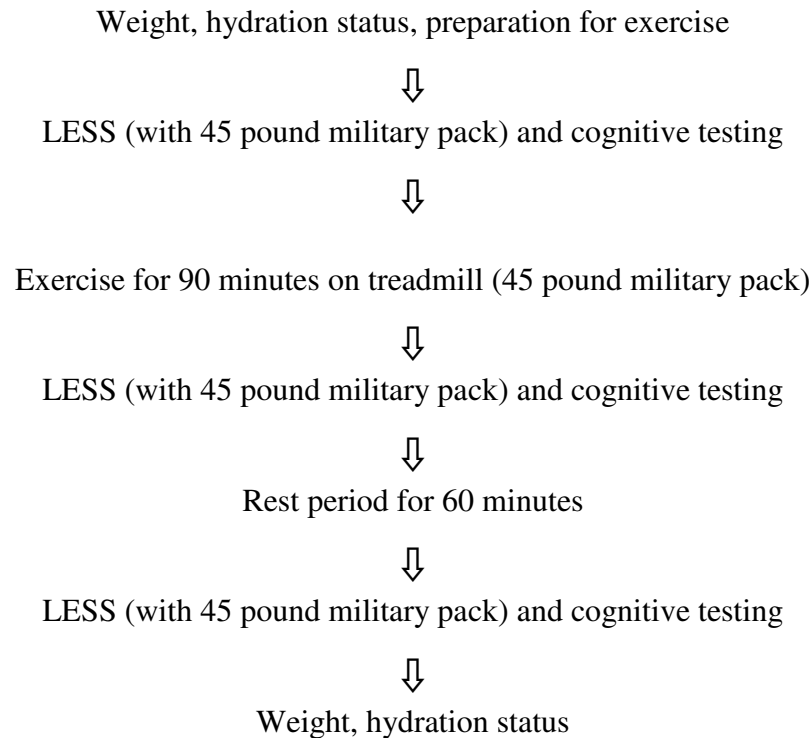
Immediately post exercise and after the 60 minute recovery period, cognitive testing was conducted. Each time it was conducted after the movement testing.

**Psychomotor Vigilance Task:** This test is extremely sensitive to a wide variety of environmental conditions, nutritional factors, sleep loss, and very low doses of hypnotic drugs and stimulants. Subjects continuously scanned a laptop or desktop computer screen to detect the occurrence of infrequent, difficult to detect stimuli. Subjects detected a faint stimulus that appears randomly on a computer screen (about once per minute) for two seconds. Upon detection of the stimulus, subjects pressed the space bar on the keyboard as rapidly as possible. The computer records whether or not a stimulus is detected, the response time (in milliseconds) for detections, and false alarms. This test was administered on a notebook or desktop computer.

**Profile of Mood States (POMS) Questionnaire:** The POMS is a widely used, standardized inventory of subjective mood states (McNair, 1971). It takes less than 5 minutes to complete. Subjects rated a series of 65 mood-related adjectives on a five-point scale, in

response to the question, “How are you feeling right now?” Previous research has shown that the adjectives factor into six mood sub-scales (tension, depression, anger, vigor, fatigue, and confusion).

**Figure 2. Timeline of Events for Research Protocol:**



**Data Analysis/Reduction**

**LESS**

All jump-landing trials were transferred from standard videocamera memory to a video-editing software (iMovie) after data collection was complete. Files were then exported to Quicktime software so they could be viewed. All jump-landing trials were scored using the LESS by one researcher. A calculation of the average subject’s LESS score was done

by taking the mean of the total LESS scores from the 3 jump-landing trials. Then, we calculated a change score for the average total LESS score (posttest-pretest, recoverytest-post test, recovery test-pretest), causing a negative change score to indicate the subject's quality of jump-landing decreased from one time point to the next.

## **Cognitive**

### *Psychomotor Vigilance Test*

This test was performed on a laptop from the Human Performance Laboratory. The software system incorporates two utility programs. One is used to set up the psychomotor vigilance task and pseudo-random timing/position files, and then to run a threshold test. The second program is used to analyze the output files. Scores are categorized into reaction time, number of errors, and number of hits that were invalid. However, we calculated changes for each variable and time point of testing (post test-pre test, recovery test-post test, recovery test-pre test).

### *POMS*

This test was performed on a laptop from the Human Performance Laboratory. The software includes the program, built with 65-mood related questions. The POMS uses six scales: vigor, fatigue, depression, confusion, tension, and anger. Total Mood Disorder is calculated adding the negative adjective scores together, and subtracting the vigor. The

program software calculates these figures. From this data, we calculated changes for each “mood” and time point of testing (post test-pre test, recovery test-post test, recovery test-pre test).

### *Statistical Analysis*

Separate one-way (condition: HyN, DehyN, HyHot, DehyHot) within subject analyses of variance (ANOVA) were used to analyze changes scores (post-pre, recovery-post, recovery-pre) for the LESS and cognitive data. We also ran a 3x4 (time x condition) repeated-measures for Psychomotor Vigilance Testing (mean reaction time, errors, and valid responses). We used SPSS 15.0 (SPSS Inc, Chicago, IL) for all analyses with a-priori level of significance of .05. Tukey HSD test was for post hoc testing when necessary.



## Results

Twelve subjects that met the inclusion criteria for this study completed all four test trials.

Subject demographics are presented in Table 2.

**Table 2. Subject Demographics**

Subjects	Age (yrs)	Height (cm)	Body Mass (kg)	Body Fat (%)
n=12 males	20±2	182±8	73.8±8.4	8.5±2.7

## Body Temperature

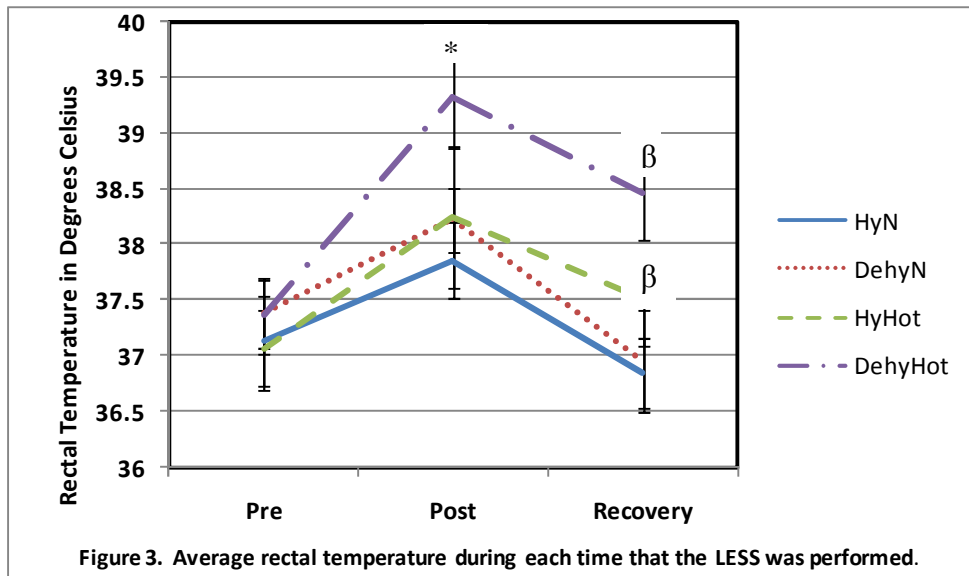
Body temperature (rectal temperature assessment) increased during exercise (from pre to post), and decreased during resting (post to recovery). Also, in the normothermic conditions, temperature was lower at the end of recovery when compared to the starting temperature. DehyHot was significantly different than all other conditions during post testing. HyHot and DehyHot were significantly different at recovery testing compared to pre testing (Table 3, Figure 3).

**Table 3. Average Rectal Temperature (Degrees Celcius)**

	Pre-test	Post-test	Recovery
Condition	Mean±SD	Mean±SD	Mean±SD
HyN	37.13±.41	37.84±.34	36.82±.31
DehyN	37.38±.31	38.22±.29	36.96±.45
HyHot	37.06±.36	38.25±.63	37.52±.43^
DehyHot	37.35±.34	39.33±.45*	38.48±.46^

\* denotes  $p<0.05$  DehyHot significantly different from all other conditions during post test.

^ denotes  $p<0.005$  HyHot and DehyHot significantly different at recovery compared to pre test



\* denotes  $p < 0.05$  DehyHot significantly different from all other conditions during post test.

$\beta$  denotes  $p < 0.005$  HyHot and DehyHot significantly different at recovery compared to pre test

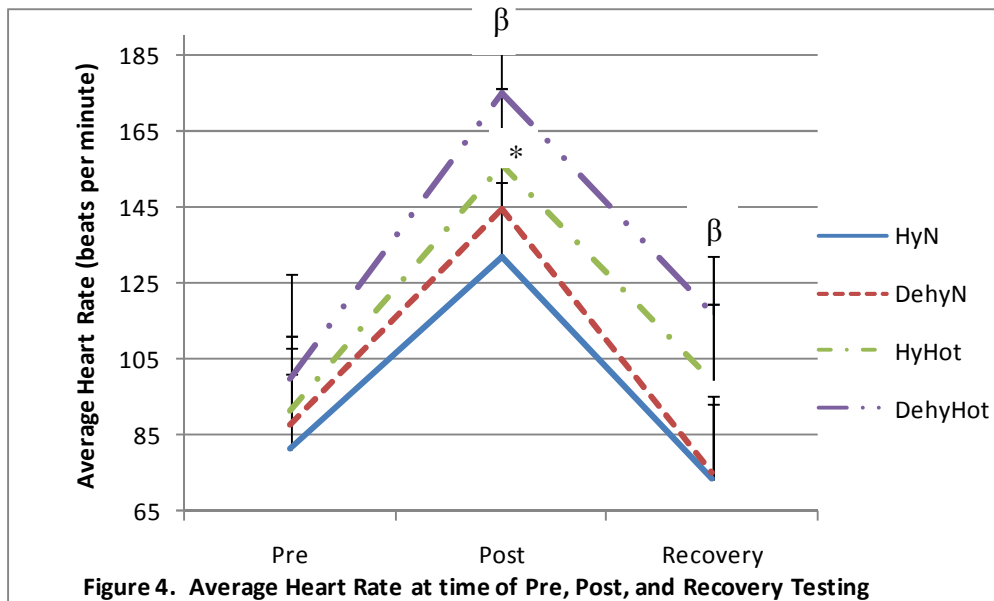
### Heart Rate (HR)

Heart rate increased during exercise (from pre to post), and decreased during resting (post to recovery). Also, in the normothermic conditions, HR was lower at the end of recovery when compared to the starting temperature. In the hyperthermic conditions, HR was higher at recovery when compared to pre- exercise. HyHot was significantly different than HyN and DehyHot during post testing, while DehyHot was significantly different from all other conditions during post and recovery testing. (Table 4, Figure 4)

**Table 4. Average Heart Rate in Beats per Minute (Mean  $\pm$  SD)**

	Pre Trial	Post Trial	Recovery Trial
Condition	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD
HyN	81 $\pm$ 20	132 $\pm$ 12	74 $\pm$ 14
DehyN	87 $\pm$ 25	145 $\pm$ 10	75 $\pm$ 14
HyHot	91 $\pm$ 19	156 $\pm$ 17 <sup>^</sup>	99 $\pm$ 18
DehyHot	100 $\pm$ 28	175 $\pm$ 12*	117 $\pm$ 15*

<sup>^</sup> denotes  $p < 0.05$ , HyHot significantly different than HyN and DehyHot; \* denotes  $p < 0.05$  DehyHot significantly different from all other conditions



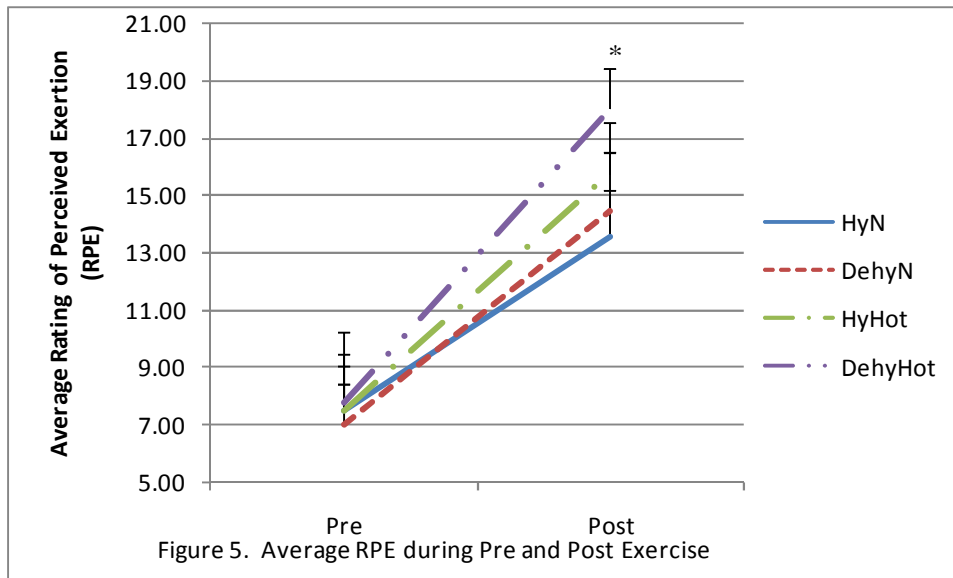
\* denotes  $p < 0.05$ , HyHot significantly different than HyN and DehyHot;  $\beta$  denotes  $p < 0.05$  DehyHot significantly different from all other conditions

### Rating of Perceived Exertion (RPE)

RPE increased during the exercise protocol. Data points presented were taken immediately before and after exercise, while the pack was still on and subjects were standing. DehyHot was significantly different from all other conditions at post testing (Table 5, Figure 5)

Table 5. Average Rating of Perceived Exertion (Mean $\pm$ SD)		
	Pre Trial RPE	Post Trial RPE
Condition	Mean $\pm$ SD	Mean $\pm$ SD
HyN	8 $\pm$ 2	14 $\pm$ 2
DehyN	7 $\pm$ 1	14 $\pm$ 2
HyHot	8 $\pm$ 2	16 $\pm$ 2
DehyHot	8 $\pm$ 2	18 $\pm$ 1*

\* denotes  $p < 0.05$ , DehyHot significantly different from all other conditions at post testing



## Urine Osmolality

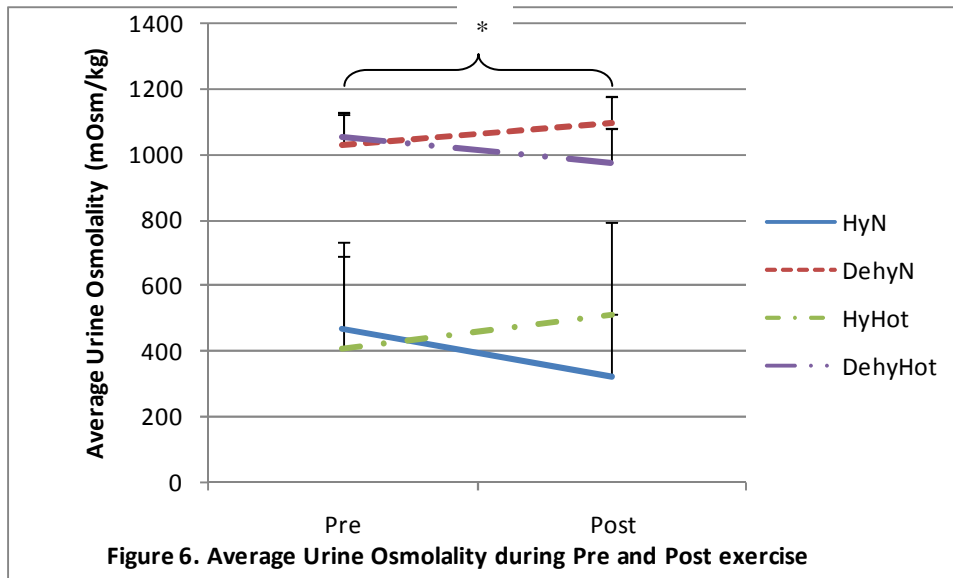
Urine osmolality was higher in the dehydrated conditions than the hydrated conditions.

This confirms that during the dehydrated protocol, the subjects were indeed dehydrated (Table 6, Figure 6)

**Table 6. Average Urine Osmolality in mOsm/kg (Mean ± SD)**

Condition	Pre Trial Osmo Mean±SD	Post Trial Osmo Mean±SD
HyN	464±266	320±190
DehyN	1027±92*	1095±81*
HyHot	405±283	512±279
DehyHot	1053±72*	971±109*

\* denotes p<0.05, DehyN and DehyHot different from HyN and HyHot at pre and post values



\* denotes  $p < 0.05$ , DehyN and DehyHot significantly different than HyN and HyHot at pre and post values

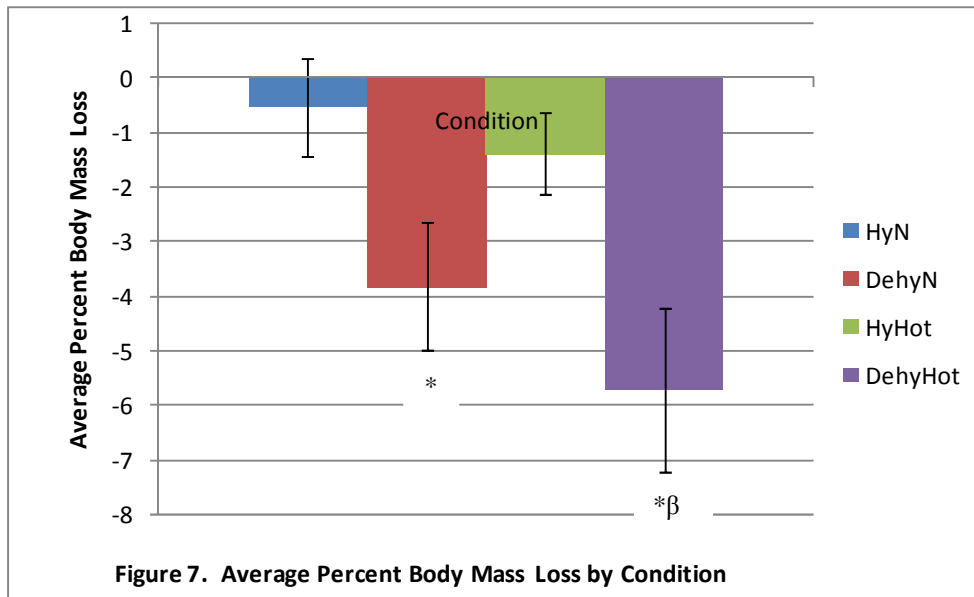
### Body Weight Changes

Body mass change was assessed at each session. After subjects gave a urine sample, they were dressed with a rectal thermometer and heart rate monitor. Then subjects removed their socks, shoes and shirts for a pre-exercise weigh in. Once the subjects completed the entire session, they again removed their socks, shoes and shirts and were weighed again (with all equipment on again). This was done before the final urine sample (Table 7, Figure 7).

**Table 7. Average Body Mass Loss (Mean  $\pm$  SD)**

Condition	Pre Trial Weight Mean $\pm$ SD (kg)	%Body Mass Loss Mean $\pm$ SD
HyN	73.88 $\pm$ 8.11	-.10 $\pm$ .90
DehyN	72.08 $\pm$ 7.98 <sup>^</sup>	-3.80 $\pm$ 1.22*
HyHot	73.74 $\pm$ 8.05	-1.30 $\pm$ .85
DehyHot	71.98 $\pm$ 8.06 <sup>^</sup>	-5.66 $\pm$ 1.57* <sup>β</sup>

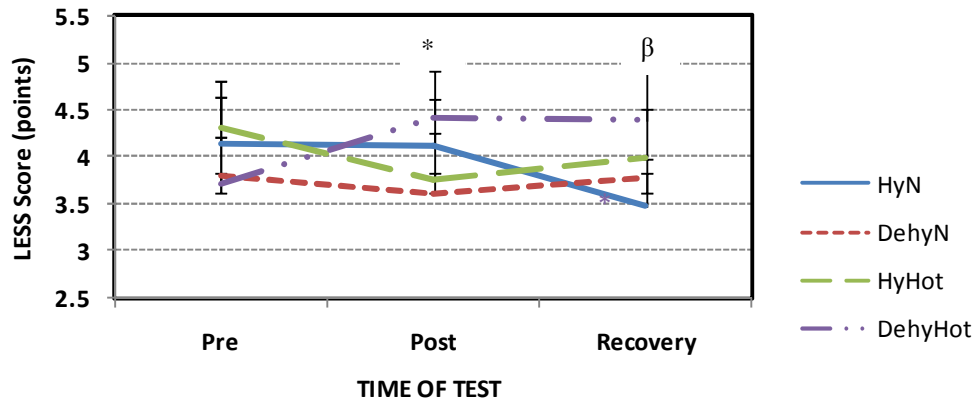
\* denotes  $p < 0.05$ , DehyHot and DehyN significantly different from HyN and HyHot;  $\beta$  denotes DehyHot also significantly different from DehyN; <sup>^</sup> denotes  $p < 0.05$ , DehyN and DehyHot significantly different than HyN and HyHot pre-weight



\* denotes  $p < 0.05$ , DehyHot and DehyN significantly different from HyN and HyHot;  $\beta$  denotes DehyHot also significantly different from DehyN

### Landing Error Scoring System

We observed a significant difference between condition for the change from pos-test to pre-test score ( $F_{(3, 33)} = 6.17$ ,  $p = 0.002$ ). Post hoc testing revealed that the DehyHot condition resulted in a greater change between post-test and pre-test LESS scores compared to the other three conditions (Figure 8). We observed no significant difference between condition for the change from post-test to recovery-test score ( $F_{(3, 33)} = 2.70$ ,  $p = 0.06$ ). We observed a significant difference between condition for the change from recovery-test to pre-test score ( $F_{(3, 33)} = 7.28$ ,  $p = 0.001$ ). Post hoc testing revealed that the DehyHot condition resulted in a greater change between recovery-test and pre-test LESS scores compared to the other three conditions. Means and standard deviations of average LESS scores across conditions and time are presented in Table 8. Change scores means and standard deviations are presented in Tables 9, 10, and 11.



**Figure 8. Average LESS scores (Mean ± SD) for condition by time.** \* denotes  $P < 0.05$  changes from pre to post test significantly different than all other trials.  $\beta$  denotes  $P < 0.05$  changes from pre to recovery test significantly different than all other trials

**Table 8. Mean LESS Scores As Described Condition By Time**

Condition	Pre-test		Post-test		Recovery	
	Mean±SD	95% CI	Mean±SD	95% CI	Mean±SD	95% CI
HyN	4.14±2.36	2.64, 5.64	4.11±2.17	2.73, 5.49	3.47±2.05	2.17, 4.78
DehyN	3.81±1.93	2.58, 5.03	3.61±1.71	2.52, 4.70	3.78±1.90	2.57, 4.99
HyHot	4.31±2.03	3.02, 5.61	3.75±1.76	2.63, 4.87	4.0±2.03	2.71, 5.29
DehyHot	3.72±1.73	2.62, 4.82	4.42±1.75*	3.31, 5.53	4.39±1.47^	3.46, 5.32

\* denotes  $p < 0.05$ , DehyHot significantly different from all other conditions from post to pre test; ^ denotes  $p < 0.05$ , DehyHot significantly different from all other conditions from recovery to pre test

**Table 9. Changes in LESS Score from Pre to Post Test**

	Mean±SD	95% CI
HyN	(-)0.03±0.90	(-)0.60, 0.54
DehyN	(-)0.19±0.56	(-)0.55, 0.16
HyHot	(-)0.56±0.92	(-)1.15, 0.02
DehyHot	0.69±0.89*	0.13, 1.26

\*  $P < 0.05$  denotes significantly different than all other trials

**Table 10. Changes in LESS Score from Post to Recovery Test**

	Mean±SD	95% CI
HyN	-0.64±0.07	-1.09, -.18
DehyN	0.17±0.69	-0.27, 0.60
HyHot	0.25±0.71	-0.20, 0.70
DehyHot	-0.03±1.11	-0.74, 0.68

**Table 11. Changes in LESS Score from Pre to Recovery Test**

	Mean±SD	95% CI
HyN	-0.67 ±0.65	(-)1.08, (-)0.25
DehyN	-0.03 ±0.80	(-)0.53, 0.48
HyHot	-0.31±0.98	(-)0.93, 0.31
DehyHot	0.67 ±0.72*	0.21, 1.13

\* P < 0.05 denotes significantly different than all other trials

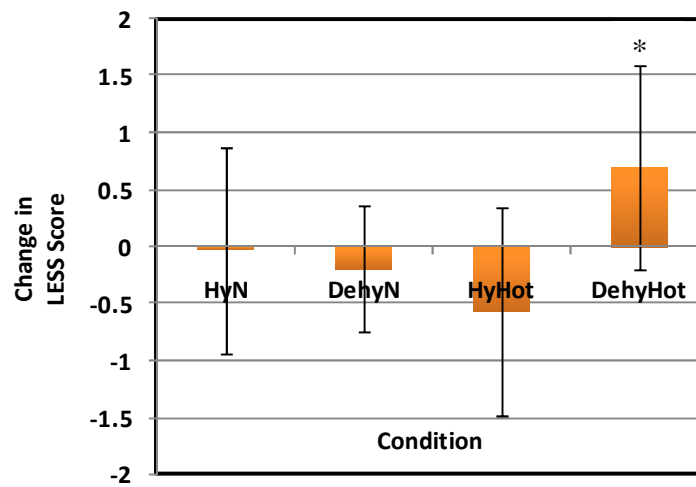
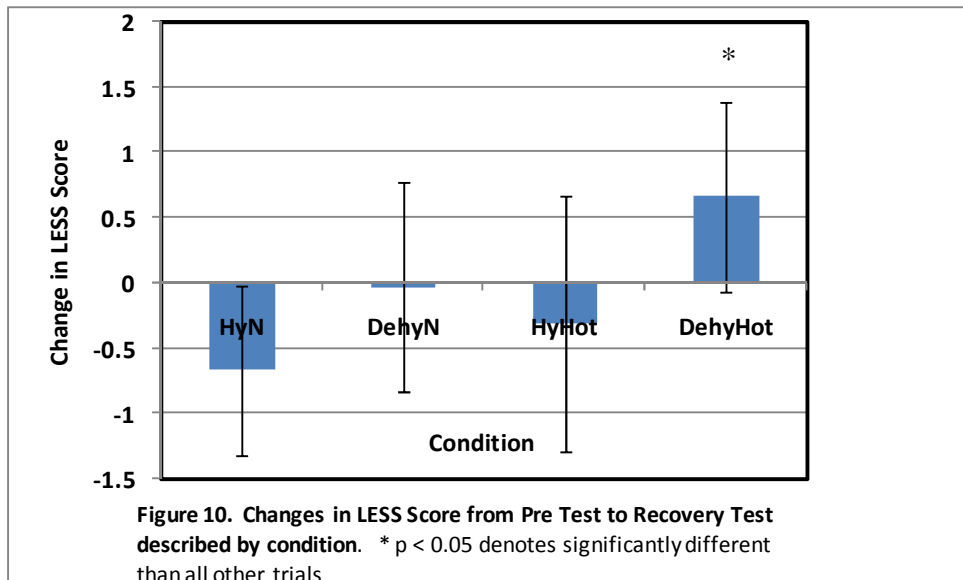


Figure 9. Changes in LESS Score from Pre Test to Post Test described by condition \* P < 0.05 denotes significantly different than all other trials





## Psychomotor Vigilance Test

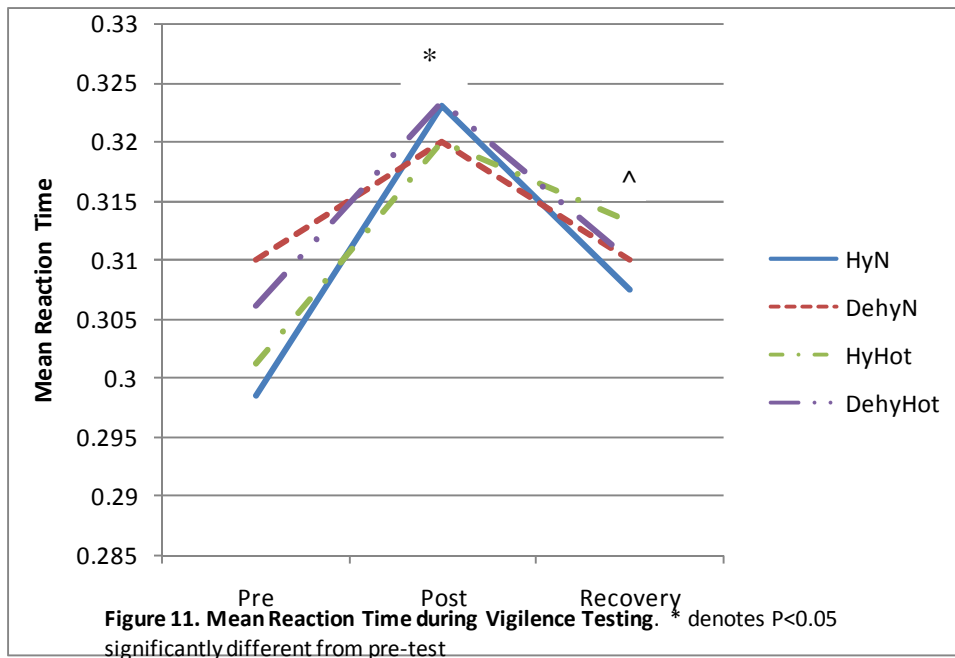
We observed a significant main effect for time with the psychomotor vigilance testing.

The time of testing produced a significant effect for mean reaction time. Post testing was significantly slower than pre testing, and recovery was significantly different than post test (Table 11). Means and standard deviations of reaction time are presented in Table 12 and Figure 11. In all conditions, an increase in reaction time was seen from pre test to post tests, and a decrease in reaction time was seen from post test to recovery tests. No difference was found with number of errors or non valid responses ( $p > 0.05$ ). No difference was found in changes with these variables from pre, post, and recovery.

**Table 11. Mean Reaction Time for Psychomotor Vigilance Test**

	Pre-test	Post-test*	Recovery^
Condition	Mean±SD	Mean±SD	Mean±SD
HyN	0.29± 0.04	0.32±0.03	0.30±0.04
DehyN	0.31± 0.02	0.32±0.02	0.31±0.03
HyHot	0.30±0.03	0.31±0.05	0.31±0.04
DehyHot	0.30±0.04	0.32±0.05	0.31±0.05

\*P < 0.05 denotes post test significantly different than pre test; ^ p < 0.05 denotes recovery test significantly different than post test.



### Profile of Mood State (POMS)

Significant changes for POMS from pre to post testing included: *total mood disorder* ( $F_{(3,33)}=13.38$ ,  $p<0.001$ ), *dejection-depression* ( $F_{(3,33)}=5.32$ ,  $p=0.004$ ), *vigor-activity* ( $F_{(1.63,17.93)}=2.95$ ,  $p=0.09$ ), *fatigue* ( $F_{(1.49,16.40)}=7.52$ ,  $p=0.008$ ), and *confusion-bewilderment* ( $F_{(3,33)}=8.22$ ,  $p<0.001$ ). No significant changes were found from post to recovery. Significant changes were also found for POMS from pre to recovery testing included: *total mood disorder* ( $F_{(3,33)}=5.28$ ,  $p=0.004$ ), *fatigue* ( $F_{(3,33)}=11.26$ ,  $p<0.001$ ), and *confusion-bewilderment* ( $F_{(2.07,22.77)}=2.94$ ,  $p=0.07$ ). DehyHot was the condition with most significance. (See Tables 12, 13 and 14 respectively).

**Table 12. Significance Values for Changes in POMS Score**

Mood	$\Delta$ POMS Post-Pre		$\Delta$ POMS Post-Recovery		$\Delta$ POMS Recovery-Pre	
	F	P	F	P	F	P
Tension	$F_{(3,33)}=2.00$	0.13	$F_{(3,33)}=0.57$	0.64	$F_{(3,33)}=1.64$	0.2
Depression	$F_{(3,33)}=5.32$	0.004*	$F_{(1.56, 17.13)}=2.61$	0.11	$F_{(3,33)}=2.34$	0.09
Anger	$F_{(3,33)}=2.33$	0.09	$F_{(3,33)}=1.72$	0.18	$F_{(1.23, 13.54)}=1.59$	0.24
Vigor	$F_{(1.63, 17.93)}=2.95$	0.09*	$F_{(3,33)}=1.41$	0.26	$F_{(1.36, 14.92)}=0.96$	0.37
Fatigue	$F_{(1.49, 16.40)}=7.52$	0.008*	$F_{(1.20, 13.17)}=0.61$	0.48	$F_{(3,33)}=11.26$	<0.001*
Confusion	$F_{(3,33)}=8.2$	<0.001	$F_{(3,33)}=2.87$	0.05	$F_{(2.07, 22.77)}=2.94$	0.07*
TMD	$F_{(3,33)}=13.38$	<0.001	$F_{(1.80, 19.77)}=2.09$	0.15	$F_{(3,33)}=5.28$	0.004*

\* denotes  $p < 0.05$  and significantly different;  $\Delta$  denotes 'change'

**Table 13. Changes in Profile of Mood States Score (Post - Pre)**

Condition	Tension	Depression	Anger	Vigor	Fatigue	Confusion	Total Mood Disturbance
HyN	1 $\pm$ 3	-1 $\pm$ 2	0.08 $\pm$ 1	-0.25 $\pm$ 4	3 $\pm$ 3	0 $\pm$ 2	3 $\pm$ 10
DehyN	-1 $\pm$ 4	-1 $\pm$ 3	0.33 $\pm$ 3	0.08 $\pm$ 5	4 $\pm$ 5	0.33 $\pm$ 3	3 $\pm$ 16
HyHot	2 $\pm$ 5	3 $\pm$ 7	2 $\pm$ 6	4 $\pm$ 10	3 $\pm$ 13	1 $\pm$ 4	16 $\pm$ 26
DehyHot	2 $\pm$ 5	6 $\pm$ 7 <sup>3</sup>	3 $\pm$ 4	5 $\pm$ 6	13 $\pm$ 4 <sup>2</sup>	5 $\pm$ 5 <sup>2</sup>	35 $\pm$ 21*

\*denotes  $P < 0.05$  significantly different from all conditions, <sup>2</sup> denotes  $P < 0.05$  significantly different from HyN and DehyN, <sup>3</sup> denotes  $P < 0.05$  significantly different from DehyN

**Table 14. Changes in Profile of Mood States Score (Recovery - Post)**

Condition	Tension	Depression	Anger	Vigor	Fatigue	Confusion	Total Mood Disturbance
HyN	-0.8 $\pm$ 3	-0.17 $\pm$ 1	-0.1 $\pm$ 1	-0.5 $\pm$ 3	-1 $\pm$ 2	-0.3 $\pm$ 1	-3 $\pm$ 7
DehyN	-1 $\pm$ 3	-0.3 $\pm$ 1	-0.5 $\pm$ 2	-1 $\pm$ 4	-1 $\pm$ 3	-1 $\pm$ 3	-6 $\pm$ 11
HyHot	-3 $\pm$ 6	-4 $\pm$ 8	-3 $\pm$ 6	-0.2 $\pm$ 7	1 $\pm$ 12	-3 $\pm$ 3	-15 $\pm$ 26
DehyHot	-2 $\pm$ 7	-4 $\pm$ 4	-1 $\pm$ 3	-4 $\pm$ 6	-3 $\pm$ 4	-3 $\pm$ 4	-17 $\pm$ 23

**Table 14. Changes in Profile of Mood States Score (Recovery-Pre)**

Condition	Tension	Depression	Anger	Vigor	Fatigue	Confusion	Total Mood Disturbance
HyN	0.3 $\pm$ 3	-1 $\pm$ 2	0 $\pm$ 2	-1 $\pm$ 4	2 $\pm$ 3	-0.25 $\pm$ 2	1 $\pm$ 13
DehyN	-2 $\pm$ 4	-1 $\pm$ 3	-0.2 $\pm$ 2	-1 $\pm$ 6	3 $\pm$ 5	-1 $\pm$ 5	-3 $\pm$ 20
HyHot	-1 $\pm$ 3	-1 $\pm$ 3	-0.4 $\pm$ 1	4 $\pm$ 15	3 $\pm$ 7	-1 $\pm$ 4	2 $\pm$ 20
DehyHot	0.3 $\pm$ 4	2 $\pm$ 6	2 $\pm$ 6	1 $\pm$ 6	10 $\pm$ 3*	2 $\pm$ 3	18 $\pm$ 18 <sup>3</sup>

\*denotes  $P < 0.05$  significantly different from all conditions, <sup>3</sup> denotes  $P < 0.05$  significantly different from DehyN

## **Discussion**

The goal of this study was to evaluate the effects of dehydration, hyperthermia, and fatigue on movement patterns and cognition. For review, a lower score on the LESS means that an individual demonstrates fewer movement-based risk factors for injury and thus may be at a decreased risk for injury. Conversely, a higher score on the LESS indicates that an individual has several biomechanical errors during the task and may have a higher risk of sustaining a lower body injury.<sup>16</sup> However, we do not know how additive effects of dehydration, hyperthermia, or fatigue affect injury risk. This is one of the reasons our study is unique, as it is the first to examine movement-based risk factors for injury under different physiological conditions.

Overall, we found the dehydrated-hyperthermic condition resulted in most changes. This condition showed significant changes in LESS scores, reaction time, and mood. We believe that fatigue was not a significant factor due to the fact that during other conditions, subjects actually performed the same when they were fatigued. This strongly suggests that hyperthermia and dehydration combined were the main reason we saw changes during these tests. Therefore we can hypothesize that an individual is at a higher risk for injury when they are dehydrated and hyperthermic. Future research needs to evaluate a possible relationship between cognitive function and LESS score. We found similar patterns in change scores for the LESS and cognitive testing. If a person has decrements in cognition and are not thinking as “clearly”, this may add predisposition to injury risk. Our research may suggest that the decreases in cognitive function were a reason for the increase in LESS score for the dehydrated-hyperthermic condition,

possibly causing changes in the ability to control the body. This lack of body control may lead to increased injury risk.

### *Dehydration*

This is the first study to evaluate if hydration status affects movement-based risk factors for injury. Our results indicate dehydration does not alter an individual's movement during a jump-landing task. During the dehydrated trial, subjects LESS score did not statistically change. We believe subjects in this study were dehydrated as we observed increased heart rate (HR), body temperature, rating of perceived exertion (RPE), urine osmolality, and observed body mass loss. These findings are in agreement with several previous studies, which found that physiologic responses such as HR, body temperature, RPE, urine osmolality, and body mass loss are increased during exercise with dehydrated individuals.<sup>2, 3, 6</sup>

It is known throughout the literature that dehydration affects cognitive function.<sup>12, 13, 18-20</sup> Gopinathan et al. and Lieberman et al. both completed studies examining how dehydration affects cognitive function.<sup>12, 18</sup> In 1998 Gopinathan et al. examined cognitive performance of eleven subjects with exercise-induced dehydration. They found that dehydration of 2% (body weight loss) and greater affected word recognition, serial addition, and trail-marking test. In 2004 Lieberman et al. assessed cognitive stress on a computer before, during, and after an intense military training exercise. The authors found a decrement in cognitive function in part with dehydration. The authors found that vigilance, mood reaction time, attention, memory, and reasoning were significantly impaired after exercise. In our study, dehydration alone did not cause a significant effect

for reaction time or mood. Many previous studies fail to solely isolate dehydration, and often examine cognitive function with many other factors. More research needs to be completed to see the isolated effects of dehydration on cognitive function.

### *Hyperthermia*

This is the first study to evaluate if hyperthermia affects movement-based risk factors for injury. Our results indicate hyperthermia does not alter an individual's movement during a jump-landing task. During the hyperthermic trial, subjects LESS score did not statistically change when they were hyperthermic and fatigued. We found similar thermoregulatory physiologic responses to other research during our exercise protocol such as increases in temperature, HR, and RPE. Rowell<sup>21</sup>, Gonzalez-Alonso<sup>22</sup> and Brotherhood<sup>23</sup> wrote reviews of heat stress and its affect on the body. They indicated that increases in temperature, HR, and RPE are normal thermoregulatory responses of humans during exercise in the heat. Therefore, we knew subjects were hyperthermic but yet we did not see changes in movement patterns.

Many past cognitive studies fail to isolate hyperthermia. Instead, these studies examine the combined effects of dehydration, hyperthermia, fatigue, and sleep deprivation.<sup>19, 24, 25</sup> Our results did not indicate that hyperthermia alone had an effect on cognitive function. Future research needs to be done to see if there are true changes in cognition with hyperthermic individuals.

### *Fatigue*

Fatigue has been shown to alter biomechanics during a stop-jump landing task.<sup>15</sup> Chappell et al. used an exercise protocol to induce fatigue consisting of unlimited

repetitions of 5 consecutive vertical jumps followed by a 30 meter sprint. They concluded that fatigued individuals did have altered lower leg biomechanics, which may place them at a higher risk for non-contact anterior cruciate ligament (ACL) tears. Other studies agree with the findings of Chappell et al., that fatigued individuals are at a higher risk of movement-based injury.<sup>26-28</sup> However, our results did not find that fatigue alone caused a change in movement-based risk factors. The only condition that encountered changes from the exercise protocol was the dehydrated hyperthermic condition, but this condition did not show changes from the exercise period through recovery. This time allowed for fatigue to dissipate. This may be due to the fact that Chappell's exercise protocol was until "volitional exhaustion". Other studies have used repeated step-up drills/plyometrics<sup>26</sup>, repeated leg squats<sup>28</sup>, and 60 minute shuttle run<sup>27</sup>. It is possible that our subjects did not reach the same level of fatigue as with the research that showed significant changes. Our exercise protocol had a set activity level in a controlled setting (treadmill). While HR, RPE, and rectal temperature increased during the exercise protocol to suggest fatigue, it may not be comparable to these other research.

As shown with other studies, our results demonstrated that the time when cognitive tests were taken resulted in changes.<sup>12, 29</sup> We found most cognitive changes in mood and reaction time during post testing. This suggests that fatigue played a role with cognitive testing. Fogt completed a study in 2010 using cognitive testing in a simulated military duty protocol over a 24 hour period. Authors also assessed sleep deprivation and caloric/fluid intake. The authors found decreases in POMS and Stroop Color-Word Conflict Test.<sup>29</sup> Again, Lieberman's in 2005 study assessing cognitive stress before, during, and after an intense military training exercise also examined fatigue. The authors

in this study found a decrement in cognitive function regarding the time of testing. The authors found that vigilance, mood reaction time, attention, memory, and reasoning were significantly impaired after exercise. Reaction time decreased as much as 20% from beginning to end of exercise.<sup>24</sup> Our findings are in agreement with Fogt and Lieberman who found that fatigue resulted in cognitive decrements. Lieberman's subjects were physically stressed in areas of sleep deprivation, exercise, under nourishment, and dehydration, possibly explaining why they found such a great decrement in reaction time. However, the subject's in our study were equally stressed with dehydration and exercised fatigue. Our results of slower reaction time and mood changes found after exercise is an important variable to military and athletic populations. Military personnel need to operate vehicles, shoot rifle with accuracy, and athletes need quick/agile movements for best performance. Soldiers and athletes need to ensure that their cognitive ability is minimally affected.

#### *Dehydration and Hyperthermia*

Dehydration and hyperthermia are known to have detrimental impacts on the body.<sup>2, 6, 8, 30, 31</sup> Gonzalez-Alonso's study in 1997 demonstrated that dehydration and hyperthermia individually decreased stroke volume by 7-8%, which indicates stress of the body. As a combined effect, these two factors decreased stroke volume by about 20% and cardiac output by 13 %.<sup>2</sup> Sawka et al. found that core temperature and heart rate response increased with higher levels of dehydration. Results showed an increase in heart rate of about four beats per minute for each percent decrease in body weight.<sup>3</sup> Other studies



have demonstrated that core temperature can increase from 0.1°C to 0.49°C for each percent of body mass lost.<sup>3, 6, 30, 31</sup>

Dehydration and hyperthermia had a significant influence on LESS scores. Subjects in the dehydrated hyperthermic condition had highest scores at post testing, but their scores also remained elevated during recovery testing. This indicates that even when fatigue is no longer present, hyperthermia and dehydration still cause higher scores on the LESS. Therefore, we can interpret that dehydration and hyperthermia puts individuals at a higher movement based risk during this condition. The LESS has never been studied before in combination with dehydration/hyperthermia, making this study very unique. Dehydration and hyperthermia showed differences not only in LESS score, but also reaction time and mood changes. Future research examining a relationship between LESS score and cognition would be important. Motor control is critical for proper movement, and proper cognitive function is necessary for this to occur.

#### *Dehydration, hyperthermia, and fatigue*

The highest average LESS scores from this study were seen after exercise in the dehydrated hyperthermic condition. This means that fatigue has some interaction with dehydration and hyperthermia. However, fatigue may not be as significant of a factor as dehydration and hyperthermia. From post to recovery testing when fatigue would decrease, we saw reductions in HR, RPE, and temperature to suggest that fatigue was no longer present. Yet, we still saw high LESS scores. This is important to the literature because now we have evidence that these factors combined (dehydration, hyperthermia, and possibly fatigue) can cause the greatest risk for movement-based injury.

Mood was also affected the most directly after exercise in the dehydrated hyperthermic condition. Since mood was affected so greatly, this may suggest that cognitive function can influence LESS scores. This would need to be investigated in future studies.

Coaches, athletes, and military need to use this knowledge to their advantage. If factors such as dehydration, hyperthermia, and fatigue can be limited, then injury risk can be lowered as well.

### *Practical Implications*

Our results have many practical implications for athletes, coaches, soldiers, athletic trainers, and other labor workers. We now have data that suggests that hyperthermia and dehydration can predispose individuals to a higher injury risk and decrements in cognitive function. Coaches and health care providers need to be aware of situations where athletes may be placed in these situations. Not only will proper hydration and control of body temperature improve performance, but it may lower the risk of injury. While hyperthermia may be more difficult to control, if hydration can be controlled injury risk may be decreased. We found no evidence that movement patterns were affected by hyperthermia alone, only when in combination with dehydration and hyperthermia.

This study also has significance for soldiers in the military: We now know that LESS scores significantly change while wearing a 45 pound military pack in dehydrated and hot conditions. Injury prevention programs attempting to improve movement patterns have proved to be effective, so we can use these during military training to decrease injury

risk. Soldiers could complete these programs in full uniform (with packs/gear on), as this simulates their true work. Also, future studies can attempt to answer the question that if factors such as hyperthermia and dehydration can be controlled, can the risk of injury ultimately be prevented or reduced? Additionally, we know that reaction time is slowed after exercise, possibly affecting shooting accuracy, driving, agility, and other such things. This, again, demonstrates the need to limit these factors.

While these findings may seem like common knowledge, prior to this study there was no data to support such claims. Now we have research that truly demonstrates when a person gets hot, dehydrated, and fatigued, it will affect jump landing techniques and cognitive function. This creates an even stronger reason to educate coaches, athletes, and healthcare professionals of the importance about hydration and hyperthermia. If an individual can remain hydrated, ultimately injury risk can be decreased.

### *Limitations*

While our inclusionary age range was wide, we mostly had college aged males participate in this study. Therefore, our findings may only be applicable to the males in this age range. There were also some parts of the study that were beyond our control. The LESS and cognitive testing took place in the heat chamber, so at times there was some noises (pipes, air) during testing, when ideally there would be no noise for best concentration. Lastly, our sample size only consisted of twelve subjects. While this was a strong number for the length of our testing, future research could test a larger sample to make broader recommendations.

### *Future Research*

While injury prevention programs have been shown to reduce LESS scores, it would be interesting to see if we can implement injury prevention programs to overcome external factors such as dehydration/hyperthermia. Research can also be completed to evaluate methods to reduce injury risk when dehydration and hyperthermia are present.

Additionally, research can be completed to investigate if LESS score and cognitive function have a true relationship. A larger scale study regarding physiological factors and LESS scores would allow for a broader range of recommendations. Other studies could focus on at what percent dehydration or level of hyperthermia the LESS score becomes affected.

1. Casa DJ, Clarkson PM, Roberts WO. American college of sports medicine roundtable on hydration and physical activity: Consensus statements. *Curr Sports Med Rep*. 2005;4:115-127.
2. Gonzalez-Alonso J, Mora-Rodriguez R, Below PR, Coyle EF. Dehydration markedly impairs cardiovascular function in hyperthermic endurance athletes during exercise. *J Appl Physiol*. 1997;82:1229-1236.
3. Sawka MN, Montain SJ, Latzka WA. Hydration effects on thermoregulation and performance in the heat. *Comp Biochem Physiol A Mol Integr Physiol*. 2001;128:679-690.
4. Sawka MN. Fluid balance and replacement in the heat. (abstract). In: *In International Paralympic Committee, Pushing the Limits: Congress Program and Abstract Book, [Sydney], [International Paralympic Committee], 2000, p.52*. Australia: ; 2000.
5. Murray B. Hydration and physical performance. *J Am Coll Nutr*. 2007;26:542S-548S.
6. Montain SJ, Coyle EF. Influence of graded dehydration on hyperthermia and cardiovascular drift during exercise. *J Appl Physiol*. 1992;73:1340-1350.
7. Casa DJ, Armstrong LE, Hillman SK, et al. National athletic trainers' association position statement: Fluid replacement for athletes. *J Athl Train*. 2000;35:212-224.
8. Sawka MN. Hydration effects on thermoregulation and performance in the heat. In: *In, Proceedings of the International Conference on Physiological and Cognitive Performance in Extreme Environments, 27 to 20 March 2000, Canberra, Dept. of Defence, 2000, p.21-23*. Australia: ; 2000.
9. Judelson DA, Maresh CM, Anderson JM, et al. Hydration and muscular performance: Does fluid balance affect strength, power and high-intensity endurance? *Sports Medicine*. 2007;37:907-921.
10. Judelson DA, Maresh CM, Farrell MJ, et al. Effect of hydration state on strength, power, and resistance exercise performance. *Med Sci Sports Exerc*. 2007;39:1817-1824.
11. Mudambo KS, Leese GP, Rennie MJ. Dehydration in soldiers during walking/running exercise in the heat and the effects of fluid ingestion during and after exercise. *Eur J Appl Physiol Occup Physiol*. 1997;76:517-524.
12. Lieberman HR, Bathalon GP, Falco CM, Kramer FM, Morgan CA, 3rd, Niro P. Severe decrements in cognition function and mood induced by sleep loss, heat, dehydration, and undernutrition during simulated combat. *Biol Psychiatry*. 2005;57:422-429.

13. Patel AV, Mihalik JP, Notebaert AJ, Guskiewicz KM, Prentice WE. Neuropsychological performance, postural stability, and symptoms after dehydration. *J Athl Train*. 2007;42:66-75.
14. Racinais S, Gaoua N, Grantham J. Hyperthermia impairs short-term memory and peripheral motor drive transmission. *J Physiol*. 2008;586:4751-4762.
15. Chappell JD, Herman DC, Knight BS, Kirkendall DT, Garrett WE, Yu B. Effect of fatigue on knee kinetics and kinematics in stop-jump tasks. *Am J Sports Med*. 2005;33:1022-1029.
16. Padua DA, Marshall SW, Boling MC, Thigpen CA, Garrett WE, Jr, Beutler AI. The landing error scoring system (LESS) is a valid and reliable clinical assessment tool of jump-landing biomechanics: The JUMP-ACL study. *Am J Sports Med*. 2009;37:1996-2002.
17. DiStefano LJ, Padua DA, DiStefano MJ, Marshall SW. Influence of age, sex, technique, and exercise program on movement patterns after an anterior cruciate ligament injury prevention program in youth soccer players. *Am J Sports Med*. 2009;37:495-505.
18. Gopinathan PM, Pichan G, Sharma VM. Role of dehydration in heat stress-induced variations in mental performance. *Arch Environ Health*. 1988;43:15-17.
19. Cian C, Koulmann N, Barraud PA, Raphael C, Jimenez C, Melin B. Influences of variations in body hydration on cognitive function: Effect of hyperhydration, heat stress, and exercise-induced dehydration. *Journal of Psychophysiology*. 2000;14:29-36.
20. Grego F, Vallier JM, Collardeau M, Rousseu C, Cremieux J, Brisswalter J. Influence of exercise duration and hydration status on cognitive function during prolonged cycling exercise. *Int J Sports Med*. 2005;26:27-33.
21. Rowell LB. Human cardiovascular adjustments to exercise and thermal stress. *Physiol Rev*. 1974;54:75-159.
22. Gonzalez-Alonso J. Hyperthermia impairs brain, heart and muscle function in exercising humans. *Sports Med*. 2007;37:371-373.
23. Brotherhood JR. Heat stress and strain in exercise and sport. *J Sci Med Sport*. 2008;11:6-19.
24. Lieberman HR, Bathalon GP, Falco CM, Kramer FM, Morgan CA, 3rd, Niro P. Severe decrements in cognition function and mood induced by sleep loss, heat, dehydration, and undernutrition during simulated combat. *Biol Psychiatry*. 2005;57:422-429.

25. Sharma VM, Sridharan K, Pichan G, Panwar MR. Influence of heat-stress induced dehydration on mental functions. *Ergonomics*. 1986;29:791-799.
26. McLean SG, Fellin RE, Suedekum N, Calabrese G, Passerallo A, Joy S. Impact of fatigue on gender-based high-risk landing strategies. *Med Sci Sports Exerc*. 2007;39:502-514.
27. Sanna G, O'Connor KM. Fatigue-related changes in stance leg mechanics during sidestep cutting maneuvers. *Clin Biomech (Bristol, Avon)*. 2008;23:946-954.
28. Borotikar BS, Newcomer R, Koppes R, McLean SG. Combined effects of fatigue and decision making on female lower limb landing postures: Central and peripheral contributions to ACL injury risk. *Clin Biomech (Bristol, Avon)*. 2008;23:81-92.
29. Fogt DL, Kalns JE, Michael DJ. A comparison of cognitive performance decreases during acute, progressive fatigue arising from different concurrent stressors. *Mil Med*. 2010;175:939-944.
30. Ekblom B, Greenleaf CJ, Greenleaf JE, Hermansen L. Temperature regulation during exercise dehydration in man. *Acta Physiol Scand*. 1970;79:475-483.
31. Gisolfi CV, Copping JR. Thermal effects of prolonged treadmill exercise in the heat. *Medicine & Science in Sports*. 1974;6:108-113.