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# Individual & Combined Effects of Hyperthermia, Dehydration & Fatigue Balance

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Individual and Combined Effects of Hyperthermia, Dehydration and Fatigue Balance

Megan M. VanSumeren

B.S., Central Michigan University, 2008

A Thesis

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Individual and Combined Effects of Hyperthermia, Dehydration and Fatigue Balance

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## TABLE OF CONTENTS

I.	Abstract	7
II.	Review of the Literature	9
	a. Hyperthermia's Effects On:	
	i. Fatigue/Balance	11
	ii. Balance in Real Life	15
	iii. Body Systems & Musculoskeletal	15
	iv. Brain	16
	v. Cognition	17
	vi. Effects on Injury Risk	18
	b. Balance Testing Procedures	19
	i. BESS	20
	ii. LESS	21
	c. Balance Deficits & Injury Risk	21
	d. Methods to Eliminate Fatigue	22
	e. Conclusion	23
	f. References	27
III.	Introduction	38
IV.	Methods	42
	a. Subject Demographics	42
	b. Testing Procedures	42
	c. Familiarization Session	42
	d. Dehydration Protocol	47
	e. Temperature Assessment	47
	f. Rating of Perceived Exertion	47
	g. Heart Rate	48
	h. Body Mass Change	48
	i. Statistical Analysis	48
V.	Results	49
	a. Subject Demographics	49
	b. Temperature	49
	c. Rating of Perceived Exertion	50
	d. Heart Rate	51
	e. Body Mass Loss	53
	f. Urine	54
	g. SLFirm	55
	h. TanFirm	56
	i. SLFoam	57
	j. TanFoam	58
	k. Static Area	60
	l. Static Path	61
	m. Static Velocity	62
	n. Dynamic Stance Area	63
	o. Dynamic Stance Path	64
	p. Dynamic Stance Velocity	66
	q. Additional Summary Tables	68
VI.	Discussion	70
	a. Fatigues Effect on Balance	70

b. Hydrations Effect on Balance	.....71
c. Hyperthermias Effect on Balance	.....71
d. Combination Effects	.....73
e. Injury Risk	.....74
f. Balance Assessments	.....75
g. Practical Implications	.....75
h. Concussions	.....77
i. Limitations	.....78
j. Future Directions	.....79
k. References	.....80

## ABSTRACT

Individual and Combined Effects of Hyperthermia, Dehydration and Fatigue on Balance. Megan M. VanSumeren, University of Connecticut

**Purpose:** The purpose of this controlled, randomized laboratory study is to determine the effect of hyperthermia, dehydration and fatigue as both combined and individual factors on balance performance as tested with three separate balance assessment tools.

**Methods:** 12 healthy male subjects ( $20\pm 2$  yrs old,  $181.83\pm 7.53$ cm ,  $74.09\pm 8.43$ kg) completed four trials in a randomized order. The four trials were Normothermic, Hydrated day (HyN), aNormothermic Dehydrated (DehyN), Hyperthermic, Hydrated (HyHot), and Hyperthermic, Dehydrated (DehyHot). Balance was assessed using three tests; static stance, clinical tool Balance Error Scoring System (BESS), and a dynamic stance. The static stance required the subjects to stand on one leg with their hands on their hips and eyes closed for 10 seconds. The BESS involved four different stances, all with eyes closed; single leg on a firm surface (SLFirm), tandem stance on a firm surface (TanFirm), single leg on a foam pad (SLFoam), and a tandem stance on a foam pad (TanFoam). Subjects performed the balance assessments three times during each trial; before exercise (pre-test), immediately after exercise (post-test) and after an hour of recovery (rec). The exercise component of this study required subjects to walk on a 5% incline treadmill for 90 minutes at a pre-determined speed between 3.0mph-4.0mph. During the recovery period, subjects sat in the heat chamber with a water perfused suit on in order to maintain their exercising rectal temperature. Subjects were required to wear a 20.45kg pack during the entirety of the trial with the exception of the seated recovery period. Dependent variables were : center of pressure (COP), mean sway velocity, mean COP sway path, and average elliptical sway area for both the static and dynamic tests, as well as BESS individual



stance scores and BESS total score. Separate repeated measures analyses of variance were performed to evaluate the dependent variables between time (pre-post-rec) and trials (HyN, DehyN, HyHot, DehyHot).

**Results:** For the BESS test, a main effect for time was observed for three of the four stances; SLFirm ( $F_{(2,22)}=5.37$ ,  $p=.01$ ), TanFirm ( $F_{(2,22)}=4.64$ ,  $p=.02$ ), TanFoam ( $F_{(2,22)}=3.44$ ,  $p=.05$ ). The post-test held the highest number of errors on any stance compared with the pre-test and the recovery test. Both the TanFirm and TanFoam revealed a main effect for condition ( $F_{(3,33)}=3.05$ ,  $p=.04$ ,  $F_{(3,33)}=7.14$ ,  $p=.001$ , respectively). Overall, the DehyHot condition caused the highest BESS scores. For the Dynamic stance, a main effect for time was noticed for the variables of mean COP sway path and velocity ( $F_{(2,22)}=7.60$ ,  $p=.003$ ,  $F_{(2,22)}=7.61$ ,  $p=.003$ , respectively) with the post-test resulting in the longest and fastest measures. All three variables demonstrated a main effect for condition; sway area ( $F_{(1.93, 21.26)}=3.56$ ,  $p=.048$ ), sway path ( $F_{(3,33)}=3.39$ ,  $p=.029$ ), velocity ( $F_{(3,33)}=3.58$ ,  $p=.024$ ). The DehyHot trial caused the biggest changes in postural sway. Static results revealed a main effect for time in sway path and sway velocity ( $F_{(2,22)}=4.03$ ,  $p=.032$ ,  $F_{(91.2, 13.5)}=5.56$ ,  $p=.045$ , respectively). Post-test scores caused the biggest change in sway.

**Conclusions:** For all three of the balance assessments, there was a decrease in balance ability at post-test. While this can be attributed to fatigue, there is a noted failure to return to baseline after the recovery period, which may be that hyperthermia and dehydration may play roles in the unsatisfactory recovery scores. By condition, the highest values on any balance assessment took place in the DehyHot trial, suggesting that when combined, dehydration and hyperthermia affect balance. Overall, balance deficits were driven mostly by fatigue, but in combination with dehydration and hyperthermia, decreases in balance were even more pronounced.

## REVIEW OF THE LITERATURE

The physiological effects of heat on exercise performance have been well documented for over 60 years. Studies in the past 30 years have shown that reasons for this decrease in performance are a result of thermoregulatory stress, hypohydration, and muscle metabolism.<sup>46</sup> Hyperthermia causes a significantly increased physiological strain on the body and when you consider exercise in a hot environment, exercise capacity can be greatly impaired causing a noteworthy decrease in time to exhaustion.<sup>34</sup> Among the things we can say for certain occur in the body during heat stress, the following are especially important to keep in mind:

- Core body temperature has been stated as the number one factor in limiting performance in the heat. In untrained subjects, core temperature at exhaustion from heat strain has been clearly shown to occur over a range of 38–40°C and to be independent of exercise intensity.<sup>52</sup>
- Higher core body temperatures have been well documented to show a reduced stroke volume, increased heart rate, lower cardiac output, and lower central blood volume. (However, in a study done by Gonzales-Alonso et al, they showed that hyperthermic alone did not cause any change in cardiac output up to 39.3 °C.)
- It has been demonstrated that hyperthermia alone (i.e. not in conjunction with fatigue or other factors that may occur during exercise) will decrease athletic performance and put an individual at greater risk for a heat illness.<sup>52</sup>

In several studies, it has been shown that individuals will fatigue at similar core temperatures, no matter their starting body temperature. Hot conditions leading to a hyperthermic individual also tends to cause a quicker time to exhaustion and a reduction in optimal function of the central nervous system. Central nervous system dysfunction classically presents with certain signs and symptoms (confusion, apathy, irritability, collapse etc).<sup>29</sup> Due to

hyperthermia's effect on the central nervous system and the possibility that previous studies examining balance did not control for body temperature, the influence of hyperthermia on balance is unknown.

Hot conditions during exercise also cause a significant challenge to human cardiovascular control, which leads to provisions of oxygen to exercising muscles and organs due to enhanced thermoregulatory demand for skin blood flow. Cardiovascular strain is defined by reductions in cardiac output, skin and locomotor muscle blood flow and systemic and muscle oxygen delivery.<sup>50</sup> As stated in Dr. Lawrence Armstrong's book, *Exertional Heat Illness*, "Exercise-heat stress, even without dehydration, causes cardiovascular drift. Over time, heart rate increases steadily until the high heart rates, in effect, lead to exhaustion."<sup>13</sup>

Critical cardiovascular adjustments accompany heat dissipation in exercising individuals as mentioned earlier.<sup>36</sup> The outcome of combined heat stress and exercise on cardiovascular function are dependent on the intensity of exercise. One of the biggest bodily changes during an increase in exercise intensity, is the battle for blood flow between the skin and muscles. The muscles blood flow becomes markedly reduced while blood flow to the skin increases. Rowell et al. showed that 20% more blood flow was diverted away from the hepatic-splanchnic system during exercise in the heat (exercise as 43.4 °C compared with 25.6 °C).<sup>88</sup> This could very well be the phenomenon that eliminates the necessity for greater increments in cardiac output: Because the heart cannot meet both the needs of the exercising individual's skin and muscle, cardiac output is increased in order to meet the thermoregulatory demand of the skin.<sup>88</sup> In order to understand this process a little better, it's important to remember that during heat stress and exercise, cutaneous vasodilation is restrained. Additionally, if heat is not or cannot be dissipated from the skin, internal temperatures are likely to reach upper limits in about ten minutes. While a large variation in environmental temperatures is tolerable by an individual, even a slight variation in internal body temperatures (about 3 °C) can lead to death.

In trained individuals, at the early stages of heat stress the higher demand for skin blood flow is met with a 1-2L/min higher cardiac output. Coincidentally, the more hyperthermic the individual gets, the more quickly the cardiovascular system is pushed to its limit causing the cardiac output and blood flow to the exercising muscles to no longer be able to be maintained. This decrease in cardiac output is accompanied by a decrease in stroke volume, which is likely to be caused by several factors that all negatively affect cardiac preloading, ventricular after loading and myocardial contractility.<sup>36</sup> Additional reasons for the decreasing stroke volume may include a decreased venous return, severe tachycardia and a blunted myocardial oxygen supply in relation to actual cardiac work.

To summarize, when an individual exercises in the heat, several cardiovascular and cerebral changes occur within the body. In addition to decreasing athletic performance, any slight increase in internal body temperature will put them at risk for heat injury if the body cannot respond. In order to work efficiently, the body reacts to the competing demands of physiological heat stress by decreasing the amount of blood flow to the exercising muscles, and increasing the amount of blood flow to the skin.

## **Hyperthermia Effects**

### *Fatigue/Balance*

Noakes et al has stated that fatigue seems to represent a specific point in time, such as task failure or exhaustion.<sup>77</sup> Numerous studies regarding the relationship between fatigue and balance have been conducted.

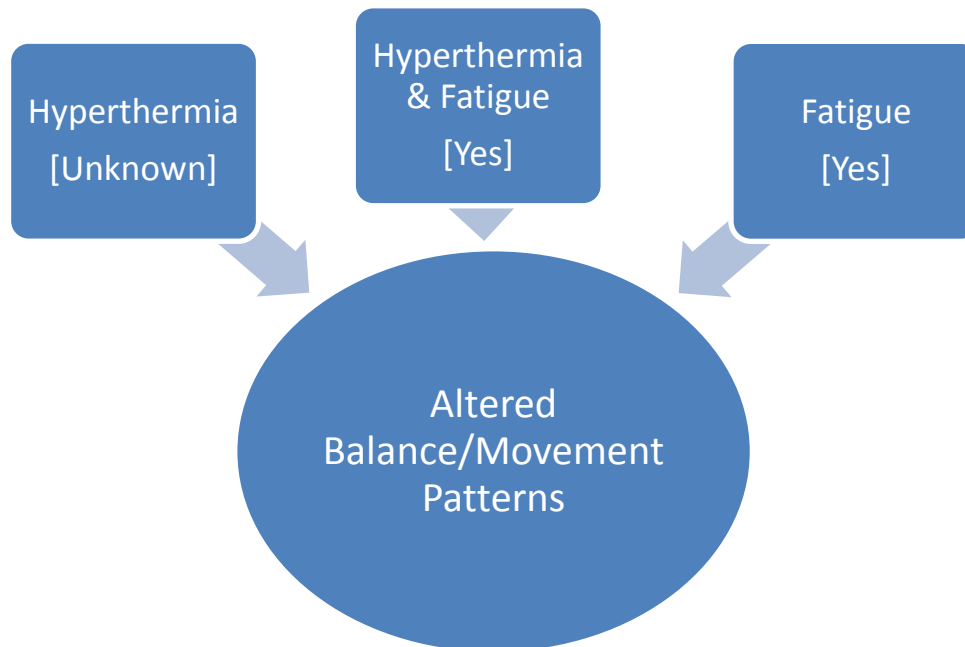


Figure 1. Current understanding of the individual and combined effects of hyperthermia and fatigue on balance and movement patterns

It has been said that fatigue during exercise-heat stress occurs when a “critical core temperature” is achieved, which was proven correct by a study in Denmark by Nielson *et al.*<sup>52,74</sup> In different literature, investigators have stated that fatigue can be conceptualized as being driven by changes that occur anywhere among the path between brain and muscle fibers. Peripheral fatigue’s domain causes effects within the motor unit while central fatigue affects areas in the brain and spinal cord.<sup>15,42,93</sup> Similarly, Noakes *et al.* goes further saying that if we do indeed understand fatigue as a sensory perception resulting from integration of physiological, biochemical and other sensory feedback from the periphery that may or may not actually be associated with any alteration in muscle force production, then sensations of fatigue can be present when no work is even being performed (i.e. Chronic fatigue syndrome), or beginning shortly after the onset of exercise. This also means that fatigue could peak as the workout progresses (which are most familiar to us).<sup>77</sup>

Fatigue has also been brought on by walking, running, cycling, or a combination of these. Nardone *et al.* examined effects on balance following fatiguing and non-fatiguing

exercise sessions using treadmill walking and cycling. The authors found no significant increase in body sway following either of the non-fatiguing exercise sessions. However, they did find significant increases following the treadmill fatiguing session, but only a negligible increase in body sway following the cycling fatiguing session. Any effects seen after exercise went away after about 15 minutes after the end of exercise.<sup>73</sup> A second study by Nardone et al. investigated the time course of balance changes after a fatiguing treadmill walking exercise session. This study also showed an increase in body sway after exercise, but the effects again went away after about 15 minutes.<sup>72</sup>

Several other studies have shown significant increases in postural sway following strenuous exercise. Seliga et al. investigated the additional effects of wearing a respirator while cycling at different workloads and found that body sway was increased linearly when compared to the non-respirator condition.<sup>89</sup> Lepers et al. investigated the effects on balance after a 25-km run and after cycling for the same amount of time as the run. While balance decreased after both types of exercise, it was more pronounced following the running session.<sup>67</sup> Wilkins et al. used a 20 minute fatigue protocol with a circuit design which included jogging, sprints, push-ups, sit-ups, and step-ups. Subjects scored significantly more errors on the Balance Error Scoring System (BESS) after exercise and when compared to the control group which rested for 20 minutes instead of exercising. Fatigue affected the performance on the tandem stance more than on the double-leg or single-leg stances.<sup>95</sup>

The studies using walking, running, and cycling have shown more significant decreases to balance, suggesting that more intense exercise will have an effect on balance, but will most likely return to baseline after about 15 minutes.<sup>67,72,73,89,95</sup> Conversely, when fatiguing subjects with a less intense exercise regime (calf raises), balance was only slightly compromised if at all.<sup>72,73</sup> One note of importance from this battery of studies is that strenuous exercise can have a significant effect on balance, especially immediately following termination of an exercise session. While balance decrements were shown by several studies to cease after 15 minutes,

it's still an imperative finding for sports medicine professionals who may be evaluating an athletic injury immediately after cessation of exercise on the sideline. Since fatigue has been shown to decrease balance performance, the athletic trainer or team physician needs to recognize this as pertinent information when attempting to perform a sideline evaluation. It may be necessary to wait until the afore mentioned window of fifteen minutes passes to evaluate any balance related performances in order to eliminate fatigue from skewing the athletes presentation.

While information is scarce on the effect hyperthermia as an isolated factor on balance, several studies have looked at fatigue and balance. Within this sequence of studies, several induced fatigue with some sort of exercise regime (walking, cycling, or calf raises), which means that while the subjects may not have been hyperthermic, they were in most cases performing balance testing at an elevated core temperature. We know that performance and endurance can be impaired in hot environments, and that fatigue generally occurs ~40 °C.<sup>52</sup> It can also be noted that hyperthermia plays a factor in the development of fatigue, which we know effects balance.

<sup>6,52,67,73,95</sup> Accelerated fatigue is associated with thermal strain and physiological instability.

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Additionally, fatigue has been suggested as a possible risk factor for injury due to evidence from several studies reporting higher incidences of injuries later in activity.<sup>45</sup> Immediately following fatiguing protocols, individuals have been observed with altering movement patterns, including a stiffer landing strategy and increased knee valgum, which are both identifiers for movement-based factors for increased injury risk.<sup>32</sup>

### *Balance in Real Life*

Among the largest population of athletes that are studied extensively in regards to balance are shooters. When thinking about the accuracy needed in order to shoot a rifle, you can imagine how the slightest decrement in balance could exponentially affect the precision of the shot. Comparing expert and novice shooters has also shown that there is a relationship with body sway and level of expertise; the more veteran shooters showed less postural sway and thus increased accuracy while the beginners' postural sway was much more pronounced decreasing their accuracy.

Other jobs that need to be considered when thinking about the importance of postural sway and balance include fire fighters, construction workers, painters, lumber jacks and acrobats. With job requirements involving ladders, platforms and the necessity of maintaining balance, it's important to understand what the causes of poor balance and postural sway are in order to develop a protocol and standards to keep workers safe on the job.

### *Body Systems and Musculoskeletal*

Hyperthermia affects the heart, brain and muscle tissues. Hyperthermia will cause reductions in systemic, muscle and skin blood flow, which in turn causes muscle glycogen and cellular metabolism to be relied on more heavily. We know that as the subject's heat up, cardiac output declines more quickly, as well as muscle blood flow which can lead to suppressed oxygen delivery and uptake and in turn leads to fatigue.<sup>49</sup> In addition to these things, we know



that exercise in the heat challenges the human cardiovascular system in other ways: increased oxygen is needed in exercising muscles and vital organs, enhanced thermoregulatory demand for skin blood flow, increased cardiovascular strain, and increased cardiac output (see Figure 3).<sup>51</sup> In a hot environment, Gonzales-Alonso et al, showed that lower  $\dot{V}O_{2\max}$  and earlier fatigue are strongly associated with faster decrease in muscle activity and energy production. This finding suggests that vascular conductance is not actually reduced, but that blood flow is reduced secondary to the falling blood pressures at workloads equal to  $\dot{V}O_{2\max}$  and that the actual vasoconstriction of the active muscle plays little or no role, but is more of a passive event that is brought on by the hot environment.<sup>51</sup> (See Figure 2)

### *Brain*

Gonzales et al have shown the effects of hyperthermia as an isolated factor to only cause reduced stroke volume and increased heart rate with no noted changes in other cardiovascular responses (up to 39.3 °C).<sup>50</sup> Hyperthermia affects some aspects of CNS function, including central neuromuscular drive, increased perceived effort, and reduced maximal voluntary contraction, which all suggest that functional alterations in multiple body systems accelerate hyperthermia-mediated fatigue.<sup>49</sup>

During exercise in the heat, brain circulation becomes compromised. Hyperthermia also affects the brain blood flow and visceral blood flow which are associated with reductions in cerebral artery blood velocity, splanchnic, and renal blood flow.<sup>49</sup> Reflectively, this causes an increase in an exercising subjects rating of perceived exertion. Studies have shown that brain temperature is always higher than core body temperature which leads to decreased heat removal due to the hyperthermic brain.<sup>74,79,82</sup> Since elevated core body temperatures have been seen in experienced athletes with no harm, it may be possible that the elevated brain temperature is actually what causes the fatigue, exhaustion, and in turn, decreased postural

control. Gonzales et al additionally showed that trained subjects become exhausted at similar levels of internal body hyperthermia, cardiovascular strain and rating of perceived exertion even when there are marked differences in starting core temperature rate of heat storage and terminal skin temperature. This study magnified the effect of hyperthermia on trained cyclists who can train at the same intensity for hours by showing that after just 30 minutes of cycling that began with their core body temperatures elevated causes them to become exhausted.

Additionally, Crandall et al. showed that middle cerebral blood velocity declined significantly during prolonged exposure to exercise heat stress. After ninety seconds, however, cerebral perfusion begins to decline. When an exercising individual starts to approach exhaustion, brain metabolism and neural drive are both enhanced which leads to physiological repercussions. This includes the idea that perfusion to the brain is less severe than in skeletal and cardiac muscles because compared to the muscles exhausted oxygen reserve, the brain is still able to maintain a large oxygen reserve.

### *Cognition*

In addition to all other things hyperthermia does to a subject's body, balance, cognition and neuromuscular control may also be negatively affected. As we have previously stated, hyperthermia reduces ideal functioning of the central nervous system.<sup>49</sup> Lower extremity injury risk is increased when body awareness is compromised, such as in a situation where a subject has decreased cognitive function. While several studies have looked at the effects of the combination of hyperthermia, fatigue and dehydration, none have looked at just hyperthermia as in isolation. The studies just mentioned revealed that dehydration did in fact cause an impaired ability to balance, but that those results were likely affected by additional influences of fatigue or hyperthermia.<sup>37,47,52</sup>

A couple common simple cognitive tests used in studies are the Profile of Mood States

Questionnaire (POMS) and Visual Analog Ratings (VAR). POMS is very widely used, probably because it takes less than five minutes to complete. It's an extremely standardized inventory of a subjects mood states. Subjects rate a sequence of sixty five mood related adjectives on a five point scale. The adjectives are to be answered to the question "How are you feeling right now?" These adjectives can be separated into six mood sub-scales, including tension, depression, anger, vigor, fatigue and confusion. The VAR test requires subjects to place a mark on a one hundred millimeter line where they think the answer falls. Each end of the line represents either extreme of the answer spectrum. Questions include things such as "How hard was the effort required to complete these tests?" or "How hard did you have to concentrate to accomplish the task?". The relevance of these tests it's simple: purely to have a subjective way of looking at how a subject is feeling at that given time during the testing battery. In our study, we will be asking the subjects these cognitive questions to rate their mood after they complete the exercise portion, before they perform any balance testing.

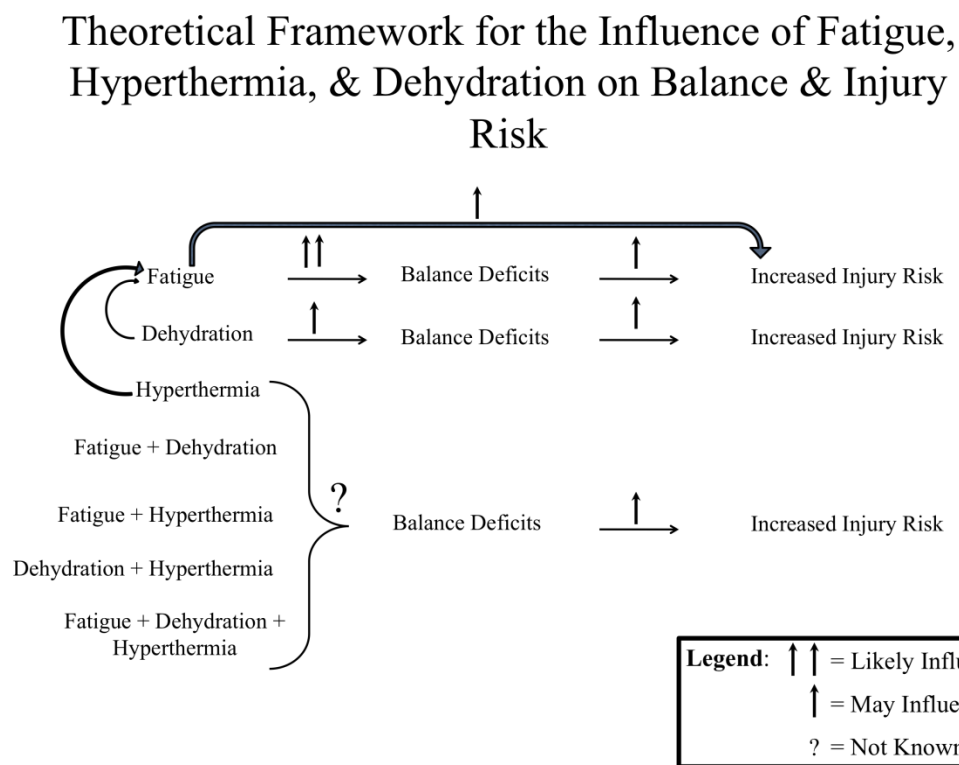
### *Effects on Injury Risk*

The effect of hyperthermia on a person's risk of injury has never been evaluated. While we know that hyperthermia directly affects many aspects of sport negatively, including time to fatigue, it is uncertain if heat stress alone can increase a person's risk of injury. We can infer that since fatigue has been shown to alter a subject's balance, and that compromised balance as shown by BESS and LESS testing has been shown to increase injury risk, that it's likely that hyperthermia may have an effect on injury risk. However, the sequence of events in a person's body when under heat stress seems to be a waterfall of related effects: A person exercising in the heat will eventually reach a point of fatigue (usually once they reach a certain core temperature), after which time their balance becomes altered, in turn increasing injury risk. There is no evidence to say that there is a direct line that runs straight from having an elevated core temperature to an increased injury risk. That is to say, a study has yet to be done that

looks at a person exposed to heat stress where fatigue has been eliminated completely.

## Balance Testing Procedures

Balance is important in everyday life and especially in athletic and military events. Having good balance can become a matter of safety. Decreased balance can lead to sports injuries, falls off high or small area platforms, and a decline in shooting accuracy.<sup>5,19,43,62,71,89</sup>



### *Balance Error Scoring System (BESS)*

To test balance, several different avenues have been taken involving more costly equipment. However, there is a much more budget-friendly route to take called the Balance Error Scoring system (BESS). While research assessing the reliability and validity of this test is minimal, Goldie et al investigated just that with the BESS method force plate measurements. In this study, relationships between the subjects force and their center of pressure measures were assessed. Results showed that those two were not significantly correlated and that force measures were more sensitive, thus the best predictors of steadiness. In conclusion, this study showed that using a force platform for measures instead of centers of pressure is the best balance testing method because it's both reliable and valid.<sup>48</sup>

As stated previously, cost is the biggest disadvantage of using force plate assessment, making them more widely used in laboratory settings than in a more traditional athletic setting (sidelines, athletic training rooms). BESS has given sports medicine personnel a much more cost effective and reliable method to test balance. Riemann *et al*/ recognized the reality that this equipment isn't going to something readily available in most sports settings and investigated the clinical administration of BESS and it's correlation to force plate measures of postural stability.<sup>48</sup> In their study, the force platform was tested at the same time as BESS. The double-leg stance was the only stance in which there was not significant correlation between the BESS and force platform target sway measures (because subjects performed no errors), while the rest of the stances had significant correlations. The study also showed that the error scores had intertester stability. BESS, therefore, can be used as a reliable measure for postural stability. The downside to BESS according to this study was the finding that a practice effect was elicited if it was administered frequently, which could cause a major problem if it's being used repeatedly to follow the recovery of athletes who have sustained concussions.<sup>91</sup>

### *Landing Error Scoring System (LESS)*

Movement assessment using the Landing Error Scoring System (LESS) requires subjects to perform a jump-landing task while being recorded. LESS has been shown to be both a valid and reliable clinical assessment tool to identify ACL and other lower extremity injuries. The subjects begin by standing with their hands on their hips on a 30 centimeter high box from which they jump and a try to land in the target area which is placed half of the participant's body height from the base of the box. They are instructed to jump with their non-dominant foot and land using only their dominant foot in the center of the target all while keeping their hands on their hips. Immediately after they land, they are required to perform a maximal vertical jump. The LESS video recordings (ground force data which is collected from the force plate) are then analyzed for potentially high-risk movement patterns.<sup>84</sup>

Using military populations and high school soccer, LESS has been validated by showing a correlation between successive injury risks. The time-to-stabilization measures are evaluated for balance assessment and have been proven to be reliable and valid when it comes to measuring dynamic postural stability.<sup>87,94</sup>

### *Balance deficits and Injury Risk*

With all the information available, deficits in balance have been tied very closely with an increased injury risk. While balance training and its effect on injury prevention is still being tested, the literature stating that poor balance and increased risk of injury is definitely not lacking. As stated previously with the shooter/rifle studies, the smallest increases in body sway greatly decrease the outcome of accuracy. If we translate accuracy into injuries, we see similar results. Several studies have attempted to look at balance training and its relationship with jumping, landing and agility. These intervention-type studies have found a significant decrease in ankle and knee injuries. When studied alone, balance training has the ability to significantly decrease recurrent ankle injuries, but hasn't been proven to reduce injury risk in athletes without

a prior injury.<sup>61</sup> Surprisingly, balance training has been shown to decrease knee injury in male soccer players but increase knee injury risk in female soccer players.

Studies that have shown direct correlations resulted in ankle sprain injury risks and a decreased balance performance.<sup>70</sup> McGuine et al. showed that subjects with the lowest sway scores experienced seven times more sprains than those who had good balance.

Consequently, most studies that have found a significant correlation between balance training and injury risk have only found that to be true in males.<sup>61,70,90,92</sup>

### **Methods to Eliminate Fatigue/Water Perfused Suits**

In order to eliminate fatigue as the middle man in the hyperthermia-fatigue-balance deficit equation, water perfused suits are going to be used. Allan Vanguard provides micro climate systems for thermal management. These personnel cooling suits were designed for military soldiers, and provide the technology needed to regulate the core body temperature. Usually these suits are used in order to help keep soldiers cool while performing their duties, however, by pumping warm water into these suits, you could potentially keep a subject hot while fatigue is eliminated.

The suit works by pumping water in and out of the suit via solenoid valves. Flow through the valves is much faster than flow through the suit, allowing for rapid temperature changes in the suit. In the military setting, once the operator becomes experienced, they can control their skin temperature accurately in desired patterns. This becomes very useful for soldiers on active

duty in extreme heat or cold. This system has been utilized without failure for over two years.

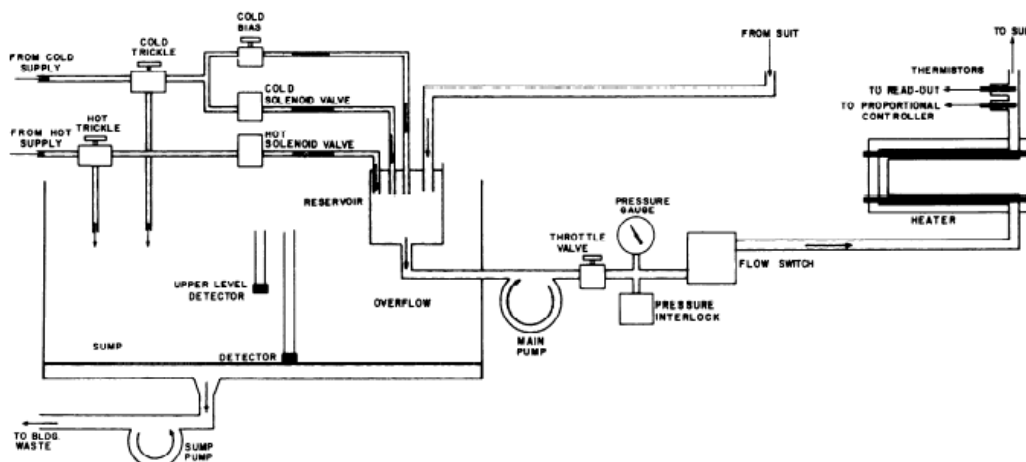


FIG. 2. Plumbing and mechanical components. Hot and cold water from building mains are supplied to reservoir through solenoid valves controlled by operator. Flow through solenoid valves is several times higher than flow circulating through the suit, so that rapid temperature changes can be produced in the suit. The additional line, labeled "cold bias," is from cold supply via a 1/4-in. needle valve. This is used to set a steady flow so that suit temperatures below ambient can be controlled by the heater system. Valves labeled "trickle" valves in the supply lines are used to maintain a flow through each line sufficient to prevent appreciable temperature

change over the length of the hoses which connect to the building mains. Overflow from the reservoir spills into a sump below. Float switches (De Leval, model LS-1700) serve as level detectors. The sump pump is turned on when the upper switch is actuated and pumps until the lower switch opens. In the suit circuit, a 3/8-in. needle valve is used to throttle outflow of pump (Eastern, model D-11). Downstream of pressure gauge and interlock and flow interlock is the heater assembly. Thermistors (Yellow Springs Instrument Co., model 410) are mounted in tee connections at outlet of the heater.

**Figure 2: Illustration of water perfused suit as seen in Brengelmann's article<sup>30</sup>**

While this suit has been used almost flawlessly, it does have some safety considerations. There is potential for electrical and thermal hazards. If the housing on the lamps breaks, water from the system would be directly connected to line voltage. Additionally if a leak were present in the suits tubing, currents could flow through the suit. While the water supply is low in ionic strength, electrical isolation in the suits is still essential.<sup>30</sup>

## Conclusion

In the field of sports medicine, the correlation between fatigue, hyperthermia and balance has several important suggestions. Among these, the fact that decreased balance performance is often related not only to a lower extremity injury, but also to athletes who have suffered a concussion. Mild head injuries and concussions have been shown to slightly decrease postural stability from the time on injury up to three days after.<sup>57,86</sup> Nevertheless,



fatigue can also influence performance on sideline evaluations measuring balance along with the effects of a concussion, therefore it's important to perform balance tests after a sufficient period of time has passed (15 minutes) in order to eliminate the fatigue factor.<sup>72,73,95</sup>

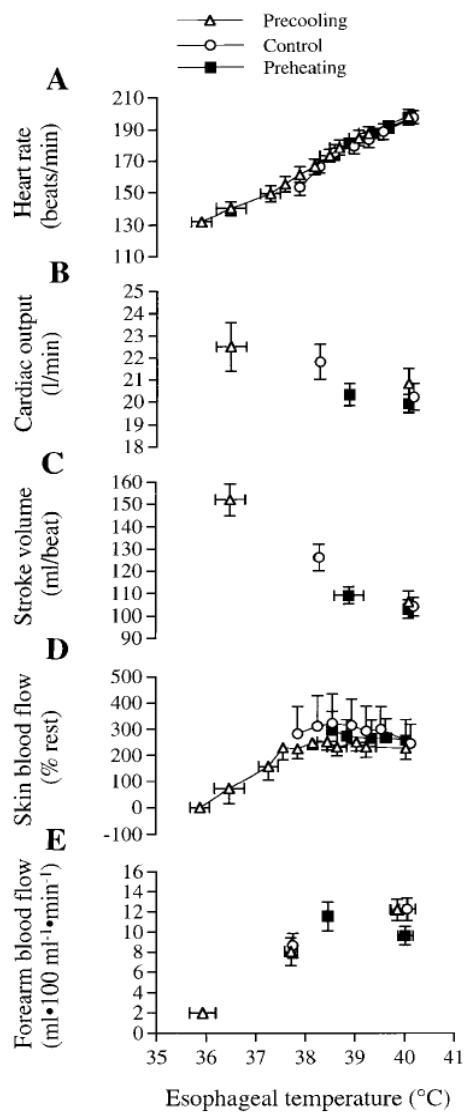
In regards particularly to ankle injuries, a decreased balance can greatly increase injury risk. Additionally, postural balance has been studied extensively in regards to rifle stability and shooting accuracy.<sup>5,19,43,75</sup> As one could imagine, the poorer a subjects postural stability, the less accuracy the shooter will have. Relationships between expert and novice shooters has also been investigated, showing that novice shooters have an increased body sway compared to those who are considered experts in the field, which leads to decreased accuracy of their shots.

Outside the athletic scope, several other types of jobs require good balance in order to maintain occupational safety. Fire fighters, construction workers, painters and lumberjacks are all required work on ladders or high platforms which necessitate maintenance of balance. Additionally, in a study conducted by Seliga et al., the effect of wearing a respirator during different workloads was examined. Over 85 W body sway increased which shows the need for more thorough assessment of the effects fatigue may have on balance. Further studies either proving or disproving these findings would be crucial to sports medicine professionals understanding of the relationships between hyperthermia, fatigue and balance and in the long run, if hyperthermia alone increases injury risk.

It's very clear from all these studies that hyperthermia, fatigue and balance all exist together in the world of sport. While arrows can be drawn clearly between hyperthermia and fatigue, and from fatigue to decreased balance, jumping from hyperthermia directly to altered balance hasn't yet been proven. Studies have shown a relationship between all of these factors, but have not been successful in showing any effects of them as individual causes of balance deficits, altered cognitive function, or movement patterns in combination with athletic performance. In addition, these three factors have been only minimally, if at all, shown to

influence an individual's injury risk. Balance is a pivotal component of everyday life, from sport and exercise, to activities of daily living and work. Any decrease in an individual's balance can result not only in a general increased injury risk, but falls at a job site, or decreased shooting accuracy in the armed forces. There is a major disconnect in the literature regarding whether or not hyperthermia plays any detrimental role in a person's balance or not. The types of exercise intensities, exercise regimes, and balance testing could all be factors of the results we have seen, or lack thereof. Currently, there are no field studies that investigate the relationship that hyperthermia as an isolated factor on balance, and because the inferences and hypotheses we do have on the correlation are limited, it's necessary to further dive into the association between the two. As health care professionals, it's pertinent to fully understand how hyperthermia fatigue and balance all interact and affect each other and cognition and movement. Once there is a basic knowledge of the relationships between all of these, interventions and preventative measures can be taken in order to ease these problems. Not only are hyperthermia and fatigue present in physical activity, they are involved in processes that can lead to decreased balance and injury. If better understood, injury risk could then be alleviated.

	<b>Hyperthermia</b>	<b>Fatigue</b>	<b>Hyperthermia &amp; Fatigue</b>
<b>Effect On Balance</b>	Unknown	Alters Balance	Alters Balance
<b>Injury Risk</b>	Unknown	Likely Increases Injury Risk	Unknown



**Figure 3:** Table borrowed from Gonzales-Alonso et al (Gonzalez-Alonso, J. 2007). showing the effects of a heightened core temperature on heart rate (A), cardiac output (B), stroke volume (C), skin blood flow (D) and forearm blood flow (E)



**Figure 4:** Image of the Vanguard cooling suit (Allen Vanguard 2010)

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## INTRODUCTION

Injury in sport can cause debilitating long-term consequences. Sports and physical activity related injuries are associated with high cost and time lost from sport and sometimes even activities of daily living (i.e. going to school, work). 3 million emergency room and 7 million physician visits are due to musculoskeletal injuries annually.<sup>32, 33</sup> With 66% of injuries occurring in the lower extremity, especially at the knee joint, we can start to visualize the importance of good balance.<sup>34,35,36,37</sup> Of the most disappointing of these lower extremity injuries is a tear of the anterior cruciate ligament (ACL). Messina et al stated that even after a successful surgery and rehabilitation, only 75% of athletes return to their previous level of activity.<sup>38</sup> Since this injury has such an impact it's imperative to implicate prevention strategies and interventions that can help alleviate the high amount of lower extremity injuries. These injuries are not only devastating to athletes, but to soldiers. Research has stated that 70% of all out-patient injuries in soldiers were from physical training, sports and falls.<sup>40</sup> The Defense Medical Surveillance System reported that 31% of total medical expenses were due to musculoskeletal injuries. Both athletes and soldiers are in need of prevention strategies in order to avoid critical consequences of lower extremity injuries.

Balance requires full concentration and integration of visual cues and vestibular or proprioceptive inputs in order to control center of pressure or body sway and to ensure proper balance.<sup>2,43,44,45,46,</sup> Any interruption of these cues can result in a loss of balance, leading to injury. If we can design a program that effectively changes a person's risky movements into correct biomechanics, then we could decrease the risk of lower extremity injury. While there are several studies on balance and ACL injury in athletes, research has failed to translate these finding to military populations. More research is needed to understand the effects of injury prevention programs on identified risk factors (movement patterns, balance, and loss of cues). Another direction research needs to take is identifying secondary risk factors for balance deficits such as hyperthermia, dehydration and fatigue. These three factors are common during

physical activity, especially in the military. If we can better understand how these factors affect movement and balance, we could potentially limit the long-term effects of injury, and even decrease the risk of obtaining an injury in the first place.

Hyperthermia, dehydration and fatigue are possible factors in impaired balance and neuromuscular control, especially of the lower extremity. Hyperthermia can lead to a quicker time to exhaustion and a reduction in optimal function of the central nervous system, which may impair judgment and awareness in the lower extremity leading to injury.<sup>4</sup> While we know that hyperthermia affects body processes and the CNS, currently we are unsure of its direct effect on balance ability. Individuals will fatigue at similar core temperatures, no matter their starting body temperature. As stated in Dr. Lawrence Armstrong's book, *Exertional Heat Illness*, "Exercise-heat stress, even without dehydration, causes cardiovascular drift. Over time, heart rate increases steadily until the high heart rates, in effect; lead to exhaustion."<sup>5</sup> It might be that this heat stress athlete's are experiencing is in fact leading them to exhaustion and fatigue, and in turn compromising their balance.

Dehydration elevates core body temperature, causing individuals to become predisposed to hyperthermia.<sup>12</sup> Several recent studies have revealed that dehydration impairs balance ability.<sup>7,10</sup> These studies have failed to isolate dehydration as a factor, allowing the additional influences of fatigue or hyperthermia (as a result of exercise to induce dehydration) to be possible. Dehydration diminishes balance performance, especially when combined with fatigue.<sup>6,7,8,10</sup> Dehydration negatively affects muscular performance by decreasing muscle strength, power and endurance. Judelson et al conducted a literature review and found that a 3-4% increase in dehydration resulted in a 2% strength reduction 3% decrease in muscular function and a 10% decrease in muscular endurance.<sup>19</sup> These deficits are huge, especially to endurance athletes and soldiers.



Fatigue has been demonstrated to impair balance and increase injury risk, especially late in games or practices.<sup>46,47</sup> After completing a fatiguing exercise, individuals adopt poor biomechanics and alter their movement patterns. Often times these fatigued individuals exhibit a stiffer landing with increased knee valgus, which are both identified risk factors for lower extremity injury.<sup>46,47,48</sup> Fatigue has been shown as a huge detriment to decreased balance, however, several studies have shown that the effects of fatigue seem to wear off within 15 minutes.<sup>3,20,21</sup>

When looking at athletic performance and physical activity, there are many possible interactions between dehydration, fatigue and hyperthermia, individually and combined. Perhaps due to the variety of combinations and the close relationship these factors have, few studies have successfully isolated the effects and influences of these three variables. In the sport and military world, it is important to understand how dehydration, fatigue and hyperthermia can affect a physically active person, individually and collectively. If we can understand these influences on movement and neuromuscular control, we may be better able to design and implement successful prevention strategies to help alleviate the high number of lower extremity injuries. Therefore, the primary purpose of this study was to identify the individual and combined influence of dehydration, fatigue and hyperthermia on decreased balance in order to understand possible methods to prevent injury in both the athletic and military populations. A secondary focus is to gain a better understanding of the lone influences of dehydration fatigue and hyperthermia in order to implement individual prevention strategies to alleviate injury risk.

We hypothesized that: 1.) Fatigue, dehydration and hyperthermia will all have a negative effect on balance performance; 2.) Fatigue's effect will be the most detrimental as an individual effect; 3.) Each factor's effect will increase when coupled with another factor; 4.) Balance will decrease from pre-exercise to post exercise; 5.) Balance will return to baseline after the

recovery period in the normothermic hydrated trial, but not in the normothermic dehydrated trial or either of the hyperthermic trials.

## METHODS

### *Subjects*

Twelve healthy un-acclimatized adults from the local university and community volunteered for this study, which took place in the Human Performance Laboratory (HPL) at the University of Connecticut (See Table 1). The project was completed in the thermal physiology laboratory, which contains a climatic chamber (Model 2000, Minus Eleven, Inc., Malden, MA). The IRB approved this study. Subjects completed an informed consent form, background questionnaire, medical history questionnaire, and general workout log. Fourteen subjects were tested, and two did not make the fitness cut-off ( $\dot{V}O_{2\max}$  test). Other requirements included being active for minimum of 6 hours a week, interest in physical activity and availability.

### ***Test Procedures***

Subjects attended six sessions in total: two familiarization days and four test sessions that only differed based on the test condition of the participant. The conditions were hypothermic and hydrated (HyN), hypothermic and dehydrated (DehyN), hyperthermic and hydrated (HyHot) and hyperthermic and dehydrated (DehyHot). The four test sessions were separated by at least 3 days, which allowed the subjects complete recovery from the previous session.

### *Familiarization Sessions:*

The familiarization trials included instruction on the use of a rectal thermometer, wearing heart rate monitor, and walking on the treadmill at a standard speed (3.5 mph-4.0 mph) and incline (5%) for 30 minutes while carrying a standard 20.45kg pack. This pack is used to replicate the standard pack commonly issued in military scenarios. It was filled with common objects instead of weights. Subjects were allowed to pick a speed within the 3.5mph-4.0mph range that they could sustain for the 90 minute exercise protocol. For the first familiarization

session, the heat chamber heat stress was mild (18°F, 40-50% humidity). The second familiarization was performed in the heat (35°C, 40-50% humidity). Subjects were weighed prior to the familiarization sessions (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 ( $U_{sg} \leq 1.020$ ), urine color ( $U_{color} \leq 4$ ) and urine osmolality ( $U_{osmo} \leq 800$ ). On the first familiarization trial subjects performed a  $VO_{2max}$  test in order to ensure sufficient physical fitness ( $VO_{2max} > 50$ ). This was done prior to the 30 minutes of walking on the treadmill. After the exercise protocol, subjects were then instructed on the correct procedures for the balance assessment portion of trial and asked to perform two correct repetitions of each task, or until they indicated they felt comfortable with the tasks. These tasks included a static stance on a single leg which was held for 12 seconds, the Balance Error Scoring System tasks (single leg firm, tandem firm, single leg foam, tandem foam), and dynamic balance test (Time to Stabilization(TTS)). During the second familiarization session, percent body fat was calculated using skin fold calipers. Subjects also completed another 30 minutes of walking with the pack and repeated all balance assessment tasks to ensure understanding of the task.

### *Testing Sessions:*

The four test sessions each began with the same measurements: a baseline mass, urine specific gravity, urine color, urine osmolality, rectal temperature, and heart rate (HR). Once the subject was equipped with the rectal thermometer and HR monitor, they entered the chamber and were fitted with the pack. After the pack was fitted, around 2 minutes from the time they entered the chamber, they immediately began the balance testing procedures. First, they completed the static stance, which was held for 10 seconds. Next, they completed the BESS test which included Single Leg Stance on a firm surface (SLFirm), Tandem Stance on a firm

surface (TanFirm), Single Leg on a foam surface (SLFoam) and Tandem Stance on a foam surface (TanFoam). Each stance was to be held for 20 seconds. Errors were counted if the subject performed any of the following: lifted hands off the iliac crest, opened the eyes (when inappropriate), stepping, stumbling, or falling, moving the hip more than 30 degrees of flexion or abduction, lifting the forefoot or heel, remaining out of the testing position for more than 5 seconds. A subject's score was calculated by adding one (1) point for each error. All tests were performed for 20 seconds with the score equaling the number of errors that occurred; therefore the higher the score the worst the performance.

Lastly, the Dynamic Stance was performed until three trials were completed correctly OR they had surpassed five trials. Three trials of each task will be completed, but will be repeated if the participant performs the tasks incorrectly (up to 5 trials). Dynamic stance was evaluated for the balance assessment and have been shown to be a reliable and valid measure of dynamic postural stability. Subjects will stand on a 30-cm high box placed half of their body height away from a force plate with their hands on their hips. Subjects will jump forward from the box with their non-dominant foot and land with their dominant foot in the center of the force plate while keeping their hands on their hips and their non-dominant foot off of the ground. Subjects will be instructed to balance as quickly as possible without putting their non-dominant foot down.

For both the static stance and the dynamic stance, subjects were standing or landing on a non-conductive forceplate (Model #4060-NC; Bertec Corporation, Columbus, OH). Data from the force plate were collected through Motion Monitor Software (Innovative Sports Training Inc., Chicago, IL) at a sampling frequency of 180Hz. Once balance was complete, they continued to the treadmill to begin the exercise protocol.

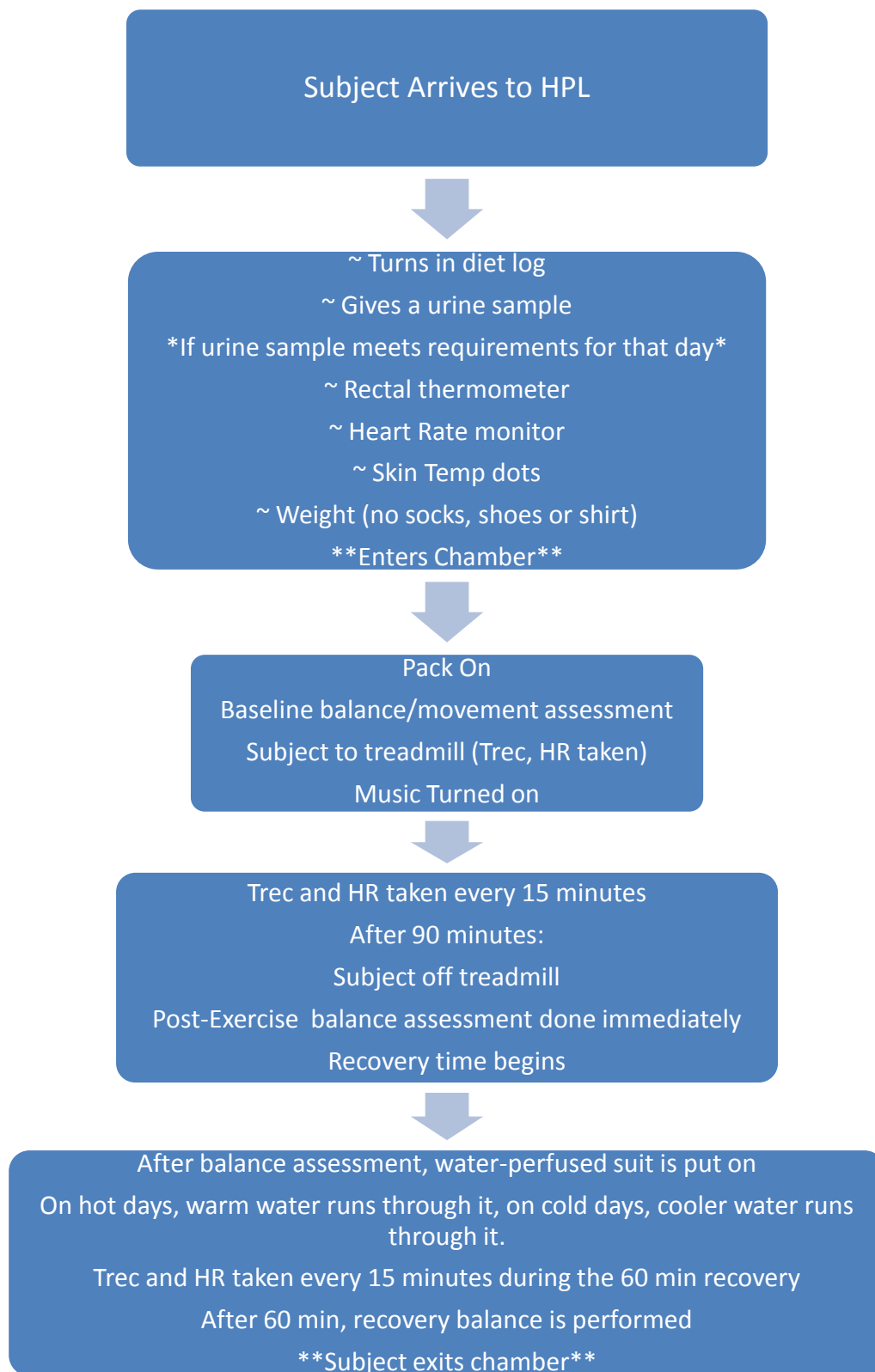
The exercise protocol consisted of 90-minutes of walking at each subject's individual

chosen speed (between 3.5-4.0 mph) at a 5% incline. During this time, heart rate and rectal temperature were measured every 15 minutes. This exercise protocol was intended to not only get the subjects rectal temperatures to a hyperthermic level, but to also facilitate fatigue. Immediately at the cessation of walking, they began another round of balance assessment (Static, BESS, and Dynamic Stance).

Sixty minutes after the completion of the exercise bout, subjects were asked to repeat the balance/movement assessments for a third time. This rest period hopefully allowed the potential confounding influence of fatigue to be removed. The subjects were able to remove their packs (only during the rest period) and wore a water-perfused suit during this time to maintain their exercising rectal temperature. On hyperthermic days, warmer water ran through the suits and on normothermic days, cooler water ran through the suits. As with during the exercise protocol, rectal temperature and heart rate were measured every 15 minutes.

Once the third and final balance assessment was complete the subjects removed the pack, were weighed, removed their rectal probes and submitted a final urine sample. At this point they were given water (if it was a dehydrated day). With hyperthermic trials, subjects who reached high temperatures were asked to keep their rectal thermometers in until we observed a return to baseline temperature in order to assure safety.

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 (from their familiarizations), but not during the 60 minute recovery period.



Flow Sheet: Algorithm for the testing session

### *Dehydration Protocol*

Subjects in the dehydrated condition were fluid restricted starting 22-24 hours prior to their scheduled testing session. Each subject received a call at least 24 hours prior to their testing session to inform them of their hydration status for the next days trial. It was estimated that with this fluid restriction, in addition to a controlled exercise period of 60 minutes done the night before, subjects would start the trial at about 1-2% dehydrated as measured by body weight changes. Subjects were instructed to perform 60 minutes of exercise on either an elliptical, bike or treadmill. Whichever they choose, the same exercise protocol was repeated the evening before every test day. The exercise was completed between 2pm and 6pm the previous day. If using a treadmill, was avoided. A suggested pace of 3.5-4.0 mph 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. Subjects turned in their diet logs before each session and they were reviewed in order to assure consistency.

### *Temperature Assessment*

All subjects were instructed on insertion of a rectal probe for the purposes of assessing rectal temperature throughout the study. The probe was inserted 10cm into the anal sphincter to best insure that it stay in place the entire trial.

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

Subjects were asked every fifteen minutes their perceived exertion level; "How hard are you working right now?" A sheet was held in front of them with the number 0-20 along with word descriptions from "not hard at all" to "Extremely hard". Subjects were asked to point at a number, or say a number which was repeated back to them by the therapist to ensure correct data collection.



### *Heart Rate (HR)*

Subjects were fitted with a chest strap polar heart rate monitor before each testing session that stayed on them until their entire session was complete and they were dismissed from the HPL. Every 15 minutes, the therapist held up a polar wrist watch that read the heart rate and recorded the number.

### *Body Mass Change*

Body mass change was assessed at each session. After subjects gave a urine sample, they were dressed with a rectal thermometer and had their heart rate monitor on, they 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.

### *Statistical Analysis*

At the end of the study, all data was imported into an Excel spreadsheet (Microsoft Excel 2007). The balance data were reduced using Matlab 6.1 and then entered into SPSS (PASWStatistics 18.0) for analysis. We analyzed data for differences between conditions and time of balance testing and interactions between the condition and time. We conducted a 4x3 (condition\*time) repeated measures analysis of variance (ANOVA). A Bonferroni correlation was employed for pairwise comparisons to evaluate any significant differences.

## RESULTS

Results on the clinical balance assessment (BESS), the static balance assessment (Static), and the dynamic balance assessment (Dynamic Stance) will all be provided below. All 12 subjects completed the familiarizations and 4 testing sessions (HyN, DehyN, HyHot, DehyHot).

**Subject Demographics:** Below in Table 1 you will find characteristics of the subjects. Body fat percentage was calculated using a three-site skin fold measure taken during the second familiarization day.

Subjects	Age (yrs)	Height (cm)	Body Mass (kg)	Body Fat (%)
n=12 males	20±2.46	181.83±7.53	74.09±8.43	8.76±2.75

Table 1: Subject demographics

### Temperature

As you can see in Table 2, subjects' temperatures all began similarly when they came in to begin each session. At the post-test, subjects who were either hot or dehydrated or both had increased  $T_{\text{rec}}$  as compared to the normothermic, hydrated trial (See Figure 5). At recovery, the subjects who exercised in the heat were still at a heightened rectal temperature as compared to the normothermic condition days.

<b>Subjects T<sub>rec</sub></b>	Pre-test	Post-test	Recovery
Condition	Mean±SD	Mean±SD	Mean±SD
Normothermic, Hydrated	37.13±.41	37.84±.34	36.82±.31
Normothermic, Dehydrated	37.38±.31	38.22±.29	36.96±.45
Hyperthermic, Hydrated	37.06±.36	38.25±.63	37.52±.43
Hyperthermic, Dehydrated	37.35±.34	39.33±.45	38.48±.46

Table 2: Subject T<sub>rec</sub> at each balance testing interval

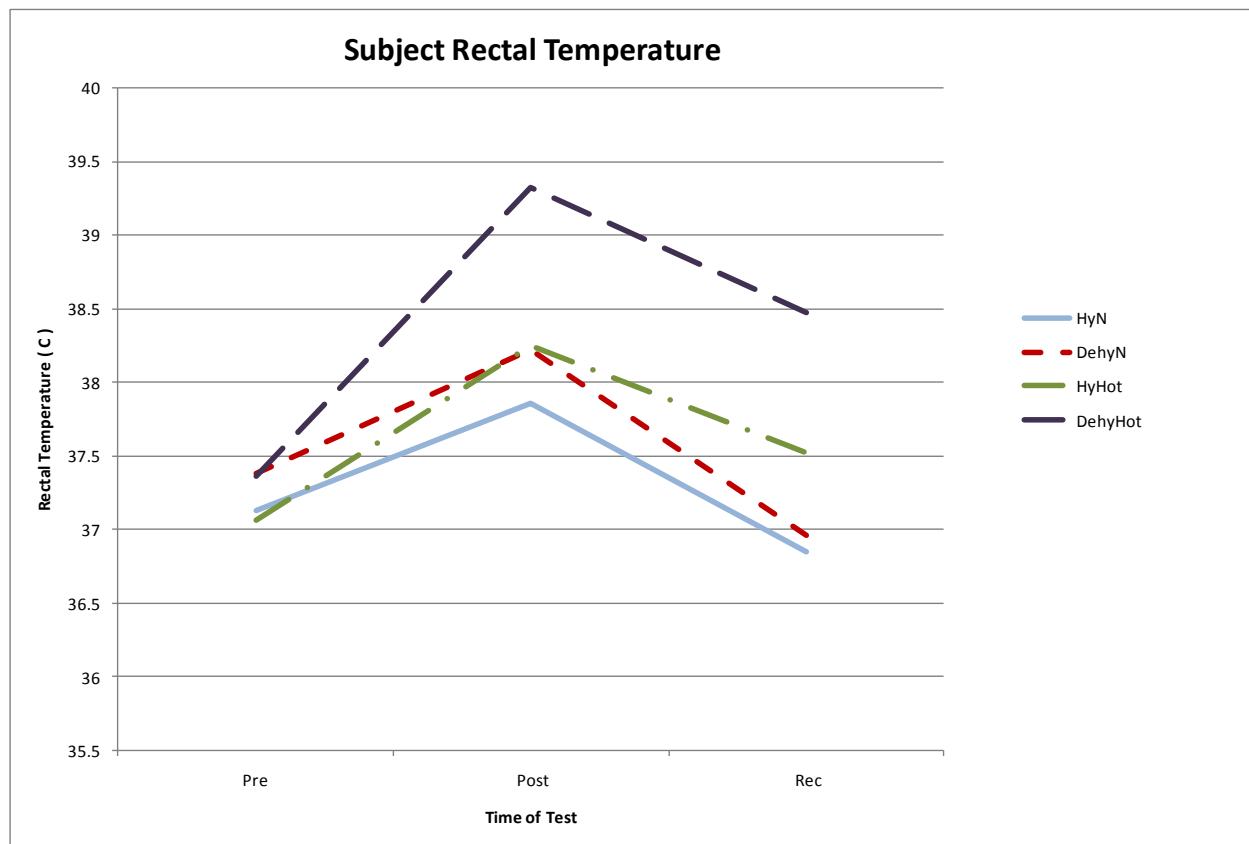


Figure 5: Mean T<sub>rec</sub> for subjects during each condition for each time point

## Ratings of Perceived Exertion (RPE)

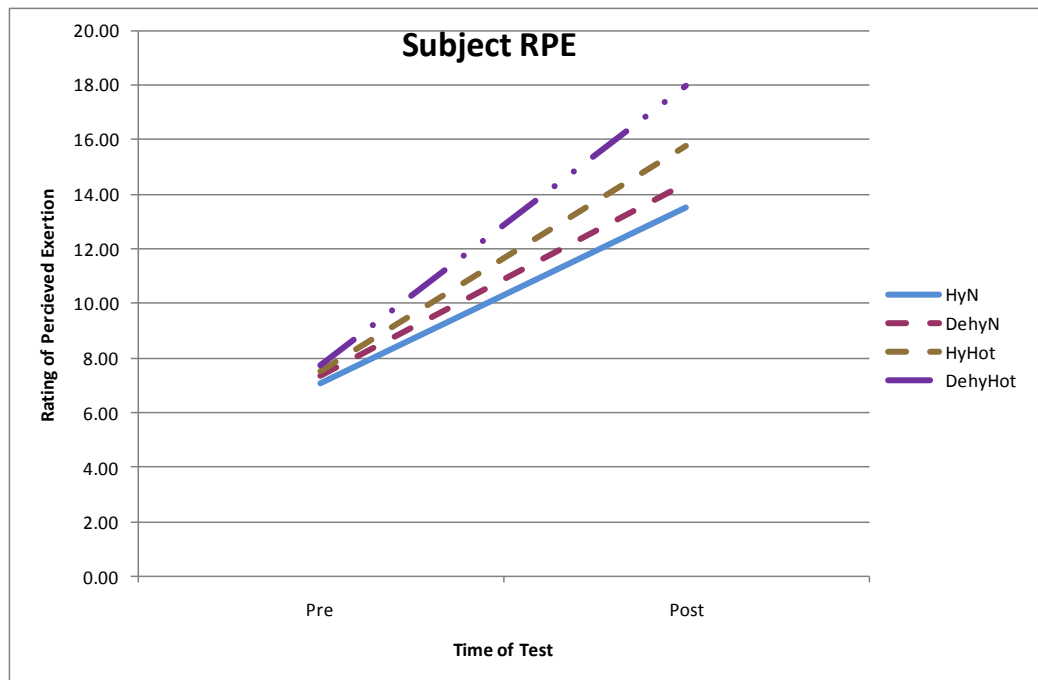


Figure 6 Subject mean RPE at Pre and Post test during each condition. Subjects felt that they were working harder as the exercise continued, especially in the DehyHot condition

	Pre Trial RPE	Post Trial RPE
Condition	Mean±SD	Mean±SD
Normothermic, Hydrated	8±2	14±2
Normothermic, dehydrated	7±1	14±2
Hyperthermic, hydrated	8±2	16±2
hyperthermic, dehydrated	8±2	18±1

Table 3 Subject mean RPE at pre-test and post-test

## Heart ate (HR)

	Pre Trial HR	Post Trial HR	Recovery HR
Condition	Mean±SD	Mean±SD	Mean±SD
Normothermic, Hydrated	81±20	131±12	72±14
Normothermic, dehydrated	88±27	145±10	75±14
Hyperthermic, hydrated	97±17	156±17	99±18
hyperthermic, dehydrated	100±13	174±11	117±16

Table 4 Subjects mean HR at each testing time during each condition.

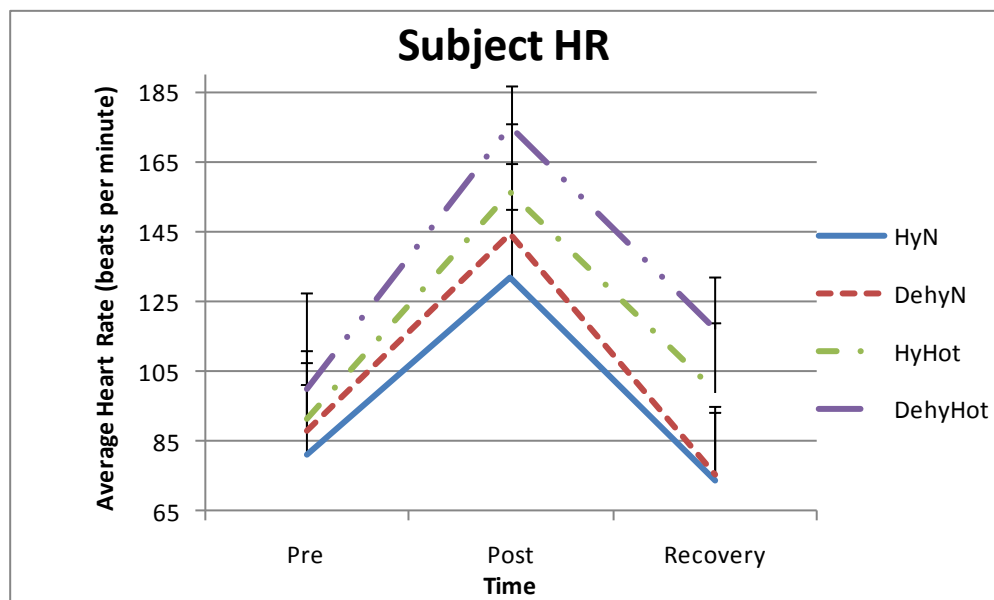


Figure 7 Average HR for each condition taken at each balance testing point.

## Total Body Weight Loss

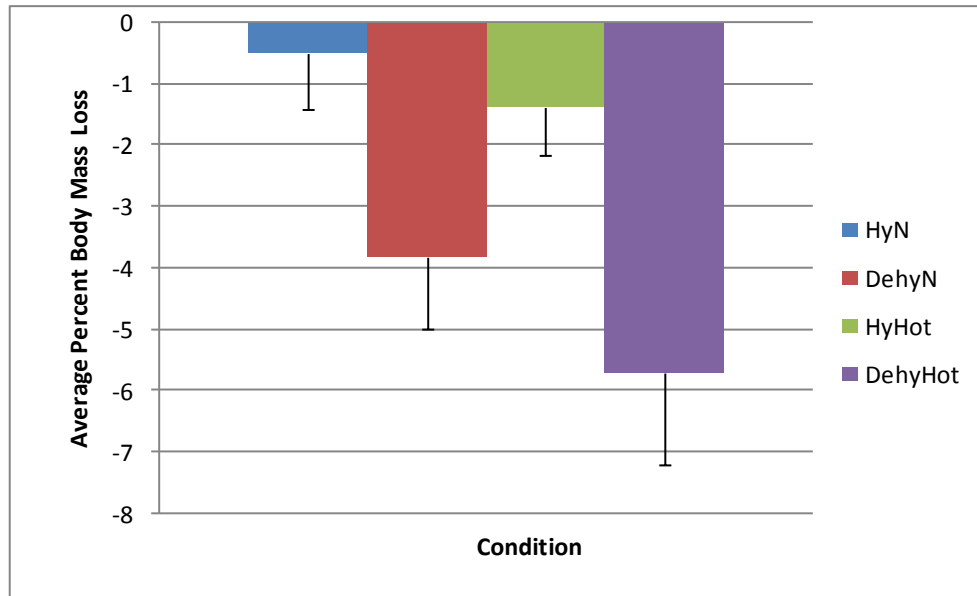


Figure 8 Subjects mean body weight loss for each condition. We successfully created two separate conditions in which the hydrated subjects were in fact hydrated and the dehydrated subjects were dehydrated.

	Pre Trial Weight	Post Trial Weight	%Body Mass Loss
Condition	Mean±SD	Mean±SD	Mean±SD
Normothermic, Hydrated	73.88±8.11	73.58±8.06	.10±.90
Normothermic, dehydrated	72.08±7.98	71.12±7.87	-3.80±1.22
Hyperthermic, hydrated	73.74±8.05	72.93±7.77	-1.30±.85
hyperthermic, dehydrated	71.98±8.06	69.77±7.84	-5.66±1.57

Table 5 Subjects Pre-trial weights and post-trials weights along with %Body mass loss. Used to show successful dehydration of subjects on both the dehydrated days.

## Urinary Status Indices

	Pre Trial Osmo	Post Trial Osmo
Condition	Mean±SD	Mean±SD
Normothermic, Hydrated	464±266	320±189
Normothermic, dehydrated	1026±92	1095±80
Hyperthermic, hydrated	404±282	511±279
hyperthermic, dehydrated	1052±72	971±107

Table 6 Subject average osmo measures at Pre-Trial and Post-Trial

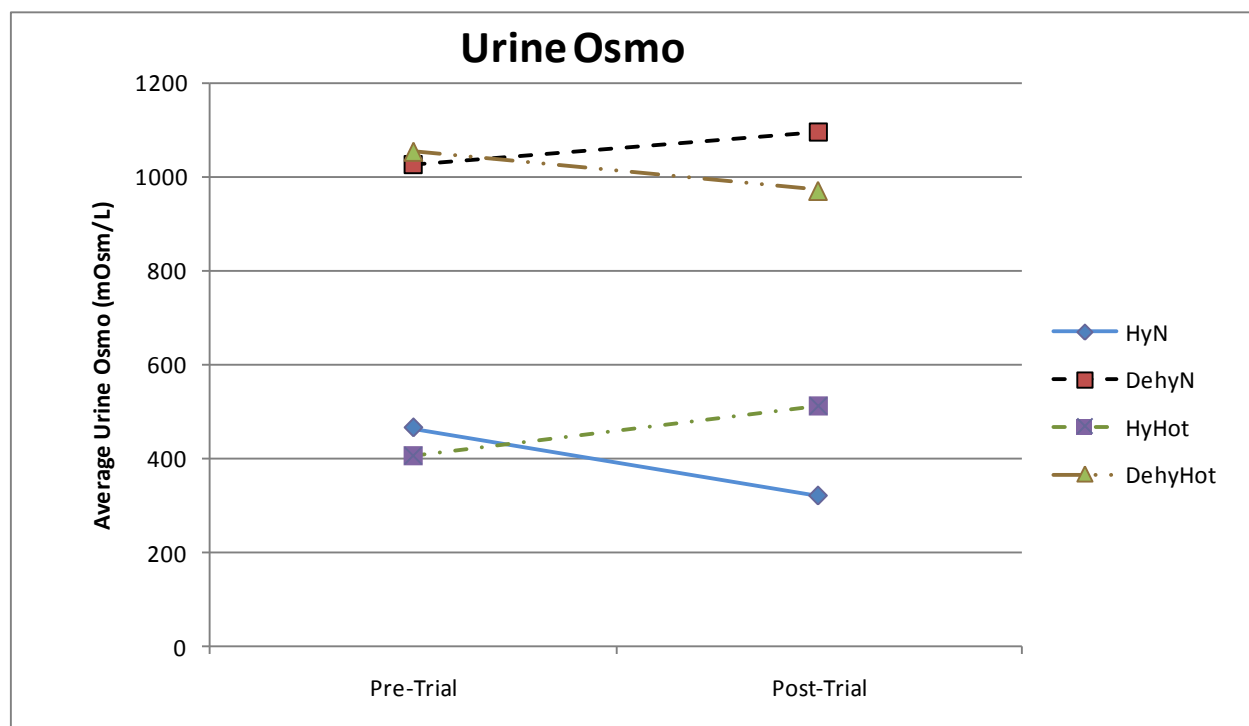


Figure 9 Subject average urine osmo at pre-trial and post-trial.

## Balance Error Scoring System (BESS)

### *Single Leg Firm*

We observed a significant main effect for time ( $F_{(2,22)}=5.37$ ,  $p=.01$ ) for the BESS score from the Single Leg Firm stance (see Figure 15). Pairwise comparisons between conditions revealed that post-test scores were significantly higher than recovery scores ( $p=.01$ ). The difference between pre-test and post-test values was also statistically significant ( $p=.02$ ).

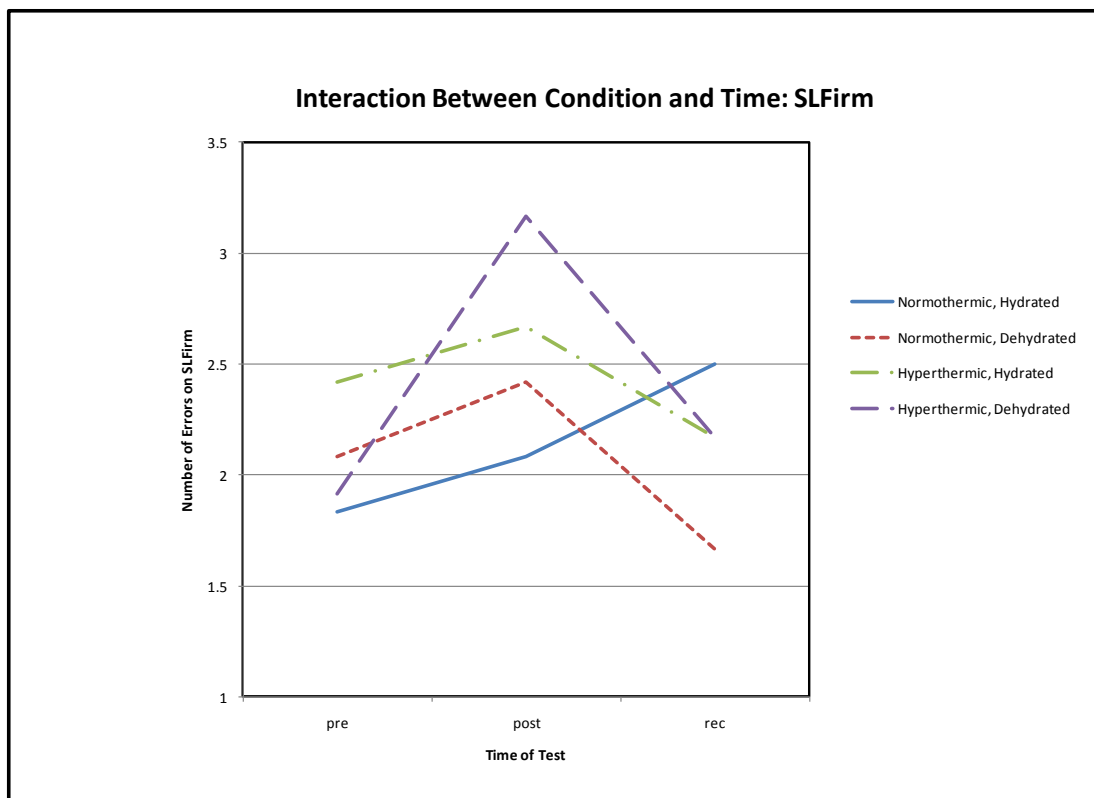


Figure 10 Interaction between condition and time for SLFirm stance. No significance was found.



### *Tandem Firm*

We observed a significant main effect for time ( $F_{(2,22)}=4.641$ ,  $p=.021$ ) and condition ( $F_{(3,33)}=3.048$ ,  $p=.042$ ) for the BESS score from the Tandem Firm stance. Differences revealed that subjects scores were higher on the post-test scores than their pre-test scores ( $p=.017$ , see Figure 15). Subjects also performed worse during the DehyHot trial than any other trial, most significantly was the difference in performance from HyN to DehyHot (see Figure 11). No other findings were significant.

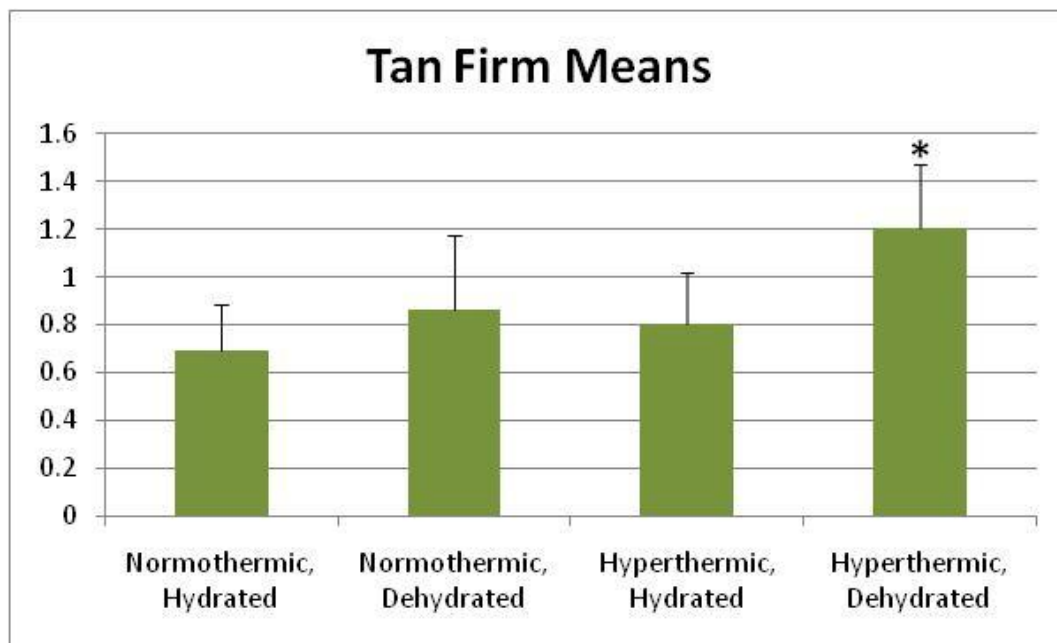


Figure 11 Subjects' average scores on the TanFirm stance. Significance was found during the DehyHot trial ( $p=.042$ ) \*indicates significance

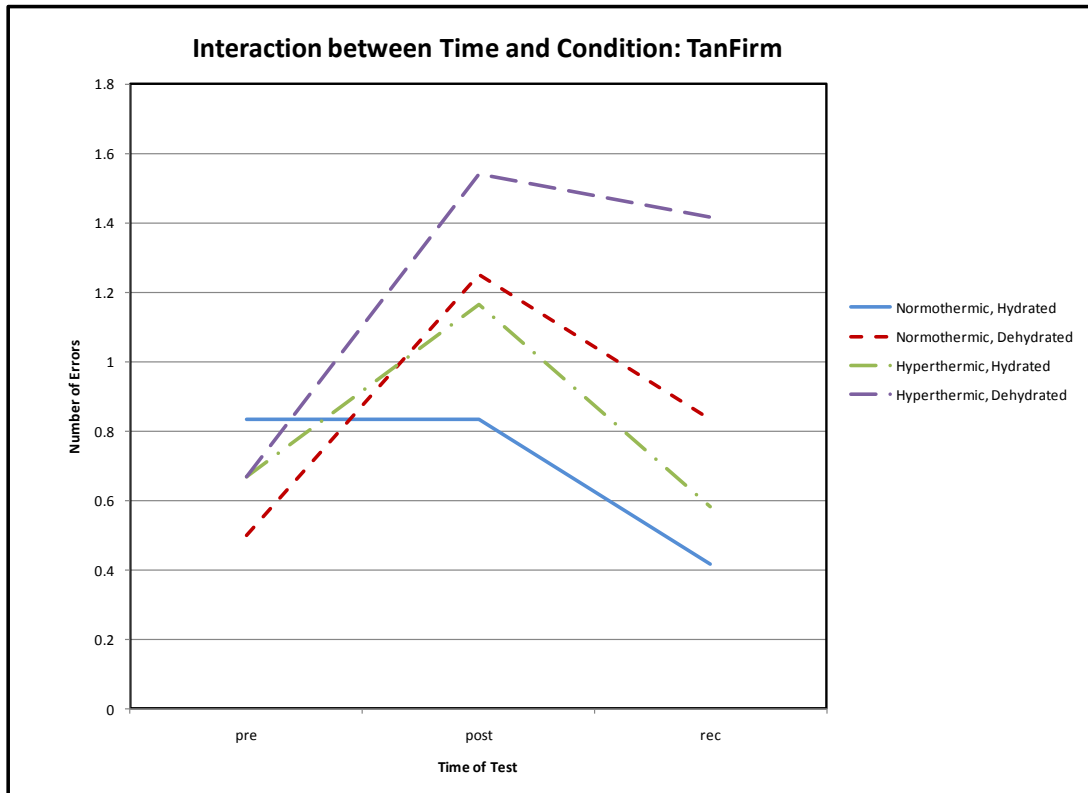


Figure 12 Interactions between condition and time showed no significance for the TanFirm stance

### Single Leg Foam

SLFoam stance was not shown to be affected by either condition or time.

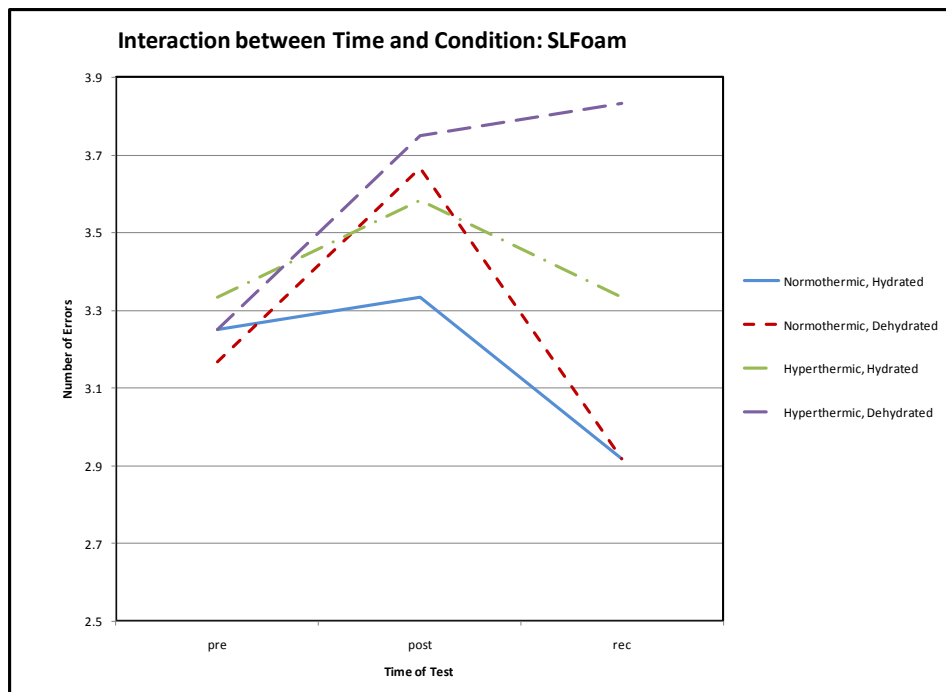


Figure 13 No significance was found between condition and time for the SLFoam stance

### *Tandem Foam*

We observed a significant main effect for both condition ( $F_{(3,33)}=7.14$ ,  $p=.001$ ) and time ( $F_{(2,22)}=3.44$ ,  $p=.05$ ) for the BESS score from the Tandem Foam stance. Subjects scores showed a significant decrease in scores between the HyN and DehyHot conditions ( $p=.003$ ) and HyN and HyHot ( $p=.002$ ) conditions (see Figure 14). The difference between pre and post-test scores were statistically significant as well ( $p=.025$ ), revealing that subjects performance decreased after the exercise protocol (see Figure 15). We did not find anything else of significance.

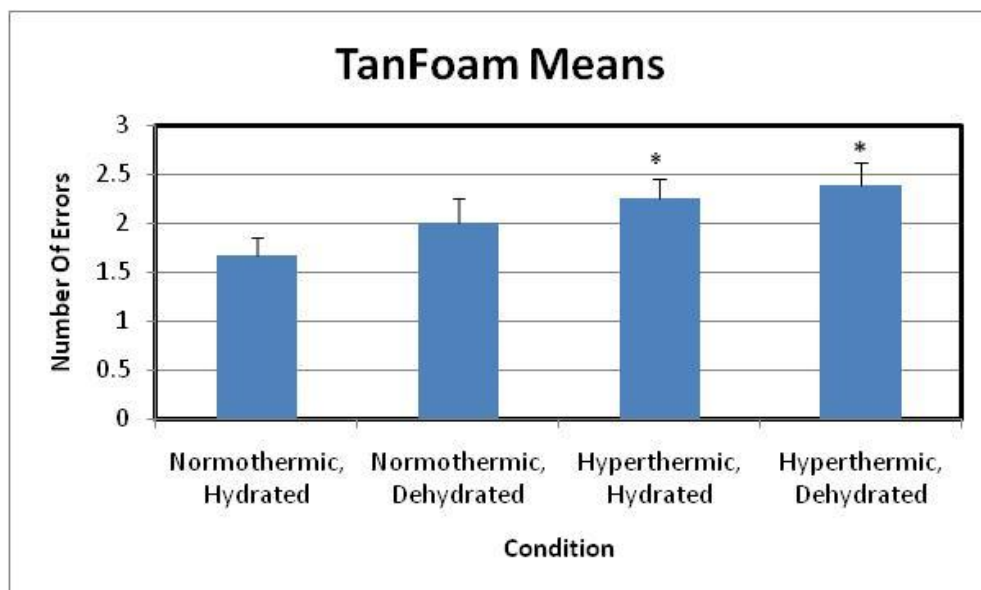


Figure 14 Significant differences were found between the HyN condition and both the HyHot and DehyHot conditions ( $p=.002$ ,  $p=.003$  respectively) \*indicates significance

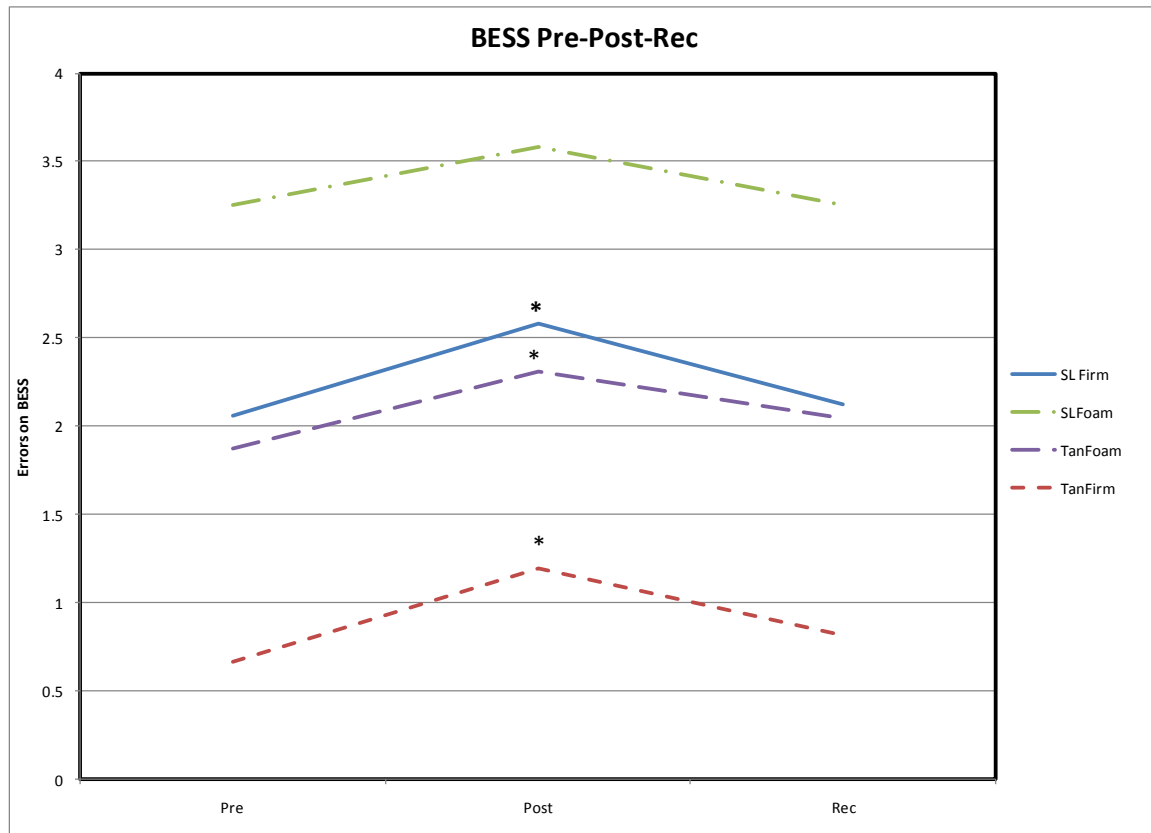


Figure 15 BESS scores for each stance shown. Significance was found for the SLFirm, TanFirm and TanFoam ( $p=.01$ ,  $p=.021$ ,  $p=.05$ ) between post-test scores and pre-test scores. For SLFirm, there was also a significant difference between post-test score and recovery score ( $p=.02$ ) \*indicates significance

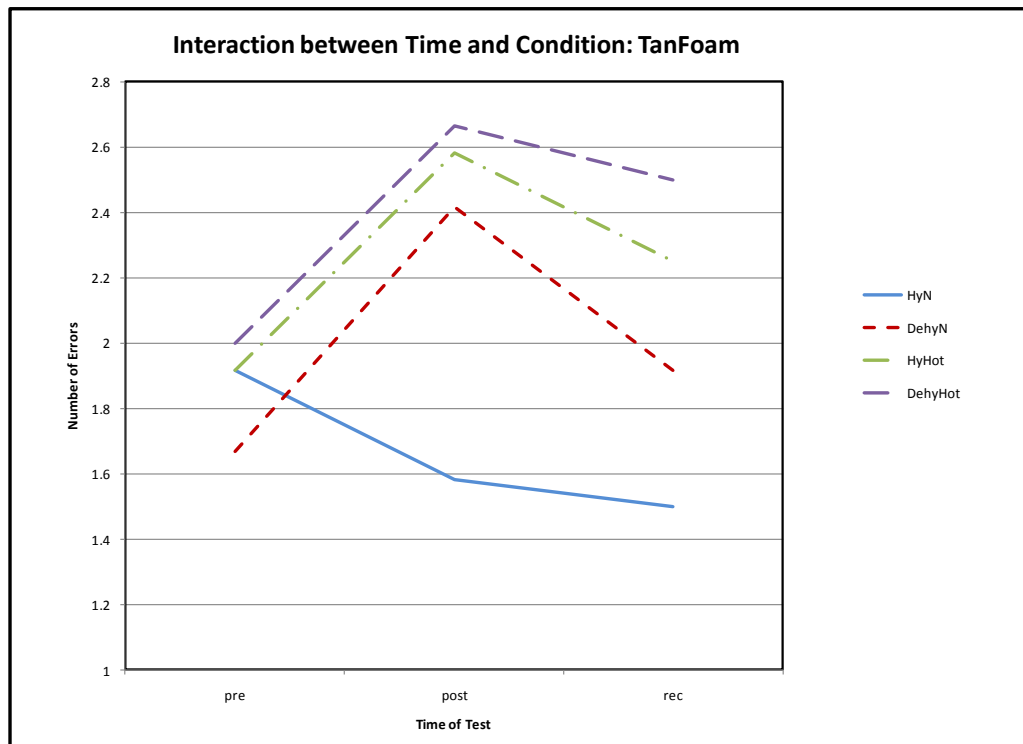


Figure 16 No significance was found between time and condition for the TanFoam stance.

## Static

### Static Area

No significance was observed, however for time the pre-recovery change in test scores approached significance ( $p=.05$ )

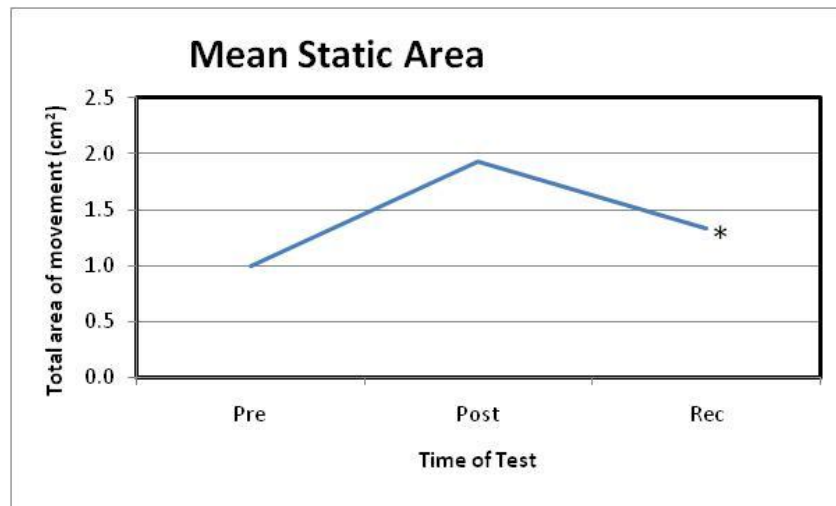


Figure 17 The change in scores from post-test to recovery approached significance ( $p=.05$ ) for the static stance, mean elliptical sway area. \*indicates significance

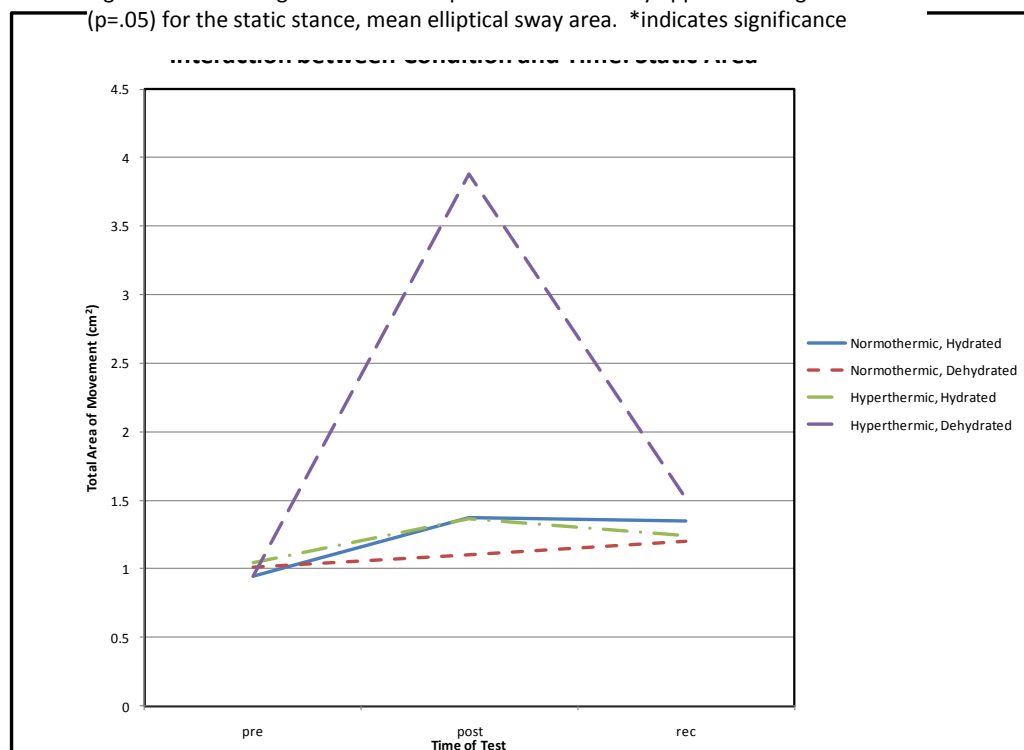


Figure 18 No significance was found between time and condition for the static stance for the mean elliptical sway area

## Static Path

We observed a main effect for time ( $F_{(2,22)}=4.026$ ,  $p=.032$ ) for the Static stance' sway path variable (see Figure 19). Subjects performed worse at the post-exercise test than at the pre-test ( $p=.042$ ). As fatigue increased, subjects' performance decreased.

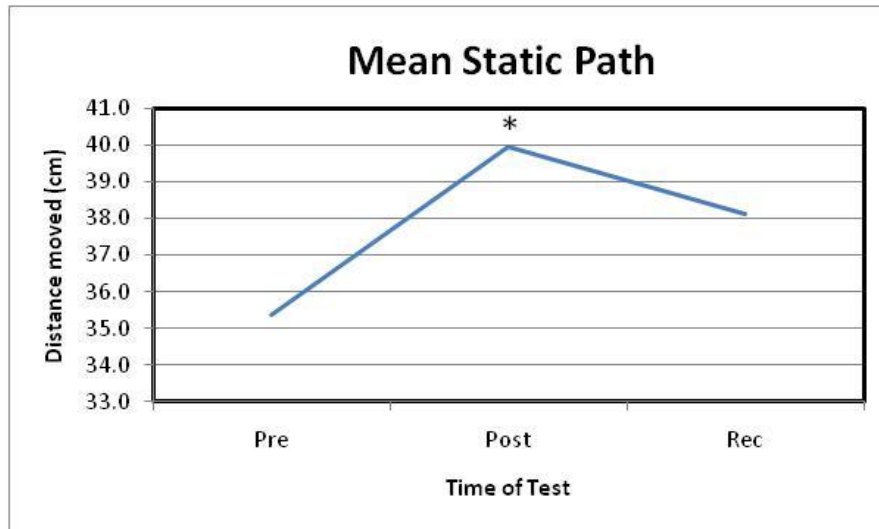


Figure 19 Average COP sway path changes were significant from pre-test to post-test ( $p=.042$ ) \*indicates significance

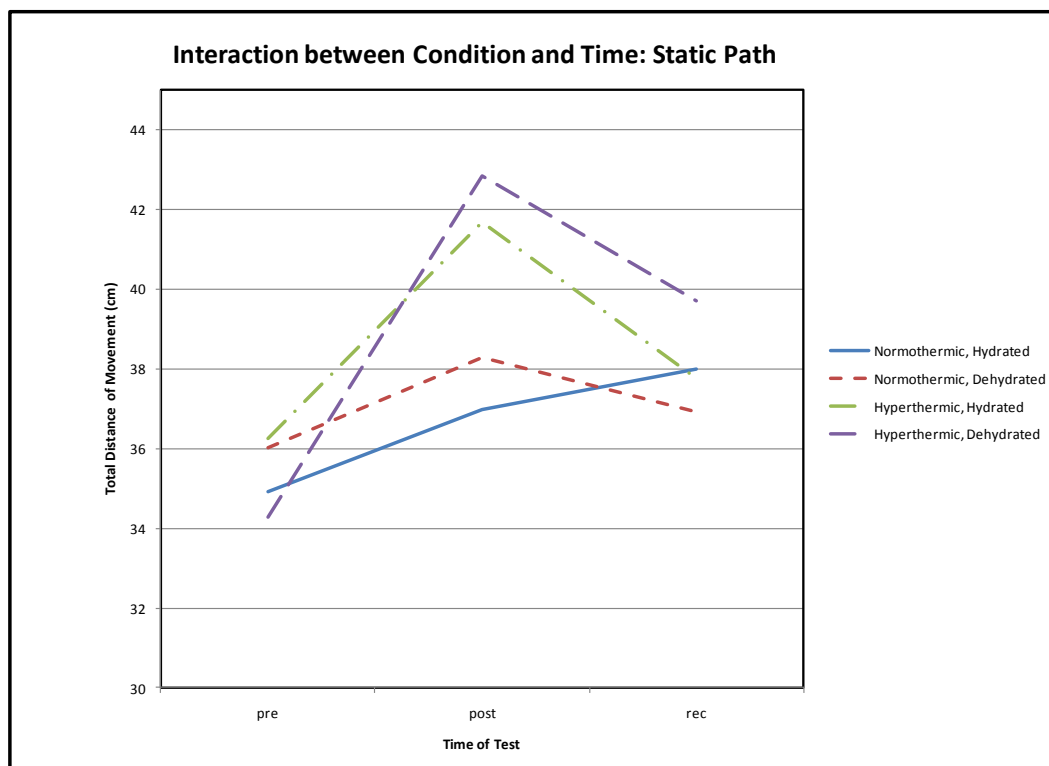


Figure 20 No significance was found between time and condition for static mean COP path

## Static Velocity

A main effect for time was observed ( $F_{91.2,13.5}=4.562$ ,  $p=.045$ ,) for the Static stance velocity variable (see Figure 21). The biggest deficits occurred for the subjects during the post-exercise assessment ( $p=.045$ ). Subjects' difference in performance for condition approached significance ( $p=.066$ ).

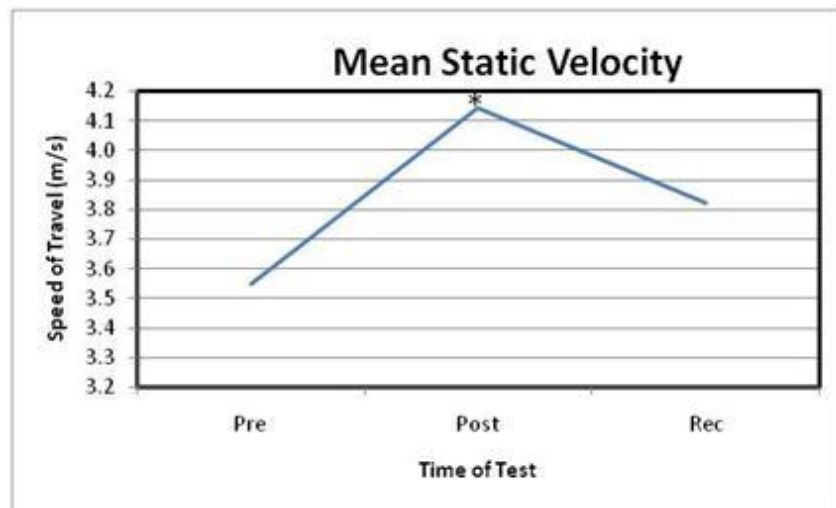


Figure 21 Significance was found between the pre and post test for the static stance variable mean sway velocity ( $p=.045$ ) \*indicates significance

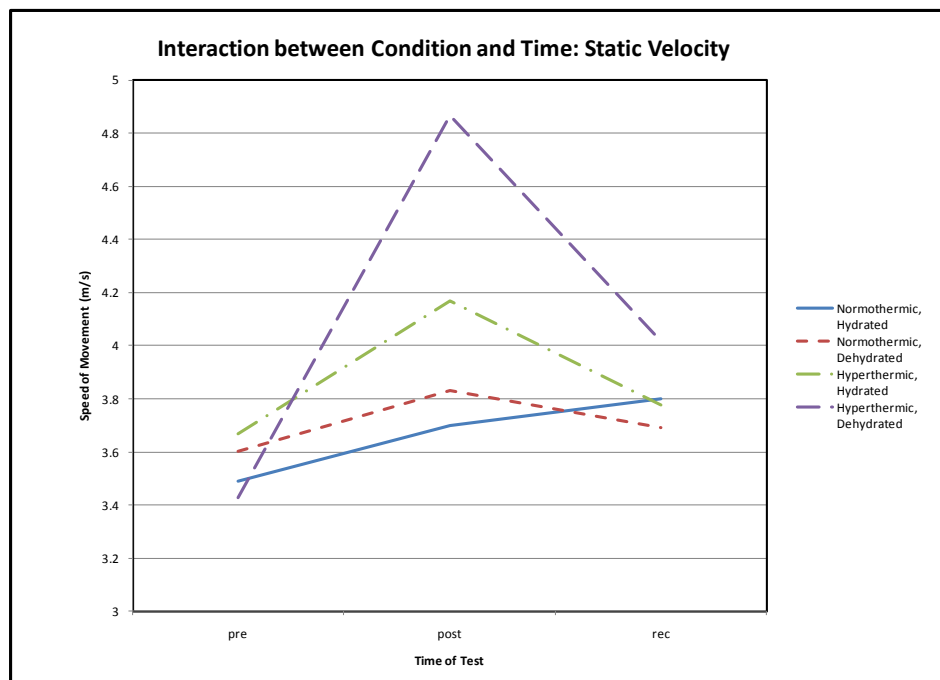


Figure 22 No significance was found between condition and time for static stance variable mean sway velocity

## Dynamic Stance

### Dynamic Stance Area

We observed a significant main effect for condition ( $F_{(1.93,21.26)}=3.56$ ,  $p=.048$ ) for the Dynamic Stance Area variable (see Figure 22). Subjects performance decreased between DehyN and DehyHot ( $p=.004$ )

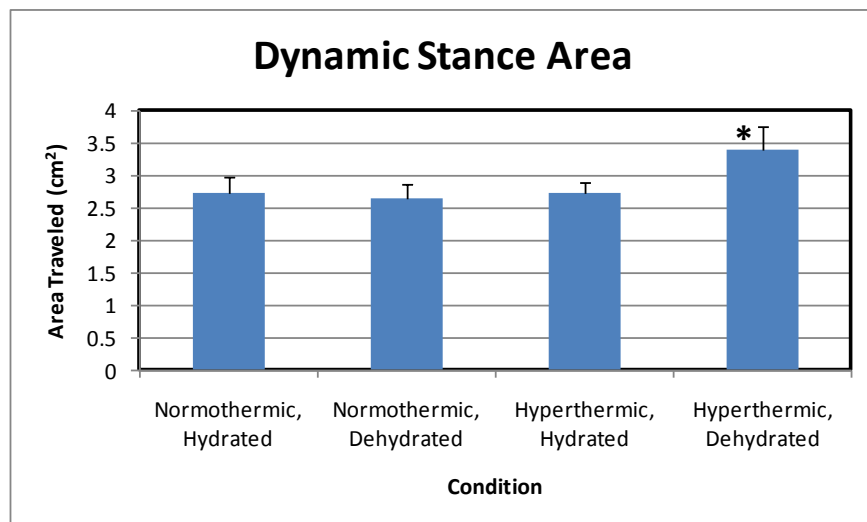


Figure 22 Significance was found between the DehyHot condition and DehyN ( $p=.004$ ) \*indicates significance

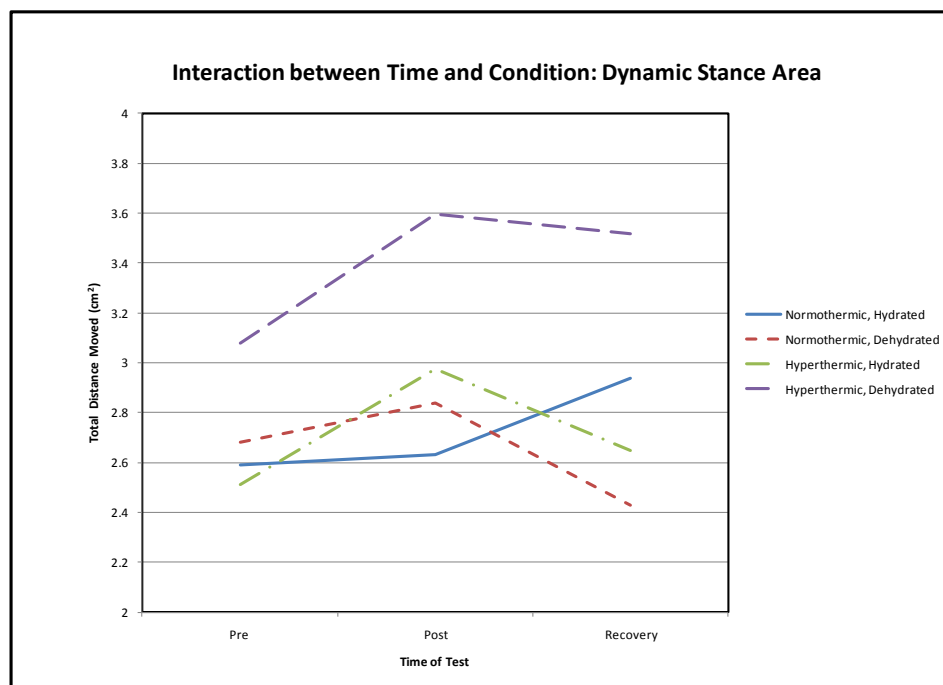


Figure 23 No significance was found between time and condition for the dynamic stance area



## Dynamic Stance Path

We observed a significant main effect for time ( $F_{(2,22)}=7.60$   $p=.003$ ) and condition ( $F_{(3,33)}=3.39$ ,  $p=.029$ ) for the Dynamic Stance Path variable. Subjects center of pressure distance traveled increased at the post-test ( $p=.002$ ,  $p=.014$  see Figure 24). Subjects averaged a farther path in the DehyHot condition than any other ( $p=.056$ ,  $p=.029$ ,  $p=.029$ - See Figure 25)

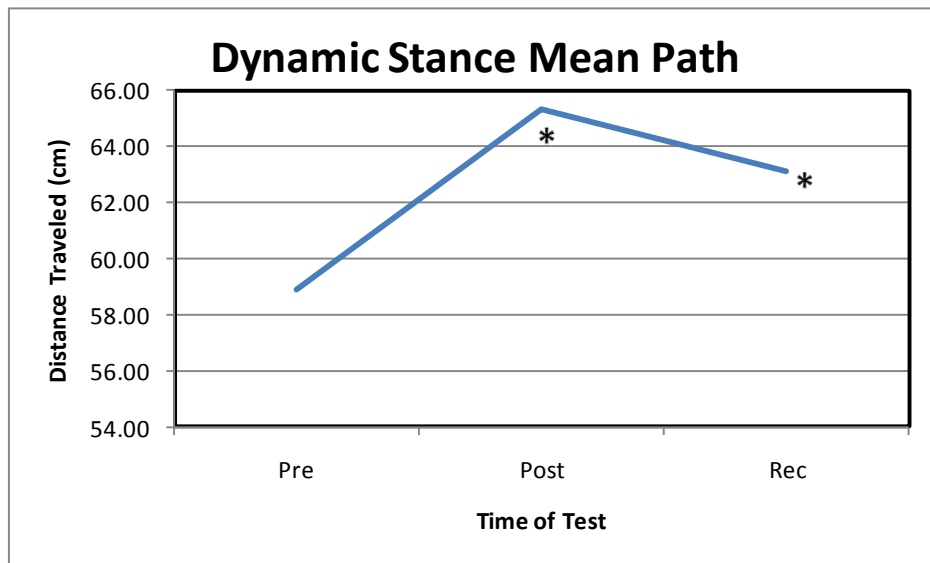


Figure 24 Both post-test and recovery test COP distance traveled was farther than at pre-test ( $p=.002$ ,  $p=.014$ ) \*indicates significance

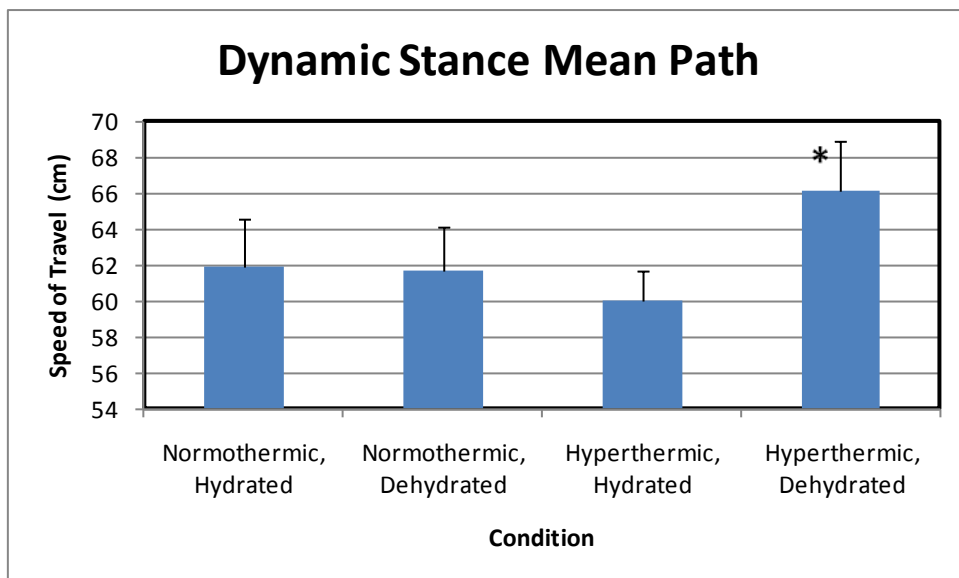


Figure 25 Subjects COP covered the largest distance during the DehyHot condition as compared to all other conditions ( $p=.056$ ,  $p=.029$ ,  $p=.029$  respectively) \*indicates significance

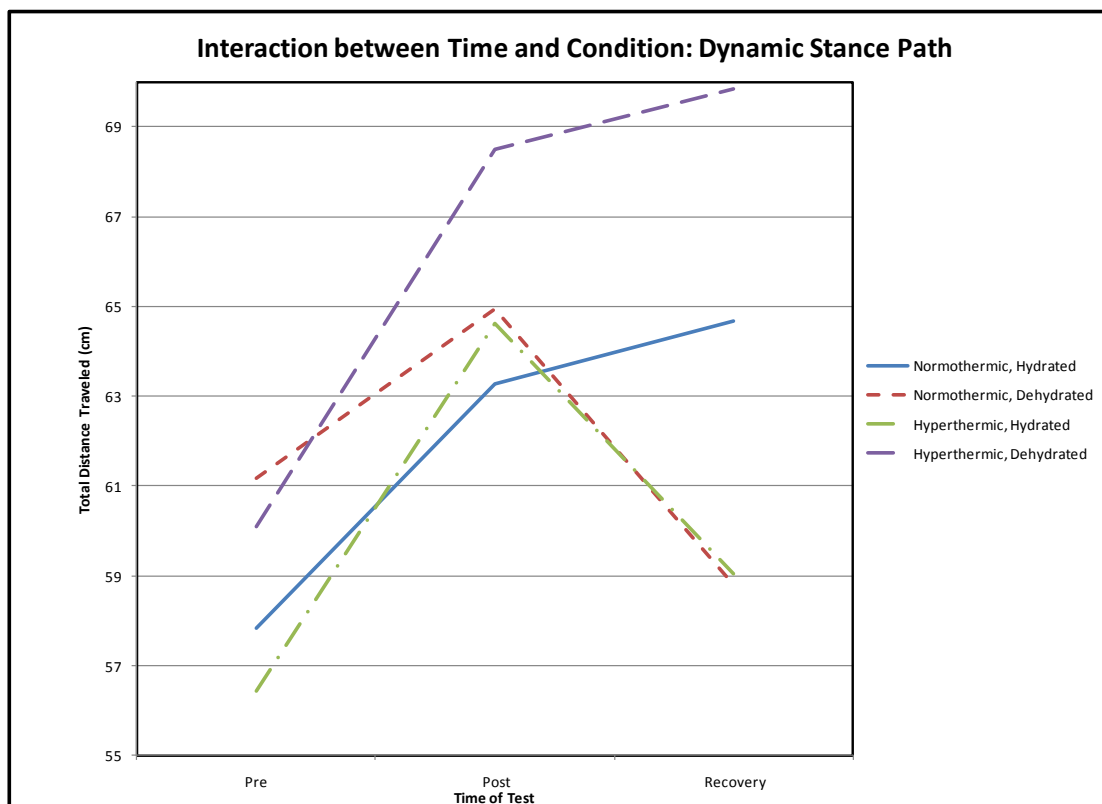


Figure 26 No significance was seen between condition and time for the dynamic stance path

### Dynamic Stance Velocity

We observed a significant main effect for time ( $F_{(2,22)}=7.61$ ,  $p=.003$ ,) and condition ( $F_{(3,33)}=3.58$ ,  $p=.024$ ) for Dynamic Stance velocity variable. Subjects sway velocity increases post-exercise ( $p=.002$ , see Figure 28). Sway velocity was at its highest during DehyHot when compared to the DehyN and HyHot ( $p=.029$ ,  $p=.03$ , see Figure27 ).

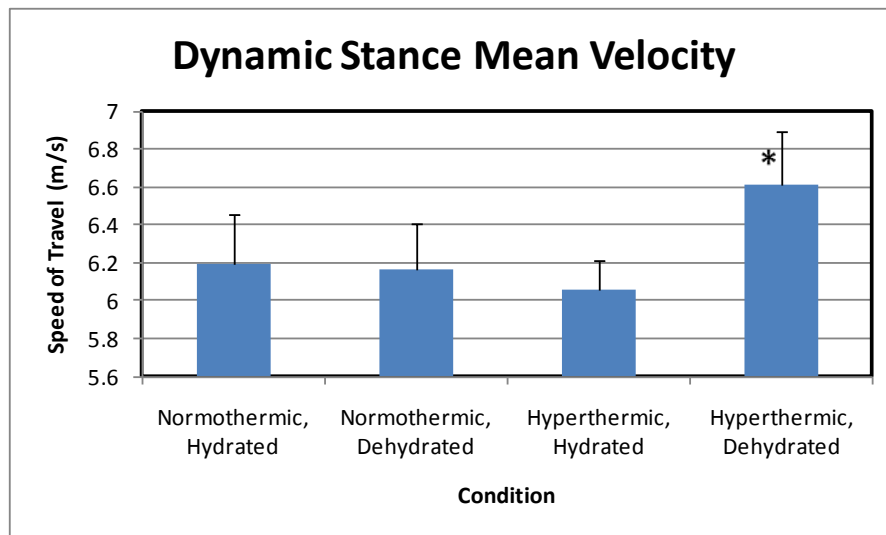


Figure 27 The DehyHot condition caused subjects COP to travel at significantly faster speeds than both the DehyN and HyHot conditions ( $p=.029$ ,  $p=.03$ ) \*indicates significance

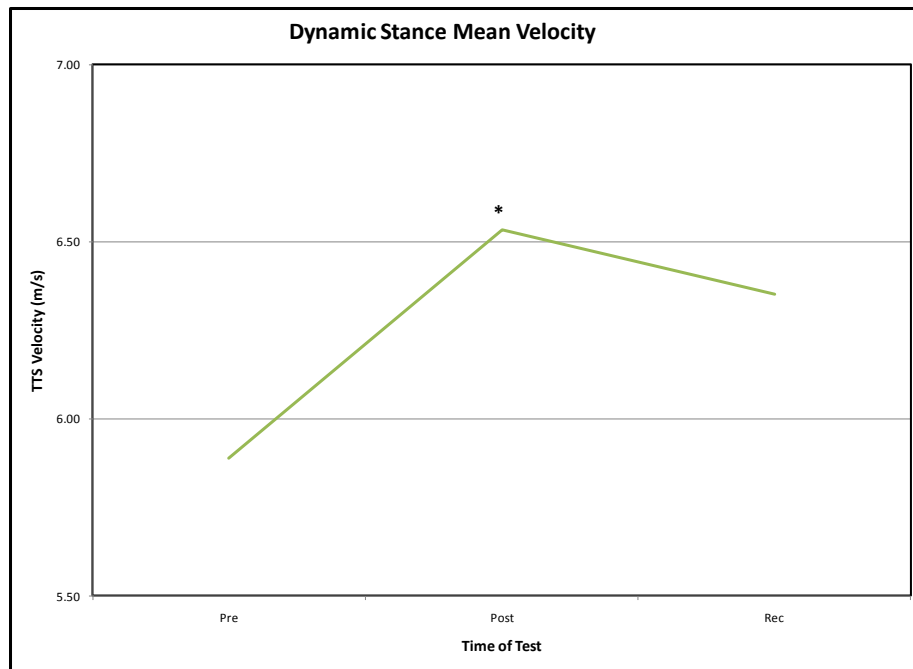


Figure 28 Subjects COP traveled at a faster speed during the post-test balance assessment than at any other testing time ( $p=.002$ ) \*indicates significance

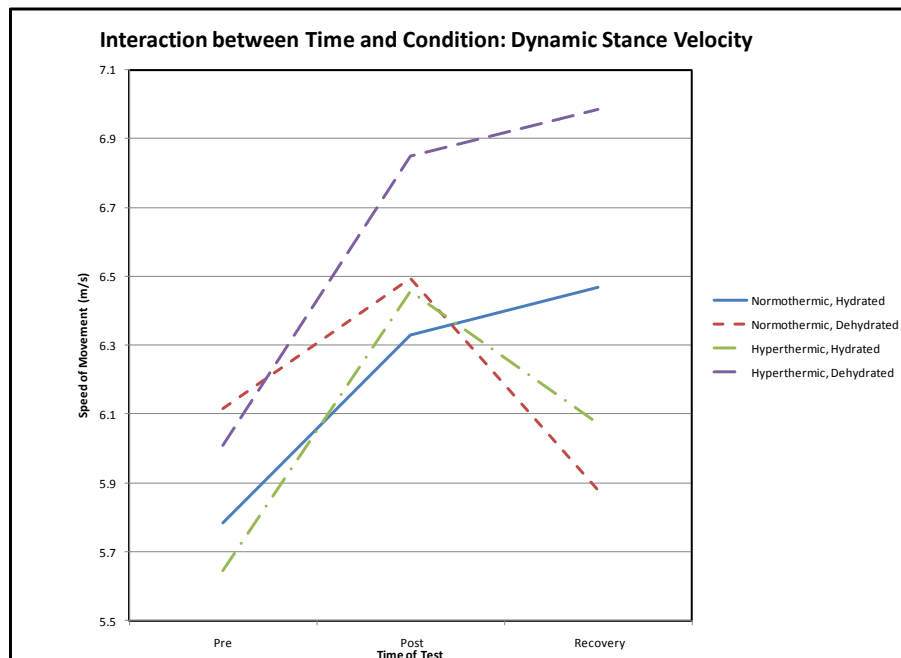


Figure 29 No significance was found between condition and time for the dynamic stance velocity

## Summary Tables

### BESS Value Tables

<b>SL Firm Means</b>						
	Pre-test		Post-test		Recovery	
Condition	Mean±SD	95%CI	Mean±SD	95%CI	Mean±SD	95%CI
Cold, Hydrated	1.83±1.40	1.83±1.40	1.83±1.40	1.83±1.40	1.83±1.40	1.83±1.40
Cold, Dehydrated	2.08±.90	2.08±.90	2.08±.90	2.08±.90	2.08±.90	2.08±.90
Hot, Hydrated	2.42±1.78	2.42±1.78	2.42±1.78	2.42±1.78	2.42±1.78	2.42±1.78
Hot, Dehydrated	1.92±1.31	1.92±1.31	1.92±1.31	1.92±1.31	1.92±1.31	1.92±1.31

<b>TanFirm Means</b>						
	Pre-test		Post-test		Recovery	
Condition	Mean±SD	95%CI	Mean±SD	95%CI	Mean±SD	95%CI
Normothermic, Hydrated	.83±1.11	(.13, 1.54)	.83±1.11	(.13, 1.54)	.42±.51	(-.09, .74)
Normothermic, Dehydrated	.50±.90	(-.08, 1.08)	1.25±1.48	(.31, 2.19)	.83±1.48	(-.06, 1.73)
Hyperthermic, Hydrated	.67±.89	(.10, 1.23)	1.17±1.19	(.41, 1.93)	.58±1.00	(-.05, 1.22)
Hyperthermic, Dehydrated	.67±.89	(.10, 1.23)	1.54±1.37	(.67, 2.41)	1.42±1.44	(.05, 2.33)

<b>SLFoam Means</b>						
	Pre-test		Post-test		Recovery	
Condition	Mean±SD	95%CI	Mean±SD	95%CI	Mean±SD	95%CI
Normothermic, Hydrated	3.25±.75	(2.77, 3.73)	3.33±.65	(2.92, 3.75)	2.92±1.08	(2.23, 3.61)
Normothermic, Dehydrated	3.12±.94	(2.57, 3.76)	3.67±1.07	(2.99, 4.35)	2.92±.90	(2.35, 3.49)
Hyperthermic, Hydrated	3.33±.98	(2.71, 3.96)	3.58±.79	(3.08, 4.09)	3.33±1.37	(2.46, 4.20)
Hyperthermic, Dehydrated	3.25±1.22	(2.48, 4.02)	3.75±.87	(3.20, 4.30)	3.83±1.19	(3.08, 4.59)

<b>TanFoam Means</b>						
	Pre-test		Post-test		Recovery	
Condition	Mean±SD	95%CI	Mean±SD	95%CI	Mean±SD	95%CI
Normothermic, Hydrated	1.92±1.24	(1.13, 2.71)	1.58±.79	(1.08, 2.09)	1.50±.67	(1.07, 1.93)
Normothermic, Dehydrated	1.67±1.07	(.99, 2.35)	2.42±1.00	(1.78, 3.05)	1.92±1.08	(1.23, 2.61)
Hyperthermic, Hydrated	1.92±.90	(1.35, 2.49)	2.58±.79	(2.08, 3.09)	2.25±1.22	(1.48, 3.02)
Hyperthermic, Dehydrated	2.00±.85	(1.46, 2.54)	2.67±.98	(2.04, 3.29)	2.50±1.17	(1.76, 3.24)

### Static Value Tables

<b>Static Area Means</b>						
	Pre-test		Post-test		Recovery	
Condition	Mean±SD	95%CI	Mean±SD	95%CI	Mean±SD	95%CI
Normothermic, Hydrated	.95±.57	(.59, 1.31)	1.38±.78	(.88, 1.87)	1.35±.47	(1.05, 1.65)
Normothermic, Dehydrated	1.01±.66	(.60, 1.43)	1.11±.51	(.78, 1.43)	1.20±.46	(.91, 1.50)
Hyperthermic, Hydrated	1.05±.69	(.61, 1.48)	1.37±.44	(1.08, 1.65)	1.24±.56	(.89, 1.60)
Hyperthermic, Dehydrated	.95±.52	(.62, 1.28)	3.88±6.93	(-.53, 8.29)	1.51±.74	(1.04, 1.99)

<b>Static Path Means</b>						
	Pre-test		Post-test		Recovery	
Condition	Mean±SD	95%CI	Mean±SD	95%CI	Mean±SD	95%CI
Normothermic, Hydrated	34.91±11.20	(27.79, 42.03)	36.99±7.34	(32.32, 41.65)	38.00±9.13	(32.20, 43.80)
Normothermic, Dehydrated	36.01±10.75	(29.18, 42.84)	38.29±8.72	(32.75, 43.84)	36.93±8.25	(31.69, 42.17)
Hyperthermic, Hydrated	36.26±10.19	(29.78, 42.73)	41.69±7.05	(37.22, 46.17)	37.78±9.77	(31.57, 43.99)
Hyperthermic, Dehydrated	34.27±10.93	(27.32, 41.22)	42.83±9.67	(36.68, 48.98)	39.71±10.87	(32.80, 46.61)

<b>Static Vel Means</b>						
	Pre-test		Post-test		Recovery	
Condition	Mean±SD	95%CI	Mean±SD	95%CI	Mean±SD	95%CI
Normothermic, Hydrated	3.49±1.12	(2.78, 4.20)	3.70±.73	(3.23, 4.17)	3.80±.91	(3.22, 4.38)
Normothermic, Dehydrated	3.60±1.07	(2.92, 4.28)	3.83±.87	(3.28, 4.38)	3.70±.82	(3.17, 4.22)
Hyperthermic, Hydrated	3.67±1.12	(2.96, 4.38)	4.17±.70	(3.72, 4.62)	3.78±.98	(3.16, 4.40)
Hyperthermic, Dehydrated	3.43±1.09	(2.70, 4.12)	4.87±1.71	(3.78, 5.95)	4.02±1.06	(3.35, 4.69)

### Dynamic Stance Value Tables

<b>Dynamic Stance Mean Area</b>						
	Pre-test		Post-test		Recovery	
Condition	Mean±SD	95%CI	Mean±SD	95%CI	Mean±SD	95%CI
Normothermic, Hydrated	2.59±0.75	(2.12, 3.07)	2.63±.08	(2.01, 3.25)	2.94±1.29	(2.12, 3.76)
Normothermic, Dehydrated	2.68±.96	(2.07, 3.29)	2.84±.75	(2.36, 3.31)	2.43±.80	(1.92, 2.93)
Hyperthermic, Hydrated	2.51±1.30	(1.69, 3.34)	2.97±.73	(2.51, 3.43)	2.65±.91	(2.07, 3.23)
Hyperthermic, Dehydrated	3.08±1.72	(1.99, 4.18)	3.69±1.50	(2.65, 4.55)	3.51±1.00	(2.88, 4.15)

<b>Dynamic Stance Mean Path</b>						
	Pre-test		Post-test		Recovery	
Condition	Mean±SD	95%CI	Mean±SD	95%CI	Mean±SD	95%CI
Normothermic, Hydrated	57.83±8.74	(52.28, 63.39)	63.29±12.35	(55.44, 71.13)	64.69±10.64	(57.92, 71.45)
Normothermic, Dehydrated	61.17±11.40	(53.93, 68.41)	64.95±9.88	(58.68, 71.23)	58.80±9.98	(52.46, 65.14)
Hyperthermic, Hydrated	56.44±9.54	(50.39, 62.50)	64.62±8.94	(58.94, 70.30)	59.03±8.41	(53.69, 64.38)
Hyperthermic, Dehydrated	60.10±10.03	(53.73, 66.47)	68.50±13.53	(59.91, 77.10)	69.86±9.23	(63.99, 75.73)

<b>Dynamic Stance Mean Velocity</b>						
	Pre-test		Post-test		Recovery	
Condition	Mean±SD	95%CI	Mean±SD	95%CI	Mean±SD	95%CI
Normothermic, Hydrated	5.78±.87	(5.23, 6.34)	6.33±1.23	(5.54, 7.11)	6.47±1.06	(5.79, 7.15)
Normothermic, Dehydrated	6.128±1.14	(5.39, 6.84)	6.50±.99	(5.87, 7.12)	5.88±1.00	(5.25, 6.51)
Hyperthermic, Hydrated	5.648±.95	(5.04, 6.25)	6.46±.90	(5.88, 7.03)	6.07±.62	(5.68, 6.47)
Hyperthermic, Dehydrated	6.018±1.00	(5.37, 6.65)	6.85±1.35	(5.99, 7.71)	6.99±.92	(6.40, 7.57)

## DISCUSSION

The goal of this laboratory study was to determine whether hyperthermia, dehydration and fatigue affected balance performance, individually or in combination. We hypothesized that all three would have some negative effect on balance, but that fatigue's effect would be the greatest as an individual factor. Our most important finding was that fatigue, hyperthermia and dehydration all play a role in decreased balance as measured by the BESS, Static stance, and Dynamic stance. Not only did we find that individually these factors negatively affected balance, but we also found that in combination these factors deteriorated balance even farther. At the post-exercise testing, balance was the most decreased compared to the pre-test. Overall balance scores were the most diminished during the dehydrated and hyperthermic trial. Of great value to athletic trainers and other health care professionals, the effects of fatigue seemed to be the biggest factor in decreased balance. Interestingly, fatigue's role in decreased balance seemed to dissipate by the time recovery-testing was conducted., as most scores were improved from post-test to recovery assessment.

### **Fatigues Effect on Balance**

In every condition for all balance tasks (with the exception of SLFoam and the area variables for Dynamic and Static stance) highest scores were revealed to occur immediately after exercise. One thing that has been well documented is that fatigue negatively influences balance, but only for a short time.<sup>3,20,21,23</sup> While fatigue played the largest role in the dramatically increased scores at post-test, the scores weren't increasing at similar rates. It seems as though fatigue is accelerated by other factors; a hotter environment or lack of hydration may increase the effects of fatigue on balance. Interestingly, in the mentioned balance tasks, recovery scores improved after the 60 minutes of rest. From a physiological stand point, we know that heat increases the rate at which the body fatigues and that fatigue

peaks as exercise progresses.<sup>12,13,14,22,23,24</sup> Several studies have also stated that fatigue only plays a factor in decreased balance if the exercise done is actually fatiguing.<sup>27,28</sup> The more demanding the exercise, the more significant the deficits.<sup>20</sup> Our study's exercise protocol was high intensity. This could be a possible explanation why we see such poor scores at post-test.

Additionally, RPE scores have been used in multiple studies to confirm fatigue. These studies have confirmed that a RPE score of 15 correlates with 75%-90% of maximal oxygen consumption. Our study also utilized the RPE scale as a way to measure subject's feelings of fatigue. As you can see in Figure 6, subjects RPE increased towards the end of their 90 minutes of exercise and was also greater in hot conditions and when they were dehydrated. Another measure that increased along with RPE during exercise was HR. In Figure 7, it is apparent that as subjects exercised, their HR increased steadily. HR returned to a more steady state during the recovery period. During the trials in the heat, or when the subjects were dehydrated their HR increased more rapidly (See Table 4). From these measures we can be sure that decreased balance at post-test was most likely due to fatigue.

### **Dehydrations Effect on Balance**

We observed a significant decrease in performance on total BESS score for both dehydrated conditions. In a number of studies, decreased proprioception seemed to result from both fatigue and dehydration and that dehydration alone can alter balance.<sup>8,10</sup> Additionally, dehydration levels have been directly linked to decreased vestibular input.<sup>29</sup> Eberman *et al* showed that total BESS scores were 21.5% higher in the dehydrated trial. We also found increased scores on the BESS on dehydrated condition days. Jensen *et al* found that dehydration played a role in decreased balance during the BE SS task.<sup>30</sup> Since we know that dehydration causes fatigue to occur, it's important to point out that a majority of these studies measure balance performance after exercise-induced dehydration and also reported finding



return to baseline scores within 20 minutes.<sup>6,7</sup> Our study involved subjects being dehydrated prior to their exercise protocol and continued dehydration during the trial. Our findings make it highly possible that fatigue was driving the poor scores at post test more so than the dehydration alone.

### **Hyperthermia's Effect on Balance**

Both of the hot conditions revealed significantly higher scores for both the total BESS and Dynamic stance. These differences were seen overall, and at post-test. Hyperthermia is a factor that has never been isolated before. By having a recovery period before the last balance assessment, we can successfully remove a large amount of a subjects fatigue as a factor in recovery balance assessment. In both the hot trials subject's recovery performance was still not quite back to baseline. Overall BESS scores showed significance between recovery performance and pre-test performance. Being hot and hydrated also revealed similar scores as the normothermic hydrated conditions for the total BESS score and Dynamic stance, this might indicate that the heat can also negatively influence balance on its own. This finding is extremely important as it's a new contribution to the literature that's never been quantified before.

Because this is the first study to isolate hyperthermia, we had to think about why we saw this effect and why it may not have been as impactful as we had hypothesized. Hyperthermia plays a significant role in decreasing the functionality of several body processes; thermoregulation, reduced stroke volume, increased heart rate, lower cardiac output and lower central blood volume.<sup>11,12,13,14</sup> Central nervous system function is often times reduced in hyperthermic individuals, causing confusion, apathy, irritability, and sometimes collapse.<sup>4</sup> Hot conditions significantly challenge cardiovascular control. Oxygen that was once being distributed to exercising muscles and organs is decreased so that more blood flow can get to the skin to meet those increased demands.<sup>11,13</sup> Exercise heat stress (without the presence of

dehydration) can cause increased heart rates over time and lead to exhaustion.<sup>5</sup> Our study required subjects to not only exercise in a hot room, but they were heating themselves up as well. With the combined effects of increasing fatigue from exercise, cardiovascular drift and lower CNS function, it's possible that the physiological complications that come from heat stress played a large role in the effect that hyperthermia had on performance.

### **Combined Effects**

Best performance on the balance tasks occurred when subjects were normothermic and hydrated. Conversely, when both were factors, subject's performance deteriorated for all tests. We know that balance performance decreases with these factors individually, but together we can see that the deterioration in performance is much more obvious. Total BESS scores and Dynamic stance performances decreased tremendously due to the introduction of heat and dehydration as a combined factor.

Being hot, dehydrated and fatigued seemed to cause the biggest decreases in balance performance, which was observed in the dehydrated, hyperthermic condition. As with most phenomena, you put multiple disadvantageous factors into a scenario and you can expect the outcome to worsen. This is also the case with individuals exercising in the heat and their balance capabilities. Our study showed that fatigue from the exercise protocol caused deficits in the post-test scores, but those differences were much more statistically significant when heat or dehydration were added.

### **Injury Risk**

This study has shown that fatigue, heat and dehydration all negatively affect balance, individually and especially combined. Decreased balance performance is seen in athletes who have had a recent lower extremity injury or a head injury. Studies have shown that balance deficits from injury can be sustained for up to three days.<sup>15,31</sup> Conversely, since we know dehydration, hyperthermia and fatigue negatively affect balance, we can infer that these factors could also potentially increase injury risk. As practice and competition endure, athlete's become more fatigued, their core temperature rises, and they may become dehydrated. This is especially true for higher intensity sports and sports that take place in the warmer parts of the year.

Decreased balance increases injury risk, especially at the ankle.<sup>17</sup> The three factors we studied are controllable in any athletic world. Assuring a euhydrated status during activity should be a standard practice. Coaches, military officials and health care professionals working with athletes should work together to make sure that water is available to all athletes, all the time. In the military, carrying canteens and knowing where close fill stations are located is key to ensuring proper hydration.

Hyperthermia is controllable through appropriate rest breaks and making sure all involved personnel are aware of the heat indices. Allowing athletes at practice to not only take a water break, but a short break from activity can be detrimental to continued safe performance. Rest periods are a time for the athletes to cool down (even if only briefly) and rehydrate. This not only can revitalize them mentally, but it might also be a means to decrease injury risk in athletes.

Fatigue is also controlled through rest breaks. Stopping games and competition is not always feasible; that's where having substitutions own team sports and including water in time outs and period changes comes into play. There is a pattern here, incorporate breaks into

activity that include water and shade and not only will the athletes have a chance to rejuvenate, but they'll also decrease their injury risk.

## **Balance Assessments**

Of interest in our findings is the fact that performance on the SLFoam stance held no significance between trials or conditions. One thought on this is that the SLFoam is typically the most challenging stance, which may have caused similar “bad” performance across the board. Similarly, the SLFirm, which could be also be argued as a difficult stance, only seemed to be affected by fatigue. Wilkins et al found that fatigue affected only the tandem stances, not single leg stances, which supports our findings. The static stance only seemed to be significantly altered at the post-test. This finding suggests that fatigue is a much larger determinant of decreased balance than dehydration or hyperthermia.

The dynamic stance was hindered by fatigue, dehydration and hyperthermia. At the post-test, subjects' centers of pressure were traveling a farther distance and at a greater speed than at any other testing time, isolating fatigue as a major player in deteriorated balance. Similarly, for the Dynamic stance, being dehydrated and hot caused the largest increase in center of pressure movement. These findings help summarize that the more dynamic the task, the bigger the effect of fatigue, hydration and hyperthermia on balance performance.

## **Practical Implications**

Most health care professionals know that heat and hydration are important aspects of safety in sport. Heat indexes are utilized in sport around the country to keep our athletes safe, as well as equipment and rest regulations during activity; but now we know that heat may not only put athlete's in danger from a heatstroke standpoint, but from a balance and performance stand point. Perhaps a reason athletes' performance diminishes as practice goes on has more to do with their ability to control their posture and balance than we think. We've demonstrated in

this study that even while an athlete is hydrated in the heat their balance dissipates, so now we've got another important reason to be aware of the heat where our athletes are practicing. One way to ensure safety with these athletes is to implement a body cooling strategy for practices and games. Have athletes retire to a cool area during half time, keep cool towels near the bench or have a nearby shaded area where hot athletes can go to cool down.

Hydration status is something that can be overlooked and is often misunderstood in the sport world, especially by coaches. While it has been studied that muscle strength, power and endurance are all negatively affected by dehydration, we now know that even in a cool environment, hydration is important. We have numerated physical proof that no matter the environment, hydration can affect the ability to balance. Rehydrating needs to be a top concern for our athletes, whether they are volleyball athletes or football players. It's important to have a re-hydration strategy in place wherever sports are being played. If possible, one easy way to keep track of an athlete's need for water is to document pre-practice weights and post-practice weights. Have athletes drink enough fluid between sessions or before the evening is over so that they are back to their pre-practice weight. This doesn't mean that athletes don't need to drink during practice, it's just a way to bridge the gap between what they actually drank and what they needed to drink. Having coolers on the sideline and regular water breaks is a must for any sport.

We revealed through our study that fatigue plays a significant role in decreasing balance performances. Whether cool or hot, the fact stood strong that at the post-test, performance was the most deteriorated. However it's been well stated that the effects of fatigue wear off after an average of 15 minutes.<sup>3,20,21</sup> Since we know that fatigue decreases with rest, then hopefully we can stress the importance of rest during intense sports. Having substitutions available for athletes who are playing the most demanding positions, utilizing half time to have athletes regain their energy and incorporating rest periods or intervals into practice are all safe and

effective ways to minimize the amount of fatigue an athlete experiences, in turn, reducing injury risk and improving performance.

## **Concussion Testing**

Concussion testing is a major topic in health care these days. There's a big wave of health care professionals who have come together to impress upon the public how important concussion management and care is. With the results from this study, a discussion about timing of concussion testing on the field seems necessary.

The BESS is a concussion tool that many health care professionals use on the sideline. With the present data, there is now concern about timing of concussion testing. Since we know that just being fatigued can affect balance is sideline testing at the time of injury may not give an accurate picture of the injury severity. Most concussions are seen during football season when it's likely to also be hot. At any given time an athlete on a football team is likely to be dehydrated as well. If this is the case, we've now got three factors playing against us in a situation here a head injury is being assessed. The best policy may be, "When in doubt, hold them out" until it can be clear that these three factors have been minimized or completely dissipated.

While these results may seem like common sense, it's never been studied and there is currently no literature on exactly what kinds of deficits we're looking at when it comes to athletic performance. With results as they are, standing orders, timing of clinical use of the BESS, and further emphasis on re-hydration should become more defensible. With data to back up actions and requests, people involved in athletics without a medical background can be shown exactly what happens when their athletes are fatigued, hot, or dehydrated. Important guidelines and protocols can be put into place with more foundation than just "common sense".

Looking beyond the athlete into the military, you can still apply similar results. Military personnel often times spend more time in the heat performing tasks than an average athlete. It's quite possible that access to water or shade might be minimal if at all. It's also possible that rest might not be an option. When troops are out in combat or training, their performance and ability to articulate tasks is extremely important. If these soldiers are experiencing hyperthermia and dehydration, several imperative aspects of their job are compromised. As previously stated, it's known that if balance and postural control decrease, injury risk increases. Adding the information from this study, we can say without a doubt that the longer a soldier is in combat, training, or otherwise, the higher their risk for injury may be.

Maybe during those last few pushes at practice, drills, competition or conditioning, the athletes aren't being lazy; maybe their postural stability and balance have been compromised from fatigue, heat, dehydration or any combination of the three.

### **Limitations of the study**

Our study was performed in a controlled environment with healthy, active individuals. The subjects were carrying military-equivalent packs, which may not be comparable to many of the sports seen in America. Our study was also using walking as the mechanism of fatigue; however, most sports utilize multiple different, multi-directional modes of movement that cause fatigue. Most sports don't require Subjects to work at steady paces for the duration of the exercise. Unlike sport, our protocol did not involve a warm up or any rest periods throughout the exercise. While we tried to eliminate a learning effect by having subjects practice the balance assessments in familiarization sessions, there could have been a small learning effect throughout the study's duration.

## **Future Directions**

Since this was the first study done, to our knowledge, to isolate hyperthermia, the door is wide open for future studies. More studies are needed that study the effect of hyperthermia alone and its influence on athletic performance, balance and movement. It might be interesting to see a study that isolates hyperthermia at different levels/includes different levels of humidity to see if the decrease in balance is directly correlated to an increase in the heat index. Another aspect of interest that this study did not evaluate is the recovery time of the Subjects. After a recovery test was completed, subjects weren't tested again for a week (their next trial). If a study could make its subjects hyperthermic and then have post-tests every 15-20 minutes to track their recovery it would be interesting to see the rate at which subjects return to their baseline. Of interest also, might be how different kind of "heating up" effect balance (i.e.: sitting in a hot room, running, weight lifting).

Our study used walking on an incline as the method to fatigue/increase temperature. While this was a high intensity task, it would be interesting to see how different methods of exercise influence balance. For example, if an interval program involving some lower extremity exercises, or cutting drills were implemented, we might expect the balance deficits to be more dramatic since we're fatiguing muscles more specific to controlling balance. These movements would also require more attention and focus on the athlete's part, which may play a role in the outcome of their balance performance.

In summary, fatigue seems to be the biggest determinant for decreased balance assessment, no matter the outside factors. Since our post-test scores were the highest across the board, we can say that fatigue had the greatest impact on our subjects. When coupled with fatigue, the effects of dehydration and hyperthermia seem to be driven a little bit more significantly than when they are measured individually. Our findings also included that while



subjects balance decreased during the hot and dehydrated condition, not every stance seemed to be affected. Because the static stance was the balance assessment not affected by condition, it might indicate that this was too mundane of a task to expect to see a deficit with. Similarly, we saw no single leg stances affected by condition, indicating perhaps that they may be too large a challenge to show any changes. Further research is needed to determine exactly why and how these balance deficits did not show up.

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