ABSTRACT

THE EFFECT OF DEHYDRATION, HYPERTHERMIA, AND FATIGUE ON LANDING ERROR SCORING SYSTEM SCORES

Purpose: To examine the effects of exercise-induced dehydration, hyperthermia, and fatigue on Landing Error Scoring System (LESS) scores during a jump-landing task, and the effectiveness of a personalized hydration plan. **Methods:** Five recreationally active heat-acclimatized males 25.4 y (*SD*=5.7) completed two trials: with fluid replacement, (EXP) and without fluid (CON), in a counterbalanced, randomized, cross-over fashion. Exercise was terminated when gastrointestinal temperature (T_{gi}) = 39.5°C and fatigue ≥ 7/10, or 90 min of exercise. Percent dehydration was determined by body mass change from pre-exercise (PRE) and post-exercise (POST). T_{gi}, heart rate (HR), and perceived fatigue were measured PRE, during exercise, and POST. Three jump-landing tasks were filmed in the frontal and sagittal planes. An experienced grader evaluated jump-landing tasks using the LESS. **Statistical Analysis:** Repeated measures ANOVA assessed primary dependent and independent variables while *a priori* dependent t-tests evaluated pairwise comparisons. **Results:** No interaction, group, or time main effects were observed for LESS scores (*p*=0.437). POST dehydration (%) was greater in CON (*M*=2.59, *SD*=0.52) vs. EXP (*M*=0.92, *SD*=0.41; p<0.001), whereas hyperthermia (°C) (CON, *M*=39.29, *SD*=0.31, EXP, *M*=39.03, *SD*=0.61; p=0.425), and fatigue (CON, *M*=9, *SD*=1, EXP, *M*=9, *SD*=2; p=0.424) were similar. **Conclusion:** LESS scores were not affected by exercise-induced dehydration, hyperthermia, and fatigue, nor by a personal hydration plan.

Alexandria Brooklyn Gregory
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THE EFFECT OF DEHYDRATION, HYPERTHERMIA, AND FATIGUE ON LANDING ERROR SCORING SYSTEM SCORES

by

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We, the undersigned, certify that the thesis of the following student meets the required standards of scholarship, format, and style of the university and the student's graduate degree program for the awarding of the master's degree.

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CHAPTER 1: INTRODUCTION

During physical activity in hot conditions athletes can become dehydrated, hyperthermic, and fatigued especially as exercise prolongs. Dehydration occurs during exercise due to the loss of total body water via sweat in an attempt to lower core body temperature (Armstrong, 2007). This loss of fluid through sweat can lead to dehydration if proper fluid replacement is not attempted during exercise (Armstrong, 2007). In return, dehydration further increases core temperature leading to exercise-induced hyperthermia (Armstrong et al., 1997). Exercise-induced hyperthermia commonly occurs in long distance exercise bouts in which individuals experience dehydration, thus, triggering cardiovascular drift causing a decrease in muscular blood flow (Gonzalez-Alonso, 2007). In addition, fatigue is a common factor that affects exercise performance. Individually dehydration, hyperthermia, and fatigue display consequences in physical activity performance. But, all three-combined present a complex condition and could display even more detrimental consequences during physical activity.

Dehydration, hyperthermia, and fatigue can occur in individuals who exercise in the heat. But, little research has focused on how these physiological insults specifically affect lower extremity movement behavior and injury prevention. Poor neuromuscular control and movement technique has been recognized to influence the risk of a lower extremity injury, such as anterior cruciate ligament (ACL) tear (Hewett et al., 2005).

An ACL injury is one of the most common injuries associated with poor lower extremity neuromuscular control (Padua et al., 2015). Over 100,000 ACL injuries occur in the United States every year (Brown, Johnston, Saltzman, Marsh, & Buckwalter, 2006) and most ACL injuries occur when athletes are performing cutting and jumping movements (Griffin et al., 2000). These types of movements are commonly seen in soccer and other sports, which often occur in dehydrated, hyperthermic, and fatigued conditions. In addition, ACL injuries are more common during games and competition than during practice (Dragoo, Braun, Durham, Chen, & Harris, 2012).

Individually several factors can increase the risk for a lower extremity injury, such as dehydration, hyperthermia, and fatigue. Dehydration during exercise reduces plasma volume in the body, which can decrease the delivery of oxygen to the working muscles and reduces neuromuscular performance in the lower extremity (Minshull & James, 2013). Hyperthermia reduces optimal function of the central nervous system which may reduce body awareness and judgement, and therefore may increase risk for lower extremity injuries (Gonzalez-Alonso, 2007). Nybo and Nielsen (2001) found that hyperthermia can lead to a decrease in neuromuscular control, which increases the risk for injury. Fatigue has shown to affect lower extremity neuromuscular control by altering the ability of muscle fibers to absorb energy (Chappell et al., 2005). Individually, dehydration, hyperthermia, and fatigue display decrements in lower extremity neuromuscular control, but little research has focused on all three factors at once.

One study found a decrease in lower extremity neuromuscular control in a hypohydrated, hyperthermic, and fatigued condition after exercise (DiStefano et al., 2013). The study investigated this effect with the use of the Landing Error Scoring System (LESS). The LESS is a validated field-assessment tool used for recognizing high-risk movement patterns during a jump-landing task (Padua et al., 2015). The results showed that movement control decreased significantly, resulting in increased LESS scores from pre- (M = 3.72, SD = 1.73) to post-test (M = 4.42, SD = 1.75) (DiStefano et al., 2013). The increase in LESS scores demonstrates increased lower extremity movement errors in a hypohydrated, hyperthermic, and fatigued condition. This presents the need for injury prevention and a plan to reduce this risk for lower extremity injuries.

A personalized hydration plan could reduce dehydration seen in long bouts of exercise. The personal hydration plan could reduce cardiovascular strain by minimizing the decrease in blood volume seen due to increased sweat rate during exercise. By preventing this reduction in plasma volume, stroke volume will be maintained, allowing heart rate (HR) to remain lower while maintaining cardiac output steady during exercise. Hence, cardiovascular strain will not be significantly increased during long bouts of exercise.

Furthermore, a personalized hydration plan could prevent the early onset exercise-induced hyperthermia as exercise prolongs. Hydration during exercise will mitigate the decrease in plasma volume due to increased sweat rate from exercising in the heat. Thus, the body continues to dissipate heat through sweat, preventing drastic hyperthermia during exercise and decreases the negative effects of reduced lower extremity neuromuscular control. By developing a personalized hydration plan we may be able to prevent athletes from developing an ACL injury or other lower extremity injures.

Dehydration, hyperthermia, and fatigue may show decrements in lower extremity neuromuscular control and may increase chances for injuries. Thus, understanding these physiological insults may provide a way to prevent these injuries. Therefore, the purposes of this study were to determine if exercise-induced dehydration, hyperthermia, and fatigue affect LESS scores during a jump-landing task and to determine if implementing a personalized hydration plan during exercise affects LESS scores during a post-exercise (POST) jump-landing task.

Purpose

The primary purpose of this study was to determine if exercise-induced dehydration, hyperthermia, and fatigue affect LESS scores during a jump-landing task.

The second purpose of this study was to determine if implementing a personalized hydration plan during exercise affects LESS scores during a post-exercise jump-landing task.

Research Questions and Hypotheses

Question 1: Do exercise-induced dehydration, hyperthermia, and fatigue affect LESS scores during a jump landing task?

Hypothesis 1: Exercise-induced dehydration, hyperthermia, and fatigue will increase LESS scores during a jump landing task.

Question 2: Does a personalized hydration plan during exercise affect LESS scores during a jump landing task in an exercise-induced in an exercise-induced hyperthermic and fatigued individual?

Hypothesis 2: A personalized hydration plan during exercise will decrease LESS scores during a jump landing task in a hyperthermic and fatigued individual.

Significance

Lower extremity neuromuscular injuries occur frequently during physical activity and competitions (Hootman et al., 2002). These injuries can lead to long term consequences and can be career ending in sports (Lohmander, Ostenberg, Englund, & Roos, 2004). Due to how frequently these injuries occur, an injury prevention plan is needed. Research demonstrates that dehydration, hyperthermia, and fatigue each negatively affect neuromuscular control individually. Dehydration decreases neuromuscular control by decreasing muscular strength during exercise (Bosco, Terjung, & Greenleaf, 1968). Hyperthermia decreases muscle function, decreasing neuromuscular control, thus may increase injury risk (Gonzalez-Alonso, 2007). Fatigue may significantly increase risk of injury as shown by higher injury rates late in games (Hawkins, Hulse, Wilkinson, Hodson, & Gibson, 2001). However, dehydration, hyperthermia, and fatigue are commonly present together during physical activity (Armstrong, 2000). Distefano et al. (2013) found that in a hypohydrated, hyperthermic, and fatigued individual, lower extremity control and performance decreases, which may lead to an increased chance of an injury. To our knowledge, research has not examined interventions such as a personalized hydration plan to reduce these performance decrements.

Delimitations

1. Females were not included in this study.
2. Gastrointestinal temperature (T_{gi}) was used, introducing possible error if the pill was not consumed 8-10 hours prior to testing or the pill was damaged.
3. Data was collected outside, not in a temperature-controlled environment. Therefore, each trial was performed under slightly different temperate conditions.
4. T_{gi} cutoff was limited to 39.5°C. If possible higher core temperatures could have displayed a greater influence on neuromuscular control.
5. POST measures were performed in an air-conditioned lab, which resulted participants' T_{gi} to decrease prior to performing jump-landing task.

Limitations

1. Participants were not as dehydrated (2.6%) in CON, or euhydrated (0.9%) in EXP, as intended.

2. Variability was found between environmental conditions between testing sessions. Participants were scheduled at the same time of day on days with similar conditions to control for this variability.
3. Ambient temperature was not high enough during testing, therefore making it more difficult for participants to reach the target T_{gi} of 39.5°C. Some participants did not reach 39.5°C.
4. Variability in the exercise heat stress time, T_{gi} and/or fatigue between EXP and CON. Exercise duration, intensity, and T_{gi} were matched as well as possible between sessions to control for variability.
5. The air-conditioned lab caused increased body heat dissipation and reduced heat stress during POST jump-landing task.
6. Time from exercise to performance of jump-landing allowed for reductions in T_{gi} and fatigue.
7. The study was underpowered, $n = 5$.

Assumptions

1. Participants abided by the pre-test instructions; no alcohol or strenuous exercise performed within 24 hours of testing, no caffeine consumption within 8 hours, consumption of similar diet on the day prior to each testing session, and gastrointestinal pill taken 8-10 hours prior to testing.
2. Participants did not have any prior ACL injury, chronic ankle instability, and lower extremity injury that occurred within the past six months.
3. Participants gave full effort during the intermittent exercise protocol.
4. Participants were heat-acclimatized, due to testing occurring at the end of summer.

Definitions of Terms

Hyperthermic: A T_{gi} greater or equal to 39.5°C (Casa et al., 2015).

Dehydration: A body mass loss that is greater or equal to 2% (L. E. Armstrong et al., 1997).

Fatigue: A rating greater or equal to 7 out of 10 on the perceived fatigue scale.

CHAPTER 2: REVIEW OF LITERATURE

Many athletes compete and perform in a dehydrated, hyperthermic, and fatigued condition which may alter lower extremity neuromuscular control and increase injury risk. Commonly, exercising in the heat leads to dehydration due to lack of adequate fluid replacement, which increases core body temperature. This increase in core body temperature can lead to hyperthermic conditions. In addition, most athletes become fatigued as they exercise. Therefore, an intervention of how to reduce these decrements under these conditions is needed. This review of literature addresses the effects of exercise-induced dehydration, hyperthermia, and fatigue on lower extremity neuromuscular control. Sections of this literature review include: assessment of lower extremity biomechanics, exercise-induced dehydration, exercise-induced hyperthermia, fatigue and a combination of dehydration, hyperthermia, and fatigue.

Assessment of Lower Extremity Biomechanics

ACL and lower extremity injuries occur due to irregular movement patterns of loading and forces placed on the knee ligaments (Padua et al., 2009, 2015). These irregular movements can include knee-extension movement, proximal anterior tibial shear force, knee valgus-varus movement, and knee internal-external rotation movement (Padua et al., 2015). In addition, low knee flexion angles from 0° to 30° can greatly affect anterior tibial shear forces, therefore increasing the amount of ACL loading (DeMorat, Weinhold, Blackburn, Chudik, & Garrett, 2004; Draganich, Jaeger, & Kralj, 1989). Furthermore, isolated knee valgus and tibial rotation increase ACL loading and when combined with anterior tibial shear force the loading is magnified, increasing the risk of developing an

ACL injury (Bell, Smith, Pennuto, Stiffler, & Olson, 2014; Kanamori et al., 2000, 2002; Markolf et al., 1995).

Thus, a tool was developed called the LESS to identify athletes' movement patterns of the lower extremity that could increase the risk of developing ACL injuries. The LESS is an inexpensive clinical assessment tool that Padua and colleagues (2009) developed to provide standardized assessment of lower extremity neuromuscular control. Additionally, the LESS is a tool that has been used to predict noncontact ACL injuries (Padua et al., 2011, 2015). The LESS uses two standard video cameras in the frontal and sagittal planes for identifying potentially high-risk movement patterns during a jump-landing task (Padua et al., 2009). The jump-landing task incorporates vertical and horizontal movements as the participants jump from a 30-cm high box to a distance 50% of the subject's height away from the box and immediately rebounded for maximal vertical jump up on landing (Padua et al., 2009).

The recorded jump-landing tasks are then reviewed by a blinded rater to evaluate movement patterns. The rater uses a 17-point LESS scale to evaluate landing technique in the sagittal and frontal planes. The 17-point scale is divided into four separate sections. The first section examines the lower extremity and trunk positioning at initial contact (1-6) while the second section examines the positioning of the feet (7-11). The third section examines the lower extremity and trunk movements between initial contact and moment of maximal knee flexion (12-15). The final section assesses the rater's perception of the landing technique in the sagittal plane (16-17) (Padua et al., 2009). A LESS score is simply a count of landing technique "errors" on a range of readily observable items of human movement (Padua et al., 2009). A higher LESS score indicates poor landing technique and a lower LESS score displays good landing technique.

Padua et al. (2011) found that interclass correlation coefficient (ICC) and standard error of the mean (SEM) between raters (1 and 2) were 0.81 (95% confidence interval = 0.56-0.92) and 0.69, respectively. Looking at raters 1 and 3 similar values were found, ICC=0.72 (95% confidence interval = 0.42-0.88), and SEM=0.79. These results show that the LESS is a reliable clinical assessment tool that can be used by researchers to identify individuals that may be at risk for lower extremity injuries (Padua et al., 2011).

In addition, Padua et al. (2009) compared the LESS to a laboratory based motion analysis system and found a ICC (0.84) and a SEM (0.71), revealing that the LESS has good interrater reliability, meaning that between different trained raters. Also, intrarater reliability values were found as excellent for the LESS, ICC (0.91) and SEM (0.42) (Padua et al., 2009). These results display that the LESS is an accurate and reliable tool when compared to the motion capture analysis software. Thus, the LESS is a valid and reliable tool for identifying potential high-risk movement patterns during a jump-landing task and potential noncontact ACL injury (Padua et al., 2009).

Due to the good reliability between motion capture software and the LESS, this simple to implement tool has been used in research to assess lower extremity movement. A study by DiStefano and colleagues (2013) looked at recreationally active males performing a standardized jump-landing task pre-exercise (PRE) and POST to evaluate lower extremity movement with the LESS. The exercise consisted of a 90-minute treadmill protocol to implement exercise-induced hyperthermia. Distefano et al. (2013) showed that under a hypohydrated (*M* = 1052 mOsm kg^{-1}, *SD* = 72) and hyperthermic (*M* = 39.33°C, *SD* = 0.45) condition, LESS scores significantly increased from PRE (*M* = 3.72, *SD* = 1.73) to POST (*M* = 4.42, *SD* = 1.75) (DiStefano et al., 2013). These data indicate that lower extremity neuromuscular control can be evaluated with the LESS and was impaired in a hypohydrated and hyperthermic state.

Lower extremity neuromuscular control is negatively altered during exercise. Therefore, research is needed to learn how to decrease poor lower extremity neuromuscular control during prolonged exercise. In addition, if the athletes are exercise-induced dehydrated, hyperthermic, and/or fatigued during exercise poor lower extremity neuromuscular control may further increase. Thus, if athletes are provided with a personalized hydration plan this may improve these physiological decrements to lower extremity neuromuscular control. But, first we must understand how exercise-induced dehydration, hyperthermia, and fatigue affect lower extremity neuromuscular control independently.

Exercise-Induced Dehydration

Hydration status is an important factor that can affect exercise performance. There are different levels at which an athlete can be hydrated: euhydrated, hypohydrated, and dehydrated. Euhydration is defined as a normal or balanced body water content; hypohydration is described as chronic total body water loss; and dehydration is a state of acute body water loss (Armstrong, 2007; Sawka et al., 2007). Each different level of hydration affects the body and exercise performance differently.

Hypohydration occurs through fluid restriction prior to an exercise session (DiStefano et al., 2013). Total body water loss due to hypohydration is primarily from the extracellular space; however, under conditions of high total body water loss, fluid is lost more from the intracellular space (Sawka et al., 2001). Hypohydration specifically affects fluid loss at the cell and how the cell functions.

Hypohydration has shown to reduce muscular strength, muscular endurance, and aerobic performance (Sawka et al., 2001).

On the other hand, dehydration occurs with uncompensated total body water loss via urine, sweat, and respiratory vapor during exercise (Armstrong, 2007). Dehydration total body water loss is primarily from sweat via exercise. The fluid is lost from the blood, reducing the athlete's plasma volume. Dehydration can increase if the athlete has a high sweat rate and participates in exercise in a hot, humid environment (Casa et al., 2000). A reduction in total body weight by 1-2% via dehydration begins to impair physiological function and negatively impacts athletic performance (Casa et al., 2000).

The "elusive gold standard" for assessing hydration status is plasma osmolality, but a combination of percent body mass loss, urine color (U_{col}), and urine specific gravity (U_{sg}) is an acceptable way to determine hydration status (Armstrong, 2007). In addition to measuring dehydration, it is important for an athlete to know his or her sweat rate. Armstrong (2000) has found that mild to moderate work can result in whole-body sweat losses of $0.8\text{-}1.4 L \cdot h^{-1}$. Therefore, knowing one's sweat rate can reduce fluid loss during exercise. High intensity exercise can result in sweat rates over $3 L \cdot h^{-1}$.

One way to reduce total body water loss during exercise is to determine an individual's sweat rate. By determining sweat rate the athlete can determine how much fluid to consume while exercising to reduce dehydration throughout exercise preventing performance decrements (Casa et al., 2000). An individual's sweat rate can be determined by measuring PRE nude body mass then exercising for a specific time followed by an immediate POST nude body mass. In addition, the researcher must account for fluid intake and urine output. The individual's sweat rate is then determined by taking total body mass loss during exercise divided by exercise time. This is the amount of fluid the athlete should consume during exercise to replenish sweat lost. Knowing one's sweat rate allows the athlete to accurately replace fluids throughout exercise to reduce dehydration.

Furthermore, it is important to consider the environment where the exercise is performed because the sweat rate may increase or decrease depending on the environment's temperature. If exercising in a hot environment sweat rate will increase due to the increased skin blood flow in an the attempt to dissipate heat via evaporation (Casa et al., 2000). The reduction in fluid causes a decrease in plasma volume. This reduction leads to a decreased delivery of oxygen to muscles causing a potential decrease in performance.

Additionally, a greater total body water loss leads to a greater decrease in overall athletic performance (Bosco et al., 1968; Casa et al., 2000). With aerobic performance it has been found that if an athlete loses water ≥ 3% of body weight in a cool environment, maximal oxygen uptake (VO_{2max}) declines (Armstrong, 2000). These alterations in athletic performance due to dehydration suggest that dehydration may alter neuromuscular control at the lower extremity.

Minshull and James (2013) examined the effects of hypohydration by fluid restriction on indices of voluntary and magnetically evoked neuromuscular performance of the lower extremity in 10 healthy males. Static volitional peak force, evoked peak twitch force and rate of force were measured at the knee extensors in two isokinetic conditions. The study reported a reduction of 7.8% in volitional peak force ($P < 0.05$) in the hypohydrated condition (2.1% body mass loss) compared to a euhydrated condition. These decrements in neuromuscular performance due to hypohydration could lead to a decrease in knee joint stability and increased risk for lower extremity injury (Minshull & James, 2013).

In contrast, Stewart et al. (2014) observed how dehydration (~4%) independently affected the performance of a 5-km cycling time trial and neuromuscular drive. Neuromuscular drive was assessed by measuring the maximal voluntary torque (MVT), MVT development, surface electromyography amplitude, and superimposed maximal torque. Seven male subjects were tested before exercise, after exercise, and after fluid replenishment. Results showed that dehydration (~4%) did not independently affect neuromuscular drive nor performance in a 5-km cycling time trial. Although, dehydration alone did not significantly affect performance it is common that exercise-induced dehydration occurs in a hot environment. Thus, under a hot and dehydrated condition neural drive to the muscle may be affected, impacting performance (Stewart, Whyte, Cannon, Wickham, & Marino, 2014).

Research suggests that dehydration independently affects lower extremity neuromuscular control. But, research implies that exercise-induced dehydration is commonly seen in a hot environment. Thus, it is important to understand how lower extremity neuromuscular control is affecting in a hyperthermic environment.

Exercise-induced Hyperthermia

Exercise-induced hyperthermia is when body temperature rises above resting ranges (36.5- 37.5 °C). Some have defined hyperthermia as a minimum of 39.0°C (Morrison, Sleivert, & Cheung, 2004) while others define hyperthermia as 39.5°C (Casa et al., 2015). Hyperthermia more often occurs while exercising in a hot environment because the body struggles with keeping the core temperature at normal temperatures. Exercise-induced hyperthermia is commonly found in long distance events such as cycling, running, and soccer tournaments because of the reduction in plasma volume due to constant sweating (Armstrong, 2000).

Exercising in a hot environment increases blood flow to the skins surface to dissipate heat through sweating. Therefore, less blood is available to transport oxygen to the muscles during exercise. This situation creates a competition for blood flow in the body. This competition can lead to a decrease in stroke volume leading to a decreased cardiac output and increased perceived exertion, which reduces overall aerobic performance (Gonzalez-Alonso, 2007). Furthermore, a rise in body temperature reduces leg blood flow which may lead to reduced oxygen delivery to muscles and reduce removal of metabolic waste (Gonzalez-Alonso, 2007). This decrease in leg blood flow is due to the increased blood flow to the skin to dissipate heat. Thus, exercising in the heat may alter lower extremity neuromuscular control increasing risk for injury due to the decrease blood flow at the lower extremity.

Research by Morrison et al. (2004) examined the effect of passive whole body heating (without exercise-induced fatigue) on measures of lower extremity neuromuscular control including the maximal isometric force production and voluntary activation (VA) of the quadriceps femoris. The results showed that heating decreased maximal isometric force production by 13% and VA by 11%, which indicates that increased rectal temperature was related to VA during a MVC (Morrison et al., 2004). This suggests that hyperthermia alone may alter extremity lower extremity neuromuscular control.

In addition to an increase in core body temperature, the exercise duration is also important to neuromuscular control. An increase in muscle temperature during a warm-up improves power production during short-duration exercise, but as the duration continues power production decreases (Racinais & Oksa, 2010). Therefore, how hyperthermia affects anaerobic performance is dependent upon the duration (Racinais & Oksa, 2010).

For example, Lars, Nybo, and Nielsen (2001) found that in prolonged exercise duration with hyperthermia decreases maximal voluntary contraction (MVC) and aerobic performance. Fourteen men exercised at 60% VO_{2max} on a cycle ergometer under either a hot or thermoneutral environment. Immediately after exercise participants performed two minutes of sustained MVC with either a knee extension or with a hand grip. This study found that MVC decreased with hyperthermia (*M* = 40.0°C, *SD* = 0.1) and voluntary activation percentage displayed a decrease in central activation (*M* = 54%, *SD* = 7) in both groups (Nybo & Nielsen, 2001). In conclusion, this study demonstrated that the ability to generate force is attenuated with hyperthermia and impairs performance due to the reduction voluntary activation percentage (Nybo & Nielsen, 2001).

Many studies examined the effects of physiological decrements on neuromuscular control. However, neuromuscular control has historically been evaluated using isolated single muscle performance on isokinetic dynamometers and may not be practical to sport specific motions. Hence, more research needs to assess more sport like motions such as a jump-landing task. To my knowledge only one study examined the effects of exercise-induced hyperthermia on jump-landing technique using the LESS (DiStefano et al., 2013). Recreationally active males completed a 90-minute exercise protocol on a treadmill. The LESS scores increased from PRE to POST under an exercise-induced hyperthermic environment. The highest LESS score difference was observed at PRE (*M* = 3.72, *SD* = 1.73) to POST (*M* = 4.42, *SD* = 1.75) in the hypohydrated and hot condition (DiStefano et al., 2013). These findings demonstrate that under a hyperthermic and hypohydrated condition lower extremity neuromuscular control is reduced. Therefore, it is important to examine the effects on lower extremity neuromuscular control in more complex conditions.

Thus, exercising in a hyperthermic and dehydrated condition often leads to an increased level of fatigue. Past studies have found that dehydration and prolonged exercise in the heat can cause early onset of fatigue (Gonzalez-Alonso, Calbet, & Nielsen, 1999). Consequently, it is important to understand how fatigue independently affects lower extremity neuromuscular control.

Fatigue

Neuromuscular fatigue is a type of fatigue that influences of lower-limb control and can lead to injury risk. The ability of muscle fibers to absorb energy is decreased when fatigued which can alter neuromuscular function. There is decrease in shock absorption and knee stabilization in landing, which could potentially lead to non-contact lower extremity injuries (Chappell et al., 2005).

Chappell et al. (2005) researched the effects of neuromuscular fatigue by evaluating three different jump-landing tasks. The results showed that both males and females demonstrated altered motor control strategies when fatigued, which may increase anterior tibial shear force, strain on the ACL, and risk of injury (Chappell et al., 2005). This study supports that fatigue can independently affect landing technique and increase risk of injury.

Furthermore, a study using the LESS examined the effect of fatigue on landing technique. The study consisted of 12 anterior cruciate ligament reconstruction (ACLR) and 10 uninjured male and female subjects (Gokeler et al., 2014). Landing technique was altered after a CMJ and squat based fatigue protocol in both uninjured and ACLR individuals (Gokeler et al., 2014). The altered landing technique demonstrates that under a fatigued condition there is a decrease in lower extremity neuromuscular control and an increased risk for injury. To my knowledge this is the only study to specifically examine only fatigue and lower extremity neuromuscular control with the LESS.

One study examined the relationship between hydration status and lower extremity neuromuscular control during a jump-landing task. Using the LESS, 12 healthy males performed a standardized jump-landing task in both a hypohydrated temperate (HYT) and euhydrated temperate environment (EUT). The results showed no significant change in LESS scores between EUT and HYT at PRE, but there was a small difference found at POST, EUT (*M* = 3.47, *SD* = 2.05) and HYT (*M* = 3.75, *SD* = 1.76). Therefore, it was concluded that the increase movement errors during the LESS was due to the fatigue developed from the exercise protocol.

Mclean and associates examined the effects of fatigue on a drop landing task on NCAA Division I athletes. The subjects completed 10 drop landing tasks PRE and POST. The exercise included several game-like drills performed under a specific fatigue protocol. Females had a greater increase in lower extremity movements compared to the males after completing the fatigue protocol. Additionally, there was an increase in lower extremity movements in males, therefore it was concluded that there is an increased chance of non-contact knee injury after fatiguing exercise (McLean et al., 2007).

In contrast, another study found that an intermittent exercise protocol that stimulated a ‘game-like’ situation did not induce fatigue nor showed a significant reduction in lower extremity performance (Shultz et al., 2015). But, fatigue may occur sooner with an intermittent exercise protocol when combined with dehydration and hyperthermia. Therefore, it is important to examine fatigue under more complex situations.

One study examined the effects of voluntary and magnetically evoked neuromuscular performance with acute fatigue and hypohydration (Minshull & James, 2013). Minshull and James concluded that the decrease in neuromuscular performance at the knee following the fatigue protocol could lead to decreased joint stability and increased risk for injury late in competition or training. Thus, it can be concluded that under a more complex situation, like the combination of dehydration, hyperthermia, and fatigue may alter movement control at the lower extremity, increasing injury risk.

The Combination of Dehydration, Hyperthermia, and Fatigue

Prolonged physical activity commonly leads to dehydration, which may cause hyperthermia, and therefore cause an increase in fatigue. The reduction of blood flow due to dehydration causes an increase in HR, which in return causes a decreased stroke volume, and prompts a decreased delivery of oxygen to working muscles creating cardiac drift (Gonzalez-Alonso, 2007; Nybo, 2008). In addition these effects trigger an increase in perceived exertion, which prompts poor performance (Gonzalez-Alonso, 2007). Dehydration, hyperthermia, and fatigue all significantly impact the performance of an athlete. Therefore, it is important to examine movement under all three of these circumstances and the effects on lower extremity neuromuscular control.

A study by DiStefano and colleagues (2013) assessed the effects of exercise-induced hyperthermia and hypohydration on jump landing technique using the LESS. Jump-landing tasks where performed in four different exercising conditions euhydrated hot (EUH) and hypohydrated hot (HYH), as well as, EUT and HYT. The results from the HYH condition (PRE, *M* = 3.72, *SD* = 1.73, POST, *M* = 4.42, *SD* = 1.75) compared to POST HYT (*M* = 3.75, *SD* = 1.76) and

POST EUH ($M = 3.61$, $SD = 1.47$) ($P < 0.05$) showed an increase in movement errors, reducing neuromuscular control. DiStefano and colleagues concluded that hypohydration ($M = 1052\text{mOsm}\cdot\text{kg}^{-1}$, $SD = 72$) and hyperthermia ($M = 39.33°\text{C}$, $SD = 0.45$) during exercise impairs neuromuscular function of the lower extremity during a jump-landing task, therefore increasing risk of injury.

Due to lack of literature, it is important for researchers to examine lower extremity neuromuscular control in this complex situation of hyperthermia, dehydration, and fatigue to prevent future injury and increase performance. Furthermore, researchers need to examine ways to help athletes better prevent these decrements from occurring during exercise.

Summary

Dehydration, hyperthermia, and fatigue independently affect lower extremity movements by decreasing neuromuscular control. In addition, the LESS has shown to accurately assess landing technique and decreases in neuromuscular control of the lower extremity. An intervention plan should be implemented to reduce these decrements in neuromuscular control. Therefore, a personalized hydration plan may mitigate poor movement patterns and prevention of lower extremity injuries.

CHAPTER 3: METHODS

Experimental Design

After a familiarization trial, participants completed two test sessions in a randomized controlled crossover counterbalanced design. One test session being control (CON) with minimal fluid replacement and the other experimental (EXP) with fluid replacement equal to the participants' specific sweat rate (Figure 1). Each test session was separated by at least 48 hours to allow participants to recover from the previous test session. All test sessions took place outdoors in a warm environment (> 35°C) where air quality was ranged from the white to green flag categories (Sawka et al., 2003).

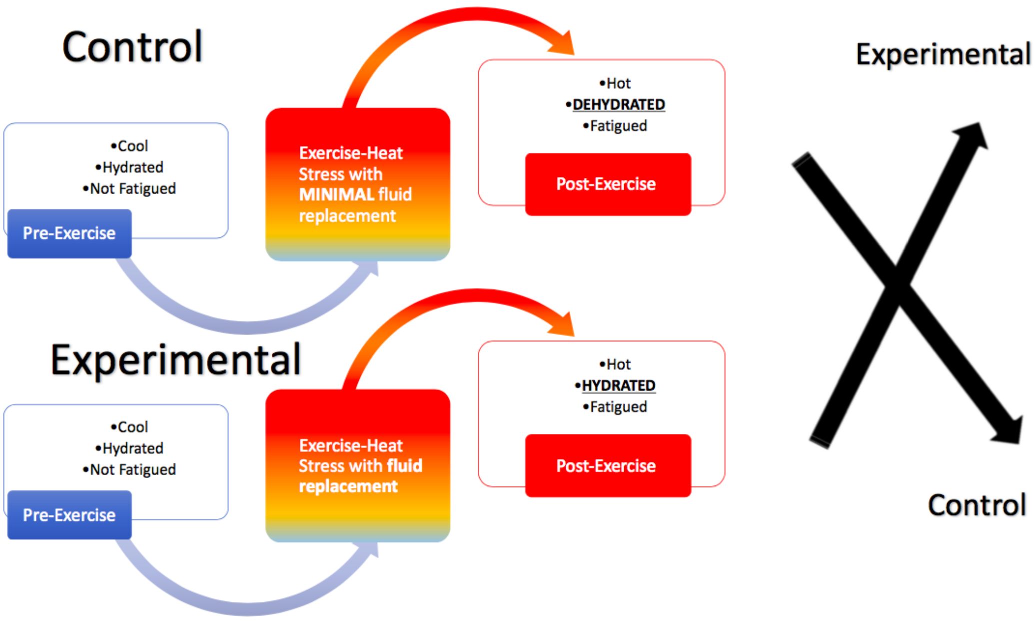

Figure 1. Experimental design.

Note: Prior to intermittent exercise protocol (Pre-exercise) participants' gastrointestinal temperature (T_{gi}) is cool (36-37.5°C), euhydrated with a urine specific gravity (U_{sg}) $\leq$ 1.025 and urine color $U_{col} \leq 4$ and not fatigued (< 7/10). After exercise (Post-exercise) participants are hot ($T_{gi} = 39.5$°C), dehydrated ($U_{sg} \geq 1.025$, $U_{col} \geq 4$) and fatigued ($\geq$ 7/10). Participants then return $\geq$ 48 hours later to perform the alternate trial.

Participants

Healthy, heat-acclimatized, and recreationally active males between the ages of 18-35 y were recruited to participate in the study. Participants were assumed to be heat acclimated due to testing being completed in late summer. A heat acclimation questionnaire confirmed acclimatization status. Recreationally active was defined as ≥ 30 minutes of exercise a day, 3-5 days a week, and a VO_{2max} that ranged from 45-55 $mL \cdot kg^{-1} \cdot min^{-1}$. Participants were excluded from the study if they had: any chronic health problems, a history of cardiovascular, metabolic, and/or respiratory disease, a fever or an injury that would affect physical activity during testing. Participants were also excluded from the study if they had previously experienced exertional heat stroke within the past 3 years. If they had a prior ACL injury, chronic ankle instability, or lower extremity injury that occurred within the past six months. All participants provided informed consent (Appendix A) prior to participation. The study protocol was approved by the University's Institutional Review Board.

Procedures

Familiarization Session

Participants attended a familiarization session at least 48 hours before the first test session to determine the participant's body composition, VO_{2max}, and sweat rate. Participants completed a medical history form (Appendix B) and a heat acclimation questionnaire (Appendix C) to ensure that the participant was cleared for testing.

Height was measured before measuring body weight and body composition. After determining percent body fat, the participants completed a VO_{2max} test.

During the VO_{2max} test HR, VO_2, respiratory exchange ratio (RER), and rating of perceived exertion (RPE) were measured to confirm $VO_{2max.}$

Prior to beginning the sweat rate test, participants provided a urine sample to measure U_{sg} and U_{col} to ensure euhydration. If a $U_{sg} > 1.025$ or $U_{col} \geq 4$ the participant was provided 500mL of water and waited 30 minutes until starting the sweat rate test.

The sweat rate test was performed in the same location and under similar environmental conditions as the test sessions. Participant's PRE nude body mass was measured prior to beginning the sweat rate test. Ambient air temperature (°C), percent relative humidity (%RH), and wet bulb globe temperature (WBGT) (°C) were recorded before and after the sweat rate test. The intermittent exercise protocol performed for all sessions included walking, jogging, running, and sprinting. Participants wore a HR monitor and a global positioning system (GPS) watch to record, exercise intensity, time, speed, and distance.

Sweat rate was determined by subtracting the participant's PRE nude body mass from their POST nude body mass divided by the exercise time completed (L. E. Armstrong, 2007; Casa et al., 2000). Water consumption was accounted for during the sweat rate determination. Urine loss was added to total body mass lost and water consumption was subtracted from total body mass. Participants were instructed to keep a 24-hour dietary log before each test session to ensure that calorie intake was the same before each test session controlling for the effects of hydration and substrate depletion induced fatigue.

Test Sessions

Upon arrival to the lab participants confirmed that no alcohol had been consumed in the past 24 hours and no caffeine had been consumed in the past 8 hours to control for the effect on performance. Participants confirmed taking the T_{gi} pill and researchers checked to ensure that the pill was working properly.

The participants then provided a urine sample to measure PRE U_{sg} and U_{col} to ensure euhydration. If a $U_{sg} > 1.025$ or $U_{col} \geq 4$ the participant was provided 500mL of water and waited 30 minutes until beginning the test session. Then the participant's PRE-nude body mass was measured in a private room. A HR monitor was then applied to the participant's chest. Perceptual scales (thirst, thermal, fatigue, and RPE; Appendix D) were then explained to the participant and recorded. The participant's baseline HR and T_{gi} were recorded before beginning lower-extremity movement assessment.

Lower-extremity movement assessment required participants to perform three standardized jump-landing tasks that were video-recorded. Video cameras were placed on tripods at a height of 48 inches from the floor and 136 inches in front and to the side of the participant in the frontal and sagittal plane (Padua et al., 2009). The participants jumped from a 30 cm high box that was placed at a distance that was 50% of the participants height, landing on a force platform, and immediately rebounded for a maximal vertical jump (Padua et al., 2009) (Figure 2).

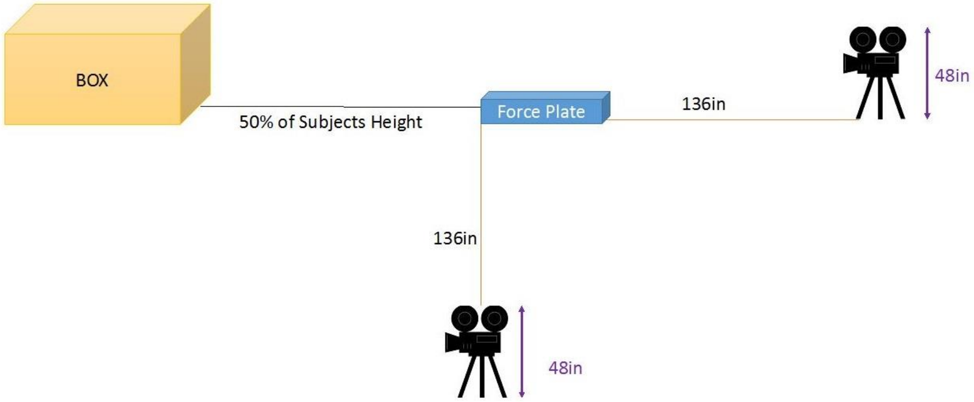

Figure 2. Landing error scoring system standardized jump-landing task set-up

Participants practiced until one successful jump landing task was completed. A successful jump was characterized by (1) jumping off with both feet; (2) jumping forward, but not vertically, to land on the force plates; (3) landing with both feet inside the force plates; and (4) completing the task in a fluid motion (Padua et al., 2009). Participants were asked to rebound as high as possible and were not given feedback regarding landing technique unless the task was performed incorrectly (Padua et al., 2009). The LESS is a field-based motion analysis in which the jump-landing tasks are evaluated for an overall LESS score (Padua et al., 2009). A LESS score is a count of landing technique “errors” that are commonly seen in human movement (Padua et al., 2009). The LESS examines 17 items at the knee, trunk, and feet (Padua et al., 2009). A higher LESS score means there is a greater number of landing errors committed, meaning that the participant had “poor” jumping technique (DiStefano et al., 2013). A lower LESS scores means that the participant has “good” landing technique (Padua et al., 2009).

As part of a larger study, following the jump-landing tasks a repeated box lifting task (RBL) and countermovement jump (CMJ) were completed. After all the tasks were completed the participants went outside to begin exercise.

Prior to beginning the exercise outdoors, environmental conditions, physiological, and perceptual measures were recorded. The intermittent exercise protocol is thought to represent a ‘game-like’ situation that involves different levels of running from sprinting to jogging to walking, simulating the biomechanical and physiological demands of high-intensity intermittent sport (Shultz et al., 2015) (Figure 3). The participants ran for 90 minutes that included various speeds and distances of running. Intermittent exercise protocol consisted of a 50-meter sprint, 25-meter 80% run, 15-meter 60% run, and 200-meter 50% jog with walking in between each run (Figure 3).

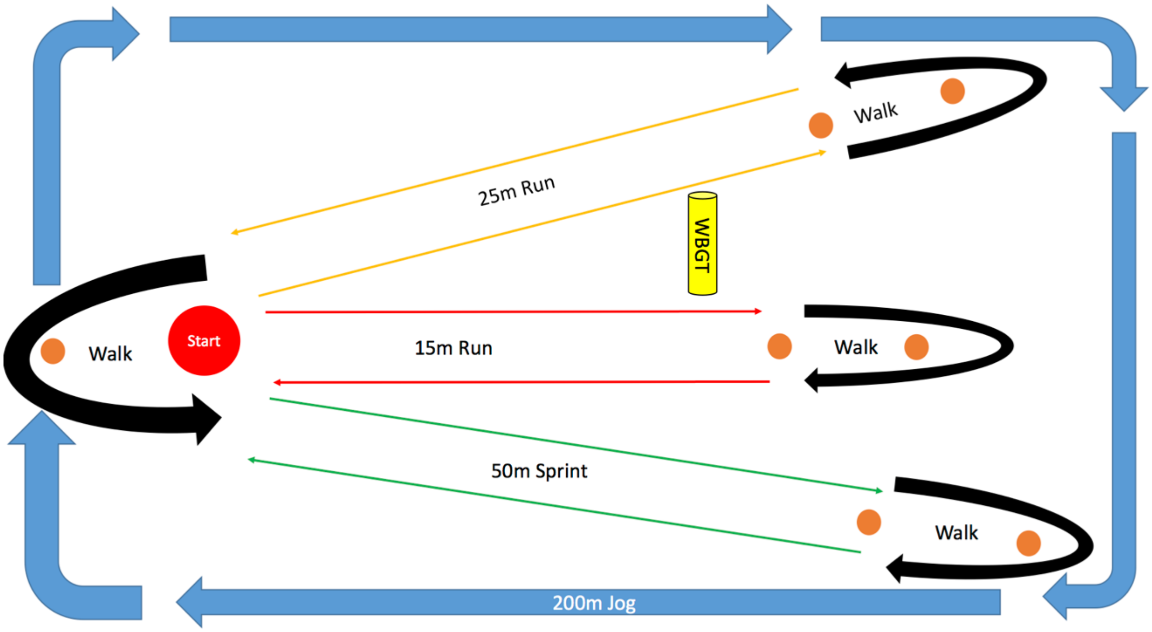

Figure 3. Intermittent Exercise Protocol: Following each run or sprint the participant walked and after completing all three runs a recovery jog (200m-jog) was completed.

During exercise, physiological and perceptual measures were recorded every 10 minutes. In CON, participants received 100mL of water every 30 minutes. In EXP, participants received water in small doses every 10 minutes to fully replace fluid lost through sweat as determined during sweat rate testing.

Exercise was stopped if the participant $T_{gi} \geq 39.5°C$, a fatigue score of ≥ 7/10 scale was reached, or participant volition. Exercise was also stopped if signs of exertional heat illness were observed for subject safety. Immediate post-exercise (IPE) environmental conditions, physiological, and perceptual measures were recorded.

Participants immediately returned to the lab POST, where pre-performance physiological and perceptual measures were recorded. The participants then performed three successful jump-landing tasks followed by the RBL and CMJ. POST post-performance physiological and perceptual measures were then recorded followed by a final POST nude body mass. Lastly, the participants provided a urine sample to measure their POST U_{sg} and U_{col} and were given fluids to rehydrate.

Instrumentation

Participants height was measured in centimeters with a wall mounted Stadi-O-Meter (Novel Products Inc., Rockton, Illinois). The weight and body fat percent of each participant was determined using air displacement plythemosgraphy in a BODPOD (Cosmend, Roma, Italy). The VO_{2max} test took place in a thermoneutral environment where subjects completed a 5-minute warm-up on a treadmill walking at 1% grade. The test continued with a treadmill ramping protocol which increases speed every 2 minutes until voluntary exhaustion. The expired gases where collected and recorded with the ParvoMedics True One 2400 Metabolic Measurement System (Sandy, Utah) and connected by a hose to a 2-way Hans-Rudolph Valve (Shawnee, Kansas). VO_{2max} was confirmed if the following criteria were met: plateau in VO_2, reached 90% of age-predicted HR maximum, plateau in HR, and RER ≥ 1.15.

The participants PRE and POST nude body mass was measured to the tenth of a kilogram on a scale (Gmbh & co., Seca, Germany). Volume fluid intake was measured with a digital scale (Ohaus Co., CSSeries, Parsippany, NJ). Urine specific gravity (U_{sg}) was measured with a refractometer (Atago inc, URC-Ne, Believue, Washington) and urine color (U_{col}) was measured on a urine color chart rated from 1-7 (L. E. Armstrong, 2007) to ensure euhydration.

Environmental conditions were measured using a WBGT device on a tripod (Kestrel Inc., 4400 Heat Stress Tracker, Bootwyn, Pennsylvania).

Internal temperature data was recorded with a T_{gi} pill (HQ, Inc. CorTemp Temperature Sensor, Palmetto, Florida) that was ingested eight hours prior to test to defend against recording an invalid T_{gi}.

Thirst sensation was rated on a scale from 1 being not thirsty at all to 9 very, very thirsty following 1 unit increments (Armstrong, 2007). Thermal sensation was rated on a scale from 1 unbearable cold to 8 unbearably hot following 0.5 increments. Fatigue was rated on a scale from 0 being no fatigue at all to 10 completely fatigued following 1 unit increments. Rating of perceived exertion was rated on the Borg scale from 6 to no exertion at all to 20 to maximal exertion following 1 unit increments (Borg & Kaijser, 2006).

HR was monitored using a HR monitor (Polar, Model H7, Lake Success, NY). A wrist mounted GPS device recorded distance and run velocity (Runtrainer, Timex, Middlebury, CT).

Jump-landing tasks were recorded on video cameras (Canon, Vixia HF R700, Irvine, California).

Data Management

Jump-landing video data was clipped (Apple Inc., iMovie 10.1.4, USA) and sent to an experienced rater to be evaluated for LESS errors. The rater, was blinded to the condition and time.

Statistical analysis was performed using IBM SPSS V23.0 (IBM Corporation, Armonk, NY, USA) with an alpha level of 0.05 to determine significance.

Statistical Analysis

Descriptive statistics were computed for demographic information. Independent t-tests were performed to compare environmental conditions. Dependent t-test evaluated exercise time, distance, and speed between trials. Additionally, dependent t-test were performed for T_{gi}, percent body mass loss, HR, and fatigue for PRE to POST, as well as IPE to prior to performing the jump-landing tasks after exercise (Pre-LESS). Data was examined as to whether it met assumptions for ANOVA; independence of cases, homoscedasticity, sphercity, and normality. A trial (CON vs EXP) by time (PRE vs POST) two-way repeated measures ANOVA was computed to examine changes in LESS scores, T_{gi}, HR, perceptual measures (fatigue, RPE, thirst, and thermal sensation). If sphericity was violated, Greenhouse-Geisser correction was applied. Pairwise comparisons were examined to assess time effects and trial effects.

The dependent variables for this study was LESS scores, % dehydration, T_{gi}, HR, and perceptual ratings. Independent variables were T_{gi}, body mass loss, fatigue, environmental conditions, and exercise time, distance, and run speed. Effect size was calculated using partial eta squared for ANOVA and Cohen's d for pairwise comparison.

CHAPTER 4: RESULTS

Demographics

Five participants (*n* = 5) completed both CON and EXP trials (Table 1). Participants were recreationally active by displaying a VO2max that ranged from 45-55 mL·kg-1·min-1 and healthy with a low percent body fat (Table 1).

Table 1

Demographic Data

Variable	Measure
Age (y)	25.40 ± 5.73
Height (cm)	175.74 ± 8.19
Weight (kg)	78.70 ± 16.79
Body Fat (%)	13.80 ± 6.42
VO_{2max} ($mL \cdot kg^{-1} \cdot min^{-1}$)	60.10 ± 6.18
Sweat Rate ($L \cdot min^{-1}$)	2.07 ± 0.51

Landing Error Scoring System

No time by trial interaction effect was seen in LESS scores, F (1,8) = 0.669, $p = 0.437$, $\eta_p^2=0.077$ nor main effects F (1,8) = 0.448, $p = 0.522$, $\eta_p^2 = 0.053$. No group difference was seen between trials for LESS scores before exercise (CON, *M* = 3.80, *SD* = 1.69; EXP, *M* = 4.53, *SD* = 1. 69), *t* (4) = -0.626, *p* = 0.565, *d* = -0.43 and for LESS scores after exercise (CON, *M* = 4.47, *SD* = 0.45; EXP, *M* = 4.47, *SD* = 0.77), *t* (4) = 0.00, *p* = 1.00, *d* = 0.00.

Although not statistically significant, LESS scores increased from PRE to POST in both trials, but a greater increase in movement errors was seen in CON ($M_{pre\text{-}post}$ = -0.667) when compared to the EXP ($M_{pre\text{-}post}$ = 0.0667) (Figure 4).

Furthermore, changes in specific movement errors were observed with heel toe contact, narrow stance, external rotation, and joint displacement occurring the most often during a jump-landing task (Table 2). Heel toe contract errors for CON (PRE, *M* = 2; POST, *M* = 3) increased by 50% and decreased by 25% for EXP (PRE, *M* = 4; POST, *M* = 3). Narrow stance errors did not change in CON and increased by 100% for EXP (PRE, *M* = 1; POST, *M* = 2). External rotation errors increased in both CON (PRE, *M* = 3; POST, *M* = 4) (-33%) and EXP (PRE, *M* = 4; POST, *M* = 5) (-25%). No change in joint displacement errors were observed in CON, but decreased by 25% in the EXP (PRE, *M* = 4; POST, *M* = 3).

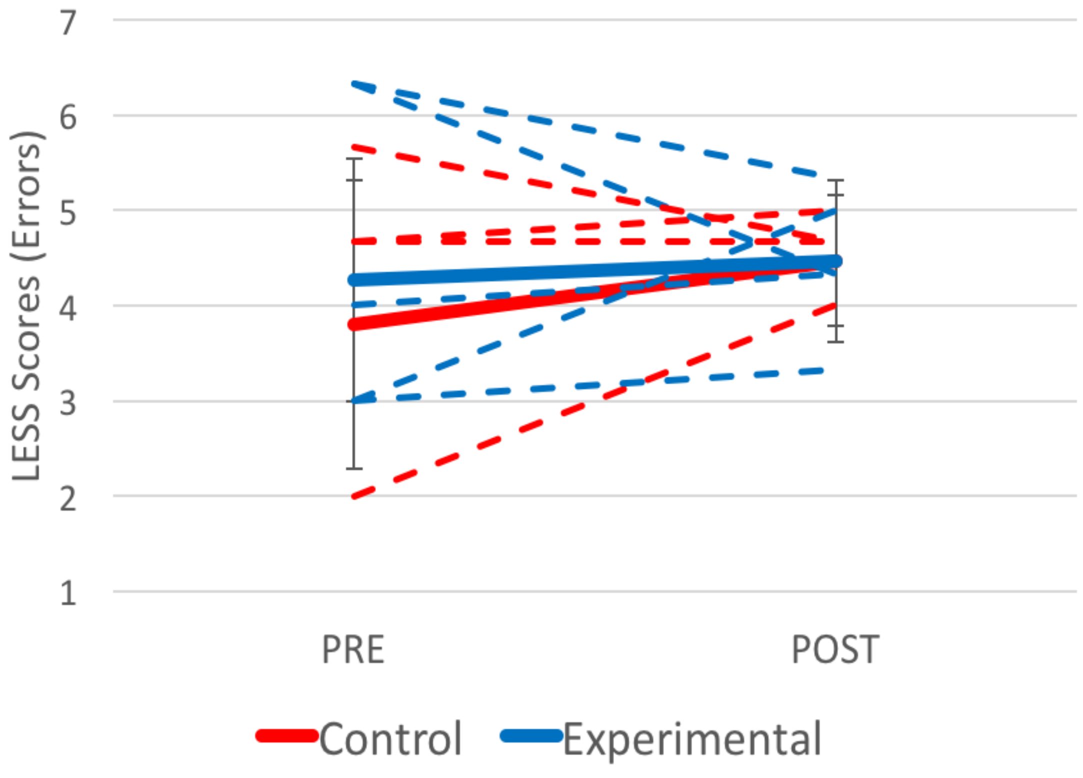

Figure 4. Mean LESS scores pre-exercise (PRE) and post-exercise (POST) between trials, with each participant's individual LESS score. * P < 0.05 for PRE to POST; † P < 0.05 for between trials.

Table 2

Top 4 Individual Movement Errors out of 22 Evaluated That Appeared Most Frequency Among Participants

Landing Error Scoring System Item	Trial	PRE ($n = 5$)	POST ($n = 5$)	% Change
Heel Toe Contact	CON	2	3	- 50
	EXP	4	3	+25
Narrow Stance	CON	2	2	0
	EXP	1	2	-100
External Rotation	CON	3	4	-33
	EXP	4	5	-25
Joint Displacement	CON	2	2	0
	EXP	4	3	+25

Note: Number of participants that performed that movement error during that time point and trial. Percent change was calculated from pre-exercise (PRE) to post-exercise (POST) out of 5. (PRE-POST)/PRE] • 100 = percent change

Heart Rate Response to Intermittent Exercise Protocol

There was no interaction effect for HR $F(2,8) = 1.60$, $p = 0.242$, $\eta_p^2 = 0.167$. A main effect for time was observed $F(2,8) = 346.86$, $p < 0.001$, $\eta_p^2 = 0.977$. HR increased steadily during the first 10 minutes and then plateaued after minute 10 throughout exercise for both trials $F(2,8) = 284.2$, $p < 0.001$, $\eta_p^2 = 0.973$ (Figure 5). HR for both trials increased from minute zero (CON, $M = 107.40$, $SD = 16.50$; EXP, $M = 102.0$, $SD = 8.69$) to IPE (CON, $M = 177.40$, $SD = 20.38$; EXP, $M = 182.2$, $SD = 13.83$), $p < 0.001$ (Figure 5). HR decreased for both trials from IPE (CON, $M = 172.50$, $SD = 19.84$; EXP, $M = 182.2$, $SD = 13.83$) to Pre-LESS (CON, $M = 134.00$, $SD = 18.22$; EXP, $M = 116.8$, $SD = 14.75$), $p < 0.001$ (Figure 5). A group difference was observed for HR at Pre-LESS (CON, $M = 134.0$, $SD = 18.22$; EXP, $M = 116.5$, $SD = 17.02$), $t(4) = 3.302$, $p = 0.046$, $d = 0.993$.

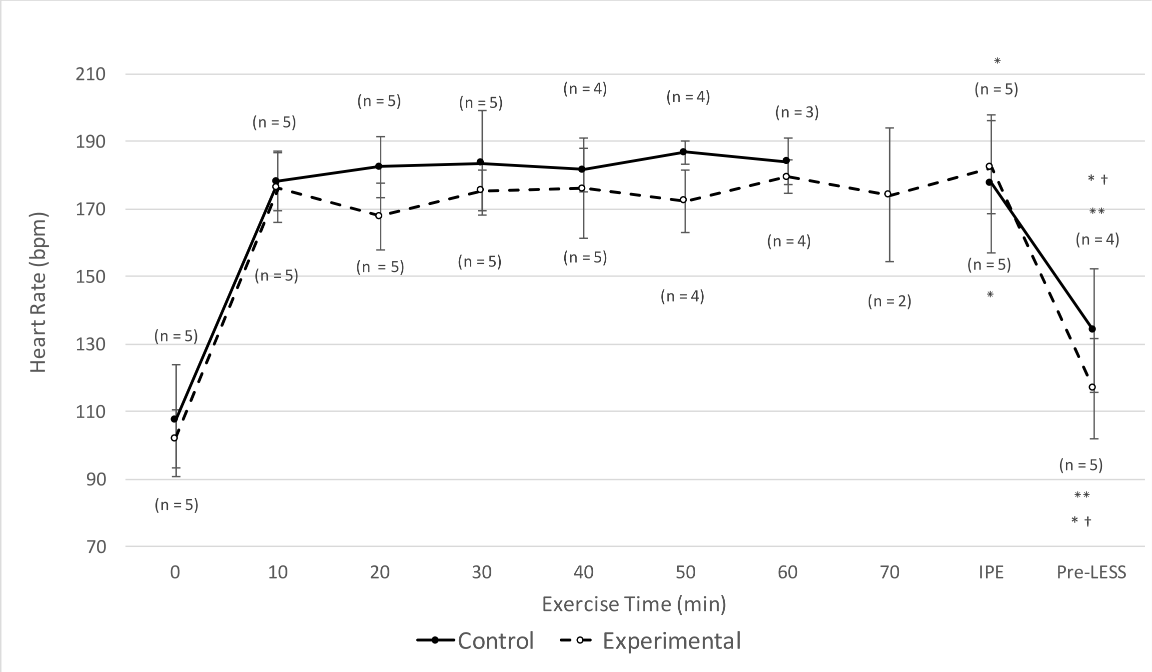

Figure 5. Heart rate response during exercise to immediately post-exercise (IPE), and prior to performing completing jump-landing tasks after exercise (Pre-LESS). * $P < 0.05$ for pre-exercise (PRE) to post-exercise (POST); ** $P < 0.05$ for IPE to Pre-LESS; † $P < 0.05$ for between trials.

Physiological and Perceptual Responses to Intermittent Exercise

RPE increased from minute zero (CON, *M* = 8, *SD* = 3; EXP, *M* = 9, *SD* = 2) to IPE in both groups (CON, *M* = 19, *SD* = 1; EXP, *M* = 18, *SD* = 3), *F*(2,8) = 128.59, $p < 0.001$, $\eta_p^2 = 0.941$ (Table 3). Additionally, RPE did not increase from IPE in CON (*M* = 19, *SD* = 1) to Pre-LESS (*M* = 13, *SD* = 3), *t* (3) = 2.60, *p* = 0.080, *d* = 2.68. Whereas, RPE increased from IPE in EXP (*M* = 18, *SD* = 3) to Pre-LESS (*M* = 12, *SD* = 6), *t* (4) = 3.80, *p* = 0.019, *d* = 1.26. An interaction effect was observed for rating of thirst sensation from minute zero (CON, *M* = 4, *SD* = 1; EXP, *M* = 4, *SD* = 2) to IPE (CON, *M* = 8, *SD* = 1; EXP, *M* = 5, *SD* = 3), *F*(2,8) = 7.85, *p* = 0.023, $\eta_p^2 = 0.495$ between groups. Rating of thermal sensation increased from PRE (CON, *M* = 4.8, *SD* = 0.75; EXP, *M* = 4.5, *SD* = 0.50) to IPE (CON, *M* = 7.0, *SD* = 0.79; EXP, *M* = 7.0, *SD* = 0.72), *F*(2,8) = 65.11, $p < 0.001$, $\eta_p^2 = 0.891$. An interaction was observed for body mass from PRE (CON, *M* = 77.88, *SD* = 16.68; EXP, *M* = 78.56, *SD* = 16.31) to IPE (CON, *M* = 75.92, *SD* = 15.97; EXP, *M* = 76.86, *SD* = 15.37), *F*(2,8) = 25.62, *p* = 0.001, $\eta_p^2 = 0.762$ between groups. U_{sg} changed from PRE (CON, *M* = 1.009, *SD* = 0.01; EXP, *M* = 1.01, *SD* = 0.01) to POST (CON, *M* = 1.01, *SD* = 0.00; EXP, *M* = 1.02, *SD* = 0.05), *F*(2,8) = 6.83, *p* = 0.035, $\eta_p^2 = 0.494$. An interaction was observed for U_{col} from PRE (CON, *M* = 1.01, *SD* = 0.007; EXP, *M* = 1.01, *SD* = 0.008) to POST (CON, *M* = 1.02, *SD* = 0.004; EXP, *M* = 1.02, *SD* = 0.007), *F*(2,6) = 6.40, *p* = 0.045, $\eta_p^2 = 0.516$ between groups.

Exercise-Induced Dehydration

CON was more dehydrated than the EXP from PRE to POST (CON, *M* = 2.59, *SD* = 0.52; EXP, *M* = 0.92, *SD* = 0.41), *t* (4) = 10.55, $p < 0.001$, *d* = 3.57 (Table 3).

Table 3

Physiological & Perceptual Responses from Intermittent Exercise Protocol

Variable	Trial	PRE	POST
Perceptual			
Rating of Perceived Exertion (RPE)	CON	8 ± 3	19 ± 1*
	EXP	8 ± 2	18 ± 3*
Rating of Thirst Sensation	CON	4 ± 1	8 ± 1*†
	EXP	4 ± 2	5 ± 3*†
Rating of Thermal Sensation	CON	5.0 ± 1.0	7.0 ± 1.0*
	EXP	4.5 ± 0.5	7.0 ± 1.0*
Hydration			
Body Mass Loss (kg)	CON	77.88 ± 16.68	75.92 ± 16.56*†
	EXP	78.56 ± 16.31	77.80 ± 15.97*†
Urine Specific Gravity	CON	1.01 ± 0.007	1.01 ± 0.004*
	EXP	1.01 ± 0.008	1.02 ± 0.007*
Urine Color	CON	3 ± 1	6 ± 1*†
	EXP	3 ± 2	4 ± 1*†

Note: * P < 0.05 for pre-exercise (PRE) to post-exercise (POST); † P < 0.05 for between trials: control (CON) and experimental (EXP).

Exercise-Induced Hyperthermia

No interaction effect was observed for T_{gi} *F* (1,5) = 1.65, p = 0.234, η_p^2 = 0.171. But, a main effect for time was seen for T_{gi} *F* (1,5) = 11.97, p = 0.009, η_p^2 = 0.599. T_{gi} was similar at minute zero (CON, *M* = 37.84, *SD* = 0.25; EXP, *M* = 37.83, *SD* = 0.23), *t* (3) = -0.073, *p* = 0.946, *d* = 0.04 and increased steadily for 30 mins for both trials (Figure 6). T_{gi} in EXP plateaued after minute 40, while CON T_{gi} continued to rise (Figure 6). Although, not significantly different between groups, T_{gi} at minute 60 (CON, *M* = 39.29, *SD* = 0.18; EXP, *M* = 38.88, *SD* = 0.60), *t* (2) = 1.65, *p* = 0.241, *d* = 0.926 and IPE (CON, *M* = 39.22, *SD* = 0.32; EXP, *M* = 39.03, *SD* = 0.61), *t* (4) = .592, *p* = 0.592, *d* = 0.390) was greater (Figure 6). T_{gi} for both trials increased from minute zero (CON, *M* = 37.83, *SD* = 0.21; EXP, *M* = 37.83, *SD* = 0.23) to IPE (CON, *M* = 39.17, *SD* = 0.45; EXP, *M* = 39.03, *SD* = 0.61) ($p < 0.05$) (Figure 6) due to the effect of exercise-heat stress. T_{gi} was similar between trials at IPE (CON, *M* = 39.29, *SD* = 0.31; EXP, *M* = 39.03, *SD* = 0.61), *t*(7) = 2.64, *p* = 0.425. T_{gi} for both trials did not significantly decrease from IPE (CON, *M* = 39.17, *SD* = 0.37, EXP, *M* = 39.03, *SD* = 0.61) to Pre-LESS (CON, *M* = 38.81, *SD* = 0.26, EXP, *M* = 38.68, *SD* = 1.11) ($p > 0.05$) (Figure 6). T_{gi} were similar at Pre-LESS (CON, *M* = 38.81, *SD* = 0.26; EXP, *M* = 39.02, *SD* = 1.07), *t* (2) = -0.303, *p* = 0.790, *d* = -0.269.

Fatigue Response to Intermittent Exercise

No interaction effect for rating of fatigue was observed *F*(2,8) = 0.853, *p* = 0.383, η_p^2 = 0.096. But, a main effect for time was observed *F*(2,8) = 189.11, $p < 0.001$, η_p^2 = 0.952. No difference between groups for fatigue was seen at minute zero (CON, *M* = 2.6, *SD* = 1; EXP, *M* = 2.80, *SD* = 1), *t* (4) = -0.250, *p* = 0.815, *d* = -0.02. Fatigue increased from minute zero (CON, *M* = 3, *SD* = 1; EXP, *M* = 3, *SD* = 2) to IPE (CON, *M* = 9, *SD* = 1, EXP, *M* = 9, *SD* = 2), $p < 0.001$ (Figure 7).

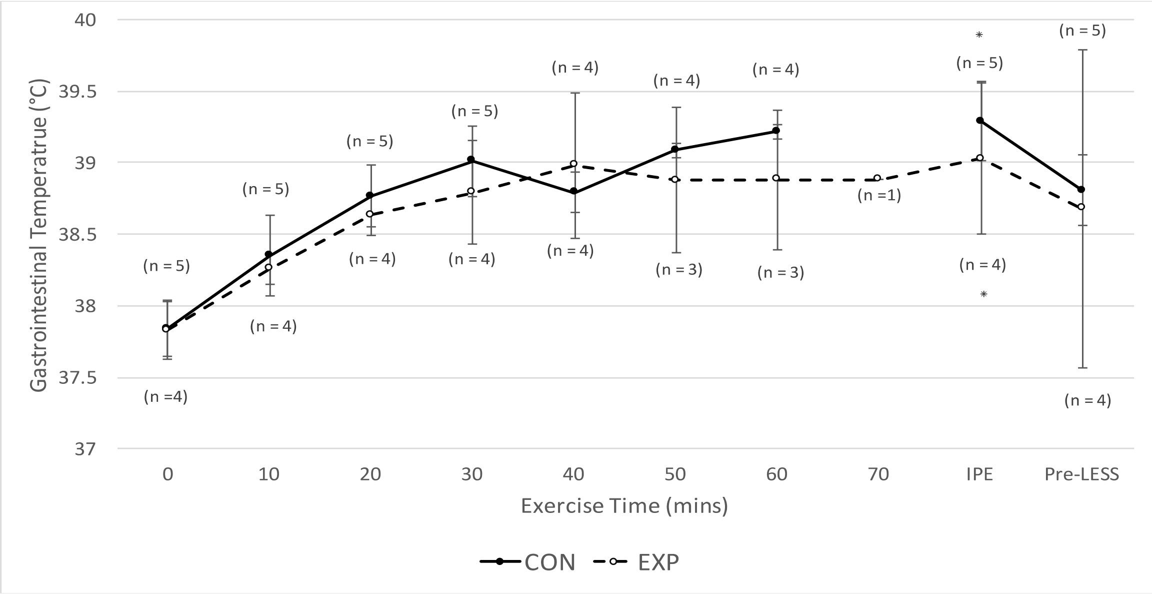

Figure 6. Gastrointestinal temperature throughout exercise to immediately post-exercise (IPE) to prior to performing jump-landing tasks after exercise (Pre-LESS).

Note: * P < 0.05 for minute 0 to IPE; ** P < 0.05 for IPE to Pre-LESS; † P <0.05 for between control (CON) and experimental (EXP) trials.

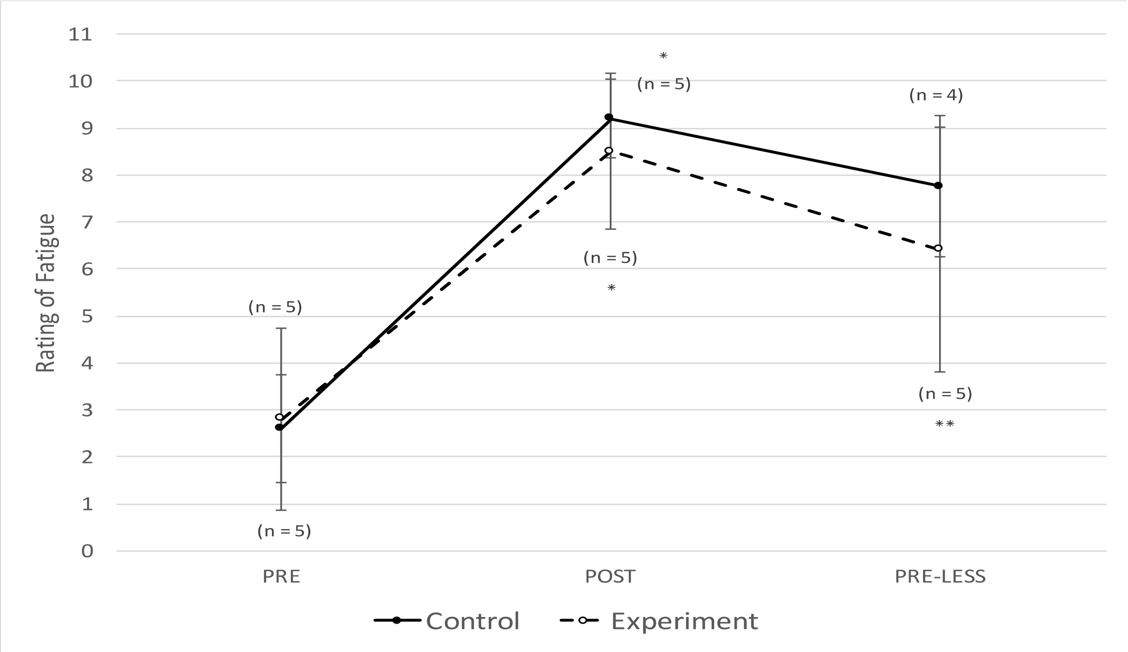

Figure 7. Rating of fatigue at pre-exercise (PRE), post-exercise (POST) and prior to performing jump-landing tasks (Pre-LESS).

Note: * P < 0.05 for PRE to POST; ** P < 0.05 for IPE to Pre-LESS; † P < 0.05 for between groups.

At IPE, no difference between trials was seen (CON, *M* = 9, *SD* = 1; EXP, *M* = 9, *SD* = 2; *t*(4) = 0.742, *p* = 0.499, *d* = 0.00). Furthermore, a difference between trials was not observed at Pre-LESS (CON, *M* = 8, *SD* = 2; EXP, *M* = 7, *SD* = 2, *t*(3) =0.302, *p* = 0.783, *d* = 0.50). No change in fatigue was observed from IPE (*M* = 9, *SD* = 1) to Pre-LESS (*M* = 8, *SD* = 2), *t*(3) = 4.02, 2.32, *p* = 0.103, *d* = 0.632, whereas for EXP rating of fatigue changed from IPE (*M* = 9, *SD* = 2) to Pre-LESS CON (*M* = 6, *SD* = 3), *t*(4) = 3.10, *p* = 0.036, *d* = 1.18.

Environmental Conditions

There were no differences in environmental conditions between groups (*p* > 0.05) (Table 4), except for a difference in percent relative humidity from pre- (CON, *M* = 30.08, *SD* = 3.73; EXP, *M* = 32.3, *SD* = 8.06) to POST (CON, *M* = 26.94, *SD* = 2.82; EXP, *M* = 28.63, *SD* = 5.53), *F* (2,8) = 5.80, *p* = 0.047, η_p^2 = 0.4530. The environmental conditions were warm and mild, ranging from the white to green flag categories (Sawka et al., 2003).

Table 4

Environmental Conditions During Intermittent Exercise.

Variable	Trial	PRE	POST
Ambient Air Temperature (°C)	CON	32.6 ± 1.08	31.8 ± 1.67
	EXP	31.2 ± 1.39	31.64 ± 0.79
Humidity (%)	CON	30.08 ± 3.73	26.94 ± 2.82*
	EXP	30.66 ± 7.89	27. 88 ± 5.07*
WBGT (°C)	CON	26.52 ± 2.53	24.50 ± 2.45
	EXP	27.46 ± 2.09	26.92 ± 3.10

Note: Values presented are Mean and Standard Deviations. * P < 0.05 for pre-exercise (PRE) to post-exercise (POST); † P < 0.05 for between control (CON) and experimental (EXP).

Exercise Intensity and Time

Exercise time completed by participants was alike between CON (M = 59.25, SD = 13.61) and EXP (M = 64.86, SD = 7.93, t (8) = 0.46, p = 0.456, d = 0.50). Distance covered was similar between trials (CON, M =9.01, SD= 0.50; EXP, M = 9.35 km, SD =1.39), t(7) = 3.01 p = 0.734 d =0.25. No significant difference was found in exercise velocity between CON (M = 8.30 $\text{km}\cdot\text{h}^{-1}$, SD = 0.61) and EXP (M = 8.62, SD = 0.95, t (7) = 0.85, p = 0. 577, d = 0.040.

CHAPTER 5: DISCUSSION

To our knowledge, the current study is the first to examine the effect of a personalized hydration plan during exercise on neuromuscular control. The current investigation hypothesized that exercise-induced dehydration, hyperthermia, and fatigue would worsen LESS scores during a jump-landing task and that a personalized hydration plan would mitigate this worsening of LESS scores. We found that the combination of dehydration, hyperthermia, and fatigue did not affect POST LESS scores during a jump-landing task (Figure 1).

Our findings contradict past research that observed that neuromuscular control was negatively affected by a hyperthermic, hypohydrated state (DiStefano et al., 2013). This discrepancy may be due to the present study having lower T_{gi} (CON, *M* = 38.81, *SD* = 0.26, EXP, *M* = 38.68, *SD* = 1.11) than DiStefano et al. (*M* = 39.33, *SD* = 0.45) in the hypohydrated and hyperthermic trial which found a reduced POST LESS scores. Additionally, the exercise bouts varied from 60-70 minutes, whereas DiStefano et al. exercise protocol consisted of 90 minutes. The varying lengths of exercise time and environmental conditions in the present study may explain the lower T_{gi}, not allowing for adequate hyperthermia and dehydration to occur. Thus, if the current study would have displayed similar T_{gi} to DiStefano et. al (2013) we may have seen similar results.

The exercise protocol in the current study resulted in 2.6% body mass loss in CON, whereas DiStefano et al. (2013) induced 5.7% body mass loss. This difference in body mass loss may explain why the present study did not see a reduction in LESS scores when performing a jump-landing task. Additionally, the previous study induced hypohydration through water restriction before exercise plus sweat induced water loss via exercise in the heat, while in the current study body mass loss was done via dehydration through sweat losses only. Furthermore, DiStefano et al. reported that LESS scores were not altered in a euhydrated hyperthermic condition. This indicates the importance of hydration during exercise to reduce the effects on neuromuscular control and that a 5% reduction in body mass loss plus hyperthermia ($T_{gi} > 39.3°C$) would suggest neuromuscular control impairment at the lower extremity.

We observed that the hydration plan did not affect LESS scores, likely because CON may not have been dehydrated enough to display an increase in LESS scores. Dehydration greater than 3-4% has reduced muscular strength, power, and high-intensity endurance which may reduce overall athletic performance (Judelson et al., 2007). Furthermore, decrements in neuromuscular control have been seen in hydration levels resulting in 3-6% body mass loss (DiStefano et al., 2013; Stewart et al., 2014). Therefore, if the current study would have shown a greater percent body mass loss to match previous studies, lower extremity neuromuscular control may have been similarly reduced. The dehydration level in CON (2.6%) was greater than EXP (0.92%) but did not result in a change in LESS scores. These results show similar percent body loss mass as Minshull and James (2013) who observed a 2.1% body mass loss impaired neuromuscular control, however, our study did not mirror their decrements. This could be due to hypohydration affecting the cell’s ability to perform, whereas with dehydration the reduction of fluid is affecting the blood plasma volume. This may be the reason why the current study did not show decrements.

While dehydration did not affect LESS scores between groups, HR increased significantly in CON compared to EXP. We found that Pre-LESS HR after exercise was significantly higher in CON (*M* = 134.0, *SD* =18.22 bpm) compared to EXP (*M* = 116.5, *SD* = 17.02 bpm). These data support a review that found that for every 1% body mass loss HR increased additional 3 - 5 bpm (Casa et al., 2015). This demonstrates an increase in cardiovascular strain due to the sweat-induced reduction in total blood volume, consequently, altering the heart's ability to pump blood to the skin to dissipate heat, deliver oxygen and substrate, and remove metabolic byproducts (Casa et al., 2000). To compensate for the reduction in plasma volume and subsequent decrease in stroke volume, HR must increase to maintain cardiac output. Additionally, dehydration may induce hyperthermia affecting cardiac output by increasing fluid loss through an increased sweat rate. Therefore, the combination of dehydration and hyperthermia may further exacerbate cardiovascular strain, and perhaps affect neuromuscular control.

Many studies have observed that hyperthermia affects lower extremity neuromuscular control (DiStefano et al., 2013; Morrison et al., 2004; Nybo & Nielsen, 2001). Reductions to neuromuscular control were found at T_{gi} ranging between 37-39.5°C (DiStefano et al., 2013; Morrison et al., 2004). Our target T_{gi} was 39.5°C, however, exercise was conducted under moderate environmental conditions (29.7-33.7°C; humidity = 22.0-39.2%; WBGT = 23.7-33.7°C). Thus, the target T_{gi} was not reached IPE (CON, M = 39.29, SD = 0.31°C; EXP, M = 39.03, SD = 0.61°C). Furthermore, T_{gi} (CON, M = 38.81, SD = 0.26°C; EXP, M = 38.68, SD = 1.11°C) decreased as participants returned the lab (22.7°C; humidity, 41.5%; WBGT, 17.6°C) for POST LESS testing for both trials. T_{gi} observed in the present study was lower than past studies that have found a relationship between hyperthermia and neuromuscular control (DiStefano et al., 2013; Morrison et al., 2004). Moreover, our current study may have observed neuromuscular impairments during a jump-landing task if conducted under similar conditions in past studies, inducing higher percent body mass loss and higher core temperatures.

In contrast, the cooler POST T_{gi} supports DiStefano et al., who found that LESS scores did not increase in the euhydrated hyperthermic (*M* = 38.35, *SD* = 0.63°C) condition. But, neuromuscular control was found to be affected greater by the combination hypohydration and hyperthermia, which was observed by DiStefano and colleagues (2013). Hypohydration has shown to reduce neuromuscular control, but dehydration through exercise did not affect neuromuscular control. Therefore, it is still unknown if dehydration through exercise affects neuromuscular control. Additionally, dehydration through exercise brings in another factor, fatigue, which presents an even more complex condition to the athlete.

Multiple studies have found that fatigue can negatively affect neuromuscular control, increasing risk for injury (Chappell et al., 2005; Gokeler et al., 2014; McLean et al., 2007). Participants were fatigued after the intermittent exercise protocol, per rating of fatigue from PRE (CON, *M* = 3, *SD* = 1; EXP, *M* = 3, *SD* = 2) to IPE (CON, *M* = 9, *SD* = 1; EXP, *M* = 9, *SD* = 2). Also, rating of fatigue was similar from POST (*M* =9, *SD* = 1) to Pre-LESS (*M* = 8, *SD* = 2) in CON. However, fatigue in EXP from IPE (*M* = 9, *SD* = 2) to Pre-LESS (*M* = 6, *SD* = 2) did significantly decrease. This observation shows that EXP was still fatigued (6/10) when performing POST jump-landing task, just not as fatigued as CON (9/10). This demonstrates that hydration during exercise allowed for faster cardiovascular recovery and perceptual feelings of fatigue from the intermittent exercise protocol. This is important because the personalized hydration plan may allow for adequate recovery reducing risk for injury.

Additionally, an increase in RPE from PRE (CON, *M* = 8, *SD* = 3; EXP, *M* = 8, *SD*= 2) to POST (CON, *M*= 19, SD = 1; EXP, *M* = 18, *SD* = 3) was observed indicating that the participants' effort during exercise was enough to reach fatigue.

Past studies have used the RPE (≥ 18) to measure fatigue (DiStefano et al., 2013; Gokeler et al., 2014). In the present study, CON displayed no significant increase in movement errors even when fatigued at POST. This supports the findings of Distefano et al. (2013) that fatigue could not independently affect LESS scores without regards to percent body mass loss and core temperature, but contradicts other studies that have found that fatigue alone can impact neuromuscular control (Chappell et al., 2005; Gokeler et al., 2014; McLean et al., 2007). Although, in the present study participants were fatigued at POST, fatigue did not independently affect LESS scores without regards to hydration level and core temperature.

The current study was limited to mild dehydration and hyperthermia, while perceived fatigue level was significant when performing a jump-landing task at POST. Although the dehydration level reached in CON was 2.6% this was not enough to show decrements in LESS scores. If dehydration was > 5% maybe more movement errors may have occurred during the POST jump-landing task. Furthermore, target T_{gi} was intended to be 39.5°C, which was not achieved immediately POST. If data collection would have been conducted earlier in the summer and under a greater heat stress participants may have displayed a higher increase in T_{gi} resulting in a more extreme hyperthermic condition. Last, a greater perceived rating of fatigue may have been needed to negatively affect LESS after exercise. The moderate levels of hyperthermia and fatigue could be due, in part, to the cool environmental condition of lab and the delay from IPE to LESS testing.

Another explanation of the lack of change in LESS scores could be due to the current study being underpowered ($n = 5$). Given the non-significant p-value (0.437) for the interaction effect in LESS scores, a post hoc power analysis (G-power) was conducted to determine sample size needed to achieve statistical power. Using partial eta squared of the POST LESS scores for both groups, to achieve power using repeated measures ANOVA with an alpha level set at 0.05 it is estimated a total of 26, or an additional 21 participants would be needed to achieve a power of 0.8.

In conclusion, exercise-induced dehydration, hyperthermia and fatigue to the extent achieved in this study did not affect LESS scores. Similarly, a personal hydration plan during exercise did not mitigate changes in POST LESS scores. However, the increase in HR observed in CON may provide evidence that during prolonged exercise under these conditions increases cardiovascular strain, and therefore increase risk for injury. However, the personalized hydration plan allowed for a faster recovery of HR and perception of fatigue from IPE to POST LESS testing (approximately 5 min) suggesting hydration is an important consideration to a speedy recovery. These findings are important for recreational or occupational athletes completing multiple bouts of exercise per day.

Further research should seek to induce greater levels of dehydration, hyperthermia, and fatigue commonly seen in long bouts of exercise. Additionally, future research should focus on dehydration compared to hypohydration because most elite athletes begin exercise or competition hydrated. Therefore, it is important to continue to understand how dehydration specifically effects neuromuscular control. Understanding how lower extremity neuromuscular control is affected under various conditions could help prevent future lower extremity injuries often seen in prolonged exercise bouts.

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APPENDICES

APPENDIX A: INFORMED CONSENT

Department of Kinesiology
Human Performance Laboratory

Consent Form for Participation in a Research Study

Principal Investigator: J. Luke Pryor, PhD, ATC, CSCS
Co-Investigators: Riana R. Pryor, PhD, ATC, Bhupinder Singh, PhD, ATC
Student Researchers: Stephen Wolf, Megan Buettner, Alexandria Gregory
Study Title: The Effects of Hydration on Neuromuscular Control in a Hyperthermic, Dehydrated, and Fatigued Condition

Introduction

You are invited to participate in a study conducted by Dr. J. Luke Pryor at California State University, Fresno. We hope to learn about the effects of high body temperature, dehydration, and fatigue on various performance tasks (repetitive box lifting, landing from a jump, and vertical jumping). A second aim of the proposed study is to evaluate the effectiveness hydration in restoring performance in individuals who are dehydrated, fatigued, and have a high body temperature. You were selected as a possible participant in this study because you are a recreationally active, healthy male, aged 18-35, with above average fitness. This consent form will give you the information you will need to understand why this study is being done and why you are being invited to participate. It will also describe what you will need to do to participate and any known risks, inconveniences or discomforts that you may have while participating. We encourage you to ask questions now and at any time. If you decide to participate, you will be asked to sign this form and it will be a record of your agreement to participate. You will be given a copy of this form.

Why is this study being done?

We hope to understand the effect of hyperthermia, dehydration, and fatigue, a common physiological condition during sports, on how body movement control during a jump-landing, continuous vertical jumping, and box-lifting task. We are also interested in exploring the effectiveness of a hydration plan to lessen poor neuromuscular control as a result of being hot, dehydrated, and fatigued. This information can help sports medicine professionals, coaching staffs, and physicians protect physically active persons by understanding how movement control changes under these conditions and the effectiveness of the proposed prevention strategy.

What are the study procedures? What will I be asked to do?

If you decide to participate, you will sign this form and complete a medical history questionnaire to ensure that you meet the inclusion criteria for the study. We expect to complete data collection from August 2016 – October 2017. To allow you to understand the commitment required to participate in this study, below is a figure illustrating the study timeline and laboratory testing days. The study consists of three lab visits totaling 5-6 hours. The lab visits will be a familiarization session followed by two exercise trials termed “control” and “experimental” completed in a randomized order.

Prior to all laboratory visits, you will be instructed to avoid alcohol and strenuous exercise for 24 hours and caffeine for 8 hours before testing. You will also be asked to drink 500 mL (2 cups) of water 3 hours before and 250 mL (1 cup) 1 hour before the lab visit to ensure normal hydration upon arrival to the lab. You may bring a hat and/or long sleeved athletic shirt to wear during exercise.

Baseline Testing and Familiarization visit

If you meet the inclusion criteria, we will schedule a familiarization session which will be approximately 90 minutes in duration. This lab visit will occur in the Human Performance Lab (HPL; located at South Gym 139). The familiarization visit procedures include the following:

1. Complete a training history questionnaire and heat acclimatization questionnaire
2. Height, body mass, hydration, and body fat percentage determined with Bod Pod
3. Maximal aerobic capacity (VO_{2max})
4. 30 minute run in the heat to determine sweat rate
5. Repeated box lifting
6. Jump-landing task
7. Countermovement jump

Height will be measured with a stadiometer without shoes and hydration via urine sample provided in clean cup. Body fat percentage will be measured with the Bod Pod where you will sit quietly in an enclosed egg shaped apparatus for approximately 90 seconds. Please wear tight fitting clothes such as biking shorts or Under Armor type apparel to increase measurement accuracy.

We will determine your maximal aerobic capacity (VO_{2max}) with a graded exercise test on a treadmill in a temperate environment. After a 5 minute warm-up period, you will begin walking at 1% grade. Treadmill speed and/or grade will increase each 2 minute stage until you decide you are exhausted while we collect expired gases. Next, you will record nude body mass behind a closed door to maintain privacy. After running on a treadmill or outdoors for 30 minute in the heat (~95°F) you will once again be weighed nude behind a door to maintain privacy. Water will be provided during the test. You will be introduced to the repeated box-lifting task where you will continually lift a 40 pound box to a height of 4.3 feet. Next, you will practice the countermovement vertical jumping task. For 20 seconds, you will continually jump in the air as high as possible with your hands on your hips. Finally, you will complete the jump-landing task by jumping forward a distance approximately ½ the distance of your height from a 12 inch wooden box. Upon landing, you will immediately jump up for maximal height. After the familiarization protocol, you will return to the HPL on two other separate occasions before the exercise trials and provide a urine sample and nude body mass measurement. After completing baseline testing, you will be randomly assigned to complete either the control trial or experimental trial first.

You will be given a 24 hour diet log to record you food and fluid intake 24 hours prior to your first exercise trial. You will be given a copy of this log to repeat the day before the second exercise trial.

Exercise Trials

Exercise trials (control and experimental) will occur next to and in the Gait Analysis and Movement Evaluation Lab (GAME; located at McLane 103). After completing the first trial, you will complete the alternate trial with a minimum of 48 hours between each trial. The two exercise trials should take approximately 2 hours each. Both exercise trials will be carried out at the same time of day. Outdoor exercise will not occur on purple air quality days. Approximately 8 hours before both exercise trials, you will ingest a small pill (about the size of a multi-vitamin) that will record internal body temperature.

Control Trial

Upon arrival for the control trial, nude body mass will be measured. In order to measure hydration status, you will be asked to urinate into a clean cup. If you are hypohydrated, you will be provided 500 mL of water and allowed to sit for 30 minutes, then retested. You will wear a heart rate monitor during all testing. Heart rate, core temperature, perceptuals, and skin temperature will be measured at baseline and throughout testing. Skin temperature will be measured by temporarily placing a small thermistor on your right calf, thigh, shoulder, and chest. You will perform three jump-landing attempts, 5 minutes of repeated box lifting, a 4-minute period of rest, and the 20 second countermovement vertical jump task. Before and after the box-lifting task, blood lactate will be measured by a finger or earlobe prick following aseptic techniques.

After baseline measures are complete, you will undergo continuous interval (walk, jog, run) outdoor exercise in the heat. We expect an exercise duration of 45-90 minutes depending upon your fitness level, exercise intensity, and ambient conditions. Outdoor exercise time will not exceed 90 minutes. Exercise duration and intensity during the first exercise trial will be recorded and repeated during the second exercise trial. To do this you will wear a wrist mounted GPS watch. We will consistently overlook and record physiological and perceptual variables throughout exercise in the heat and post-exercise testing to increase safety and adjust exercise intensity if necessary. Water will be provided every 30 minutes in 100 mL increments to ensure dehydration during this trial. Exercise will terminate if gastrointestinal temperature reaches 103.1°F and perceptual fatigue is ≥7/10, signs or symptoms of exertional heat illness, unsteady walking gait, or subject request.

Once exercise termination criteria are met, you will enter the GAME lab and record a nude body mass after wiping off excess sweat in private room. The testing protocol of jump-landing, box-lifting, 4 minutes of rest and countermovement jump repeated. Before and after the box-lifting task, your blood lactate will be measured. After completing the post-exercise performance tasks, you will remove the heart rate monitor, GPS watch, provide another nude body mass in a private room, and provide a urine sample to evaluate hydration status. As much water as you desire will be given to you so you can rehydrate.

Experimental Trial

For the experimental trial, the procedures will be similar with the following exceptions:

1. During the running protocol, you will consume water to match your fluid loss through sweat as determined at the familiarization visit.

<u>What are the risks or inconveniences of the study?</u>

Risk/Inconvenience	Risk Prevention and Mitigation
Delayed onset muscle soreness	You are a young, healthy, active person so the likelihood of developing soreness is lessened.
A fall during running	You are a young, healthy, active person so the likelihood of falling while running is lessened.
Musculoskeletal injury (muscle strain, ligament sprain, bone fracture)	You are a young, healthy, active person so the likelihood of developing a strain, sprain, or fracture is lessened. We will also provide you detailed instructions of the tasks before you exercise.
Exertional heat illness	You are a young, healthy, active person who has not experienced a heat illness in the recent past so the likelihood of developing a heat illness is only moderate. We will educate you about the symptoms and signs of exertional heat illnesses and you will notify one of the researchers if you experience any of the symptoms or signs. Signs and symptoms may include: weakness, dizziness, feeling hot, cramping, vomiting, headache, nausea, tired, disorientation, or low blood pressure. Trained researchers will monitor your heart rate, body temperature, and signs and symptoms of exertional heat illness. If deemed necessary, the researchers will immediately cold water immerse you to decrease your body temperature.
A disturbance of heart rhythm	You are a young, healthy, active person so the likelihood of developing a heart rhythm disturbance is very low. You have been screened for contraindications to vigorous exercise. At least one of the researchers is certified in CPR/AED will be present during all exercise sessions. In the unlikely event of a cardiac event, EMS will be activated.
Infection from finger or earlobe prick	Researchers will cleanse the area with alcohol, allow to dry, and with gloves donned execute the prick.

What are the benefits of the study?

You will benefit from having information regarding your general fitness and health such as body fat percentage and maximal oxygen consumption (typically ~$200 value). This study will increase knowledge of how being hot, tired, and dehydrated affects how we move. Also, we will better understand how proper hydration and body cooling influences poor neuromuscular control. These results will help medical professionals and coaching staffs mitigate the musculoskeletal injuries during similar tasks and conditions. The results of this study may influence and encourage further education and research on the topic. We cannot guarantee, however that you will receive any direct benefits from this study.

How will my personal information be protected?

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. All recorded information will remain secured in a locked office for 3 years after all publications are written. When information is entered into computer databases the information will not include your identifiable information. You will only be identified by an anonymous participant number on data sheets. There will only be one master list of these participant numbers that will be stored in the primary investigator’s office. Information will be accessible only by the principal investigator and the student researchers. At the conclusion of this study, the researchers may publish their findings. Information will be presented in summary format and you will not be identified in any publications or presentations.

Will I receive payment for participation? Are there costs to participate?

If you complete the study, you will be compensated $75. If subjects do not meet VO2max criteria and are not eligible to participant, they may not receive monetary compensation but could receive fitness assessment information, if requested, valued at $100. If you decide not to continue participation after the familiarization and first exercise trial, compensation will be prorated ($50). If you complete any portion of a single data collection session you will receive the appropriate payment. You are free to leave the study at any time, without retribution, prejudice, or negative consequences.

What happens if I am injured or sick because I took part in the study?

In the event you become sick or injured during the course of the research study, immediately notify the principal investigator or a member of the research team. If you require medical care for such sickness or injury, you will be referred to the campus health center or your primary care physician. Your care will be billed to you or to your insurance company in the same manner as your other medical needs are addressed. There is no monetary compensation for injury; each subject is responsible for all medical costs related to her or his care.

Can I stop being in the study and what are my rights?

You do not have to be in this study if you do not want to. Your decision whether or not to participate will not prejudice your future relations with California State University, Fresno nor the Central California Sports Sciences Institute. If you decide to participate, you are free to withdraw your consent and drop out at any time without penalty. You will be notified of all significant new findings during the course of the study that may affect your willingness to continue. If necessary, you may be withdrawn from the study at any time. Examples of withdrawal considerations are safety/medical concerns, missed appointments, non-adherence to procedures, disruptive behavior during study procedures, and/or adverse reactions. Committee on the Protection of Human Subjects at California State University, Fresno has reviewed and approved the present research.

Whom do I contact if I have questions about the study?

If you have any questions, please email the principal investigator, Dr. Luke Pryor (lukepryor@csufresno.edu) or call (559) 278-2990. I will be happy to answer them. The Institutional Review Board, at California State University, Fresno, has reviewed and approved the present research. Questions regarding the rights of research subjects may be directed to Kris Clarke, Chair, CSUF Committee on the Protection of Human Subjects, (559) 278-4468.

YOU ARE MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. YOUR SIGNATURE INDICATES THAT YOU HAVE DECIDED TO PARTICIPATE, HAVING READ THE INFORMATION PROVIDED ABOVE.

CALIFORNIA STATE UNIVERSITY FRESNO 1911

Consent Form for Participation in a Research Study

Principal Investigator: J. Luke Pryor, PhD, ATC, CSCS
Study Title: The Effects of Hydration on Neuromuscular Control and Power in a Hyperthermic, Dehydrated, and Fatigued Condition

Documentation of Permission:

You are making a decision whether or not to participate in this study. Your signature indicates that you have decided to participate, having read the information provided above. Its general purposes, the particulars of my involvement and possible risks and inconveniences have been explained to my satisfaction. I understand that I can withdraw at any time. My signature also indicates that I have received a copy of this permission form. Please return this form to the principal investigator.

____________________	____________________	__________
Signature:	Print Name:	Date:
____________________	____________________	__________
Signature of Person Obtaining Consent (Research Assistant)	Print Name:	Date:

APPENDIX B: MEDICAL HISTORY QUESTIONNAIRE

Medical History Questionnaire

Study The Effects of Hydration on Neuromuscular Control in a Hyperthermic, Dehydrated, Fatigued State

Name ______________________________ Sex _____ Age _____ DOB _____

Street ____

City ____________________ State _____ Zip __________ Phone _____

Email ______________________________

PLEASE ANSWER ALL OF THE FOLLOWING QUESTIONS AND PROVIDE DETAILS FOR <u>ALL</u> "YES" ANSWERS IN THE SPACES AT THE BOTTOM OF THE FORM.

YES	**NO**		
☐	☐	1.	Has your doctor ever said that you have a heart condition **<u>and</u>** that you should only do physical activity recommended by a doctor?
☐	☐	2.	Has your doctor ever denied or restricted your participation in sports or exercise for any reason?
☐	☐	3.	Do you ever feel discomfort, pressure, or pain in your chest when you do physical activity?
☐	☐	4.	In the past month, have you had chest pain when you were not doing physical activity?
☐	☐	5.	Do you lose your balance because of dizziness or do you ever lose consciousness?
☐	☐	6.	Does your heart race or skip beats during exercise?
☐	☐	7.	Has a doctor ever ordered a test for you heart? (i.e. EKG, echocardiogram)
☐	☐	8.	Has anyone in your family died for no apparent reason or died from heart problems or sudden death before the age of 50?
☐	☐	9.	Have you ever had to spend the night in a hospital?
☐	☐	10.	Have you ever had surgery?

If you answered **YES** to any of the above questions, please explain in the space below.

____

____

____

____

11. Please check the box next to any of the following for which **you** were ever diagnosed or treated.

- ☐ High blood pressure
- ☐ Asthma
- ☐ Bladder Problems
- ☐ Coronary artery disease
- ☐ High cholesterol
- ☐ Epilepsy (seizures)
- ☐ Anemia
- ☐ Lung problems
- ☐ Diabetes
- ☐ Kidney problems
- ☐ Heart problems
- ☐ Chronic headaches

YES	**NO**		
☐	☐	12.	Have you ever gotten sick because of exercising in the heat? (cramps, heat exhaustion, heat stroke)
☐	☐	13.	Have you had any other significant illnesses not listed above?
☐	☐	14.	Do you currently have any illness?
☐	☐	15.	Do you know of <u>any other reason</u> why you should not do physical activity?

If you answered **YES** to any of the above questions, please explain in the space below.

16. Please list all medications you are currently taking. Make sure to include over-the-counter medications and supplements.

Drugs/Supplements/Vitamins	Dose	Frequency (daily, 2x/day)

17. Please list all allergies you have.

Substance	Reaction

YES	NO	18. Have you smoked?	If yes, #/day	Age Started	If you quit, at what age?
☐	☐	Cigarettes			
☐	☐	Cigars			
☐	☐	Pipes			

19. Do you have a **family history** of any of the following problems? If yes, note whom in the space.

☐	High blood pressure		☐	Heart disease	
☐	High cholesterol		☐	Kidney disease	
☐	Diabetes		☐	Thyroid disease	

20. Please check the box next to any of the following body parts you have injured in the past and provide details.

☐	Head		☐	Hip		☐	Calf Shin	
☐	Neck		☐	Thigh		☐	Shoulder	
☐	Upper back		☐	Knee		☐	Upper arm	
☐	Lower back		☐	Ankle		☐	Elbow	
☐	Chest		☐	Foot		☐	Hand fingers	

YES	NO		
☐	☐	21.	Have you ever had a stress fracture?
☐	☐	22.	Have you ever had a disc injury in your back?
☐	☐	23.	Has a doctor ever restricted your exercise because of an injury?
☐	☐	24.	Do you currently have any injuries that are bothering you?
☐	☐	25.	Have you been diagnosed with any of the following: hemorrhoids, colitis, diverticulitis, or irritable bowel syndrome

If you answered **YES** to any of questions 21-25, please explain in the space below.

____

____

____

____

26. How would you consider your lifestyle?

☐ Sedentary (no exercise)
☐ Inactive-occasional light activity (walking)
☐ Active-regular light activity and/or occasional vigorous activity (heavy lifting, running)
☐ Heavy work-regular vigorous activity

27. Please list your regular physical activities.

Activity	How often do you do it?	How long do you do it?	How long ago did you start?

ADDITIONAL DETAILS:

APPENDIX C: HEAT ACCLIMATION AND TRAINING HISTORY QUESTIONNAIRE

<u>Heat Acclimation and Training History Questionnaire</u>

1. Have you recently noticed any salt or white particulate on your face or clothing after working out? If so, please provide the date.

2. For the past month, describe your typical weekly **endurance training** routine:

<u>Days/week</u> <u>Duration (miles or time)</u> <u>Intensity (min/mi or speed)</u>

Typically, what time of day do you complete this endurance training?

What percentage of this activity is conducted outdoors?

For how many years have you been endurance training?

3. List any recreational activities or sports that you devote time to on a weekly basis

Activity	**Times per week**	**Session Duration (min)**	**Other Notes (Denote if Intramural Sport, Club Sport, Rec-League, etc.)**

APPENDIX D: PERCEPTUAL SCALES

Fatigue Scale

0	**No Fatigue At All**
1	**Very Small Amount of Fatigue**
2	**Small Amount of Fatigue**
3	**Moderately Fatigued**
4	**Somewhat Fatigued**
5	**Fatigued**
6	
7	**Very Fatigued**
8	
9	**Extremely Fatigued**
10	**Completely Fatigued**

RPE Scale

6	**No Exertion At All**
7	**Extremely Light**
8	
9	**Very Light**
10	
11	**Light**
12	
13	**Somewhat Hard**
14	
15	**Hard (Heavy)**
16	
17	**Very Hard**
18	
19	**Extremely Hard**
20	**Maximal Exertion**

Rate Your Level of Thirst

1 Not Thirsty At All

2

3 A Little Thirsty

4

5 Moderately Thirsty

6

7 Very Thirsty

8

9 Very, Very Thirsty

Thermal Scale

0 Unbearably Cold
0.5
1 Very Cold
1.5
2 Cold
2.5
3 Cool
3.5
4 Comfortable
4.5
5 Warm
5.5
6 Hot
6.5
7 Very Hot
7.5
8 Unbearably Hot