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THERMOREGULATION AND DEHYDRATION IN ATHLETES: RECOMMENDATIONS AND REVIEW

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ABSTRACT

Numerous athletes have experienced some form of heat illness resulting in acute discomfort or distortion of physiological processes. Unfortunately, there are some athletes whose heat illness has caused chronic damage or even death. The purpose of this article is to review physiological mechanisms driving thermoregulation, and to summarize recent research articles on dehydration and performance in athletes. Safety recommendations based on this review include having weigh-ins before and after practice, having athletes monitor the color of their urine, and randomly measuring the urine specific gravity (Usp) of athletes. Availability of water and formulated rehydrating beverages during sporting events is necessary. Monitoring athletes during practices and competitions, and educating athletes on how to properly hydrate should be emphasized. Further research regarding safety standards in extreme environments are needed to ensure the safety, health, and optimal performance of athletes.

Keywords: dehydration, hydration, heat stress, athletes, temperature regulation, environment

INTRODUCTION

The detrimental effects of dehydration can affect athletes of all ages, genders, training status, level of competition, and sport. Numerous athletes have experienced some form of heat illness resulting in acute discomfort or distortion of physiological processes. Unfortunately, there are some athletes whose heat illness has caused chronic damage or even death. For example, in 1997, three collegiate wrestlers died from hyperthermia in an attempt to “cut weight” prior to their competition (1). The purpose of this article is to review physiological mechanisms driving thermoregulation, and to summarize recent research articles on dehydration and performance in athletes.

THERMOREGULATION

The hypothalamus is responsible for maintaining and regulating the core temperature of human beings. The hypothalamus attempts to maintain a core temperature of 37 ± 1 C^{o}; however, numerous factors can cause the body’s core temperature to lower or rise. The body produces and gains heat by the thermic effect of foods, the environment, postural changes, the basal metabolic rate, muscular activity, and hormones (2). To counteract the addition of heat, the body relies on four mechanisms to dissipate heat which include: radiation, conduction, convection, and evaporation.

When the body is placed under thermal heat stress, its primary goal is to ensure that the body's core temperature does not elevate to dangerous levels (2). As mentioned, the body regulates the loss of heat through radiation, conduction, convection, and evaporation; however, as ambient air temperature of the environment increases, the ability of the body to dissipate excess heat through radiation, conduction, and convection decreases dramatically (3). If the environmental temperature exceeds that of the human body, the body will gain additional heat through radiation, conduction, and convection. As the environmental temperature increases, the reliance on evaporation to maintain a low core temperature is increased. Due to the fact that water has a large capacity for vaporization of heat, it is able to help thermoregulate the human body when the ambient air temperature exceeds that of the human body (4). One gram of water evaporated from the surface of the skin removes 2.2 kilojoules of heat from the body (5).

Numerous factors affect how well an individual can thermoregulate their internal body temperature. The factors that contribute to an individual's level of heat tolerance include the individual's training status, age, gender, body composition, and degree of acclimatization (2). However, if the individual is not properly hydrated, their degree of heat tolerance will be impaired. Prior to competition, every athletes' goal should be either to initiate the competition hyperhydrated or at the very least euhydrated to avoid mental and physical impairments (6). Hyperhydration and euhydration require a continual supply of water. Humans receive water through three processes: 1.) 70-80% comes from liquid beverages, 2.) 20-30% comes from food intake, 3.) and a minimal amount (250-350 ml·day^{-1}) is produced through aerobic metabolism (5). The proportion of liquid consumed on daily basis from liquid beverages and solid foods will depend on the amount of fluid consumed, amount of food consumed, and the water content of the food consumed.

WATER AND HYDRATION

For the body to be able to optimally regulate its internal temperature though evaporation, there are numerous criteria that need to be constantly met. An important factor necessary for the mechanism of evaporation to work optimally is adequate water stores in the body. The importance of appropriate water stores in the body to regulate a person's core temperature is dramatically increased when that person is simultaneously engaging in exercise because of the extra metabolic heat produced by the active musculature (7). An individual's hydration status is manipulated by exercise duration, exercise frequency, exercise intensity, environmental factors, and rehydration methods.

Water is the main component of cells, tissues, and organs and is necessary for optimal performance of numerous body systems, as well as life (8). Water has numerous properties and functions necessary for life such. It is used as a building material, a solvent, a reaction medium, a reactant, and a reaction product. It also acts as a carrier as well as a lubricant and shock absorber. Water is also necessary for thermoregulation (5). The distribution of water in the human body can be broken down into intracellular (~66%)

and extracellular fluid (ECF) stores (~33%). ECF stores are primarily located in the blood plasma (~3 L), the transcellular fluid (~1 L), and the interstitial fluid (~10 L) (5). Increased fluid loss through sweating depletes the water reserves of the ECF. The ECF needs to be kept at a constant equilibrium in order to maintain homeostatic properties, such as its pH, temperature, osmotic pressure, and composition (5). Humans, especially athletes who practice and compete in the heat, must have optimal levels of hydration to increase performance and decrease the chance of developing heat related illnesses. People who rely solely on their thirst mechanism to regulate their hydration status will often be in a state of hypohydration. This is referred to as "voluntary dehydration." The sensation of thirst is stimulated by an increase ECF and plasma osmolarity resulting from a decrease in plasma volume.

DEHYDRATION

"Dehydration can be defined as the dynamic loss of body water or the transition from euhydration to hypohydration" (9). When a person loses more water stores than what is gained through intervention, the resulting effect is a state of dehydration. The three types of dehydration include isotonic, hypertonic, and hypotonic dehydration. Isotonic dehydration occurs when an individual's salt and water depletion are equal. Isotonic dehydration results only in the reduction of ECF, and is often associated with diarrhea. Hypertonic dehydration is a result of extreme water loss or insufficient water intake. Hypotonic dehydration occurs when a person replenishes lost fluids with plain water that lacks electrolytes (5).

Dehydration from sweating can occur through exercise or non-exercise methods. Non-exercise methods for inducing dehydration include the use of diuretics, spitting, vomiting, and voluntarily restricting fluids, as well as the routine of sitting in hot environments, such as saunas, to induce sweating. The use of diuretics to induce weight loss has a greater detriment on performance than dehydration from exercise because diuretics exacerbate the increase in mineral loss, impairs neuromuscular function, and accelerates the reduction of plasma volume (2). Most organizations ban the use of diuretics to lose weight prior to sporting events (10). Non-exercise methods for inducing dehydration and sweat loss are very common in weight classification sports, such as mixed martial arts, boxing, power-lifting, and wrestling. Athletes who engage in methods to promote dehydration in order to make a weight class are at increased risk for developing heat illnesses. This is due to the fact that these athletes are engaging in physical activity while in a dehydrated state.

Sweat loss causes a depletion of the body's electrolytes stores. A primary electrolyte lost through sweat is sodium. The need to increase the amount of ingested sodium for optimal performance, as well as to decrease the likelihood of developing varying levels of heat illnesses, is increased for athletes who compete in hot and humid environments, who are heavy sweaters, or who are not acclimated to the environment (2). There are numerous benefits of ingesting a sodium solution for rehydration and subsequent performance.

Ingestion of pure water will dilute the body's plasma volume thus decreasing the individual's thirst drive (11). This is counterproductive for rehydration goals and promotes the likelihood that the athlete will initiate exercise in a less than optimally hydrated state. Research has shown that athletes are usually hypohydrated (12-14). Ingesting a sodium beverage decreases urine production, promoting rehydration (10). It is recommended that athletes consume 25-50% more fluids than are lost in sweat due to the

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fact that the kidneys are continually forming urine (2). Sodium beverages will increase the amount of water absorbed from the small intestine, as well as glucose absorption (15). In addition to the mentioned benefits of consuming a sodium solution, the ingestion of extra sodium in the presence of excessive amounts of water counteracts the possibility of developing hyponatremia, which occurs when a person's serum sodium levels are less than 135 $mmol \cdot L^{-1}$. Hyponatremia causes several physiological disturbances, which include nausea, vomiting, headaches, cramping, seizures, muscle weakness, and can result in death. In fact, acute hyponatremia has nearly a 50% mortality rate (15).

HEAT ILLNESSES

Individuals who are less than optimally hydrated will display the following signs and symptoms: thirst, dry mouth, headache, confusion, dizziness, irritability, lethargy, excessive fatigue, difficulty seeing, and/or cramps (16). If unchecked, a hypohydrated individual can develop some form of heat illness. Common heat illnesses include: heat syncope, heat cramps, heat exhaustion, heatstroke, and hyponatremia (16). Heat syncope is the result of a decrease in blood pressure usually associated with individuals who are under-hydrated. This results in a decrease in plasma volume. Heat syncope occurs in individuals who are unaccustomed to the heat. Heat cramps are painful involuntary muscle contractions. Although the exact mechanism for heat cramps is unknown, heat cramps are associated with excessive losses of water and/or electrolytes, specifically sodium (16).

Heat exhaustion, heatstroke, and hyponatremia are the most serious forms of heat illness. Heat exhaustion, a moderate form of heat illness, occurs when an individual is exercising in the heat and becomes dehydrated. The signs of heat exhaustion include: pale skin, profuse sweating, stomach cramps, nausea, vomiting, diarrhea, headache, persistent muscle cramps, dizziness, loss of coordination (2). During heat exhaustion, the cardiovascular system is unable to meet the needs of the body due to a decreased cardiac output. Mild hyperthermia (where the rectal temperature is under 40 ^{o}C) does not pose a threat to the central nervous system (16). Heatstroke is a life threatening condition that occurs when the core temperature is equivalent to or exceeds 40 ^{o}C. Heatstroke can lead to damage to various tissues, as well as to the central nervous system. Symptoms of heatstroke include: rapid or strong pulse, nausea, vomiting, diarrhea, headache, dizziness, weakness, hypotension, dehydration, and decreased cognition (16). A person who is experiencing heatstroke loses their ability to dissipate heat through sweating. Hyponatremia is the result of low serum sodium levels, usually associated with excessive sweating and consumption of pure, unaltered water.

CIRCULATORY SYSTEM

The circulatory system plays a crucial role in the maintenance and regulation of internal body temperature, especially during exercise. While exercising in the heat, the body's circulatory system must continually supply blood to the active musculature, the heart, and the peripheral tissues in order to dissipate heat. The cardiovascular system's ability to provide adequate blood flow is severely diminished as a person loses water stores through perspiration. As a person loses water stores though perspiration, they face the following negative physiological factors: decreased plasma volume, reduced skin blood flow, reduced stroke volume, decreased cardiac output, decreased blood pressure, decreased venous return, increased heart rate,

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increased core temperature, adverse effect on the psyche of the individual, and decreased serum sodium levels. Marked decreases in efficiency of the circulatory system and thermoregulatory mechanisms of the human body are noted, which leads to increased risk of heat syncope, heat exhaustion, and heat stroke (2, 17-19) These negative factors cause dysfunction of the cardiovascular system, and lead to hyperthermia if left unchecked (20). It is important to note that when a person is exercising while dehydrated, central circulation as well as circulation to active musculature takes priority over circulation to the periphery (2).

Muscle blood flow is maintained over cutaneous blood flow due to functional sympatholysis. Functional sympatholysis is where vasodilation occurs in an arteriole despite an increase in the concentration of vasoconstrictors which are arteriole constrictors (21). Functional sympatholysis occurs due to three possible mechanisms: 1.) pre-synaptic inhibition, 2.) post-synaptic inhibition, and 3.) an abundance of vasodilators. Pre-synaptic inhibition is suggested to result from the vasodilators (which are produced from the endothelium and/ or active skeletal muscle) decreasing the amount of norepinephrine (a known vasoconstrictor) released from sympathetic nerve fibers; whereas, post-synaptic inhibition occurs due to the vasodilators decreasing the sensitivity of norepinephrine's receptors on the arteriole. The third possible mechanism for functional sympatholysis is a result of the vasodilators simply overriding the constrictor effect of the sympathetic nervous system. Functional sympatholysis allows arterioles to dilate despite the presence of vasoconstrictors. Functional sympatholysis only occurs in the active musculature. Since the cutaneous arterioles do not benefit from functional sympatholysis, skin blood flow is impeded over active muscular blood flow. Decreased cutaneous blood flow is elevated while exercising at higher intensities, and while in a state of hypohydration. The reduction in skin blood flow increases the chance of developing heat illnesses and hyperthermia, especially while performing in hot and/or humid climates.

The decreased blood flow to the participant's periphery resulting from dehydration will increase internal temperature. A slight rise in body temperature, as a result of exercise, provides the body with desirable physiological and metabolic capabilities through a phenomenon known as the Bohr Effect (22). However, when the body's core temperature exceeds 40.0 ^{o}C, the person will experience detrimental effects to their performance and their personal well-being (23).

DEHYDRATION AND PERFORMANCE

A two percent loss in body mass due to dehydration has been reported to negatively affect aerobic performance (24-26). Dehydration causes a reduction in plasma volume, which causes negative physiological effects on the circulatory system. These negative physiological effects cause a decrease in the following for a hypohydrated individual: end-diastolic volume, stroke volume, oxygen transport, reduced blood flow to active musculature, VO_2 max, altered substrate utilization during prolonged exercise, and thermoregulation capabilities (27-30). Exercising in the heat causes premature fatigue at a given percent of a person's VO_2 max due to an inability to maintain cardiac output, blood pressure, and muscle blood flow, as well as an increase in blood lactate concentration.

Research has shown hypohydration to increase lactate accumulation in individuals at a lower absolute percentage of their VO_2 max (31-34). Blood lactate forms when pyruvate, an end product of glycolysis, combines with hydrogen ions (H^+) by the enzyme lactate dehydrogenase. An increase in H^+ produces negative effects on exercise performance (35). These negative effects are a direct result of the decrease in pH resulting in the decrease and inhibition glycolytic enzymes, the depletion of phosphorcreatine, changes in myosin ATPase, ionic imbalances of sodium, calcium, potassium, and the disturbance in the T-tubules (36-40). As a result of these intracellular disturbances, the individual must increase effort and motivation to continue exercise at the same work rate, thus increasing their rate of perceived exertion.

RECENT RESEARCH

Hypohydration leads to a reduction in plasma volume, which decreases arterial blood flow to the active musculature, as well as venous return to the heart. This increases the reliance of anaerobic metabolism for exercising individuals. Glycolysis, a component of anaerobic metabolism, increases lactate accumulation when the presence of oxygen at the end of the respiratory chain is insufficient. Lactate accumulation negatively affects performance and the sarcomere of the muscle. Kenefick et al. (41), aimed to determine the effect of hypohydration (four percent reduction in body mass) on lactate threshold in well trained collegiate athletes. The subjects (N=14) consisted of both males (n=8) and females (n=6) from a collegiate ski team. Each subject performed two treadmill sessions to determine their lactate threshold, once in a hypohydrated state, and once in a euhydrated state. The researchers determined that lactate threshold occurred at a lower absolute VO_2, V_E, RER, RPE, and blood lactate concentration. Kenefick et al. (41) findings agree with previous research on the effect of lactate threshold and hypohydration (31-32, 41).

Hydration in Athletes

Research (42) as recently as 2005 has demonstrated that numerous collegiate athletes are not properly educated on how to optimally hydrate for their respected sport's practice and competitions. In 2009, Volpe et al. (43) studied the pre-practice hydration status of National Collegiate Athletic Association (NCAA) division 1 athletes from a variety of sport teams. The study's participants (N=263) included both males (n=138) and females (n=125) ages 18-23 years of age. Hydration status was based on the participant's urine specific gravity (Usp). Based on the participant's Usp, subjects were divided into three groups, which are as follows: "euhydrated" (Usp <1.020), "hypohydrated" (Usp 1.020-1.029), and "significantly hypohydrated" (Usp >1.030). Volpe et. al (43) discovered that 66% of the participants' were in a state of hypohydration prior to practices. Of that 66%, 13% of the athletes were significantly hypohydrated (Usp >1.030), while 53% were hypohydrated (Usp 1.020-1.029). The researchers discovered that hydration status among seniors, juniors, sophomores, and freshmen did not differ from each other. In addition to these findings, Volpe et al. (43) determined that males (47%) had a greater percentage of hypohydration than females (28%).

Research by Finn and Wood (44) was conducted to determine the incidence of pre-game dehydration of athletes competing in various sports in a dry tropical environment. The participants (N=93) competed in the Arafura Games in Australia. The subjects competed in indoor volleyball (n=43), touch football (n=32), or basketball (n=18). The subjects were asked at random one hour prior to their event to provide a urine sample to determine their normally occurring hydration status via Usp. Sixty-eight of the subjects were tested again one hour prior to a second event to determine if testing for dehydration would alter their hydrating methods prior to game situations. Football players had three days between measurements, while volleyball and basketball players had four days between testing. Finn and Wood (44) had four classifications for hydration status which are as follows: Hydrated (Usp <1.010), minimal dehydration (Usp 1.010-1.020), significant dehydration (Usp 1.021-1.030) and serious dehydration (Usp >1.030). In regards to the first assessment, 87% of the tested athletes were at some stage of dehydration. The average Usp of all the samples collected for the first assessment was 1.018 ± 0.0009. The average Usp for the second assessment was 1.020 ± 0.008. Finn and Wood (44) found that most of their subjects were less than optimally hydrated prior to their games. In addition to this, the researchers discovered that testing for dehydration alone is not adequate for ensuring athletes are optimally hydrate, and therefore further intervention is needed to optimally hydrate prior to games.

Meir et al. (45) observed the hydration status of professional English rugby players (N=36) over the first four months of the 2003-2004 season. Ironically, Meir et al. (45) showed that when athletes had three days to rehydrate between strenuous exercise, they were more dehydrated than when they had one or two days to rehydrate. The researchers suggested that when players had more time between games and the next practice, their focus on rehydrating decreased. In 2009, MacLeod and Sunderland (46) studied fluid loss and hydration status of elite female field hockey players (N=16). The researchers determined that the athletes only rehydrated 79-82% of their lost fluids for two subsequent matches. MacLeod and Sunderland (46) noted that players who played less and had more substitutions drank more during the matches; thus, their level of dehydration was less than the players who received more playing times. Therefore, it appears that the starters have an increased chance of developing heat illnesses due to the fact that they are exercising more and rehydrating less.

Wrestling

It has been reported that some wrestlers will lose up to 5-10% of their body weight in order to make a certain weight class (45-47). Severe “weight cuts” often cause wrestlers to be both physically and mentally fatigued (48). Research by Yankanich et al. (49) showed that most wrestlers will cut most of their weight immediately before weigh-ins. Yankanich et al. (49) observed that wrestlers did not regain their weight loss overnight prior to the competition. The methods of rapid weight loss used by wrestlers include: restriction of foods and fluids, strenuous exercise in a hot environment, spitting, vomiting, the use of diuretics, and simply sitting in a hot environment. The resulting state of hypohydration can lead to heat syncope, heat exhaustion, and heat stroke (50).

In 1997, three collegiate wrestlers died from hyperthermia in an attempt to “cut weight” prior to their competition (51). The NCAA developed new rules to prevent wrestlers from making such drastic weight cuts as observed in previous research (45-49). The new rules require wrestlers to weigh in one to two hours prior to their competition in hopes to avoid drastic weight cuts. Although collegiate wrestlers are now required to officially weigh-in one to two hours before competitions, mixed martial art (MMA) athletes typically weigh-in 24 hours in advance. Some professional MMA athletes have self-reported cutting weight as much as 25 pounds in a week through manipulation of their diet, starvation, and fluid restrictions, as well as exercising and/or passive sitting in heated environments.

In 2010, Lingor and Olson (52) observed the fluid and diet patterns associated with weight cycling and changes in body composition throughout a collegiate wrestling season. Despite the new NCAA regulations on cutting weight, the subjects (N=9) lost an average of 5.3% of their total body weight for their first preseason match, and an average of 4.7% of their total body weight for the remaining competitions of the season. One subject loss over seven kilograms of body weight on four separate occasions in a time span less than 72 hours, which placed him at high risk for developing heat illnesses. The subjects in the study used a variety of methods to cut weight, which included a combination of exercise (92%), calorie restriction (92%), and dehydration (77%).

In 2011, Marttinen et al. (53) studied the effects of self-selected mass loss on performance and mood in male collegiate wrestlers (N=16). The subjects were given 10 days to cut the necessary amount of weight to make their weight class. The researchers noted that the wrestlers chose to cut the majority of their weight drastically and immediately prior to their competition. The weight cut significantly affected their mental status by increasing their amount of confusion. Marttinen et al. (53) noted a positive correlation between the amount of weight loss and the amount of tension in the subjects, which is in agreement with other research (54).

American Football

American football players have an elevated chance of becoming dehydrated though practices and games, especially when the athletes are engaging in 2-a-days. Heat illnesses, including heat stroke, have occurred in individuals who participate in football at all levels of competition (54). Research (55) has shown that athletes who participate in football will have increased sweat rates compared to "average-size" athletes who exercise in the same environmental conditions. Football players are at an increased chance of becoming dehydrated, having elevated core temperatures, and developing heat illnesses due to the fact the their equipment covers over 50% of their body, as well as their large amounts of muscle mass, which causes more metabolic heat to be produced. Linemen are at an increased risk for heat complications due to the fact that they have more body fat and have lower body surface area-to-mass ratios thus causing increased heat storage when compared to non-linemen (56). Research conducted by Godek et al. (57) demonstrated that linemen (n=8) sweat rates (SwtR) (2.3 ±0.2 $L \cdot hr^{-1}$) were greater than non-linemen (n=8) SwtR (1.6 ± 0.2 $L \cdot hr^{-1}$) among Division II and professional football players. Godek et al. (57) found a moderate correlation (r = 0.56) between body surface area and mean SwtR.

Godek et al. (57) investigated the core temperature and percentage of dehydration in professional football lineman and backs during preseason practices. All of the subjects' (N=14) core temperatures were assessed via an ingested temperature sensor, while their body dehydration was assessed using weigh-ins, which monitored their fluid intake and fluid excretion (urination). The authors noted that the lineman had the highest core temperatures (38.81 ± 0.48 ^{o}C) compared to the backs' core temperature (38.36 ± 0.44 ^{o}C). These findings agree with previous research conducted by Wailgum et al. (58). Although the lineman had higher internal temperatures than the backs, the backs (-1.3 ± 0.7%) were more dehydrated than the lineman (-0.94 ± 0.6%). The authors determined that the rise in core temperature did not correlate with the level dehydration in the athlete in their particular study. Godek et al. (57) stated that the hydration protocol implemented by the team was successful in maintaining the hydration level of each athlete being studied due to the fact that no participant exceeded a 2.5% reduction in body weight. This suggests that the rise in internal body temperature is the result of the intensity of the exercise, the player's percent

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body fat, muscle content, body surface area-to-mass ratio, and equipment. Football programs, such as high school programs, that do not have the resources or knowledge capable of rehydrating the athletes as optimally as a well-funded professional team would be expected to have increased levels of dehydration, and potentially increased core temperatures due to the fact that hypohydration is linked with elevated core temperatures. Research (59) has shown that football players of the same mass will have the same effect on SwtR regardless of level of competition.

REHYDRATION RECOMMENDATIONS

Sodium ingestion is known to increase hydration through decreased urine formation, as well as an increased thirst drive (42). Research (52) has shown that the amount of sodium concentration will determine the amount of fluid retention. Consuming a glucose-electrolyte solution has been proven to restore plasma volume better than pure-unaltered water (42). However, rehydration through consumption of a sodium or a glucose-electrolyte beverage requires time in previously dehydrated subjects. Research conducted by Valiente et al. (47) employed a randomized crossover study to study the effects of the consumption of plain water, a glucose-electrolyte beverage, or a commercially formulated water supplement on rehydration on collegiate wrestlers who had one hour to rehydrate from a 3% body weight reduction through water loss. The authors concluded that none of the fluids restored body weight back to normal in the one hour time period. Research (31, 52, 56, 59) states it takes approximately two to four hours to restore water stores following acute hydration when using a carbohydrate-electrolyte beverage.

CONCLUSIONS

Hydration is extremely important in athletics, and should be a priority in safety, training, and performance of athletes. Safety recommendations include having weigh-ins before and after practice, and practicing indoors or at the coolest, less-humid time of the day. Acclimation of athletes should be a priority, and should commence in the appropriate environmental conditions as the seasons progress. The environment that the athletes will perform in should be the focus of acclimation efforts.

Monitoring urine and associated variables should be considered. Urinalysis is a relatively inexpensive as well as a safe, easy method to ensure optimal performance, health and safety of athletes. Having athletes monitor the color of their urine and randomly measuring the Usp of athletes can be accomplished with relative ease, and can have important considerations in optimizing performance.

Other safety measures should include having water and formulated rehydrating beverages readily accessible during sporting events. Monitoring all athletes during practices and competitions (especially those prone to heat illnesses i.e. lineman) and educating athletes on how to properly hydrate are important preventative methods. Suggestions to improve nutrition and encouraging athletes to carry fluids with them at all times are methods that are recommended. Education and a focus on monitoring hydration and fluid replacement will aid in reminding athletes to rehydrate, which may lead to increases in performance. Further research regarding safety standards in extreme environments are needed to ensure the safety, health, and optimal performance of athletes.

REFERENCES

1. Oppliger RA, Utter AC, Scott JR, Dick RW, Klossner D. NCAA rule change improves weight loss among national championship wrestlers.. Med Sci Sports Exerc 2006;38(5):963-970. Available from: http://www.nlm.nih.gov/medlineplus/bodyweight.html PubMed PMID: 16672852. doi:10.1249/01.mss.0000218143.69719.b4 [Google Scholar]

2. McArdle WD, Katch FI, Katch VL. Exercise and thermal stress. Exercise physiology: Nutrition, energy, and human performance. 7th rev. ed. Philadelphia: Lippincott Williams & Wilkins; 2010.[Google Scholar]

3. Leiper JB, Broad NP, Maughan RJ. The effect of intermittent high-intensity exercise on gastric emptying in man. Med Sci Sport Exer 2001;33:1270-8. [Google Scholar]

4. Montain SJ, Latzka WA, Sawka MN. Fluid replacement recommendations for training in hot weather.. Mil Med 1999;164(7):502-508. Available from: http://www.nlm.nih.gov/medlineplus/drugabuse.html PubMed PMID: 10414066. [Google Scholar]

5. Jéquier E, Constant F. Water as an essential nutrient: the physiological basis of hydration.. Eur J Clin Nutr 2009 Sep;64(2):115-123. Available from: http://www.nlm.nih.gov/medlineplus/dehydration.html PubMed PMID: 19724292. doi: 10.1038/ejcn.2009.111. [Google Scholar]

6. Robergs RA, Ghiasv F, Parker D. Biochemistry of exercise induced metabolic acidosis. Amer J Physio Reg Integra Compara Physiol 2004;287:502-16.[Google Scholar]

7. González-Alonso J, Mora-Rodríguez R, Below PR, Coyle EF. Dehydration markedly impairs cardiovascular function in hyperthermic endurance athletes during exercise.. J Appl Physiol1997;82(4):1229-1236. Available from: http://jap.physiology.org/cgi/pmidlookup?view=long&pmid=9104860 PubMed PMID: 9104860.[Google Scholar]

8. Sawka MN. Physiological consequence of hypohydration: Exercise performance and thermoregulation. Med Sci Sport Exerc 1992;24(6):657-70. [Google Scholar]

9. Schoffstall JE, Branch DJ, Leutholtz BC, Swain DP. Effects of dehydration and rehydration non the one-repetition maximum bench press of weight-trained males. J Strength Cond Res 2001;15:102-8. [Google Scholar]

10. Nose H, Mack GW, Shi XR, Nadel ER. Role of osmolality and plasma volume during rehydration in humans.. J Appl Physiol 1988;65(1):325-331. Available from: http://toxnet.nlm.nih.gov/cgi-bin/sis/search/r?dbs+hsdb:@term+@rn+7440-23-5 PubMed PMID: 3403476. [Google Scholar]

11. Mnatzakanian PA, Vaccaro, P. Effects of 4% dehydration and rehydration on hematological profiles, urinary profiles, and muscular profiles and muscular endurance of college wrestlers. Med Sci Sports Exerc 1982;14:117. [Google Scholar]

12. Morgan W. Psychological effect of weight reduction in the college wrestler. Med Sci Sport Exer 1970;2:24-7. [Google Scholar]

13. Nichols PE, Jonnalagadda SS, Rosenbloom CA, Trinkaus M. Knowledge, attitudes, and behaviors regarding hydration and fluid replacement of collegiate athletes.. Int J Sport Nutr Exerc Metab 2005;15(5):515-527. Available from: http://www.scholaruniverse.com/ncbi-linkout?id=16327032 PubMed PMID: 16327032. [Google Scholar]

14. Mueller FO. Catastrophic sports injuries: who is at risk?. Curr Sports Med Rep 2003;2(2):57-58. Available from: http://www.scholaruniverse.com/ncbi-linkout?id=12831659 PubMed PMID: 12831659. [Google Scholar]

15. Ivy JL. Nutrition before, during, and after exercise. In: Antonio J, Kalman D, Stout JR, Greenwood M, Willoughby DS, Haff GG, editors. Essentials of sports nutrition and supplements. Totowa (NJ: Human Press; 2008. [Google Scholar]

16. Prentice WE. Environmental considerations. Principles of athletic training: A competency-based approach. 14th rev. ed. New York: The McGraw-Hill Companies, Inc; 2011. [Google Scholar]

17. Binkley H, Beckett J, Casa D. National athletic trainers' association position statement: Exertional heat illness. J Athl Train 2002;37:329. [Google Scholar]

18. Armstrong LE, Soto JA, Hacker FT, Casa DJ, Kavouras SA, Maresh CM. Urinary indices during dehydration, exercise, and rehydration. Int J Sport Nutr 1998;8(4):345-55. Available from: http://www.scholaruniverse.com/ncbi-linkout?id=9841955 PubMed PMID: 9841955. [Google Scholar]

19. Oppliger RA, Steen SA, Scott JR. Weight loss practices of college wrestlers. Int J Sport Nutri Exerc Metab 2003;12:29-46. [Google Scholar]

20. González-Alonso J, Calbert JA, Nielson B. Metabolic and thermodynamic responses to dehydration-induced reductions in muscle blood flow in exercising humans. J Phys 1999;520:577-89. Available from: http://www.jphysiol.org/cgi/pmidlookup?view=long&pmid=10523424 PubMed PMID: 10523424. [Google Scholar]

21. Buckwalter JB, Clifford PS. The paradox of sympathetic vasoconstriction in exercising skeletal muscle. Exer Sport Sci Rev 2001;29(4):159-63.[Google Scholar]

22. Moss RI. Another look at sudden death and exertional hyperthermia. Athl Ther Today 2002;7(3):44.[Google Scholar]

23. Cheuvront SN, Carter R, Sawka MN. Fluid balance and endurance exercise performance. Cur Sport Med Rep 2003;2:202-208. [Google Scholar]

24. Sawka MN, Burke LM, Eichner ER, Maughan RJ, Montain SJ, Stachenfield NS. Exercise and fluid replacement. Med Sci Sport Exer 2007;39:377-90.[Google Scholar]

25. Yoshida T, Takanishi T, Nakai S, Yorimoto A, Morimoto T. The critical level of water deficit causing a decrease in human exercise performance: a practical field study.. Eur J Appl Physiol 2002 Jul;87(6):529-534. Available from: http://www.nlm.nih.gov/medlineplus/dehydration.html PubMed PMID: 12355192. doi: 10.1007/s00421-002-0651-z. [Google Scholar]

26. González-Alonso J, Calbert JA, Nielson B. Muscle blood flow is reduced with dehydration during prolonged exercise in humans. J Phys 1998;513:895-905. Available from: http://www.jphysiol.org/cgi/pmidlookup?view=long&pmid=9824726 PubMed PMID: 9824726.[Google Scholar]

27. Goodman JM, Liu PP, Green HJ. Left ventricular adaptations following short-term endurance training. J Appli Physiol 2005;98(98):454. [Google Scholar]

28. Hagberg JM, Goldberg AP, Lakatta L, O'Conner FC, Becker LC, Lakatta EG. Expanded blood volumes contribute to increased cardiovascular performance of endurance-trained older men. J Appl Physiol 1998;85(2):484-489. Available

from: http://jap.physiology.org/cgi/pmidlookup?view=long&pmid=9688724 PubMed PMID: 9688724.[Google Scholar]

29. Gorostiaga EM, Asiáin X, Izquierdo M, Postigo A, Aguado R, Alonso JM, et al. Vertical jump performance and blood ammonia and lactate levels during typical training sessions in elite 400-m runners.. J Strength Cond Res 2010;24(4):1138-1149. Available from: http://toxnet.nlm.nih.gov/cgi-bin/sis/search/r?dbs+hsdb:@term+@rn+7664-41-7 PubMed PMID: 20300013. doi: 10.1519/JSC.0b013e3181cf769f. [Google Scholar]

30. England P, Powers SK, Dood S, Callender T, Brooks E. The effect of acute thermal dehydration on blood lactate accumulation during incremental exercise. J Sport Sci 1984;2:105-11. [Google Scholar]

31. Hargreaves M, Dillo P, Angus D, Febbraio M. Effect of fluid ingestion on muscle metabolism during prolonged exercise.. J Appl Physiol 1996;80(1):363-366. Available from: http://toxnet.nlm.nih.gov/cgi-bin/sis/search/r?dbs+hsdb:@term+@rn+50-21-5 PubMed PMID: 8847329. [Google Scholar]

32. Shirreffs SM, Aragon-Vargas LF, Keil M, Love TD, Phillips S. Rehydration after exercise in the heat: a comparison of 4 commonly used drinks.. Int J Sport Nutr Exerc Metab 2007;17(3):244-258. Available from: http://www.scholaruniverse.com/ncbi-linkout?id=17693686 PubMed PMID: 17693686. [Google Scholar]

33. Moquin A, Mazzeo RS. Effect of mild dehydration on the lactate threshold in women.. Med Sci Sports Exerc 2000;32(2):396-402. Available from: http://toxnet.nlm.nih.gov/cgi-bin/sis/search/r?dbs+hsdb:@term+@rn+50-21-5 PubMed PMID: 10694123. [Google Scholar]

34. Robergs RA, Keteyian SJ. Pulmonary adaptations to exercise. Fundamentals of exercise physiology for fitness, exercise testing and prescription. 8th rev. ed. Philadelphia: Lippincott Williams & Wilkins; 2002.[Google Scholar]

35. Danforth WH, Helmreich E. Regulation of glycolysis in muscle. The conversion of phosphorlyase b to phosphorlyase a in frog muscle. J Bio Chem 1964;239:3133-8. [Google Scholar]

36. Gaitanos G, Williams L, Boobis L, Brooks S. Human muscle metabolism during intermittent maximal exercise. J Appl Phys 1993;75(2):712-9. Available from: http://toxnet.nlm.nih.gov/cgi-bin/sis/search/r?dbs+hsdb:@term+@rn+50-21-5 PubMed PMID: 8226473. [Google Scholar]

37. Hogan MC, Gladden LB, Kurdak SS, Poole DC. Increased [lactate] in working dog muscle reduces tension development independent of pH.. Med Sci Sports Exerc 1995;27(3):371-377. Available from: http://www.scholaruniverse.com/ncbi-linkout?id=7752864 PubMed PMID: 7752864. [Google Scholar]

38. Nakamaru Y, Schwartz A. The influence of hydrogen ion concentration on calcium binding and release by skeletal muscle sarcoplasmic reticulum.. J Gen Physiol 1972;59(1):22-32. Available from: http://jgp.rupress.org/cgi/pmidlookup?view=long&pmid=5007263 PubMed PMID: 5007263.[Google Scholar]

39. Renaud J, Allard MY, Mainwood GW. Is change intracellular pH during fatigue large enough to be the main cause of fatigue? Canadian. J Physiol Pharmac 1986;64:764-7. [Google Scholar]

40. Lang F, Waldegger S. Regulating cell volume. Amer Scientists 1997;85:456-63. [Google Scholar]

41. Kenefick RW, Mahood NV, Mattern CO, Kertzer R, Quinn TJ. Hypohydration adversely affects lactate threshold in endurance athletes.. J Strength Cond Res 2002;16(1):38-43. Available from: http://www.scholaruniverse.com/ncbi-linkout?id=11834105 PubMed PMID: 11834105. [Google Scholar]

42. Godek SF, Bartolozzi AR, Burkholder R, Sugarman E, Dorshimer G. Core temperature and percentage of dehydration in professional football lineman and backs during preseason practices. J Athl Train 2006;41(1):8-17. [Google Scholar]

43. Volpe SL, Poule KA, Bland EG. Estimation of prepractice hydration status of National Collegiate Athletic Association Division I athletes.. J Athl Train 2009;44(6):624-629. Available from: http://europepmc.org/abstract/MED/19911089 PubMed PMID: 19911089. doi: 10.4085/1062-6050-44.6.624. [Google Scholar]

44. Finn JP, Wood RJ. Incidence of pre-game dehydration in athletes competing at an international event in dry tropical conditions. Nutrit & Diet 2004;61:221-25.[Google Scholar]

45. Meir RA, Brooks LO, Rogerson S. What do changes in prematch vs. postmatch, 1, 2, and 3 days postmatch body weight tell us about fluid status in English Premiership rugby union players?. J Strength Cond Res 2011;25(8):2337-2343. Available from: http://www.scholaruniverse.com/ncbi-linkout?id=21734605 PubMed PMID: 21734605. doi: 10.1519/JSC.0b013e3181f15945. [Google Scholar]

46. MacLeod H, Sunderland C. Fluid balance and hydration habits of elite female field hockey players during consecutive international matches.. J Strength Cond Res 2009;23(4):1245-1251. Available from: http://www.scholaruniverse.com/ncbi-linkout?id=19528861 PubMed PMID: 19528861. doi: 10.1519/JSC.0b013e318192b77a. [Google Scholar]

47. Valiente J. S., Utter, A.C., Quindry, J.C., and Nieman, D.C. (2009). Effects of commercially formulated water on the hydration status of dehydrated collegiate wrestlers. J Strength Cond Res 2009;23:2210-6. [Google Scholar]

48. Houston ME, Marrin DA, Green HJ, Thompson JA. The effect of rapid weight loss on physiological functions in wrestlers. Physician an Sport Med 1981;9:73-8.[Google Scholar]

49. Yankanich J, Kenney WL, Flack SJ, Kraemer WJ. Precompetition weight loss and changes in vascular fluid volume in NCAA =Division I college wrestlers. J Strength Cond Res 1998;12:138-45. [Google Scholar]

50. Klinzing JE, Karpowicz W. The effects of rapid weight loss and rehydration on wrestling performance test. J Sport Med Phys Fitness 1986;26:149-56. [Google Scholar]

51. Godek SF, Bartolozzi AR, Godek JJ. Sweat rate and fluid turnover in American football players compared with runners in a hot and humid environment. Brit J Sport Med 2005;39(4):205-11. [Google Scholar]

52. Lingor RJ, Olson A. Fluid and diet patterns associated with weight cycling and changes in body composition assessed by continuous monitoring throughout a college wrestling season.. J Strength Cond Res 2010;24(7):1763-1772. Available from:

http://www.nlm.nih.gov/medlineplus/bodyweight.html PubMed PMID: 20555285. doi: 10.1519/JSC.0b013e3181db22fb. [Google Scholar]

53. Marttinen RHJ, Judelson DA, Wiersma LD, Coburn JW. Effects of self-selected mass loss on performance and mood in collegiate wrestlers.. J Strength Cond Res 2011;25(4):1010-1015. Available from: http://www.nlm.nih.gov/medlineplus/bodyweight.html PubMed PMID: 21399531. doi: 10.1519/JSC.0b013e318207ed3f. [Google Scholar]

54. Wemple RD, Morocco TS, Mack GW. Influence of sodium replacement on fluid ingestion following exercise-induced dehydration. Int J Sport Nutr 1997;7(2):104-116. Available from: http://toxnet.nlm.nih.gov/cgi-bin/sis/search/r?dbs+hsdb:@term+@rn+7647-14-5 PubMed PMID: 9189781. [Google Scholar]

55. Ribisl PM. Rapid weight reduction in wrestling. Amer J Sport Med 1975;3:55-7. [Google Scholar]

56. Yoshioka Y, Umeda T, Nakaji S, Kojima A, Tanabe M, Mochida N, et al. Gender differences in the psychological response to weight reduction in judoists. Int J Sport Nutri Exerc;16:187-98. [Google Scholar]

57. Godek SF, Bartolozzi AR, Peduzzi C, Heinrichs S, Garvin E, Sugarman E. Fluid consumption and sweating in national football league and collegiate football players with different access to fluids during practice. J Athl Train 2010;45(2):128-35. Available from: http://europepmc.org/abstract/MED/20210616 PubMed PMID: 20210616. doi: 10.4085/1062-6050-45.2.128. [Google Scholar]

58. Wailgum TD, Paolone AM. Heat tolerance of college football lineman and backs. Physician Sport Med 1984;12(5):81-6. [Google Scholar]

59. Maughan RJ, Leiper JB. Sodium intake and post-exercise rehydration in man.. Eur J Appl Physiol Occup Physiol 1995;71(4):311-319. Available from: http://toxnet.nlm.nih.gov/cgi-bin/sis/search/r?dbs+hsdb:@term+@rn+7440-23-5 PubMed PMID: 8549573. [Google Scholar]