

Advances in Research on the Effects of Hydration Status on Exercise Performance and Health

Tengxu Cai^{1,a}, Jixue Yuan^{1,b}, Yifei Li^{1,c}, Shuya Fan^{2,d}

¹College of Physical Education, Yunnan Normal University, Kunming, China;

²Pan-Asian Business School, Yunnan Normal University, Kunming, China.

^acaitengxu@126.com, ^bchaoxuejiang@163.com, ^c2436188582@qq.com, ^dfanshuya0725@163.com

Abstract. The importance of hydration status as an important influence on athletic performance and health status has received increasing attention from athletes and coaches. This paper presents a detailed review of the factors affecting hydration status and the effects of hydration imbalance on athletic performance and health. Hydration imbalance was found to mainly affect athletes' aerobic endurance, although the mechanism is not clear, while the effect on anaerobic strength is debated; the main health effects of hydration imbalance are hyponatremia, cerebral infarction, body metabolism, cognitive function, immune function, cardiovascular health, gastrointestinal health, oral health, and urinary tract health.

Keywords: hydration status; exercise performance; exercise health; Sports Tonic Liquid.

1. Introduction

Water is the most important nutritional element in the body and plays an important role in dissolving and regulating cell volume in the body cycle, as well as in regulating body temperature and bodily functions. The importance of water implies the need to maintain a good balance of water in the body, i.e., the balance between water intake and water output of the body. According to the relationship between water intake and water output, there are three states: Hydration, Hypohydration, and Hyperhydration, Euhydration. The body maintains a balance between water intake and water output, which is the normal hydration state; water intake is greater than water output, which is the high hydration state; and water intake is less than water output, which is the low hydration state. After exercise, it is called "voluntary dehydration" when an athlete is unable to compensate for water loss through water intake, but this term has since been changed to "involuntary dehydration" to express the reluctance of the dehydrated individual to hydrate even though he or she has sufficient water to do so. However, it is important to note that dehydration and hypohydration are closely related, but they are not the same. Dehydration is a process of acute water loss, i.e., dehydration is the loss of water from the body, and hypohydration is the result of water loss[[[Summary and outlook.[J]. European journal of clinical nutrition,2003,57 Suppl 2.]]. Similarly, the same is true for the normally hydrated and highly hydrated states, all three of which are outcomes rather than processes.

In sports training and athletic competition, hydration status has been recognized as a factor affecting athletic performance[1]. Normal hydration is the optimal state of water content in the human body, other than that, both low hydration and high hydration can cause some damage to human health and sports performance[2]. Research has proven that water intake and output do not have to be exactly equal to maintain optimal body function, i.e. the optimal stable range of water intake and output is $\pm 1\%$ [3]. At the same time, there is a clear "threshold" for dehydration when an athlete starts training in a normal hydrated state, i.e., when dehydration reaches 2% of body mass, the body will start to suffer certain impairments, such as cardiovascular strain, impaired cognitive function, physical function. Although this threshold has become the recommended threshold for fluid intake to stabilize normal hydration, according to the published articles to date, this threshold has shown varying degrees of individual variation in different athletes. It is then particularly necessary for coaches and related practitioners to properly understand the effects of

different hydration states on athletes' health and performance in order to develop individualized hydration strategies for athletes.

2. Effect of Hydration Status on Exercise Performance

2.1 Endurance Performance

The effect of dehydration on endurance performance during endurance sports is usually studied by inducing some degree of dehydration in the athlete's body during the start of the exercise or by the development of dehydration during the exercise. In a detailed review of the effects of dehydration on performance, Cheuvront concluded that dehydration of 2%-7% of body weight during exercise reduces endurance performance. However, the magnitude of the reduction in endurance performance was greater for different testing methods, ranging from 7% to 60%. It should be noted that under cool conditions, when athletes train for less than 90 minutes, dehydration levels below 2% of body weight have no effect on endurance performance, but endurance performance is impaired when exercise lasts longer than 90 minutes. When exercising in hot environments, endurance performance is impaired when water loss reaches 2% of body weight. Of course, in the absence of no or little rehydration[4]. When combined with heat stress, the decline in endurance performance is further exacerbated[5]. In conclusion, as per the current research, dehydration affects athletes, making them more difficult to tolerate in hot environments and is the main cause of early onset fatigue in athletes. Hypohydration limits or impairs endurance performance through multiple mechanisms, with underhydration elevating core temperature, skeletal muscle glycogen use, fatigue/discomfort, respiratory alkalosis, afferent feedback, skeletal muscle motor unit recruitment and brain function. Although the exact mechanism of action is a topic of debate in current research, one of the more widely accepted claims is that the presence of both absolute and relative hypovolemia is a prerequisite for hypohydration to impair aerobic capacity. Both types of hypovolemia increase cardiovascular stress, so it is thought that challenges in blood pressure regulation may often be the "key" mechanism by which hydration impairs aerobic performance. Although hypohydration reduces endurance performance, hyperhydration shows no significant endurance improvement in endurance sports and even increases the risk of hyponatremia.

In summary, being in a hypohydrated state decreases the endurance performance of the athlete, and the degree of endurance performance increases as the degree of dehydration increases. In particular, in a hot environment, the effects of dehydration and heat stress are superimposed on each other to further reduce the athletes' endurance performance. There are a number of mechanisms by which hydration imbalance causes a decrease in endurance performance, and even more so, they interact with each other, so the exact mechanisms are not yet clear and need to be studied in depth. In addition, the effect of endurance performance in a hyperhydrated state remains to be determined.

2.2 Strength Performance

Based on the current literature on the effect of needle hypohydration on strength, a portion of researchers have indicated that hypohydration has an effect on reducing strength. The loss of water to 7% of body weight does not produce a reduction in maximum isometric contraction. If the dehydration is due to chronic inadequate intake of food and fluids, the likelihood of reduced strength will be greater[6]. The mechanism may be that insufficient body water has an effect on electromyography (EMG) and muscle membrane excitability[7]. But it is more likely that perhaps the loss of body water will have a detrimental effect on certain components of the neuromuscular system. However, some studies have shown different results for anaerobic sports such as sprinting and jumping. Firstly, the effect of low hydration status on the performance of 50m and 200m sprinters was studied for different types of sprinting. The study induced a change in hydration status by administering diuretics to the athletes, resulting in a 1.7kg reduction in water, but ultimately

found no significant change in either performance or finish time[8]. Similarly, when athletes were tested at 3*30m, it was still found that low hydration status did not have a significant effect on. However, there are conflicting findings for jumping-type exercise. Jumping performance has often been studied as a means of assessing the effect of body water loss on muscle strength, with levels of weight loss ranging from 1% to 3% in most studies, although studies have shown 6% weight loss when energy restriction is combined with dehydration, and most of these studies have not found a significant effect of weight loss on jumping ability or height. However, it has been suggested that hypohydration may lead to improved jumping ability, but it has also been suggested that hypohydration does not affect jumping ability, perhaps because the decrease in muscle strength is offset by the decrease in body weight due to the hypohydrated state.

In summary, the results of the tests were not the same between different types of programs, or even contradictory between the same types of programs. Combining the results of the current study, it is not possible to determine whether hypohydration or dehydration has an effect on muscle strength, although such conflicting results may be due to exercise patterns, body weight lost, and recovery time. As dehydration occurs, body mass decreases, which in turn allows the athlete to exercise with less "weight", which can promote improved performance, which may mask any potential negative effects of hypohydration on strength performance. This means that if hypohydration does not reduce muscle strength, then it is possible that hypohydration will improve strength performance.

3. Health Effects of Hydration Status

3.1 Hyponatremia

Hyponatremia is defined as a blood sodium concentration below 135 mmol/L, which may have some health consequences. First described EAH (exercise-associated hyponatremia) in the scientific literature as "water intoxication". The incidence of EAH increases with the distance of the race and its onset does not vary from nausea, vomiting and headache to altered mental status, seizures or even death. This condition often occurs during prolonged exercise and is caused by excessive intake of hypotonic fluids and loss of solutes (sodium and potassium) beyond the replacement rate or a combination of both, and even sometimes in the absence of excessive hydration, resulting in EAH[9]. Although all of these mechanisms are plausible in the development of EAH, the evidence suggests that excessive systemic water intake, as opposed to sodium replacement, is the primary cause of EAH[10]. Excessive intake of hypotonic fluids leads to weight gain during exercise, and the rate of water intake is higher than the rate of sweating, urination and respiratory losses, resulting in lower plasma sodium concentrations and consequently the development of EAH. According to Almond's investigation, a weight gain of 3 kg and 4.9 kg due to hydration during marathon exercise resulted in a 30% and 70% increase in the probability of developing hyponatremia, respectively, and in this study, water intake greater than 3L was a significant predictor of the development of EAH[11]. This also demonstrates that there is a significant negative correlation between post-competition serum sodium concentration and weight change in endurance events. In addition to this, inappropriate secretion of arginine pressor (AVP) in the presence of excessive intake of hypotonic fluids can accelerate the development of EAH[12].

3.2 Cardiovascular Health

There is a relationship between hydration status and cardiovascular health, and although it is not clear whether this relationship is causal or correlated, there is a need to understand the different symptoms and potential problems that can occur in different states of hydration. Sympathetic activation during exercise is higher in the low hydration state, as this allows for a significant increase in vascular resistance and plasma, as well as a substantial increase in heart rate, which in turn compensates for the reduction in blood volume to maintain the required supply of skeletal muscle, means that the probability of hypertension during exercise in a low hydration state is greatly

increased[13].Furthermore, studies have shown that hypohydration significantly affects adhesion, causing normal erythrocytes to exhibit adhesion properties similar to those of sickle cells and vice versa[14].The increased blood concentration and red blood cells are precisely the risk factors for thrombosis, which means that thromboembolism may be exacerbated in the hypohydrated state[15].In addition, it has also been shown that not only does the acute stress response of the cardiovascular system decrease but also promotes the development of atherosclerosis-related predisposing factors in a state of low hydration.Although there is a certain probability of serious cardiovascular disease in athletes in a hypohydrated state, a hyperhydrated state can improve cardiovascular regulation[16].

In some studies, it has been suggested that increased hydration status via glycerol decreases exercise heart rate, increases cardiac filling and output per beat, and better maintains plasma volume. Moreover, increased hydration may lead to a decrease in sympathetic-estradiol ratio, reduce the drive for fluid retention in the sympathetic nervous system, and increase parasympathetic activation to remove water, thereby decreasing the probability of hypertension and reducing symptoms after the onset of hypertension. More importantly, increased hydration greatly reduces the probability of coronary heart disease and the risk of fatalities in both men and women.

3.3 Cognitive Function

Recent studies have shown that cognitive function is impaired by body dehydration reaching 1% of body mass, not 2%. Problems with cognitive function that may occur in a hypohydrated state caused by dehydration include poor concentration, increased reaction time, short-term memory impairment, and emotional anxiety[17].Experiments have been published on the effects of dehydration on cognitive function, in which the methods often used are heat exposure, exercise, fluid restriction, or a combination of all three in combination with each other. It was found that hypohydration through heat exposure or exercise resulted in significant decreases in alertness, attention, visual tracking ability, and short-term memory, and increased fatigue, headache, and reaction time[18].Of course the extent of this cognitive decline may also depend on the environment and the individual's level of health,Also, the degree of cognitive impairment increases with increasing dehydration.The mechanisms by which deficits in cognitive function arise in the hypohydrated state are not well understood at this stage of research. It is important to understand that many substrates and neurotransmitters are affected by antidiuretic hormone and angiotensin II when the body is in a state of hypohydration,This is the key hormone for maintaining the fluid balance.Thus, different neurotransmitters exhibit different effects following dehydration that may trigger different cognitive dysfunctions. The mechanism proposed by researchers in the field for the deficits in cognitive function during the hypohydrated state may be the elevation of cortisol, which is normally released during the stress response.Because higher cortisol reduces memory function and processing speed,which can lead to memory-related cognitive deficits.5-Hydroxytryptaminergic and dopaminergic systems alter blood-brain barrier permeability and, if sustained, can lead to central nervous system dysfunction[19].It has also been shown that d-aminobutyric acid and glutamate levels increase during chronic dehydration, affecting inhibitory and excitatory activity in the brain.

3.4 Immunologic Function

Changes in immune function after exercise are associated with hydration statusand circulating stress hormone levels[20].Compared to exercise in a normally hydrated state, exercise in a dehydrated state leads to increased heat stress, which in turn induces an excessive stress hormone response and promotes elevated stress hormone concentrations,thus having an impact on immune function.

Studies have shown that weight loss through 24-hour fluid restriction not only impairs athletes' performance, but also their immune cell count and function[21].Weight loss through dehydration, especially in female athletes, can cause a suppressive effect on immune function after the athlete

starts exercising. And because the redistribution of immune cells during exercise is influenced by cardiac output and catecholamine response[22]. Thus, physical activity can also lead to disturbances in the number and function of leukocytes, but this depends on the intensity and duration of the exercise, as well as the release of stress hormones[23]. Nielsen et al. found a significant increase in leukocyte concentration and immune cell activity after forceful exercise, returning to resting values after two hours. This means that changes in immune function do not last very long after a single bout of exhaustive exercise. However, continuous changes in immune function from exercise can make athletes much more likely to become ill during exercise. Likewise, Shade says that frequent use of dehydration to lose weight can kill cellular activity, which in turn has a long-term negative impact on immune function. This means that strenuous exercise under different dehydration conditions can amplify physiological changes that can negatively affect performance and enhance post-exercise immunosuppression[24]. However, according to Mitchell et al. dehydration does not affect immune cell numbers or function, and in particular the distribution of leukocytes, lymphocytes or lymphocyte subsets is not affected by hydration status.

3.5 Others

In addition to the above-mentioned frequent or easy to occur hydration imbalance on the health of athletes, the health effects of hydration imbalance include gastrointestinal health, oral health, urinary tract health, cerebral infarction, body metabolism, connective tissue and obesity.

4. Summary

Athlete hydration imbalances can seriously interfere with training effects and performance, and left untreated can seriously affect the health status of the athlete and even threaten life safety - especially in endurance athletes. In addition, when an athlete is found to have been in a chronic state of hydration imbalance, a detailed examination of the athlete's health needs to be a priority to avoid unavoidable athletic and/or health injuries.

References

- [1] Coyle Edward F. Fluid and fuel intake during exercise.[J]. Journal of sports sciences,2004,22(1).
- [2] Montain S J,Sawka M N,Wenger C B. Hyponatremia associated with exercise: risk factors and pathogenesis.[J]. Exercise and sport sciences reviews,2001,29(3).
- [3] Influence of Hydration on Physiological Function and Performance During Trail Running in the Heat[J]. Journal of Athletic Training,2010,45(2).
- [4] James L J, Funnell M P, James R M, et al. Does hypohydration really impair endurance performance? Methodological considerations for interpreting hydration research[J]. Sports Medicine, 2019, 49(2): 103-114.
- [5] Nybo L, Jensen T, Nielsen B, et al. Effects of marked hyperthermia with and without dehydration on V o 2 kinetics during intense exercise[J]. Journal of Applied Physiology, 2001, 90(3): 1057-1064.
- [6] Bosco J S, Terjung R L, Greenleaf J E. Effects of progressive hypohydration on maximal isometric muscular strength.[J]. The Journal of sports medicine and physical fitness,1968,8(2).
- [7] Costill D L, Coté R, Fink W. Muscle water and electrolytes following varied levels of dehydration in man.[J]. Journal of applied physiology,1976,40(1).
- [8] Watson Greig, Judelson Daniel A, Armstrong Lawrence E, Yeargin Susan W, Casa Douglas J, Maresh Carl M. Influence of diuretic-induced dehydration on competitive sprint and power performance.[J]. Medicine and science in sports and exercise,2005,37(7).
- [9] Riebl Shaun K, Davy Brenda M. The Hydration Equation: Update on Water Balance and Cognitive Performance.[J]. ACSM's health & fitness journal,2013,17(6).
- [10] Krabak Brian J, Waite Brandee, Lipman Grant. Injury and illnesses prevention for ultramarathoners.[J]. Current sports medicine reports,2013,12(3).

- [11] Almond Christopher S D,Shin Andrew Y,Fortescue Elizabeth B,Mannix Rebekah C,Wypij David,Binstadt Bryce A,Duncan Christine N,Olson David P,Salerno Ann E,Newburger Jane W,Greenes David S. Hyponatremia among runners in the Boston Marathon.[J]. The New England journal of medicine,2005,352(15).
- [12] Hew-Butler Tamara,Loi Valentina,Pani Antonello,Rosner Mitchell H. Exercise-Associated Hyponatremia: 2017 Update.[J]. Frontiers in medicine,2017,4.
- [13] Yun A Joon, Lee Patrick Y, Bazar Kimberly A. Clinical benefits of hydration and volume expansion in a wide range of illnesses may be attributable to reduction of sympatho-vagal ratio.[J]. Medical hypotheses,2005,64(3).
- [14] Wandersee Nancy J,Punzalan Rowena C,Rettig Michael P,Kennedy Michael D,Pajewski Nicholas M,Sabina Richard L,Paul Scott J,Low Philip S,Hillery Cheryl A. Erythrocyte adhesion is modified by alterations in cellular tonicity and volume.[J]. British journal of haematology,2005,131(3).
- [15] Kelly J,Hunt B J,Lewis R R,Swaminathan R,Moody A,Seed P T,Rudd A. Dehydration and venous thromboembolism after acute stroke.[J]. QJM : monthly journal of the Association of Physicians,2004,97(5).
- [16] Goulet E.D.B.. Pre-exercise hyperhydration: Comments on the 2007 ACSM position stand on exercise and fluid replacement[J]. Journal of Exercise Physiology Online,2008,11(2).
- [17] Armstrong Lawrence E,Ganio Matthew S,Casa Douglas J, Lee Elaine C,McDermott Brendon P,Klau Jennifer F,Jimenez Liliana,Le Bellego Laurent,Chevillotte Emmanuel,Lieberman Harris R. Mild dehydration affects mood in healthy young women.[J]. The Journal of nutrition,2012,142(2).
- [18] C Cian,P.A Barraud,B Melin,C Raphel. Effects of fluid ingestion on cognitive function after heat stress or exercise-induced dehydration[J]. International Journal of Psychophysiology,2001,42(3).
- [19] Maughan R J,Shirreffs S M,Watson P. Exercise, heat, hydration and the brain.[J]. Journal of the American College of Nutrition,2007,26(5 Suppl).
- [20] Gleeson M,Bishop N C. Special feature for the Olympics: effects of exercise on the immune system: modification of immune responses to exercise by carbohydrate, glutamine and anti-oxidant supplements.[J]. Immunology and cell biology,2000,78(5).
- [21] Penkman Michael A,Field Catherine J,Sellar Christopher M,Harber Vicki J,Bell Gordon J. Effect of hydration status on high-intensity rowing performance and immune function.[J]. International journal of sports physiology and performance,2008,3(4).
- [22] Foster N K,Martyn J B,Rangno R E,Hogg J C,Pardy R L. Leukocytosis of exercise: role of cardiac output and catecholamines.[J]. Journal of applied physiology (Bethesda, Md. : 1985),1986,61(6).
- [23] Gabriel H,Schwarz L,Steffens G,Kindermann W. Immunoregulatory hormones, circulating leucocyte and lymphocyte subpopulations before and after endurance exercise of different intensities.[J]. International journal of sports medicine,1992,13(5).
- [24] Mitchell J B, Dugas J P, McFarlin B K, et al. Effect of exercise, heat stress, and hydration on immune cell number and function[J]. Medicine and science in sports and exercise, 2002, 34(12): 1941-1950.