JPJO 6 (2) (2021) 161-168

Jurnal Pendidikan Jasmani dan Olahraga

Available online at:
https://ejournal.upi.edu/index.php/penjas/article/view/30522
DOI: https://doi.org/10.17509/jpjo.v6i2.30522

Intervention of Hydration Protocol on Strength, Endurance, and Muscle Power Performance

Wahyu Syahrul Ramadhan [1]*, Leonardo Lubis[2,3], Nandina Oktavia[2], Daniel Womsiwor[4], Beltasar Tarigan[5]

[1]Medical Doctor Program, Faculty of Medicine, Universitas Padjadjaran
[2]Sciences Department, Division of Anatomy, Faculty of Medicine, Universitas Padjadjaran
[3]Sport Medicine Department, West Java National Sport Council (KONI Jawa Barat)
[4]Physical Education, Health, & Recreation Program; Faculty of Sport & Health Education, Cendrawasih University
[5]Physical Education, Health, & Recreation Program; Faculty of Sport & Health Education, Universitas Pendidikan Indonesia

Article Info

Article History :
Received December 2020
Revised Mei 2021
Accepted July 2021
Available online September 2021

Keywords :
Hydration Protocol, Muscle Strength, Muscle Endurance, Muscle Power, Water

Abstract

Water is a molecule that plays an essential role in the muscle contraction process because muscle is a tissue that mostly contains water (75-80%). Therefore, athletes need to maintain fluid intake to support their physical activities when competing and when training. Nevertheless, in several studies, it was noted that some athletes experienced hypohydration or dehydration, which ultimately impaired muscle performance. Therefore, this study was conducted to determine the hydration protocol intervention on muscle strength, endurance, and power performance. This research is an analytical study with quasi-experimental research methods, namely single-arm pre-post study design using secondary data. Subjects of this study were 69 athletes year 2020 (named consecutively: Muaythai 9, Pencak silat 12, wrestling 10, judo 18, and taekwondo 20 athletes). This research was conducted from December 2019 to January 2020. In the beginning, all athletes were tested for muscle strength using a leg dynamometer, then muscle endurance tests using push-up and sit-up tests, and muscle power tests using the triple hop test of the right and left legs. After the first test, all athletes were educated about the hydration protocol. The hydration protocol was determined based on each athlete's sweat rate (ISR) and the training characteristics of each sports division. Then,

✉ Correspondence Address : Jln. Ir. Soekarno km. 21. Jatinangor, Kab. Bandung. Indonesia
E-mail : wahyu17005@mail.unpad.ac.id

INTRODUCTION

Water is a molecule that plays a vital role in muscle contraction because muscle is a tissue mostly composed of water (75-80%) (Pavel et al., 2017b). Decreased water levels in the body can interfere with metabolic processes and muscle performance, resulting in decreased athlete performance. Good hydration management can prevent athletes from becoming dehydrated, reduce the risk of injury, and maintain good muscle contraction physiology (Pavel et al., 2017a).

Nutrition management for athletes is crucial to note. Athletes must pay attention to their nutritional intake, which includes maintaining fluid intake to support their physical activities when competing and when training. However, some athletes do not have sufficient knowledge in fulfilling their fluid needs and doing exercises or competing in a state of dehydration, as seen in a study in various sports which showed 31.9% of athletes started training in a state of dehydration, and 43, 6% of athletes are dehydrated after exercise. Also, 52.9% of athletes have low knowledge of nutrition (Magee et al., 2017). Another study on young athletes showed that 89.4% experienced significant dehydration, while 10.6% experienced mild dehydration (Dieny & Putriana, 2015).

In athletes, the primary excretion of fluid during exercise is through sweat. Whole-body sweat rates (WBSR) are generally in the range of 0.5-2.0 L/hr. However, the amount of WBSR can also exceed 3.0 L/hr in a minority of athletes (about 2%) (Baker, 2017). Excess fluid excretion that is not balanced with adequate water intake can cause dehydration. Dehydration in athletes can cause a decrease in the performance of muscle strength, muscle endurance, and muscle power and can even interfere with cognitive function (Magee et al., 2017; Meyer et al., 2016).

Other studies have focused more on the effects of dehydration on muscle performance, but few have investigated the effect of hydration protocols on muscle performance. This study calculates fluid needs during individual sports so that each athlete gets the proper fluid intake according to their individual needs. So, the hydration protocol applied in this study was made to improve athletes' performance in training, especially in preparation for the national level Olympics. Therefore, all athletes received hydration protocol intervention monitored independently by themselves and the coach. In addition, the hydration protocol used was also a protocol made by the researchers themselves.

Based on the description above, this study aims to investigate the effect of the intervention of hydration protocol on the performance of strength, endurance, and muscle power.

METHODS

This study is an analytical study with quasi-experimental research methods, namely single-arm pre-post study design using secondary data

Participants

The subjects in this study were 69 athletes: 9 Muay Thai athletes, 12 Pencak silat athletes, ten wrestling athletes, 18 judo athletes, and 20 taekwondo athletes. The sampling technique used in this research is nonprobability sampling (convenience sampling). Martial arts sports were chosen because they were available and easily accessible to researchers. In addition, martial arts sports also require maximum muscle performance, which a good supply of fluids can support; therefore, hydration protocol is also important for martial arts sports.

The independent variable in this study was the hydration protocol, while the dependent variables were muscle strength, muscle endurance, and muscle power. This research was conducted from December 2019 to January 2020.

First, all athletes were tested for muscle strength using a leg dynamometer, muscle endurance tests with push-up and sit-up tests, and muscle power tests using the triple hop test of the right and left legs. After the first test, all athletes were educated about the hydration protocol used. Then, all athletes undergo the training for two months and have to implement the hydration protocol. Finally, the same tests are repeated at the end of the training.

After the data was obtained, the normality test was first performed; the results showed that the data were not normally distributed; therefore, a nonparametric test was chosen to analyze the data. This study aimed to determine the differences in muscle performance before and after the intervention of the hydration protocol. Therefore the Wilcoxon test was chosen to determine these differences.

Procedure

The The hydration protocol used in this study consists of several stages and rules, namely:

1. Determine the athlete's individual sweat rate (ISR) by:
    a. Calculate body weight before and after exercise.
        - If the difference is 1 kg, then 1000 mL of additional fluid is given during exercise.
        - f possible, measure the volume of urine during exercise.
        - Goal: no or <2% weight loss.

    b. Stable urine color.
2. Emphasize continuous fluid replacement, namely:
    a. Consume fluids according to the amount of the ISR.
    b. Adaptation to fluid replacement.
    c. Increase fluid delivery gradually.
    d. Allow the body to adapt to increased fluid consumption.
    e. Use individual drinking containers so they can be monitored visually.
    f. Simply put, the liquid consumed is as much as 0.5-1 cup per 10-15 minutes. (1 cup = 240 mL)
3. Understand the dynamics of each sport, namely:
    a. Time and duration of rest/break/time-out
    b. Access to fluids
4. Apply the process of acclimatization or physiological adjustments to the training process. Symptoms and signs for athletes who have not been acclimatized will include:
    a. More sweating
    d. More electrolyte loss

Data Analysis

The data obtained will be processed using Statistical Product and Service Solution (SPSS) software version 23 for Windows. This research uses associative hypothesis testing to find the relationship between the independent variable and the control variable, using the same sample to obtain two groups of data (the group before being given the hydration protocol and the group after being given the hydration protocol), and also the variable data obtained in numerical form so that The analysis was performed using Wilcoxon test, Kruskal-Wallis test, and the Mann-Whitney U post hoc test.

RESULT

General Characteristics

The total number of subjects in this study was 69 athletes. The composition of each sport is shown in table 1.

Table 1. Characteristics of research subjects

Sport Disciplines	Male	Female
Muay thai	6	3
Pencak silat	7	5
Wrestling	5	5
Judo	9	9
Taekwondo	10	10

Wilcoxon Signed-rank Test

The difference test used in this study was the Wilcoxon signed-rank test to determine whether there was a significant difference between the pre and post hydration protocol intervention on muscle performance.

P-value <0.05, it can be interpreted that there are significant differences between the groups before and after being given the hydration protocol intervention.

Based on table 2, the results show that there are significant differences in all variables.

Table 2. Wilcoxon signed-rank test

Variable	Pre Test		Post Test		p-Value
	M	SD	M	SD	
Muscle strength	46.5	6.03	49.9	5.85	0.0001
Muscle endurance (push-up)	43.2	8.20	50.0	9.84	0.0001
Muscle endurance (sit-up)	44.5	10.2	51.5	10.5	0.0001
Muscle power (right leg)	5.71	0.73	6.55	0.98	0.0001
Muscle power (left leg)	5.73	0.81	6.54	0.92	0.0001

DISCUSSION

The Every day, water is needed by our body in more significant amounts when compared to other nutrients. Most of the human body is composed of water, namely as much as 55% in the elderly, 60% in adults, while in infants, as much as 75% (Muth & Zive, 2019; Whitney & Rolfes, 2018). 70–80% of the water in the body is contained in many body tissues, such as muscles, skin, internal organs, and the brain. Only 10-20% of water in the body is in the adipose tissue and bones. Total body water consists of two-thirds of the total amount of water in the body in the intracellular space, while the other third is extracellular, which includes plasma volume, solid connective tissue, bone, transcellular fluid, interstitial fluid, and lymph. The amount of extracellular fluid can describe a person's hydration status, while intracellular fluid reflects the body cell mass and nutrients (Muth & Zive, 2019; Whitney & Rolfes, 2018)

A person is considered to have a good hydration status (euhydration) if he has a normal osmolarity pressure (Posm) of 285-295 mOsm/kg regardless of total daily water intake (Armstrong & Johnson, 2018). The water requirement of each individual can vary each day widely depending on age, sex, body weight, physical activity, weather, and the composition of the food consumed (Armstrong & Johnson, 2018). Water content in the body and fluid balance is regulated by physiological factors, namely by osmoreceptors and baroreceptors, and non-physiological factors such as social, habit, and cultural influences (Riebl & Davy, 2013). Based on the Dietary Reference Intakes (DRIs) established by the European Food Safety Authority (EFSA), the adequate amount of water intake for adults is 2.5 liters/day for men and 2 liters/day for women. This is slightly different from the Dietary Reference Intakes released by the Institute of Medicine (IOM), which are 3.3 liters/day for men and 2.3 liters/day for women (Gandy, 2015).

Muscle tissue is composed of protein (18-20%) and water (75-80%). In addition, muscle also contains several molecules in small amounts, such as glycogen (0.5-1.5%), glucose (0.02-0.04%), phospholipids (~1%), cholesterol (0.07-0.18%), lactic acid (~0.01%), vitamins, enzymes and some other organic molecules (Pavel et al., 2017b).

In general, the role of water in muscle physiology includes acting as a solvent and is involved in various metabolic reactions in muscle cells. Each gram of muscle glycogen stores 2.7 grams of water which serves as a medium to facilitate hydrolytic enzymes to break down glycogen into glucose for later use as energy in the process of muscle contraction (Lorenzo et al., 2019). So that if the body lacks fluids in the muscles, it will also interfere with the energy production process, which ultimately results in a decrease in muscle performance. Besides, water also plays an essential role in maintaining the structural shape of a cell by binding to cytoplasmic proteins and indirectly influencing physiological mechanisms such as cell performance and regulation of cell proliferation or apoptosis (Lorenzo et al., 2019). Water also plays a vital role in mechanical functions, such as maintaining flexibility and elasticity of tissues to prevent injury (Lorenzo et al., 2019).

Muscle is a network composed of protein (18-20%) and water (75-80%). In addition, muscles also contain several molecules in small amounts, such as glycogen (0.5-1.5%), glucose (0.02-0.04%), phospholipids (~1%), cholesterol (0.07-0.18%), lactic acid (~0.01%), vitamins, enzymes and some other organic molecules (Pavel et al., 2017a).

The protein contained in muscle consists of myosin (60%) and actin (12%) which compose the elements of muscle contraction. In addition, there are nucleoproteins, globulin X, myogen, and myoalbulin that make up the sarcoplasm. And also, myoglobulin (~ 1%) is a muscle that contains oxygen deposits. 1The human body has more than 600 skeletal muscles or 40% of the total muscle, which varies in shape and size (Hall, 2016; Magyari et al., 2018). The constituent structure of skeletal muscles consists of many fibers with diameters ranging from 10 to 80 micrometers. The smallest contractile units in muscle are called sarcomeres, which are composed of different proteins. Myofibrils consist of several sarcomeres and a group of myofibrils to form one muscle fiber or cell. In addition, various types of connective tissue, called fascia, surround the muscle structure and create a stable and flexible environment (Magyari et al., 2018).

In this study, three components of muscle performance-testedwere tested: muscle strength, muscle endurance, and muscle power. Muscle strength is defined as the maximum force or torque of a muscle or muscle that can resist resistance during a specific task (Bagchi et al., 2018; Walton-Fisette & Wuest, 2018). In this study, muscle strength was tested using a leg dynamometer.

Muscle endurance is the ability of a group of muscles to contract repeatedly over a period of time. This study tested muscle endurance with push-up and a sit-up test (Riebe et al., 2018).

Muscle power is defined as the ability to produce a certain amount of force at high speed or a combination of muscle strength and speed (speed) applied in a short span of time (Walton-Fisette & Wuest, 2018). In this study, muscle power was tested by the triple hop test of the right and left legs.

The results of the different tests using the Wilcoxon test shown in Table 2 show significant differences in muscle performance in the athletes' group before and after being given the hydration protocol intervention. This difference indicates the relationship between hydration protocol and muscle strength, muscle endurance, and muscle power. Thus, hydration protocol plays an important role in maintaining the athlete's hydration status at a good level. In other studies, good hydration status has been shown to affect performance in sports, including muscle (Shirreffs, 2005). These results are supported by research showing the critical role of water in metabolism and muscle activity (Lorenzo et al., 2019).

The combat sports (i.e., wrestling, boxing, judo, Pencak silat, taekwondo, muay Thai, taekwondo) match their athletes before a competition based on gender and weight class. The weight class aims to make the opponent have the same weight to reduce injuries (Pallarés et al., 2016). Although success in combat sport has many factors, recent research has shown that muscle strength and power are the key factors influencing performance in this sport. However, the effects of dehydration and rapid rehydration on neuromuscular performance (i.e., muscle strength and strength) have not been adequately explored. Weight loss due to dehydration has been shown to affect boxing and wrestling performance. However, if weight loss recovers quickly, the effect on performance is not visible. Maximal isometric muscle strength was found to be reduced or unchanged after rapid weight loss. Pallarés et al. found that 4% dehydration reduced muscle endurance, but not knee strength isokinetic, while pH or Pi was independent of hypohydration. However, recent research suggests that hypohydration can impair isometric, eccentric forces, particularly the force development rate. (Pallarés et al., 2016)

The hydration protocol intervention has a big effect on keeping the athlete's total body water (TBW) and body mass stable during training activities. In another study, decreases in TBW and body mass were noted to reduce muscle performance in athletes (Akan, 2020). Hydration protocols made by MHealthy Physical Activity Program from the Regents of the University of Michigan recommends consuming 500-600 mL of water 2 hours before exercise, 200-300 mL every 10-20 minutes of exercise, and 500-700 mL after practice (Program, 2014).

Meanwhile, according to the American College of Sports Medicine (ACSM), athletes are recommended to consume 5─7 mL of water per kg of body weight four hours before training and consume 450─675 mL of water per 0.5 kg of body weight lost during exercise. This ACSM recommendation applies to all ages (Smith et al., 2015). In addition, if the athlete's training duration exceeds one hour, then fluids containing 30–60 grams of carbohydrates need to be added every hour (Muth & Zive, 2019; Smith et al., 2015).

Good hydration conditions in athletes are very important because if there is a decrease in hydration status, it will interfere with the physiological work of the muscles. The results of other studies show that hypohydration or dehydration conditions in athletes show a decrease in muscle performance such as muscle strength, muscle endurance, and muscle power (Goulet et al., 2018; Judelson et al., 2007; Magee et al., 2017; Meyer et al., 2016; Savoie et al., 2015). Also, hypohydration has been shown to cause decreased blood flow and changes in skeletal muscle metabolism (increased lactate, muscle glycogenolysis, and carbohydrate oxidation) (Nuccio et al., 2017).

Dehydration can interfere with normal physiological functions. A decrease in blood volume due to a decrease in the fluid can increase the strain on the heart, thereby decreasing the stroke volume and increasing the heart rate. When the core temperature increases due to exercise and dehydration, the blood flow to the skin increases and further reduces blood from its main flow, further exacerbating the stretching of the heart. Due to the increased blood flow to the skin, sweat production increases as an attempt to remove heat from the body through evaporation (Logan-Sprenger et al., 2015).

A decrease of 3%-4% of the total water in the body can reduce muscle strength by about 2% (Meyer et al., 2016). A decrease of 3% -4% of body mass can decrease the explosive power of muscles by about 3% —endurance performance, especially in hot weather (Magee et al., 2017). Even mild dehydration (~1-2% weight loss) indicates impaired cognitive performance during exercise (Magee et al., 2017).

About 2000–3100 mL of water in the body is excreted every day. A total of 1200–2000 mL by the kidneys (urine), 450 mL by the skin (sweat), 250–350 ml by the lungs (water vapor), and 100–300 mL through the digestive tract (feces) (Riebl & Davy, 2013; Whitney & Rolfes, 2018). Humidity, temperature environment, along the intensity and duration of physical activity undertaken also affect the amount of urine output. In cold temperatures, urine output will be more, while it will be less at hot temperatures. In a hot environment, more excreted body fluids are released through sweat (Kenefick & Cheuvront, 2012).

Athletes lose sweat and electrolytes due to thermoregulated sweat during exercise, and it is known that the level and composition of sweat can vary within and between individuals. The WBSR typically ranges from about 0.5 to about 2.0 L/hour (Baker, 2017). However, the amount of WBSR can also exceed 3.0 L/hr in a minority of athletes (about 2%) (Baker, 2017).

The hydration protocol also aims to minimize the amount of excessive water intake or less than the amount of water excreted by the body, primarily through sweat. Apart from using water, rehydration can also be supplemented with foods containing water and sodium if the athlete only has 12 hours of recovery time before doing the next strenuous activity. However, if you need quick rehydration, athletes should drink 1.5 liters of water per kg of body weight lost. If you are more than 7% dehydrated, fluid rehydration should be done intravenously (Muth & Zive, 2019).

Recent research on the relationship between water and muscle work is discovering the fourth phase of water or EZ-water, which is directly related to the muscle contraction mechanism (Pollack, 2013, 2018; Yoo et al., 2014).

EZ-water or exclusion zone water is a form of the fourth phase of water in which water has properties between solid and liquid, it also has the characteristic of pushing whatever is in it out, so that in this phase, water cannot dissolve anything, so it is called the exclusion zone water. This phenomenon makes water play a role in increasing the density or viscosity of hydrophilic molecules (such as proteins) by up to sixfold (De Ninno, 2017; Pollack, 2013, 2018). The bonding force on the hydrophilic surface with water is a major factor in forming the high-density intermediate phase (viscous interphase). EZ-water (negatively charged) envelops all macromolecules in cells and plays a vital role in metabolic and mechanical processes in muscle cells. The increase in the density of the water surrounding the protein does not support the muscle contraction process. The water molecules in the relaxed myofibrils are associated with hydrogen bonds, with very few free hydroxide ions. However, when the muscles contract, there is a large breaking of the bonds in the water hydrogen bonds that surround the protein that plays a role in contractility (contractile protein) so that the number of free water molecules increases and forms a water mass. This means that some of the water bonds in the contractile proteins are released when the muscles contract due to the breaking of hydrogen bonds and destruction of EZ-water (Lorenzo et al., 2019; Pollack, 2018).

Furthermore, when the myofibrils relax, it appears that they bind to hydrogen extensively with little or no free OH-. In measurements using synchrotron radiation-Fourier transform infrared (SF-FTIR) spectromicroscopy, it was found that water absorption was relatively higher in the central region of the sarcomere than in the I-band region, implying a higher hydration capacity in thick filaments compared to thin filaments. When myofibrils contract, there is a change, namely a significant release of hydrogen from the water. The separation of the amide accompanies the change induced by this contraction I peak, implying that the muscle protein transitions from the alpha-helix to beta-sheet-rich structures. Therefore, muscle contraction can be characterized by a loss of regularity in the muscle-protein complex, accompanied by changes in the structure of water (Pollack, 2013; Yoo et al., 2014). The mechanism shows how important the role of water is in the process of muscle contraction.

In addition, the composition of water that is maintained in the body can also protect the cardiovascular system and body temperature regulation system. When exercising, sweating is the best temperature-lowering mechanism to keep your body temperature from rising too high. An increase in body temperature that is too high can cause heat injury as well as a decrease in endurance performance (Akan, 2020; James et al., 2019). The hydration protocol plays an important role in fulfilling body fluid replacement so that the fluid that comes out is replaced immediately. A good fluid replacement can reduce excess temperature rise and improve performance during training (Akan, 2020).

Apart from maintaining good hydration status, training also affects muscle performance improvement. A study on judo athletes during an 8-week training period showed an increase in the components of muscle endurance and muscle power (Mohammed & Choi, 2017). Another study conducted on Mixed Martial Arts (MMA) athletes during a 4-week training period also showed an increase in the components of muscle strength, muscle endurance, and muscle power (Kostikiadis et al., 2018). However, this training variable is one of the confounding factors that bias this study.

CONCLUSION

Based on data that has been processed through influence analysis tests, it can be concluded that there is an influence of the hydration protocol intervention on muscle performance, namely muscle strength, muscle endurance, and muscle power. The influence of the hydration protocol is to maintain a good hydration status (euhydration) in the athlete so that the athlete does not experience hypohydration which will later impair the athlete's muscle performance. Not only in martial arts sports but all sports, it is important to apply hydration protocols individually according to the training program (volume of training).

CONFLICT OF INTEREST

The authors declared no conflict of interest.

ACKNOWLEDGEMENT

We would like to deliver our gratitude to West Java KONI for facilitating this research so that it can be implemented. We would also deliver our sincere gratitude to all participants who had involved in the study.

REFERENCES

Auxter. at. al. (2001). Principles and Methods of Adapted Physical Education and Recreation. New York. Mc. Graw-Hill.

Akan, L. S. (2020). The Importance of Hydration. Innovations in Health Sciences, 130.

Armstrong, L. E., & Johnson, E. C. (2018). Water Intake, Water Balance, and the Elusive Daily Water Requirement. Nutrients, 10(12). https://doi.org/10.3390/nu10121928

Bagchi, D., Nair, S., & Sen, C. K. (2018). Nutrition and enhanced sports performance: muscle building, endurance, and strength. Academic Press.

Baker, L. B. (2017). Sweating rate and sweat sodium concentration in athletes: A review of methodology and intra/interindividual variability. Sports Medicine, 47(1), 111-128.

De Ninno, A. (2017). Dynamics of formation of the Exclusion Zone near hydrophilic surfaces. Chemical Physics Letters, 667, 322-326.

Dieny, F. F., & Putriana, D. (2015). Status hidrasi sebelum dan sesudah latihan atlet sepak bola remaja. Jurnal Gizi Indonesia (The Indonesian Journal of Nutrition), 3(2), 86-93.

Gandy, J. (2015). Water intake: validity of population assessment and recommendations. European journal of nutrition, 54(2), 11-16.

Goulet, E. D., Mélançon, M. O., Lafrenière, D., Paquin, J., Maltais, M., & Morais, J. A. (2018). Impact of mild hypohydration on muscle endurance, power, and strength in healthy, active older men. The Journal of Strength & Conditioning Research, 32(12), 3405-3415.

Hall, J. E. (2016). Guyton and Hall Textbook of Medical Physiology, Jordanian Edition E-Book. Elsevier.

James, L. J., Funnell, M. P., James, R. M., & Mears, S. A. (2019). Does Hypohydration Really Impair Endurance Performance? Methodological Considerations for Interpreting Hydration Research. Sports Medicine, 49(2), 103-114. https://doi.org/10.1007/s40279-019-01188-5

Judelson, D. A., Maresh, C. M., Anderson, J. M., Armstrong, L. E., Casa, D. J., Kraemer, W. J., & Volek, J. S. (2007). Hydration and Muscular Performance. Sports Medicine, 37(10), 907-921. https://doi.org/10.2165/00007256-200737100-00006

Kenefick, R. W., & Cheuvront, S. N. (2012). Hydration for recreational sport and physical activity. Nutrition reviews, 70(suppl_2), S137-S142.

Kostikiadis, I. N., Methenitis, S., Tsoukos, A., Veligekas, P., Terzis, G., & Bogdanis, G. C. (2018). The Effect of Short-Term Sport-Specific Strength and Conditioning Training on Physical Fitness of Well-Trained Mixed Martial Arts Athletes. Journal of sports science & medicine, 17(3), 348-358.

Logan-Sprenger, H. M., Heigenhauser, G. J., Jones, G. L., & Spriet, L. L. (2015). The effect of dehydration on muscle metabolism and time trial performance during prolonged cycling in males. Physiological reports, 3(8), e12483.

Lorenzo, I., Serra-Prat, M., & Yébenes, J. C. (2019). The Role of Water Homeostasis in Muscle Function and Frailty: A Review. Nutrients, 11(8), 1857.

Magee, P. J., Gallagher, A. M., & McCormack, J. M. (2017). High prevalence of dehydration and inadequate nutritional knowledge among university and club level athletes. International Journal of Sport Nutrition and Exercise Metabolism, 27(2), 158-168.

Magyari, P., Lite, R., Kilpatrick, M., & Schoffstall, J. (2018). ACSM'S resources for the exercise physiologist: A practical guide for the health fitness professional. Wolters Kluwer Health.

Meyer, F., Szygula, Z., & Wilk, B. (2016). Fluid balance, hydration, and athletic performance. CRC Press.

Mohammed, M. H. H., & Choi, H. J. (2017). Effect of an 8-week judo course on muscular endurance, trunk flexibility, and explosive strength of male university students. Sport Mont, 15(3), 51-53.

Muth, N. D., & Zive, M. M. (2019). Sports nutrition for health professionals. FA Davis.

Nuccio, R. P., Barnes, K. A., Carter, J. M., & Baker, L. B. (2017). Fluid Balance in Team Sport Athletes and the Effect of Hypohydration on Cognitive, Technical, and Physical Performance. Sports medicine (Auckland, N.Z.), 47(10), 1951-1982. https://doi.org/10.1007/s40279-017-0738-7

Pallarés, J. G., Martínez-Abellán, A., López-Gullón, J. M., Morán-Navarro, R., De la Cruz-Sánchez, E., & Mora-Rodríguez, R. (2016). Muscle contraction velocity, strength and power output changes following different degrees of hypohydration in competitive olympic combat sports. J Int Soc Sports Nutr, 13, 10. https://doi.org/10.1186/s12970-016-0121-3

Pavel, L. L., Tiutiuca, C., Berbece, S. I., Condratovici, A. P., & Ioanid, N. (2017a). Chemical Physiology of Muscle Contraction. Rev Chim (Bucharest), 68, 1095-1097.

Pavel, L. L., Tiutiuca, C., Berbece, S. I., Condratovici, A. P., & Ioanid, N. (2017b). Chemical Physiology of Muscle Contraction. REVISTA DE CHIMIE, 68(5), 1095-1097.

Pollack, G. H. (2013). The Fourth Phase of Water. Ebner & Sons Publishers, Seattle, Washington.

Pollack, G. H. (2018). The Fourth Phase of Water: Implications for Energy, Life, and Health. In Biological, Physical and Technical Basics of Cell Engineering (pp. 309-320). Springer.

Program, M. P. A. (2014). The Importance of Water While

Exercising. The Regents of the University of Michigan. http://www.med.umich.edu/1libr/Mhealthy/TheImportanceofWaterWhileExercising.pdf

Riebe, D., Ehrman, J. K., Liguori, G., Magal, M., & Medicine, A. C. o. S. (2018). ACSM's guidelines for exercise testing and prescription. Wolters Kluwer.

Riebl, S. K., & Davy, B. M. (2013). The hydration equation: Update on water balance and cognitive performance. ACSM's health & fitness journal, 17 (6), 21.

Savoie, F.-A., Kenefick, R. W., Ely, B. R., Cheuvront, S. N., & Goulet, E. D. B. (2015). Effect of Hypohydration on Muscle Endurance, Strength, Anaerobic Power and Capacity and Vertical Jumping Ability: A Meta-Analysis. Sports Medicine, 45(8), 1207-1227. https://doi.org/10.1007/s40279-015-0349-0

Shirreffs, S. M. (2005). The Importance of Good Hydration for Work and Exercise Performance. Nutrition Reviews, 63(suppl_1), S14-S21. https://doi.org/10.1111/j.1753-4887.2005.tb00149.x

Smith, J. W., Holmes, M. E., & McAllister, M. J. (2015). Nutritional considerations for performance in young athletes. Journal of sports medicine, 2015.

Walton-Fisette, J. L., & Wuest, D. A. (2018). Foundations of Physical Education, Exercise Science, and Sport. McGraw-Hill Education.

Whitney, E., & Rolfes, S. R. (2018). Understanding nutrition. Cengage Learning.

Yoo, H., Nagornyak, E., Das, R., Wexler, A. D., & Pollack, G. H. (2014). Contraction-Induced Changes in Hydrogen Bonding of Muscle Hydration Water. The journal of physical chemistry letters, 5(6), 947-952. https://doi.org/10.1021/jz5000879