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Macronutrient intake: A multi-sport study of female division I collegiate athletes

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Background: Macronutrients play a critical role within collegiate athletes' performance and health, with carbohydrates providing most of the energy needs for most athletes. There is little research examining the macronutrient intake of healthy collegiate female athletes across sports. The aim of the present study was to compare macronutrient intakes of female collegiate athletes within different sports and compare their intakes to recommendations.

Methods: An observational study was conducted to determine whether a sample of female collegiate athletes (n=26) consumed the IOC nutritional recommendations. Sports included within the study were soccer, basketball, volleyball, and cross-country. Athletes were asked to complete a 6-day food log over a 2-week span, which included 2 weekend days during their in-season training phase. The body composition of athletes was also recorded. Macronutrient and overall caloric intakes were then compared to the IOC recommendations.

Results: Overall caloric and carbohydrate intake were significantly lower than the IOC recommendations. Carbohydrate intake was notably low within soccer players (2.92 ± 1.01 g/kg/day) and basketball players (1.61 ± 0.41 g/kg/day). Fat intakes were recorded significantly higher than the IOC recommendations of 15-20%. Athletes demonstrated a significantly higher protein intake than the IOC recommendations when measured in g (100.56 ± 24.01) and g/kg (1.65 ± 0.54).

Conclusion: This study found that female soccer, basketball, and volleyball players do not consume adequate macronutrient intakes compared to the IOC recommendations. The current study is one of the first to demonstrate a cohort of female cross-country runners consuming the daily recommendations of both overall caloric intake and carbohydrate intakes during their in-season phase of training.

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CHAPTER I

INTRODUCTION

Over recent years research within female athletic performance has grown, as well as a focus on nutritional imbalances within female athletes. Much of this research has examined the impacts of imbalanced health on corresponding health implications, such as menstrual cycle imbalances (Allaway et al., 2016; Muia et al., 2016; Southmayd et al., 2019), and diminished bone mineral density (Brook et al., 2019; MacKnight, 2017; Southmayd et al., 2019). Currently, there are few multi-sport studies that examine the macronutrient intake of female athletes across sports. Research has shown that different disciplines of sport such as mixed-sports, endurance sports, and strength sports each benefit from different macronutrient intake (Ramana, 2010). Studies have demonstrated that female athletes do not consume the recommendations set by organizations such as, the International Olympic Committee (IOC), American College of Sports Medicine (ACSM), and the International Society of Sports Nutrition (ISSN) (De Sousa et al., 2008; Madden et al., 2017; Shriver et al., 2013). Each organization has specific recommendations set for the different categories of sports, which can be seen within Appendix A. Many nutritional, observational studies focus more on energy deficiencies within female endurance sports, resulting in limited research within the team, strength, and power sports (Onyweraet al., 2004; Beis, et al., 2011). While there is a wide variety of literature that focuses on the impacts of energy and iron deficiencies within female athletes (Malczewska-Lenczowska, et al., 2018; Melin, et al., 2016; De Souza, et al., 2017), there are fewer contributions that investigate the macronutrient intakes of female athletes.

There are three main macronutrients: carbohydrates, fats, and proteins. Each of these macronutrients plays a vital role within the body. Carbohydrates are a key source of energy within the body, metabolizing rapidly to yield adenosine triphosphate (ATP), which is vital for a large array of sports (Burke et al., 2006). Proteins are essential due to their role in synthesizing hormones, enzymes, receptors, transporters, playing a role in the storage of other molecules and protection of the body, and building muscle (Campbell, et al., 2007). Fats also have a multitude of roles to play within the body, producing hormones, creating myelin sheaths, storing energy, transporting fat-soluble vitamins, and forming cells within the body (Thong et al., 2000). Due to each of the key roles each of these macronutrients plays for athletes' health; it is crucial athletes receive precise information of their dietary needs and ensure they follow the correct recommendations to aid their training and performances. Carbohydrate ingestion during training has not only demonstrated increases in endurance performance, but also strength performance (Krings, et al., 2016; Temesi et al., 2011; Learsi, et al., 2019) Protein ingestion has been shown to enhance recovery within athletes, assisting and further enhancing athlete performance (Cintineo et al., 2018; Sollie, et al., 2018). These macronutrients have extensive research into suggested recommendations and supplementation to enhance performance (Krings et al., 2016; Learsi, et al., 2019; West, et al., 2017).

Therefore, the purpose of this study was to examine a wide range of sports to distinguish the current intake of macronutrients and determine if there were any implications these intakes may have on the athletes' performance. Research has shown that within different seasonal phases, athlete macronutrient needs will differ due to different energy requirements

(Stellingwerff et al., 2011; Heydenreich et al., 2017; Holway & Spriet, 2011) and tissue damage (Gowdak, et al., 2017; Heydenreich, et al., 2017). This project examined the overall caloric intake of female athletes across a multitude of sports to compare the macronutrient consumption with existing guidance by the IOC. To our knowledge, this study will contribute to a gap in the literature as it would be one of the first studies addressing the multiple macronutrient recommendations set by various organizations (ACSM, ISSN, and the IOC). The IOC recommendations were selected for comparison as these were the recommendations developed by the athlete's university dietitians (see Appendix A for recommendations). The IOC recommendations encompass a wide range of sports from extensive research. Based on previous research, there were two main hypotheses: 1) Female athletes do not consume the recommended intake of each macronutrient; 2) A significant difference will be seen between the macronutrient intakes of female athletes between different sports.

Based on previous research in male athletes, it was hypothesized that female carbohydrate intake would be significantly lower than the recommendations, with fat and protein being significantly higher. Therefore, the null hypothesis for this study is: female athlete macronutrient intakes meet the respective recommendations set by the IOC. This work seeks to support female athletes' sporting performance and influence sports scientists and policy guidance related to athlete diets. In addition, the project outlines opportunities for future research pertaining to macronutrient intake and presents policy recommendations for governing bodies such as the IOC.

CHAPTER II

REVIEW OF LITERATURE

Introduction

Many researchers have explored and examined nutritional intervention to enhance athletic performance, although most of the research focuses on male athletes. Organizations, such as IOC, ACSM, and ISSN, have been able to determine possible macronutrient requirements for different athletes. However, these recommendations have been generated through extrapolated data of male athletes and used in a general context for female athletes. However, little research has been conducted to examine the impacts of these nutritional interventions within females, ultimately questioning whether the recommendations set by these organizations are applicable for this population. Macronutrients are vital for survival and have a key role within sports to improve performance, with mechanisms including but not limited to providing increased energy availability and aiding recovery rates (Ivy, et al., 2002; Alghannam, et al., 2016; Alghannam, et al., 2018; McCartney, Desbrow & Irwin, 2018). Energy demands vary between sports, with high-intensity strength/power sports lasting less than 10 seconds utilizing stored adenosine triphosphate (ATP) and creatine phosphate (CP), and longer duration sports metabolizing complex energy sources including carbohydrates (glucose, glycogen) and fats (triglycerides). There has been an abundance of research conducted to assess the optimal intake required to improve athletic performance and enhance recovery within male athletes (McCartney, Desbrow & Irwin, 2018; Amiri et al., 2019; Cintineo et al., 2018).

Understanding the correct macronutrient intakes of an athlete is not only important for performance but also for overall health. Within female sports, there is an abundance of studies focusing on overall energy deficit within female collegiate athletes and the subsequent impacts on performance and health (Mountjoy, et al., 2018; Melin, et al., 2019; Fahrenholtz, et al., 2018; Brown, et al., 2017). It is suggested that collegiate athletes struggle to determine the correct macronutrient intake, demonstrated by athletes limiting their nutritional intake or overeating for their sport demands (Weeden, et al., 2014; Spronk, et al., 2014). It is possible that collegiate athletes lack adequate nutritional knowledge, which could be one reason for the inability to consume the correct recommendations (Weeden, et al., 2014; Spronk, et al., 2014). While several governing bodies provide recommendations, alternatives exist throughout the internet that provide contradictory information and can confuse athletes and influence their understanding of the macronutrient intake required to perform optimally within their chosen sport.

There is evidence that the current recommendations for both carbohydrates and protein are not sufficient for female athlete performance due to differences in female and male metabolism (Blaak, 2001). The purpose of this literature review is to examine the importance of each of these macronutrients, the current evidence of macronutrient intakes in female athletes, and how these current intakes compare to the recommendations currently being set. Further, this literature review is set to examine whether these current recommendations are sufficient for athletes to compete and train to enhance performance.

Background of Information

Macronutrient Importance

It is widely accepted that a well-balanced diet plays a crucial role within the health field; however, there are many misconceptions as to what can be defined as a well-balanced diet. The

World Health Organization (WHO) describes a healthy diet as one which prevents malnutrition, provides sufficient energy for exercise, but not excessive energy, and consists of fat, carbohydrate, and protein (as well as the required micronutrients) (WHO, 2020). A balanced diet is commonly recognized as being 55-60% carbohydrate, 15-20% protein, and 30% from fat (Rondanelli, et al., 2015), This ratio of macronutrients is shown to ensure a healthy lifestyle within the general population (Rondanelli, et al., 2015; Lim, 2018). Within the United States, there is evidence that some athletes are not following these recommendations, with many consuming diets rich in processed foods, resulting in significantly high carbohydrate and fat intakes than recommended (Steele, et al., 2017). A balanced intake of each macronutrient is essential to ensure the health, and function of the body, as explained further within this review.

Proteins are built up from amino acids, which can be either essential (not synthesized within the body), or non-essential (synthesized within the body). There is a total of twenty different amino acids, which are arranged into a variety of shapes for functional proteins. Amino acids must be placed and used within the correct order to ensure the protein in functional. Proteins are created via a process known as protein synthesis, as a demand for protein is increased, transcription is triggered, which occurs within the nucleus of cells. Transcription is the process in which DNA is transcribed to produce a messenger RNA. The messenger RNA then leaves the nucleus and enters the cytoplasm, where it enters translation. The mRNA joins to a ribosome and allows transfer RNA molecules to bind with complimentary bases. Transfer RNA contains an amino acid, as more transfer RNA binds with the messenger RNA, a chain of amino acids is produced, which creates the protein needed. This chain of amino acids then enters a three-step process: initiation, elongation, and termination, to create the correct functional structure for it. Proteins create and form multiple factors of the body, from enzymes to hair and nails. Without sufficient protein intake, the body would be unable to create enzymes, which are essential for many of the reactions within the body. If an athlete is unable to create sufficient enzymes, the body is unable to conduct muscle contractions, create ATP, regulate cell activity, and transduction of signals, all impacting athletes' performance (Cooke & Bialek, 1979; Fink & Mikesky, 2020). ATP production and muscle contraction are two vital factors within performance; without ATP the athlete has no energy to carry out muscle contractions, and without muscle contractions, the athlete is unable to move or function. The enhancement of signal transduction aids performance through increased muscle reaction time and thus can aid athletes with coordination and reactions within their sports.

Further, if the body is unable to produce sufficient enzymes, not only is performance inhibited, but it can impact overall health, as enzymes are utilized within many other reactions within the body, including supporting and regulating the immune system (Strasser, 2005; Shuai & Liu, 2005). For example, proteins such as BH3-only, are proteins known as death cells, which trigger apoptosis of useless, and potentially dangerous cells within the body (Strasser, 2005). Proteins also play a vital role in the formation of hormones, which are vital for maintaining balance of the body. Hormones act as a chemical signal to alert the body of changes required to maintain homeostasis. Specific hormones have been directly linked to athletic performance such as erythropoietin, and testosterone (Thomsen, et al., 2007; Heuberger, et al., 2017; Sattler, et al., 2009; Handelsman, et al., 2018). Erythropoietin is a hormone which stimulates and maintains red blood cells within the body. An increase in erythropoietin, has demonstrated significant increases in endurance performance. Testosterone is more predominant within males and plays a crucial role in stimulating muscle growth and bone strength. Although both hormones can elicit increases in performance, supplementation of these hormones is banned within many sports.

Due to the critical role protein has within the functioning of the body, it is important to understand the recommendations set for protein and the different requirements of proteins needed for different groups of people. The daily recommended intake (DRI) is set at 0.8g/kg/day, for an adult (19 years and older). However, children are recommended to intake higher amounts and varies depending on age, as follows: 0.3-0.5 years should consume 1.31g/kg/d; 0.75-1 years should consume 1.14g/kg/day; 1-3years should consume 1.02g/kg/day; 4-8 years should consume 0.92g/kg/day; 9-13 years old should consume 0.90g/kg/day; 14-18 (boys) should consume 0.87g/kg/day; and finally 14-18 (girls) should consume 0.85g/kg/day (Food and Agriculture Organization (FAO) et al., 2007). Children require a higher recommendation of protein to enable them to grow at a sufficient rate (Garlick, 2006). Insufficient intakes of protein have been demonstrated to decrease child development, both physically and psychologically (Grantham-McGregor & Baker-Henningham, 2005; Petrie,et al., 2004; Bonjour, et al., 2015). Bonjour et al. (2015) demonstrated that insufficient intakes of protein correlate with decreased bone growth and development within children. It has also been shown that a lack of protein ingestion is linked to increases in stress fractures among athletes (Griffin, et al., 2021). Protein requirements are also increased for those suffering from injuries, whether they are pulled muscles, broken bones, and even severe burns (Wolfe, Goodenough, et al., 1983; Shaw, Wildbore, & Wolfe, 1987). When an injury occurs, the body reacts via an inflammatory response, which catabolizes or breaks down skeletal muscle to support visceral protein (Frankenfield, 2006). Increasing protein intake can aid the recovery of these injuries and reduce the catabolic state of the body. An ingestion of up to 2g/kg/day of protein has been encouraged within serious trauma patients, such as burn patients, to maintain nitrogen balance and promote healing (Dickerson, et al., 2012; Wise, et al., 2019). Many of these recommendations are set and determine through nitrogen balance of the body (Tarnopolsky, et al., 1988). Nitrogen balance is a measure of nitrogen intake (meat, eggs, and other protein sources) minus nitrogen output (feces, sweat, urine, menstruation) (Tarnopolsky, et al., 1988). Many studies determine protein requirement for individuals as the amount of protein sufficient to maintain nitrogen balance (Rand, et al., 2003).

Protein needs for athletes are remarkably similar to those suffering from trauma injuries, ranging from 1.0g/kg/day to 2g/kg/day. The Institute of Medicine (2005) has determined that although evidence from research shows an increasing need in protein for athletes, 0.8g/kg/day is sufficient for athlete needs. This has been disputed by many researchers, who demonstrate that for athletes to consume an adequate amount of protein, their protein intakes must be increased (Tarnopolsky M. , 2004; Phillips, et al., 2007; Rodriguez, et al., 2009; Phillips & Van Loon, 2011). Phillips et al., (2007), demonstrated that guidelines for protein requirement should lie between 1.2-1.6g/kg/day, based on nitrogen balance of endurance and strength athletes. Similarly, Rodriguez et al., (2009) suggested athletes' intake between 1.2 and 1.7g/kg/day to be sufficient for athlete needs and performance, whereas, more recently, Phillips & Van Loon (2011), suggest an intake of 1.3-1.8g/kg/day to be more. Based on many of these research papers, organizations have provided different requirements of protein depending on the sports discipline and intensity of the sport: The IOC recommends athletes to consume an intake of 1.3-1.8g/kg/day of protein; The ACSM recommends both strength and endurance athletes consume 1.2 – 1.7g/kg/day; The ISSN recommends moderate-intensity sports consume 1.0-1.5g/kg/day, whereas, high volume sports should consume 1.5-2.0g/kg/day of protein. Due to the damage and stress caused by high-level and volume training, the body requires a similar amount of protein to those suffering from traumatic injuries. Protein aids resistance-trained athletes through increasing muscle mass and strength (Cermak et al., 2012; Morton et al., 2015), as well as increasing skeletal muscle repair and remodeling within endurance-trained athletes (Koopman et al., 2004; Moore et al., 2014). Sufficient dietary protein intake has demonstrated increases in muscle protein synthesis, and subsequently aided within the process of hypertrophy (Phillips & Van Loon, 2011). Further benefits of sufficient protein ingestion, is said to lead to, a higher rate in mitochondrial protein synthesis, increasing mitochondrial volume and enhancing endurance performance (Willkinson, et al., 2008).

The quantity of protein has proven to be important for athlete performance; however, more recently, it has been shown that the quality of protein is also vital for athlete development and performance. Protein quality is measured based on a Protein Digestibility Corrected Amino Acid Score (PDCAAS), which determines the quality of the protein based on the amino acids found within it, and the amino acids humans require to digest (Schaafsma, 2000). As previously stated, proteins are created from chains of amino acids, which must be arranged within the correct order to ensure the protein is functional. If there is an insufficient amount of essential amino acids within the diet, certain proteins are unable to be created, which can lead to a decrease in health and performance. High-quality proteins are given a score of 1.0, which means a high concentration of essential amino acid can be found within the protein source. Animal sourced proteins most commonly contain a PDCAAS of 1.0, specifically milk, which contains casein and whey proteins (Phillips & Van Loon, 2011). It was suggested that proteins with a high PDCAAS would enhance muscle protein synthesis and aid athlete performance compared to proteins with low PDCAAS. There is currently a wide number of studies supporting this notion, with evidence that supplementation of both casein and whey proteins can increase muscle protein synthesis and improve athlete performance (Antonio, et al., 2017; Antonio, et al., 2016;

Wilborn, et al., 2013). Non-animal-based sources of protein (soy protein) have also demonstrated to be effective in enhancing muscle protein synthesis within athletes. However, there is evidence that the use of animal-based protein sources has resulted in greater hypertrophy of the athlete (Hartman, et al., 2007). Furthermore, whey protein has demonstrated to increase muscle protein synthesis both at rest and post-resistance-training compared to other protein sources, such as soy and casein (Tang, et al., 2009). It is argued that these enhanced performance parameters are caused by the concentration of leucine found within these protein sources. Leucine is an essential, branched-chain amino acid, which has been demonstrated to stimulate protein synthesis and decrease protein breakdown within muscle (Hutson, et al., 2001; Duan, et al., 2015). It stimulates protein synthesis via activating protein kinase D-mammalian target of rapamycin (mTOR), which initiates translation. Whey protein is demonstrated to have a higher concentration of leucine within it, which can explain why performance is enhanced greater when using whey protein compared to others such as casein and soy. However, it is not simply the concentration of leucine, which has been demonstrated to impact performance, but the digestion and availability of the leucine within the protein source. For example, casein is shown to have a higher concentration of leucine compared to soy; however, casein clotting within the stomach and being much slower to digest decreases the appearance of leucine and reduces the level of muscle protein synthesis (Phillips & Van Loon, 2011).

Not only has the quantity and quality of protein demonstrated significant effects on athlete performance, but the timing of protein consumption has been shown to be vital for optimizing athlete performance and recovery. Studies have researched the impacts of protein ingestion, prior, peri, and post-exercise, each with varying results on performance (Tipton, et al., 2007; Futija, et al., 2009). Tipton et al. (2007), demonstrated that the ingestion of whey protein prior to the one-repetition max for leg extension increased amino acid concentration within the blood immediately after consumption and remained increased following the exercise. Ingesting amino acids before exercise has shown to increase the delivery of amino acids to working muscle by up to 4.4 times resting levels, resulting in an anabolic response within the muscle (Tipton, et al., 2007). More recent have supported this notion, demonstrating pre-exercise ingestion of protein can increase muscle thickness and increase maximal strength, after 10 weeks of resistance training (Schoenfeld, et al., 2017). Fujita et al. (2009), disproves this however, and demonstrates no effect on performance, nor muscle protein synthesis, when protein is ingested prior to exercise. Similarly, contradicting views have been observed with protein consumption peri-exercise.

Endurance athletes have been shown to improve whole-body protein balance during exercise while ingesting protein peri- exercise (Koopman, et al., 2004). The ingestion of protein during exercise has not only been shown to balance protein but also enhance endurance performance (Koopman, et al., 2004); however, others have also shown no effect on performance from ingesting protein during exercise. Currently, no data shows that the ingestion of protein during exercise can aid and increase muscle protein synthesis within muscles (Phillips & Van Loon, 2011). It can be argued that the research demonstrating an increase in exercise performance also used carbohydrate ingestion, and thus it is the combination of both carbohydrate and protein, which elicited the increase in performance and not just solely protein. More heavily researched is the ingestion of protein post-exercise, which is shown to decrease protein breakdown, promote protein synthesis and elicit muscle growth and repair (Res, et al., 2012; Camera, et al., 2015; Greenhaff, et al., 2008; Rennie, et al., 2006). Studies have demonstrated that consuming protein post-exercise can attenuate muscle protein breakdown.

This works as an increase in plasmas amino acids increases the levels of insulin, which is anti-catabolic, preventing further breakdown of protein (Greenhaff, et al., 2008; Rennie, et al., 2006). One of the most touted reasons for the ingestion of protein post-exercise, is the increase in protein synthesis and promotion in muscle hypertrophy, resulting in increased athlete performance (Biolo, et al., 1997; Tipton, et al., 2001; James, et al., 2019).

The concept of increased performance from post-exercise protein ingestion widely accepted among researchers, however, the timing of post-exercise protein is not. It was first thought that athletes must consume protein within an hour post-exercise, as this was seen as the 'anabolic-window', which would significantly increase myofibrillar protein synthesis (Candow & Chilibeck, 2008; Hulmi, et al., 2010; Kukuljan, et al, 2009; Esmarck, et al., 2001). Esmarck et al., (2001) first observed post-exercise protein consumption which could elicit growth in musculature when consumed immediately after exercise. Contrasting these findings, Areta et al. (2013) demonstrates that protein ingestion post-exercise can increase muscle protein synthesis, even up to 12-hour post-exercise ingestion. It further showed that protein ingestion 3-hours post-exercise elicited the greatest increase in protein synthesis compared to any other timings. Similar findings have been seen by Fabre, et al., (2017); Naclerio, et al., (2017), and Burd, et al. (2015), all demonstrating that prolonged post-exercise protein ingestion can elicit higher protein synthesis than immediate post-exercise protein ingestion. More recent studies have examined the combination of carbohydrate and protein to further enhance athlete performance through increased recovery (Saunders M. J., 2007; Koopman, et al., 2005). The ingestion of both protein and carbohydrate is shown to increase insulin response, aiding in glycogen store replenishment and increasing recovery of athletes (Camera, et al., 2015; Floyd, et al., 1966).

Carbohydrates have five key roles within the body, creating and storing energy, build macromolecules, sparing protein metabolism, and assisting in fat metabolism. Providing the body with energy, in the form of ATP, is the primary role of carbohydrates. Cells such as red blood cells, and areas of the body, such as the brain, rely on carbohydrates as a source of energy; more specifically, these areas rely on glucose (Hess, et al., 2012). Glucose is a molecule comprised of six carbon atoms, six oxygen atoms, and twelve hydrogen atoms, arranged within a hexagonal structure, and is the most abundant carbohydrate molecule, being created from photosynthesis within plants and algae (Daries, 2012). Energy from glucose is produced within a number of different steps, the first being glycolysis (the breakdown of glucose). In total, this process hastens intricate enzymatic steps, which yields a net of two ATP (Sinnott, 2007). This process is known to be entirely anaerobic, meaning the cell does not require oxygen to produce these two ATP molecules. The next step for energy production from glucose, is a step known as the Citric Cycle, which produces carbon dioxide, and electron carriers, utilized within future steps to yield further energy (Fothergill-Gilmore & Michels, 1993). The citric acid cycle also produces 2 GTP molecules, equivalent to roughly 2 ATP molecules (Fothergill-Gilmore & Michels, 1993). This step is aerobic, which means the cell must contain oxygen for it to occur (Fothergill-Gilmore & Michels, 1993).

The final stage of energy production requires the movement of electrons within a system known as the electron transport chain, which produces a total of 32 ATP molecules (Fothergill-Gilmore & Michels, 1993). Different roles of carbohydrates include energy storage, which occurs in the form of glycogen. Glycogen is mainly found within the muscles and the liver of the body and contains an excess of 50,000 glucose units within one molecule (Jeukendrop & Williams, 2011). There are roughly 3,000 kilocalories, said to be stored within muscle, and 1,000 kilocalories within the liver; during prolonged exercise, the glycogen stored within the muscle is used to produce energy, whereas the glycogen stored within the liver is used to maintain blood-glucose levels (Jeukendrop & Williams, 2011). Carbohydrates are not only important for energy needs but are also components to certain macromolecules. Without glucose, the body would be unable to create ribose and deoxyribose, essential for forming deoxyribonucleic acid (DNA), or ribonucleic acid (RNA). These molecules are essential for cell function, within the body, with DNA storing and transferring genetic material and RNA coding for specific amino acids to form protein. Glucose molecules are also used to create Nicotinamide Adenine Dinucleotide (NADH), which acts both within oxidative phosphorylation, and to protect the body from oxidative stress. Fat can also be converted from excess glucose within the body, which can then be further stored. The final role of carbohydrates is to spare both protein and fat from metabolism. Proteins can form glucose from amino acids; however, if the body has sufficient glucose, the breakdown of protein to form glucose is not needed and thus sparing proteins (Murphy, et al., 2015). Similarly, for lipids, if blood-glucose levels are high, the use of fats to produce energy is inhibited; thus, the body utilizes glucose for energy instead of fat and spares it (Kaur, et al., 2016).

With carbohydrates providing most of the fuel for the body, it is no surprise that it is recommended that an adult's diet consist of 45 - 65% carbohydrate (EFSA Panel on NDA , 2010; Trumbo, et al., 2002). There are suggestions that 130g of carbohydrate per day is sufficient for brain activity; however, evidence shows this intake is not sufficient to overall energy needs (EFSA Panel on NDA , 2010). Studies have demonstrated insufficient intakes of carbohydrates have resulted in adverse short-term and long-term effects on the body. There is currently not enough data to determine a minimum requirement for carbohydrates within the literature; however, too much carbohydrate similarly also causes adverse effects to the body (EFSA Panel on NDA , 2010). A diet containing a high percentage of carbohydrate, means that both fat and protein intakes must be reduced, leading to imbalances within the body, such as decreased bone growth, poor mineral transport etc. (EFSA Panel on NDA , 2010). Thus, the recommendations are such that 45-65% of a child's and adult's diet must be comprised of carbohydrates (EFSA Panel on NDA , 2010). Carbohydrates are commonly broken down into several further recommendations for the general public, including fiber, starch, and sugars (or added sugars), each providing a different role within the diet. Dietary fiber is essential within the diet to create decreased intestinal transit, increased stool sizes, reducing LDL cholesterol concentrations, and reducing post-prandial blood-glucose and insulin concentrations (AFSSA 2002; NNR, 2004; IoM, 2005; GR, 2006; Mann et al., 2007). There are a variety of different forms of dietary starch including; however, the most common are non-starch polysaccharides, including cellulose, hemicellulose, pectin, and hydrocolloids. There is wide variability among fiber sources, each providing its own physiological advantages, where cellulose is insoluble in water, pectin, and hydrocolloids can form water solutions (EFSA Panel on NDA , 2010). This mixture of insoluble and water-soluble complexes is vital for physiological functions, such as digestion, where soluble fiber, such as pectin, help to maintain glucose levels and blood cholesterol levels. Insoluble fiber aids digestion by attracting water to the stool to alleviate strain on the bowels. It is therefore suggested that an adult consume between 15-30g of fiber per day to maintain a healthy working gut. Although carbohydrates are composed of sugar molecules, for this review, sugars are defined as those obtained within the diet from fruits, milk, and isolated sources (Hess, et al., 2012). There are a large variety of recommendations for sugars within the diet, including total sugars and added sugars. Added sugars are defined as the sugars which cannot be obtained from the diet naturally (Hess, et al., 2012). For Americans, there are multiple recommendations for dietary sugars, however the two main findings are as follows: WHO, (2003), recommends that a maximum of 10% energy should be obtained from free sugars, IOM (2002), recommends 25% maximum of energy should be obtained from added sugars. Associations, such as the American Heart Association, recommend added sugar intake to be limited to 100 calories per day for the average American, to reduce risks in heart disease (Johnson, et al., 2009). Starch is recommended to comprise 25% of energy consumption of an adult's diet, and can be found within potatoes, rice, and wheat products. There are three classifications of starch: rapidly digestible starch, slowly digestible starch, and resistant starch, each with their own physiological and metabolic function (Lehmann & Robin, 2007). Rapidly digestible starches are important for providing a rapid source of energy, whereas slowly digestible starches provide a slow, sustained source of energy, and maintains blood glucose levels (Lehmann & Robin, 2007).

With carbohydrates being a significant source of energy within the diet, they play a crucial role within athlete performance. Recommendations between sports are shown to vary, dependent on the energy requirement. For instance, the IOC recommends endurance athletes consume between 6-10g/kg/day, whereas strength athletes are recommended an intake of 4-7g/kg/day. The ISSN recommendations differ as moderate-high intensity sports, like strength sports, are recommended 5-8g/kg/day, whereas high-volume sports, such as endurance events, are recommended 8-10g/kg/day. However, the ACSM give a much broader recommendations, suggesting sports intake 6-10g/kg/day of carbohydrate, with little guidance and differentiation between types of sports. It has been widely accepted that these recommendations are sufficient to athlete performance. However, all organizations agree that ultra-distance events (lasting 4-5hours), have been guided to ingest up to 12g/kg/day (Jager, et al., 2017; Thomas, et al., 2016). Not only do sports have different energy demands, but each sport metabolizes carbohydrates at different rates. For strength, power and short duration sports (up to 90 seconds), which are largely anaerobic, energy is metabolized from glycolysis, whereas sports which are considered aerobic metabolize energy via oxidative phosphorylation. For these shorter-duration sports, glycolysis and the production of 2ATP molecules are sufficient to meet energy demands, as well as providing energy quickly. Whereas, oxidative phosphorylation may provide a significantly higher yield of ATP, it is provided much slower and cannot meet the needs of the short-duration, power sports. Research has demonstrated that without sufficient energy athletes are unable to reach optimum performances (Vitale & Getzin, 2019; Jager, et al., 2017; Jeukendrup, et al., 2005; Getzin, et al., 2017).

Not only is the quantity of carbohydrate essential for athlete performance, but the timing has proved to increase athlete performance, whether this is carbohydrate-loading prior to events, carbohydrate ingestion during events, or recovery utilizing carbohydrates athletes (Jeukendrup & McLaughlin, 2011; Hawley, et al., 1997; Rountree, et al., 2017; Krings, et al., 2017). Early research suggested carbohydrate loading within male athletes increased time-to-exhaustion, increasing overall endurance performance within endurance sports, such as triathlon and marathon running (Hawley, Schabort, Noakes, & Dennis, 1997; Lambert & Goedecke, 2003; Kiens, 2001). The classic approach to carbohydrate loading is said to be consuming ingesting a diet of 60-70% carbohydrate diet for 3-4 days prior to competition. During this approach, it is required that glycogen stores are depleted at least 7 days prior to competition, by depleting these stores, the body adapts, to allow for a larger storage of glycogen, to prevent further glycogen depletion occurring. This approach aims to increase the body’s glycogen stores within the muscle, and delays the onset of fatigue, increasing performance. Through carbohydrate loading, glycogen stores have been shown to increase from 125mmol/kg wet weight muscle up to

200mmol/kg wet weight muscle (Sherman, et al., 1981). Impey et al., (2018) demonstrated that an increase in glycogen availability, cell signaling is increased, as well as, gene expression and oxidative enzymes, all leading to an increase in athlete performance. Much of carbohydrate-loading research has focused on endurance-based sports, with a small fraction demonstrating little to no effect on performance when used on more anaerobic sports, such as basketball (Michalczyk, et al., 2018).

As well as carbohydrate loading, carbohydrate ingestion during competition has been demonstrated to enhance performance within both endurance athletes and strength and power athletes (Jeukendrup & McLaughlin, 2011; Learsi, et al., 2019; Santos, et al., 2019). It has been widely accepted that carbohydrate ingestion during endurance athletes can delay fatigue and enhance performance. Early research of Levine, et al., (1924) first discovered the possible enhancement of carbohydrate ingestion during the Boston marathon. Since this study there have been research into not only the ingestion of carbohydrate during endurance exercise, but the concentrations and the methods of delivery (Mitchell, et al., 1989; Fielding, et al., 1985; Hassapidou M. , 2011; de Salles Painelli, et al., 2010; Doering, et al., 2014; Learsi, et al., 2019). Learsi et al., (2019), demonstrated that ingestion of 2mL/kg of body mass carbohydrate within an 8% solution, every 15 minutes during a 105minute cycle time trial, increases time trial performance. Similar results have been observed for other sports, such as marathons and ultra-running (Noakes, et al., 1988; Urdampilleta, et al., 2020). A large meta-analysis study comprised of 50 studies, examining the impacts on exercise performance from carbohydrate ingestion demonstrated that carbohydrate ingestion not exceeding 8% concentration of carbohydrate solution enhances performances within time trial and time to exhaustion studies. Not only does the ingestion of carbohydrates enhance endurance performance, but mouth rinse techniques have also been demonstrated to enhance endurance performance (Sinclair, et al., 2014; Lane, et al., 2013).

Santos, et al. (2019) similarly demonstrated increased performance within strength athletes. Ingestion of a solution consisting of 20g carbohydrate and 200ml water was administered to resistance-trained males during a resistance training protocol (Learsi, et al., 2019). The athletes demonstrated a significant increase within 1RM while consuming the carbohydrate solution (Learsi, et al., 2019). There is still conflicting research on the effectiveness of carbohydrate ingestion and mouth rinse within performance enhancements in strength sports, as many demonstrate little changes in performance (Rountree, et al., 2017; Krings, et al., 2017). Rountree, et al. (2017) demonstrated a 6% carbohydrate beverage did not elicit any significant changes within performance measures within eight resistance-trained males. As athlete's exercise, carbohydrate stores are utilized, through ingesting carbohydrate during competition blood glucose concentration can be maintained, allowing carbohydrate oxidation to continue. Through maintaining blood glucose levels athletes have a continuous energy source, and thus fatigue is delayed, increasing performance.

Consumption of carbohydrate post-exercise, has been demonstrated to be important for the resynthesis of glycogen stores. The resynthesis of glycogen occurs within a biphasic pattern, initially rapidly increasing glycogen storage (30-60mins post-exercise), followed by a much slower rate of resynthesis (Jentjens & Jeukendrup, 2003; Cartee, et al., 1989). Beck, et al., (2015), discuss the importance of carbohydrate intake post exercise, advising athletes to ingest 1.0-1.2g/kg/hour of carbohydrate for the first four hours post-exercise, as it has demonstrated significant increases in glycogen storage. The ingestion of carbohydrate post-exercise, not only aids to replenish glycogen stores, but also aids athlete endurance performance (Williams, et al., 2003). Williams, et al. (2003), demonstrated an ingestion of a protein and carbohydrate beverage containing 0.8g/kg carbohydrate enabled participants to increase performance by 55%, compared to a placebo effect. Alghannam et al. (2016), demonstrated the co-ingestion of 0.4g/kg of whey protein with 0.8g/kg of carbohydrate promotes the resynthesis of muscle glycogen similar to if only carbohydrate (1.2g/kg) was ingested. This can be explained as when a co-ingestion of carbohydrate and protein, increases the concentration of insulin, enhancing promoting the storage of glycogen (Alghannam, et al., 2016).

The importance of carbohydrate within athlete diet, is currently being tested, with the increasing number of athletes utilising high-fat, low-carbohydrate diets. Fat is vital within the diet having many essential functions including the transport and absorption of fat soluble vitamins and minerals, without fat being in the diet, increases in vitamin A, D, E and K deficiencies can occur, causing numerous health implications (Mattson, 1983; Ilankumaran & Anand, 2012; Saunders T. A., 2016). Fat is also crucial in creating myelin sheaths, vital for conducting electrical impulses, which deliver sensory information around the body (Ilankumaran & Anand, 2012). Without myelin sheath, an athlete would be unable to contract muscles. Further, fat also forms the phospholipid bilayer of cell membranes (Gibson, et al., 2002). The bilayer of cells is important for controlling the movement of molecules in and out of the cells (Gibson, et al., 2002). Fat provide protection for the body, cushioning the vital organs of the body, via a layer of visceral fat, helping to maintain position and decreasing risk in injury (Ilankumaran & Anand, 2012). Fat also provides a large portion of energy, with one gram providing nine Kcal, compared to carbohydrate, which provides 4Kcal per gram (Ilankumaran & Anand, 2012).

Without fat within the diet, our bodies would be unable to function; however, the overconsumption of fat has been linked to a number of health implications, such as cardiovascular disease, diabetes, and cancer (Hu, 2001; Ilankumaran & Anand, 2012). The ingestion of fat within the diet is therefore vital for health; however, it is important that the correct type and amount of fat is consumed. The recommendation for the general public states that 20 to 35% of total calories should be from fat (Lamarche & Couture, 2014). This percentage, however, the recommendation is divided into several different fat source categories. There is a variety of fat within the diet, which can be broadly divided into saturated and unsaturated fatty acids (Fahy, et al., 2005). Unsaturated fatty acids are identified by containing one or more double bonds, within their fatty acid chains, and are normally liquid at room temperature (Fahy, et al., 2005). Fats containing just one double bond are described as monounsaturated fats, and fats containing more than one double bond being referred to as polyunsaturated fats (Fahy, et al., 2005). Saturated fat contains no double bonds and is 'saturated' in hydrogen atoms; they are commonly identified as solid at room temperature (Fahy, et al., 2005). Trans fat is another form of fat found within the diet; although it may be a monounsaturated fat or polyunsaturated fat, they contain a trans-isomer and are generally created industrially. One form of trans fat, which occurs naturally, is vaccenic acid and is found within meat and dairy products. Monounsaturated fat, such as oleic and palmitoleic acid are essential fatty acids, to promote the roles of fat, previously stated. Each of these forms of fat has different recommendations within the diet; monounsaturated fats should contribute 15-20%, polyunsaturated fats 5-10%, saturated fat less than 10%, and trans-fat should be avoided (Lamarche & Couture, 2014).

Similar recommendations are shown for athletes, with the ACSM and ISSN suggesting an athlete's diet should be composed 20-35% (ACSM) or 30% (ISSN) fat; however, the IOC recommendations are set lower, with a recommendation of 15-20%. Recently a growing number of studies have examined the possibility of high-fat diets and athletic performance. There is some evidence that high fat-low carbohydrate diets enable athletes to increase fat metabolism, allowing them to utilize fat at higher intensities (Purdom, et al., 2018). Volek et al. (2015) suggested that keto-adapted athletes are able to reduce delayed onset of muscle soreness, increasing the time athletes can train. Typically for an ultra-athlete, who may compete in a 100-mile race, must take weeks off to allow for recovery, whereas keto-adapted athletes were able to train within the following week. Studies using a shorter adaption period have shown there is a decrease in athlete economy while endurance athletes compete at more vigorous intensities (Burke, et al., 2017). Within strength athletes, high fat diets have demonstrated no decrements in strength endurance or power after 3-4 weeks of intervention (Rhyu & Cho, 2014; Paoli, et al., 2012). While following a ketogenic diet, strength athletes have been shown to increase lean body mass, while decreasing total body weight, and maintaining overall strength performance (Rhyu & Cho, 2014; Paoli, et al., 2012).

An area of increased attention within fat ingestion in athletes is the use of medium-chain triglycerides (MCTs). MCTs are able to directly enter mitochondria and be utilized for energy via beta-oxidation (Kerksick, et al., 2018) There are mixed results in terms of the advantageous effects of MCT on endurance performance (Jeukendrop, et al., 1998; Goedecke, et al., 1999; Calabrese, et al., 1999; Angus, et al., 2000; Misell, et al., 2001). Misell et al. (2001) demonstrated an increase in runner performance when ingestion of 60g of MCT oil was added to athlete’s diet daily for 2 weeks. Many studies contract these benefits in performance, as well as showing an increase in gastric distress (Burke, et al., 2004; Thorburn, et al., 2006). Thorburn and colleagues (2006), demonstrated that utilizing a two-week high-fat diet consisting of 15g MCT within male cyclists decreases power for sprints. Further, the study demonstrated an increased feeling of nausea within the athletes, while MCT was placed within the diet compared to a carbohydrate diet. Although some studies may demonstrate increases in performance, these studies are outweighed by research demonstrating little improvements in performance, as well as gastric discomfort. There is always growing research within macronutrients, whether this is timing, amount, or co-ingestion studies. Much of the research supports that the recommendations set by the IOC, ISSN and ASCM support the needs of athletes. Not only is it important that athletes follow these recommendations, but utilising timings and supplementation, can enhance performance, and should play a role within an athlete's dietary habits. Further, it is key to highlight, many of the previously discussed research articles have simply investigated male athletes, and male participants. There is a large avoidance in performance research within females, due to the possible implications the menstrual cycle may have. Further, there is evidence that demonstrates females and males metabolize macronutrients differently. This questions whether recommendations set for athletes are truly correct.

Differences Between Female and Male Athlete Nutritional Requirement

It is evident that each macronutrient has a substantial role within athletic performance, as well as overall health and well-being. The recommendations for athletes stem from decades of male performance interventions and male athlete studies (Antonio et al., 2016; Burke et al., 2004; Getzin et al., 2017). Consequently, the use of the current recommendations for female athletic performance may not be applicable. It is believed that the lack of female participants within the literature stems from the impacts the female menstrual cycle may have on performance. The two major phases of the menstrual, the follicular and the luteal phase, are broken down further into the menstrual and late follicular phase and the ovulation and late luteal phase (Hloogeveen & Zonderland, 1996; Lowe et al., 2010). Within each of these phases, hormones such as estrogen, progesterone, follicular stimulating hormone (FSH), and luteinizing hormone (LH). Each hormone has demonstrated impacts on performance, with estrogen demonstrating an increase in skeletal muscular strength (Lowe et al., 2010), similarly progesterone has also been associated with increased strength performance (Reilly, 2000). These hormones fluctuate throughout the menstrual cycle, suggesting that performance maybe impacted, however many studies have demonstrated that little to no change in both overall strength and endurance performance, between each phase of the menstrual cycle (Arazi et al., 2019; Dombovy et al., 1987). Although strong significant changes can be seen within these performance parameters throughout the menstrual cycle, few studies have demonstrated a significant change within overall performance (Julian et al., 2020). One of the key menstrual cycle hormones, which has demonstrated an impact on female metabolism is 17-β-estradiol. Rooney et al. (1993), demonstrated 17-β-estradiol increases glycogen sparing within females. However, the glycogen sparing is shown to be within hepatic glycogen storage rather than skeletal muscle (Dawson & Reilly, 2009). 17-β-estradiol, has also demonstrated to negatively impact a female athlete's ability to glycogen load (Dawson & Reilly, 2009). After glycogen loading, female athletes demonstrated no increase in muscle glycogen, nor an increase in performance (Dawson & Reilly, 2009). This questions the effectiveness and requirement for carbohydrate loading within female athletes. It has since been noted that to ensure carbohydrate loading is sufficient within female athletes, a diet of 30% greater energy for four days, ensuring carbohydrate intake is above 8 g/kg/day provides sufficient enables the athlete to carbohydrate load (Wismann & Willeoughby, 2006).

Increased glycogen sparing within female endurance athletes could be explained through an increase in lipid utilization. It has been shown that female athletes demonstrate a higher plasma free fatty acid and glycerol concentration, while exercising (Tarnopolsky et al., 1995). This increase in utilization of lipids can be explained via the greater intramuscular triglyceride storage in females compared to males (Tarnopolsky M. A., 2000). Further, endurance-trained female athletes are shown to have increased activity of β-hydroxy-acyl-CoA-dehydrogenase, compared to male athletes, suggesting female athletes are able to undergo beta oxidation at an increased rate, compared to male athletes (Maher et al., 2010). β-hydroxyl-acyl-CoA-dehydrogenase plays a crucial role in catalyzing beta oxidation of lipids, allowing athletes to utilize fat for energy (Maher et al., 2010). Research has also noted differences within oxidation of protein within male and female endurance athletes (Maher et al., 2010). Oxidation of protein, specifically leucine, is shown to be proportionally greater during exercise in males compare to female. Both leucine and branched chain amino acids are shown to increase in oxidation by at least 40% during exercise regardless of sex, which has led to an increase in protein recommendations from the daily recommended intake (DRI) of 0.8 g/kg/day to at least 1.2 g/kg/day.

In addition to the menstrual cycle and the hormone levels, different fiber type areas can be a factor, as females are shown to have a larger ratio of type I fibers compared to type II (Costill et al., 1976). There are roughly three groups of identified muscle fiber types (Type I, Type 2A, and Type 2X) each contributing differently to athletic performance (Schiaffino, 2010). Type I muscle fiber, also named slow twitch muscle fibers are highly oxidative. Slow twitch muscle fibers contraction rate is correlated with the myosin heavy chain distribution (MyHC) (Schianffino & Reggiani, 2012). Due to a lower distribution of MyHC muscle contraction is slower (Schianffino & Reggiani, 2012). This distribution increases as does the speed of muscle contraction as you move from type I muscles fibers, to type II A and finally types IIX (Schiaffino, 2010). Due to type I muscle fibers being more oxidative in nature, there is evidence that they are more resistant to fatigue. Type II A muscle fiber types are also known as oxidative glycolytic muscle fibers, and contain both oxidative and glycolytic enzymes for energy production (Schianffino & Reggiani, 2012). These muscle fiber types contract faster than Type I, and are resistant to fatigue. Type II X muscle fibers, also known as glycolytic muscle fibers, are able to contract rapidly, however, they are highly prone to fatigue (Schianffino & Reggiani, 2012). An increase in type I muscle fibers would suggest the athlete is more adapted at oxidative metabolism, thus would be more adapted to metabolizing triglycerides. This may help to explain how female endurance athletes rely more on fats to fuel their competition and training, rather than carbohydrates. Further it has been demonstrated that female athletes experience less oxidative stress compared to male athletes. Overloading of fatty acid within the body is shown to increase oxidative stress, the decrease in oxidative stress within female athletes, may suggest the ability to overcome free fatty acids within the body greater than male athletes (Murphy, 2009). This further supports the ability for females to utilize fat as an energy source more efficiently than males. This hypothesis can be supported through female athletes out-performing male athletes within ultra-distances by relying more heavily on type I muscle fibers and fat to compete.

With these evident differences between both male and female metabolism, it is unclear why there are no differences between male and female athlete macronutrient recommendations. However, within the macronutrient guidelines, there is evidence for selected recommendations for certain types of sport, whether these are classified as endurance, strength, moderate-intensity or high-intensity sports. These recommendations can be seen within Appendices A.

Macronutrient intake of athletes

Macronutrient intake within power and strength sports

There are a wide range of sports, which can be defined as power and strength sports, which require different macronutrient intakes to other disciplines, such as endurance and team sports (Slater & Mitchell, 2019). Specific power and strength sports traditionally only last for short durations during competition, therefore macronutrient requirements for these athletes are notably different than those of endurance athletes. Although the requirements may differ for these athletes, macronutrients still play three key roles, including fueling athletes, providing recovery and, aiding and promoting training adaptations such as hypertrophy (Slater & Mitchell, 2019). Energy requirements for power and strength sports differ to endurance sports, due to predominantly using different energy systems, with power and strength utilizing the ATP-CP system and glycolysis (Lambert & Flynn, 2002). Recommendations for macronutrients differ for power and strength sports between organizations, ranging from an intake of 5 g/kg/day (IOC) to 10 g/kg/day (ACSM and ISSN) for carbohydrates, 1.2 g/kg/day (ACSM) to 2.0 g/kg/day (ISSN) for protein, and 15% (IOC) to 30% (ISSN) for dietary fat.

Observational nutrition studies examining power and strength athletes show an intake a range of 4 g/kg/day to 5 g/kg/day of carbohydrate within their diet (Nepocatych et al., 2017; Sugiura et al., 1999; Wardenaar et al., 2017; Burke et al., 2003; De Sousa et al., 2008). Although this range is within the IOC recommendations, research has demonstrated that power and strength athletes may require more than 4 g/kg/day to enhance performance. Volek et al., (2006), recommended that female strength and power athletes should consume 6 g/kg/day to ensure optimal performance and training. This recommendation is set as muscle glycogen stores have been shown to deplete by 40 percent, especially if the athlete is completing training to elicit hypertrophy (MacDougall et al., 1999; Tesch et al., 1986). Depletion and reductions of glycogen stores have shown to impair strength and power performance and reduce training capacity (Tesch et al., 1986). It is evident that many strength and power athletes may not be consuming a sufficient intake of carbohydrates to reach the athletes potential performance. However, the ingestion of high carbohydrate intakes (>8 g/kg/day), has shown little improvement within strength athlete performance, specifically within female athletes (Volek et al., 2006). Female athletes are unable to synthesize glycogen to the same extent as their male counterparts. Tarnopolsky and Ruby (2001), demonstrate that to elicit similar increases in glycogen storage as males, female athletes must increase their overall caloric intake, and not simply increase carbohydrate intake. An increase of just carbohydrate has shown to displace protein and fat, leading to deficiencies within female athletes, impacting hormone and nitrogen balance within the body (Tarnopolsky et al., 1995).

Protein intake within strength and power athletes has been highly researched, with the hypotheses that increased protein intakes, can elicit increased protein synthesis and promote increased strength. Although increased protein intake is shown to elicit increased protein synthesis, enhancing strength and performance is limited (Norton & Wilson, 2009). An intake of protein up to 2.8 g/kg/day has demonstrated significant increases in protein synthesis, as well as increases in overall athlete performance compared to when athletes consume the DRI of 0.8 g/kg/day. However, there has been no evidence to suggest significant differences in ingesting 2.8 g/kg/day and the recommended values for strength and power athletes (2.0 g/kg/day) (Hoffman et al., 2006). Overall, research has shown strength and power athletes ingest a range of protein from 1 g/kg/day to 1.6 g/kg/day (Burke et al., 2003; De Sousa et al., 2008; Nepocatych et al., 2017). This protein intake relatively low, when comparing to the recommendations that range from 1.2 g/kg/day (ACSM) to 2.0 g/kg/day (ISSN). Lemon (1996) determined athletes require at least 1.4 g/kg/day to ensure peak performance is maintained. This suggests that many female strength and power athletes do not consume sufficient protein, suggesting limited protein synthesis and inhibited recovery.

Contrary to protein intake within female strength and power athletes, fat intake is observed to be higher than the set recommendations (Wardenaar et al., 2017). There have been some concerns to health implications when athletes ingest a high fat diets, as blood lipid profiles have been noted to increase (Faber et al., 1986; Faber et al., 1990). Increased blood lipid profiles have been linked to several health implications, such as cardiovascular disease, hypertension, and glaucoma (Wang & Bao, 2019; Schwingshackl & Hoffmann, 2013) . Further, increased blood lipid levels can impact both endurance and sprint trained athlete performance, as it limits antioxidant release from the body, decreasing recovery within the body and increasing levels of free radicals (Marzatico et al., 1997). The reported high fat intakes found within strength and power athletes, have been suggested to contribute to overall energy intake, due to reduced carbohydrate intakes seen within this discipline. Recently there has been increase in research regarding high-fat diets within strength and power athletes and the implication of these diets on health and performance. It is believed that high-fat diets may be more beneficial to female athletes, as it increases the fat oxidation rates through enzymatic and metabolic adaptations. As previously discussed, females are shown to rely less on glycogen than their male counterparts. This suggests a high-fat diet may be beneficial to female performance by providing energy from intramuscular muscle triglycerides (Binzen et al., 2001). However, many studies have demonstrated high-fat diets causing detrimental impacts on high-intensity activity and causing a dysfunction within the mitochondria through an impairment in adenosine diphosphate sensitivity (Miotto et al., 2018; O'Malley et al., 2017).

Macronutrient intake within endurance athletes

Endurance athletes are some of the most researched athletes within the nutrition and performance world. An abundance of studies has examined the impacts of carbohydrate within diets, including timing, supplementation, and overall ingestion. Studies have demonstrated that carbohydrates can play a crucial role within endurance performance, whether this is through carbohydrate loading (Tarnopolsky et al., 1995), ingestion during exercise (Krings et al., 2017; Rountree et al., 2017), or utilizing carbohydrates for recovery (Costill et al., 1981). Due to the importance of carbohydrate to enhance athlete performance, the need to follow the recommendations set should be vital to athletes. However, when examining the literature there seems to be few studies examining female endurance athlete overall intakes of macronutrients, but rather the focus is on energy, Vitamin D, and iron deficiencies (Mountjoy et al., 2014; Pedlar et al., 2018; Malczewska-Lenczowska et al., 2018).

The recommendations for endurance athletes differ depending on which governing body athletes, dieticians and coaches are following; the IOC and ACSM recommends that an endurance athlete consumes 6-10 g/kg/day, whereas the ISSN recommends an intake of 8-10 g/kg/day. Few studies examine the overall macronutrient intake of female athletes, but those that do demonstrate a range of carbohydrate intakes from 6.8 g/kg/day to 10.4 g/kg/day (De Sousa et al., 2008; Beis et al., 2011; Burke et al., 2003; Martin et al., 2006; Onywera et al., 2004; Sugiura et al., 1999). While examining the literature it is evident that the lower intake of carbohydrates occurs more frequently in collegiate female athletes compared to elite distance runners

(Beermann et al., 2020; Shriver et al., 2013; Sugiura et al., 1999). These lower intakes have shown an impairment within overall endurance performance (Loucks, 2004). Costill et al. (1981) demonstrated the need for carbohydrate within aerobic athletes was greater than strength and power athletes to ensure fuel needs are met and glycogen is replaced both during competition and post-training.

Protein intakes for endurance athletes have been debated over the years, with recommendations ranging from 1.2 g/kg/day (ACSM) to 2.0g/kg/day (ISSN). Research has suggested the optimum intake of protein for endurance athletes training 4 to 5 days per week for longer than an hour should consume 1.6 g/kg/day (Tarnopolsky, 2004). However, differences have been noted between male and female athletes, with females requiring 15% to 20% less protein than their male counterparts (Tarnopolsky, 2004). Previous research has demonstrated a range of protein intake from 1.2 g/kg/day to as high as 2.4 g/kg/day within female athletes (De Sousa et al., 2008; Onywera et al., 2004; Wardenaar et al., 2017; Sugiura et al., 1999; Burke et al., 2003). However, few of these studies concentrated on collegiate athletes, with many examining elite endurance female athlete protein consumptions thus limiting the understanding of the true protein intake of collegiate female endurance athletes.

Similarly, there is little evidence of collegiate female fat intake, with previous research concentrating on elite level athletes. The current recommendation for fat within endurance athletes is widely given within a percentage ranging from 15% to 30% of the athlete's diet. ACSM recommends that athletes ingest 0.5-1.0 g/kg/day, although research demonstrates female endurance athletes consume up to 2.2 g/kg/day of fat (Sugiura et al., 1999). Horvath et al., (2000), showed that high fat diets within runners does not significantly alter physical characteristics, nor does it significantly impact body composition. Ultimately, Horvath et al.,

(2000) concluded that consumption of medium to higher fat diets (greater than 30%), can increase the athlete's choice in foods, allowing an increased intake of vitamins and minerals as well as aiding to meet energy expenditure needs.

Macronutrient intake within team sports

There are few macronutrient recommendations for team sports from any of the three main governing bodies (ACSM, IOC, and ISSN), with each organization setting recommendations for both strength and endurance sports. Mujika and Burke (2010) define team sports as moderate-to-long duration activity. The ISSN recommendations are divided into two areas: high-intensity, high-volume, and high-intensity, moderate-volume. Sports categorized as high-intensity, high-volume, would be sports such as soccer, field hockey, and tennis; with high-intensity, moderate volume being sports such as football, baseball, and softball. The physiological demand of a team sport athlete can depend on the athlete's position, game tactics, their opposition, and even the climate. These changes in physiological demands place challenges for the athlete's nutritional need. These can play a role in the why determining exact macronutrient recommendations for team sports is difficult. An example would be a goalkeeper, who within an association football match will roughly cover 600 m, with 75% of this being walking (Di Salvo et al., 2008). However, a midfield player will jog, run or sprint for roughly 49.3% of the match (Bloomfield et al., 2007). When looking at similar positions across different sports there are further differences in energy needs, as a midfield association football player, is shown to require up to 3500kcal, whereas a netball player requires 2800kcal (Young et al., 2016; Dobrowolski & Wlodarek, 2019; Rumbold et al., 2011).

Research demonstrates an average intake of 3.9 g/kg/day of carbohydrate for female team athletes (Baker et al., 2014; Nepocatych et al., 2017; Zabriskie et al., 2019; Condo et al., 2019;

Wardenaar et al., 2017; Clark et al., 2003; Valliant et al., 2012; Burke et al., 2003; Gibson et al., 2011; Mielgo-Ayuso et al., 2015). Sports such as lacrosse, volleyball and softball were noted to have the lowest intakes of carbohydrate. The lower intakes of carbohydrate within softball may be explained by heavily relying on the ATP-PC system during competition. However, during strength and conditioning sessions their energy demand becomes greater, requiring energy from glycolysis. This limited carbohydrate intake has the potential to negatively impact performance. If there is insufficient energy available for the athlete to train to an optimum level then adaptations and recovery of the athlete cannot occur to ensure performance is maximized (Burke, 2001). This has been evident within several studies, where carbohydrate has demonstrated to increase performance when supplemented prior, during and post-competition (Jeukendrup & McLaughlin, 2011; Baker et al., 2015; McCartney, Debrow, & Irwin, 2018). The only sport to demonstrate sufficient intakes of carbohydrate (using the ISSN and IOC recommendations) was soccer, ingesting 5-5.7 g/kg/day. However, if the ACSM recommendations are used to analyze the carbohydrate intakes of association football, then the players would be deemed to have insufficient intakes.

Protein intake shows a similar variance amongst the different sports. As seen with carbohydrate, volleyball demonstrates some of the lowest intakes of protein. Valliant, et al., (2012) demonstrated, an average intake of just 0.9 g/kg/day of protein ingestion within eleven elite level volleyball players using a 3-day food diary to gather data. Although, 3-day food diaries are regularly used within studies, it is important to highlight the limitations. This methodology, relies heavily on the athlete maintaining their normal diet, as well as recording exactly what they have consumed, evidence suggests that participants within these protocols, may lie recording phantom foods within their diaries (Jo et al., 2020). Papadopoulou, et al., (2002), similarly showed these low intakes of protein within 65 junior volleyball players, also using a 3-day food diary for data collection. Other teams including association football, softball, basketball, rugby sevens, and field hockey demonstrate protein intakes within the ACSM, IOC and ISSN recommendations, ingesting an average of 1.3 g/kg/day of protein (Martin et al., 2006; Nepocatych et al., 2017; Wardenaar et al., 2017).

Association football players have been noted to have some of the highest intakes of protein. Santos et al. (2016), demonstrated an average, protein intake of 2.0 g/kg/day within 30 elite female soccer players. The study examined nutritional intake during the players' pre-season, using 24-hour recalls (two during the week and one during the weekend). Raizel et al. (2017), similarly showed that soccer players protein intake, during their pre-season phase is higher than the recommendations, as nineteen players were shown to ingest 1.9 g/kg/day of protein each day as assessed via a 3-day food diary. High intakes of protein were first thought to be detrimental to renal health with athletes, however studies have demonstrated protein intakes of 3.5 g/kg/day, resulting in an increase in athlete performance (Phillips, 2004). Cintineo et al. (2018) discuss that overall increase in protein intake, and not simply protein supplementation pre- and post-exercise, demonstrates key increases in strength performance. Intakes above this limit have not shown further increases in performance, nor has it demonstrated increases in health risks.

Contemporaneous evidence suggests that fat intakes for female team sport athletes exceed the existing guidelines set by the IOC, ACSM, and ISSN (Baker et al., 2014; Nepocatych et al., 2017; Zabriskie et al., 2019; Condo et al, 2019; Wardenaar et al., 2017; Clark 2003; Valliant et al., 2012; Burke et al., 2003). De Sousa et al. (2008) demonstrated that in team sports (aged 11-14), such as soccer, indoor soccer, handball, and basketball athletes consumed an average of 1.9 g/kg/day of fat. The age of these athletes may have implications to the level of fat within their diet, as it has been shown that younger athletes rely more heavily of fat oxidation that carbohydrates (Smith et al., 2015; Jeukendrup & Cronin, 2011). Therefore, children may need a higher recommendation of fat within their diet to ensure energy demands are met for their given sport. Fat intakes have also been shown to be significantly higher than the recommendations in female volleyball players, as Mieglo-Ayuseo et al. (2015) demonstrated 22 elite players ingested an average 1.6 g/kg/day over 7 days both in-season and during pre-season. Similarly, collegiate basketball players have shown an increased intake of fat of 1.6 g/kg/day compared to the recommendations being set at 1.0 g/kg/day (Nepocatych et al., 2017). The basketball players were examined during in-season using a 3-day food diary. Although, as previously discussed, increased fat intakes can be beneficial to young athletes, it can also be detrimental to adult athletes. Nepocatych et al., (2017), demonstrated those ingesting an intake of 1.6 g/kg/day of fat, had an average body fat percentage of 30.1%. It could be suggested that this higher body fat percentage within female basketball players, may reduce performance as, Riezebos et al., (1983), demonstrated increased anaerobic, aerobic and accuracy in female basketball shooters, with a lower body fat percentage. However, due to some contact nature of basketball it is also believed that the added mass of basketball players can be advantageous (Fleck, 1983).

Conclusion

From the literature, it is evident female athletes are consuming a wide range of macronutrients, from insufficient consumption to eating in excess. However, there is very limited research on female collegiate athletes. This highlights a key gap within literature, suggesting more research is needed regarding the macronutrient intake in this population. With an increased understanding of current collegiate female athlete macronutrient intakes, dieticians, researchers, and coaches will be able to gain more knowledge in possible areas to enhance the performance and health of their athletes. The study may also help determine whether collegiate athletes are following recommendations and advice given by their team dieticians. If these recommendations and advice are not followed, this gives way to further research to examine possible influences on collegiate nutritional intake. Due to the apparent gap within literature, the current study examines the macronutrient intake of a variety of sports within female collegiate athletes.

CHAPTER III

METHODOLOGY

Study Design

A descriptive observational design was used for the study, where the macronutrient intake of female Division I athletes was recorded. Before the study began, ethical approval was given for this study by the IRB of Mississippi State University (see appendix B).

Participants

Eighty division I collegiate female athletes (age: 19.5 ± 1.5), competing within the south region, were recruited and consented to take part in the study. Athletes were recruited from the following sports: basketball, volleyball, cross-country, and soccer. Each athlete completed the study during their in-season phase of training, in which athletes are permitted to train no more than 20 hours per week (National Collegiate Athletic Association, 2000). Each athlete was assessed for injuries through completing the physical activity readiness questionnaire plus (PAR-Q+). The questionnaire also asked about medications consumed at the time of the study, ensuring participants were not on any influencing metabolic medication. Participants were excluded from the study if they had been previously identified at risk of relative energy deficiency syndrome (RED-S) by the team's registered dietician and medical staff.

Dietary Measurements

Athletes were asked to photograph any food products or beverages they consumed for six days over a two-week period. Over this two-week period, athletes were asked to record a total of two weekend days and four weekdays. The participants were asked to use the photographs taken of their daily intakes and complete an automated self-assessment 24-hour recall questionnaire (ASA24), recording their nutritional intakes 24-hours later.

Body Composition Measurements

Body composition of athletes was measured using bioelectrical impedance via InBody 370 (Cerritos, CA, USA), during their in-season phase of training. Body composition values that were recorded as follows: body mass index (BMI) (kg/m^2), weight (kg), body fat mass (% and kg), muscle mass (kg), and basal metabolic rate (BMR) (kcal). Height of athletes was measured using a stadiometer (235D, QuickMedical, Issaquah, WA, USA). Athletes were asked to avoid consuming any food and told to only consume water in the 8 hours prior to testing.

Statistical Analysis

Data were analyzed using SPSS (version 16.0, Chicago, IL). A one-sample t-test was used to detect any significant differences between sports and the IOC recommendations, with significance set a priori at $p<0.05$. A one-way analysis of variance (ANOVA) was used to determine whether there were any significant differences between macronutrient ingestion of different sports with significance was set a priori at $p<0.05$.

CHAPTER IV

RESULTS

Participants

A total of 26 (age: 19.5 ± 1.5) female division I collegiate athletes completed the study. The athletes were from the following sports: soccer (n= 7), cross-country (n= 12), basketball (n=2), and volleyball (n= 5). The descriptive data of athletes within each sporting discipline can be seen within Table 1 below. Significant differences between sports were noted between body fat percentage (%) (p=0.005, F= 7.090), fat free mass (kg) (p=0.004, F= 7.164), fat mass (kg) (p=0.039, F=3.725), BMR (p=0.005, F= 6.769) and overall body mass (p= 0.011, F=5.656). Soccer athletes' body fat percentage was significantly greater than both cross-country athletes (p=0.002, CI 2.98, 11.05) and basketball players (P=0.009, CI 2.56, 14.38), however no significant difference was noted between soccer and volleyball (p>0.005). Fat free mass was significantly greater in soccer players compared to cross-country athletes (p=0.001 CI 8.99, 26.00) and basketball players (p=0.05 CI 0.01, 24.90). Soccer and cross-country athletes were the only sports to demonstrate significant differences with fat mass (p=0.018 CI 1.10, 9.82).

Table 1

Descriptive Data of Athletes' Body Composition Within Each Analyzed Sport

Sport	*Body Composition*				
	Body fat (%)	Fat Free Mass (kg)	Body mass (kg)	BMR	Body Fat Mass (kg)
Soccer	27.60 2.25 ± 2.25†	48.40 ± 2.00†	66.70 ± 4.69	1415.40 ± 43.10	17.43 ± 4.53†
Cross Country	20.60 3.55 ± 3.55†	30.90 ± 7.59†	57.60 ± 7.01	1397.43 ± 105.60	11.97 ± 3.11†
Volleyball	29.50	29.90	68.70	1416.00	20.32
Basketball	19.20 0.92 ± 0.92†	35.95 ± 6.70†	79.00 ± 13.18	1751.00 ± 246.07	14.98 ±1.64
Overall	22.60 ± 4.62	35.38 ± 9.77	62.90 ± 9.91	1470.00 ±163.28	14.1 ± 4.19

* Significant difference to recommended intakes ($p<0.05$)

† Significant difference between sports ($p<0.05$)

Macronutrient Intake Between Sports

Carbohydrates

Carbohydrate ingestion measured in both g and g/kg were shown to be significantly different between sports (p=0.008, F=5.078; p=0.008, F=6.031, respectively). Cross-country athletes were shown to consume significantly more carbohydrates compared to both basketball players (p=0.006, CI -40.880, 214.47; p=0.004, CI -5.18, -1229.00) and soccer players (p=0.006, CI -133.59, -25.49; p=0.018, CI -3.40, -0.39) as measured in both g and g/kg. The percent of carbohydrates, which contributed to the athletes' overall caloric intake, demonstrated no significant differences between sports (p=0.070, F=7.209).

Protein

The percent of protein that contributed to the athletes' overall caloric intake was shown to be significantly different between sports (p=0.001, F=7.848). Soccer players' diets were shown to have a significantly higher percentage of protein compared to that of cross-country (p=0.011, CI 1.17, 8.23) and volleyball players (p=0.002, CI 3.04, 11.73). Similarly, the diet of basketball players showed a significantly higher percentage of protein within their diet compared to cross-country (p=0.003, CI 3.42, 14.75) and volleyball (p=0.001, CI 5.56, 17.98). No significant differences were noted between sports regarding their protein intakes, both when measures in g (p=0.388, F=1.055) and g/kg (p=0.132, F=2.240).

Fat

The percent of protein that contributed to the athletes' overall caloric intake was shown to be significantly different between sports (p=0.001, F=7.848). Soccer players' diets were shown to have a significantly higher percentage of protein compared to that of cross-country (p=0.011, CI 1.17, 8.23) and volleyball players (p=0.002, CI 3.04, 11.73). Similarly, the diet of basketball players showed a significantly higher percentage of protein within their diet compared to cross-country (p=0.003, CI 3.42, 14.75) and volleyball (p=0.001, CI 5.56, 17.98). No significant differences were noted between sports regarding their protein intakes, both when measures in g (p=0.388, F=1.055) and g/kg (p=0.132, F=2.240).

Overall Caloric Intake

A significant difference within the overall calorie intake was noted between the four different sports (p=0.035, F=3.419). Cross-country athletes consumed a significantly higher caloric diet than basketball (p= 0.023, CI -800.22, -65.90) and soccer players (p=0.017, CI: 141.76, 1321.01).

Table 2

Comparison of Macronutrient Intake of Female Cross-Country, Soccer, Basketball and, Volleyball Athletes to the IOC Recommendations.

Macronutrient Intake										
Sport	Total energy (kcal)	Carbohydrate			Protein (g)			Fat (g)		
		(g)	(g/kg)	(%)	(g)	(g/kg)	(%)	(g)	(g/kg)	(%)
Soccer	1685.35 ± 304.54$^{\dagger *}$	191 ± 58$^{\dagger *}$	2.92 ± 1.01*	45 ± 8$^{\dagger *}$	103 ± 14*	1.54 ± 0.19*	24 ± 2†	59 ± 15	0.89 ± 0.05†	31 ± 7*
Cross Country	2118.41 ± 427.44†	271 ± 57$^{\dagger *}$	4.81 ± 1.28	50 ± 5$^{\dagger *}$	105 ± 28*	1.87 ± 0.59*	19 ± 4$^{\dagger *}$	73 ± 18*	1.32 ± 0.31†	31 ± 4*
Volleyball	1892.38 ± 308.39*	224 ± 41*	-	47 ± 6*	83 ± 27	-	17 ± 3$^{\dagger *}$	78 ± 18	-	36 ± 6*
Basketball	1387.02 ± 319.23$^{\dagger *}$	143 ± 35$^{\dagger *}$	1.61 ± 0.41	42 ± 1†	99 ± 10	1.26 ± 0.08	27 ± 4†	48 ± 16	0.6 ± 0.10†	31 ± 4*
Overall	1902.09 ± 422.85*	230 ± 67*	3.84 ± 1.64	48 ± 7	101 ± 24*	1.65 ± 0.56*	21 ± 5*	68 ± 19	1.11 ± 0.36	31 ± 5*

* Significant difference to recommended intakes ($p<0.05$)
† Significant difference between sports ($p<0.05$)

Macronutrient Intake Compared to IOC Recommendations

Carbohydrates

Overall, the carbohydrate intake of athletes was shown to be significantly lower than the IOC recommendations, when measured in g (p<0.001; CI -174.047, -120.027) and g/kg (p<0.001; CI -3.006, -1.316). When accounting for carbohydrate intakes in grams, soccer (p<0.00; CI -262.9079, -115.4307), cross country (p<0.001; CI -2865.5817, -255.8132) basketball (p=0.047; CI -641.8845, -20.3177) and volleyball (p=0.001; CI -239.2748, -137.294) consumed significantly lower intakes compared to the recommendations. Similarly, when comparing the percent of carbohydrate which contributes to the athletes' diet to IOC recommendations, soccer (p= 0.002; CI -22.5800, -7.7143), cross-country (p=0.002; CI -12.2726, -4.5017), basketball (p=0.012; CI -23.3751, -14.3201) and volleyball (p=0.013; CI -20.5302, -4.4417) all showed significantly lower proportions. Only soccer (p=0.009; CI -4.6943, -1.4739), and basketball (p=0.042; CI -8.0431, -0.7433) players demonstrated significantly lower intakes of carbohydrate in g/kg compared to the IOC recommendations.

Protein

The overall protein intake measured in grams (p<0.001; CI -161.242266, -141.845391) g/kg (p=0.004; CI 0.1679768879, 0.7406084179) and percent of diet (p=0.001; CI -5.5209, -1.6200) was seen to be significantly different than recommendations set by the IOC. Both protein intakes measured in grams and g/kg were significantly higher than the IOC recommendations; however, the percent of protein that makes up the overall caloric intake was significantly lower than the IOC recommendations. Soccer and cross-country athletes both demonstrated significantly higher intakes of protein when measured in grams (soccer: p=0.005; CI 9.8621, 36.0425; cross-country p=0.001; CI 26.5051, 64.6959), and g/kg (soccer: p= 0.037; CI 0.0392, 0.6321; cross-country: p=0.006; CI 0.4856, 1.5279). When assessed as a percentage, the protein content of both cross-country (p= 0.048; CI -8.0544, -0.0399) and volleyball (p=0.005; CI -11.4475, -3.9621) athletes was the protein content of both cross-country (of overall caloric intake, was significantly lower than the IOC recommendations.

Fat

The fat percent within the athletes' diet was significantly more significant than the recommendation of the IOC (p<0.001; CI 15.116, 19.510). Overall fat intakes of athletes, measured in grams (p=0.154; CI -2.185, 13.070) and g/kg (p=0.208; CI -0.070, 0.2991), were shown to have no significant difference with the IOC recommendations. Cross-country athletes demonstrated significantly higher intakes of fat compared to the IOC recommendations when measuring in grams (p=0.037; CI 1.4183, 32.1868) and g/kg (p=0.005; CI 0.2332, 0.6753). Both soccer and cross-country athletes' diets consisted of a significantly greater percentage of fat within their diet (soccer: p<0.001; CI 9.7845, 23.2984; cross-country: p<0.001; CI 12.636, 17.5306) compared to the recommendation set by the IOC. Significantly lower intakes of fat (measured in g/kg) were observed within soccer players when comparing them to the IOC recommendations (p=0.027; CI -0.1889, 0.0225). The fat intake percentage of volleyball players was significantly lower than the IOC recommendations (p=0.001; CI 15.1931, 29.1628).

Overall Caloric Intake

Overall caloric intake was significantly lower than the IOC recommendations (p<0.001; CI -768.706399, -427.122938). Soccer, volleyball, and basketball players demonstrated significantly lower caloric intakes compared to the IOC recommendations (soccer: p<0.001; CI-

1096.3040, -533.0013; volleyball: p=0.012; CI -990.5425, -224.7060; basketball: p=0.002; CI -1099.5307, -404.4930).

CHAPTER V

DISCUSSION

Overview of Results

The overall aim of the study was to examine whether macronutrient intakes of female athletes differed from the recommended intakes set by the IOC and to determine whether female athletes from different sports consumed different quantities of macronutrients. The study demonstrated several significant differences between the macronutrient intakes of female athletes and the IOC recommendations. Overall caloric intake for athletes was found to be significantly lower than the recommendations from the IOC, as well as carbohydrate intake. Differences between macronutrient intakes were also shown between sports, with cross-country runners consuming a significantly higher caloric intake than soccer and basketball players. The study demonstrated further differences between sports and their consumption of the different macronutrients.

Interpretation of Results

The results from the study supported both alternative hypotheses, with significant differences being demonstrated between the macronutrient intakes of athletes and the IOC recommendations, as well as a significant difference between the macronutrient intakes of different sports. The results support previous research, which has demonstrated female athletes consume significantly lower overall caloric intake (Shriver et al., 2013; Nepocatych et al., 2017). Soccer, basketball, and volleyball players all demonstrated significantly lower calorie intakes compared to their recommended intakes; however, the cross country showed sufficient intakes. Previous research demonstrates cross-country athletes are notorious for reporting insufficient calorie intakes compared to their recommendations (Griffin et al., 2021; Beerman et al., 2020). Based on athletes answering a food frequency questionnaire, Beerman et al., (2020) recently demonstrated that female cross-country runners consumed a diet of 1927 kcal per day. It was suggested that a diet consisting of 1927 kcal per day was insufficient for the athletes' needs. Within the current study female cross-country runners were shown to consume a greater number of calories (2118.41kcal), which showed no statistical difference against their recommendations of energy intakes and were deemed sufficient to the needs of the athletes.

Energy intake from soccer, volleyball, and basketball players were shown to be significantly lower than the IOC recommendations, which has been shown within previous research (Braun et al, 2018; Martin et al., 2006; Moss et al., 2020; Mielgo-Ayuso et al., 2015; Panadopoulou, 2015; Zanders, et al., 2021). Braun et al., (2018), demonstrated that female soccer players consumed the recommended caloric intake; however, when assessed against the athlete's energy requirements, these values were shown to be insufficient. Earlier studies by Martin et al, (2006), however, demonstrated that soccer players consumed significantly lower than their daily recommendation; however, their intake was sufficient in comparison to their daily energy expenditure. A reason behind the decreased energy intake could be due to the reported low carbohydrate intake of athletes within the current study. Several studies have demonstrated increased numbers of female soccer players both at the collegiate and professional level consuming insufficient energy intakes (Reed et al., 2013; Magee et al., 2020; Moss et al., 2020). Magee et al., (2020) recorded a 67% prevalence in low energy availability among collegiate female soccer players. Lower prevalence has been noted among female volleyball players

(Woodruff & Meloche, 2013). Previous research has shown 20% of collegiate volleyball players consume insufficient energy recommendations for their energy needs (Woodruff & Meloche, 2013). Beals & Monroe (2007) suggested an athlete who consumes below 2,000 kcal per day cannot support their high physical demands from both training and competition. This suggests that the females within this study are performing in an energy deficit and, therefore likely unable to perform at their optimum level.

Athletes demonstrating a significantly lower overall caloric intake compared to their recommendations have shown to lead to decreased performances and increased risks in health implications. Low energy intakes have been shown to correspond with low body fat percentage and have established links with impaired bone health (through decreased bone density), reduced reproductive function, and increased risks within stress fractures within female endurance athletes (Loucks, 2007).

Increased risks in stress fractures have been recently correlated with a decreased caloric intake (Griffin et al., 2021). Griffin et al., (2021) demonstrated female athletes who consumed a diet of 1965 kcal per day or less correlated with an increased risk of generating stress fractures within female endurance athletes. It has been shown that caloric intake is correlated with femur neck bone mineral density, with lower caloric intakes decreasing the bone mineral density within the femur neck, increasing the likelihood of a stress fracture (Griffin et al., 2021). Not only are stress fractures health risks, but they also impact and decrease performance within athletes, preventing them from training or competing.

Decreased energy intakes have also been associated with decreased performance through reducing both physical and mental abilities (Bangsbo, 2000; Beals, 2002; American College of Sports Medicine (ACSM) et al., 2009; Panadopoulou, 2015; Gastrich et al., 2020). Within team and skilled sports low energy availability has been shown to inhibit key ball skills and reduces tactical performance within matches (Beals, 2002). Within the current study both volleyball and soccer, both technical and skilled sports, were highlighted as being energy insufficient. Performance is further impacted through energy deficiency as athletes require longer periods for recovery and are likely to fatigue during both training and competition quicker (ACSM et al., 2009). This can be explained as metabolic rate is shown to decrease with a lower caloric intake as the body will try to prevent starvation (Thompson, 1998). If an athlete continues to consume a low caloric diet power output will be reduced as evidence shows losses in both muscle mass and bone density, which are linked to power output in athletes (Meyer et al., 2007; Burke, 2017).

Overall carbohydrate intakes were shown to be significantly low compared to the IOC recommendations, which coincides with many other previous studies (Wardenaar et al., 2017; Beerman et al., 2020; Shriver et al., 2013). Wardenaar et al., (2017) demonstrated a 54.4%, 80.5%, and 73.0% prevalence for low intakes of carbohydrates in endurance, team, and strength sports, respectively, when comparing their intakes with a recommended 5 g/kg. Martin et al., (2006), demonstrated that although soccer players consumed a significantly lower caloric intake than recommendations, carbohydrate intakes fell within the recommendations. More recent studies have demonstrated a lower intake of carbohydrates compared to the daily recommendations (Dobrowolski & Wlodarek, 2019; Braun et al, 2018). Dobrowolski & Wlodarek (2019) demonstrated professional female soccer players consumed 3.28 g/kg of carbohydrate per day, with 92% of athletes not reaching recommended intakes. Braun et al., (2018) showed similar results, with 31% of female soccer player consuming less than 5 g/kg of carbohydrate a day.

Cross-country athletes were shown to consume their recommended daily intake of carbohydrates when measured in g/kg per day, which has not been shown within previous research. In a study conducted by Beerman et al. (2020), 73% of female cross-country runners consumed insufficient carbohydrates compared to the recommendations set. Similarly, Matt et al., (2021) found that collegiate female endurance runners did not meet the carbohydrate recommendations of 6 g/kg per day. The current study also demonstrated that although female cross-country runners consumed the recommendation of g/kg per day of carbohydrate, the proportion of carbohydrate did not reach 60% of the diet, which is also a recommendation for this sport. This could be due to a significantly higher intake of fat compared to the recommendations.

The low intakes of carbohydrates reported within the current study could lead to explaining the reduced overall energy intake from the athletes. Low intakes of carbohydrates have been proven to decrease performance within athletes as limited carbohydrates can reduce time to fatigue and prevent the athlete from getting sufficient energy during the competition (Burke et al., 2001). Enhanced glucose uptake has been shown to enhance athlete performance by ensuring sufficient energy is provided to the working muscles via maintaining blood glucose levels during competition and training (Moore, 2015). Carbohydrates are shown to be one of the main energy sources for collegiate athletes due to the body's ability to rapidly metabolize it. Muscle glycogen has been shown to be the main energy source during high-intensity bouts of exercise due to its specific intramuscular pools located near the mitochondria, sarcoplasmic reticulum, and contractile myofibrillar proteins where rapidly metabolized fuels are needed for continued muscle contraction (Nielson et al., 2011; Philip et al., 2012). When glycogen stores are depleted due to insufficient intakes, athletes are shown to suffer from hypoglycemia which results in a reduction in intensity (Coyle, 2012). This forced reduction in intensity inhibits the athlete's performance preventing them from reaching peak performance.

Reduced intakes of carbohydrates have also been shown to prolong recovery times due to inadequate amounts being present for replenishing carbohydrate liver and muscle glycogen stores (Burke et al., 2004; Burke et al., 2001). Burke et al., (2004) demonstrated that a diet consisting of less than 4 g/kg per day was insufficient to replenishing both liver and muscle glycogen for daily training, regardless of the athletes' season. Within the current study, only cross-country athletes were shown to consume above the IOC carbohydrate recommendation. This suggests that volleyball, basketball, and soccer players within the study are likely unable to fully replenish their glycogen stores between daily training sessions. Burke et al., (2011) stated that a high carbohydrate diet was essential for athlete recovery and performance, specifically when judged as a percentage of the athlete's diet. Additionally, the data collected from the athletes within the current study was collected during their in-season phase of training, when recovery is vital for performance, with some athletes competing just days after previous competitions.

Fat intakes of cross-country and soccer athletes were shown to be significantly higher than the IOC recommendations of 15-20%. Due to an increased focus on carbohydrate and protein intakes, little previous research exists comparing fat intakes to the recommendations. Ishizu et al., (2021), demonstrated a significantly higher intake of fat compared to the recommendations within endurance, aesthetic, ball, and power athletes. Increased levels in fat consumption suggest that athletes are not consuming adequate intakes of carbohydrates or protein, which athletes require for optimum performances. The result of this study supports this notion as fat percentage appears higher than the recommendations and carbohydrate intakes are shown to be significantly lower. The suggests that athletes are compensating for energy requirements through increasing fat intakes above the recommendations.

When assessing sports individually, soccer athletes were shown to consume lower fat intake than their recommendations, which does not align with previous literature (Dobrowolski & Wlodarek, 2019). Contrary to these results, Dobrowolski & Wlodarek (2019) demonstrated soccer players consuming a diet of 30% fat. It has been suggested, however that an athlete's diet consisting of over 30% fat can result in declines in athletic performance (Dobrowolski & Wlodarek, 2019).

Reduced-fat within the athlete's diet has been associated with poor immune function due to the role of fat as key mediator within the immune system (Venkatraman et al., 2000). High-carbohydrate and low-fat diets have demonstrated increases inflammation and decreased anti-inflammatory responses within athletes, which has shown to depress antioxidant response and negatively impact blood lipoprotein ratios (Venkatraman et al., 2000). Venkatraman et al., (2000), demonstrated that a diet consisting of 30% fat could reverse these effects of a low-fat diet. This evidence suggests that recommendations set by the IOC of 15-25% fat are too low for athletes and not only impact their performance but their health and immune response. It has also been shown that diets consisting of up to 42% fat can aid endurance performance within cyclists and runners when competing at 60-80% of. their VO_2max (Venkatraman et al, 2000)

Protein intakes within the current study have supported previous literature demonstrating female athletes consume a significantly higher intake of protein than the recommendations (1.2 g/kg) (Ishizu et al., 2021; Nepocatych et al., 2017; Shriver et al., 2013). Soccer and cross-country athletes notably consumed significantly higher intakes of protein compared to the recommendations (1.54 g/kg and 1.87 g/kg). High intakes of protein have been noted within both sports in previous literature (Yli-Piipari, 2019; Nieves et al., 2010; Hooper et al., 2021; Wardenaar et al., 2017). Yli-Piipari (2019), showed almost identical protein intakes of collegiate female soccer players with a consumption of 1.5 g/kg of protein daily. Hooper et al., (2021) showed lower intakes in protein in cross-country runners compared to the current study, however, intakes were still shown to be significantly higher than recommended (1.5 g/kg).

High protein intakes have been shown to be beneficial to athletes through protein's role in performance and recovery (Phillips & Van Loon, 2011). Early studies suggested that an intake of 1.4 g/kg of protein ensured peak performance within the strength and power athletes, such as volleyball players (Lemon, 1996). Higher intakes of 1.5-2.0 g/kg of protein per day have been shown to enhance muscle mass through increased protein synthesis (Cermak et al., 2012; Morton et al., 2015). Improved recovery has also been demonstrated through increased protein intakes as skeletal muscle repair and remodeling within endurance-trained athletes was shown (Koopman et al., 2004; Moore et al., 2015). These changes and adaptations from increased protein intakes have been shown to help enhance performance through enhancing muscle protein synthesis leading to muscle hypertrophy (Phillips & Van Loon, 2011). Hoffman et al., (2006) has shown intakes as high as 2.8 g/kg of protein to be significantly beneficial to athlete performance; however, few changes in performance have been reported above this level.

Wardenaar et al., (2017) demonstrated inefficient intakes of protein within 20-30% of endurance and strength sports. When assessing protein as a percentage of diet, protein intakes were shown to be significantly lower within volleyball players when compared to the recommended intakes. Papadopoulou et al., (2008) contradicts the findings of the current study as they demonstrated volleyball players consumed a significantly greater protein intake compared to basketball players when protein intakes were measured within percent of energy intake. The current study did, however, find no statistical differences between the two sports when comparing protein ingestion in g/kg, which aligns with previous research (Papadopoulou et al., 2008).

The current study raises concern for the athletes due to the small percentage of protein which makes up the athlete's diet. Basketball players were shown to be the only group of athletes to consume above the recommendation, with a diet consisting of 27%. All other sports did not comprise a sufficient percentage of protein. Low protein intakes not only impact athlete performance but are also vital for overall health. Protein is essential within bone health, playing a vital part in both bone maintenance and growth (Bonjour et al., 2015). This enhancement of growth and maintenance is triggered through amino acid stimulating the IGF-1 trophic factor to produce bone-forming cells (Bonjour et al., 2015). This may help to explain links with decreased macronutrient intakes having a correlation with increased stress fractures in athletes (Griffin et al., 2021).

Protein has widely been accepted as a vital part of athlete recovery and shown to enhance recovery when ingested alongside a carbohydrate (Burke et al., 2006; Saunders, 2007; Craven et al., 2021). To enhance recovery, it is suggested protein be ingested within 3 hours of exercise, as studies have shown delaying the ingestion of protein attenuates the anabolic effect of amino acids (Pasiakos et al., 2015). It has also been shown that protein ingestion within 24-hours post-exercise equally enhances recovery within athletes compared to 3 hours (Phillips et al., 1997). Protein ingestion post-exercise aids athlete recovery through promoting muscle protein synthesis which helps to rebuild and remodel damage done to the muscles during exercise (Kreider, 2009). Studies have shown that a general intake of 20 g high quality protein post-exercise enhances recovery within athletes through increasing oxidation of amino acids within the body (Moore et al., 2009). Macnaughton et al. (2016), demonstrated that consuming 40 g of protein within 5 hours post-exercise in strength-trained athletes can stimulate muscle protein synthesis at a 16% greater rate than consuming 20 g. More recently, a personalized recommendation of 0.25 g/kg of protein is suggested to be taken post-exercise to optimise recovery within athletes (Moore et al., 2015). Based on this research ISSN recommends athletes intake 20-40 g protein or 0.25 g/kg protein within 24-hours post-exercise.

The basketball players within the current study showed the lowest body fat percentage of the included athletes. This could be explained as the basketball players consumed a significantly lower caloric intake compared to all other sports (Burke, 2001; Silva & Paiva, 2015). Daniel et al., (2012) demonstrated similar body fat percentages within elite level female basketball players, showing an average of 19.01% compared to the 19.20% within the current study. Although this was the lowest body fat percentage within the study, 19.20% is one of the highest reporting body percentages within other basketball studies reporting body fat percentages between 12-18% (Salgado-Sanchez et al., 2009; Jelicic et al., 2002). However, evidence suggests that for optimum performance, female basketball players should have a body fat percentage between 20-25% (Jeukendrup & Gleeson, 2019). This suggests that most female basketball players are below both macronutrient intake and optimum body composition for performance.

Cross-country athletes were noted to have the second lowest body fat percentages, which has been seen within similar studies (Hassapidou & Manstrantoni, 2001). Within the study, cross-country athletes' dietary intakes showed no statistical difference between their own intakes and the recommended energy and carbohydrate intakes, which questions why body fat percentage was seen to be significantly lower than all other sports except basketball. Some evidence suggests that the recommendations used within the study do not to meet energy demands of cross-country athletes (Fraczek et al., 2019). The lack in energy intakes and carbohydrate consumption could be explained further through several reasons. Brauman et al., (2020) determined four main causes to inefficient nutrient intake within collegiate athletes: lack of knowledge, lack of cooking skills, poor access to healthy food, and lack of time for food. Studies have backed up this concept with evidence shown that many student athletes do not consume a breakfast (Shriver et al., 2013). Lesser healthy nutrition behavior has been associated within the male athlete population rather than females, as male athletes are more likely to consume fast food and consume restaurant meals more frequently than female collegiate athletes (Hull et al., 2016)

From previous research it is also evident that the body fat percentage within the cross-country athletes in the present study are higher than generally recorded (Araziet al., 2015; Griffin et al., 2021; Hooper et al., 2021). Body fat percentage has been recorded as low at 5% within female cross-country runners (Arazi et al., 2015). However, these lower percentages of body fat have also corresponded with increased risks in injury and RED-s. Hooper et al., (2021), described cross-country runners with body fat percentages between 16-18% demonstrated characteristics of RED-s, which can lead to performance detriments through decreased muscle strength, endurance, glycogen stores, training response, concentration, coordination, and menstrual function (Statuta et al., 2017; Mountjoy et al., 2014). RED-s is also shown to increase injury risk, irritability, depression and impair judgement within athletes not only impacting performance but their overall health and well-being (Statuta et al., 2017; Mountjoy et al., 2014). It is therefore encouraging to note that the female cross-country runners within the current study demonstrated body fat percentages above these values (20.6%), reducing their risks in developing RED-S. Jeukendrop & Gleeson (2019) discussed how female athletes must have a minimum of 12% body fat for the body to carry out essential functions, such as hormone control and production, creation of myelin sheaths and phospholipid bilayers.

Limitations

There were some limitations present within the current study, one being unreported products or alternative foods from the athletes' diets. While the questionnaire selected for this study was comprised of thousands of different food choices, some athletes struggled to find the exact foods consumed. To ensure all foods were recorded, athletes were also required to photograph their foods and/or the labels from the food eaten and inform the researchers of this included item. This information was then added to their overall intakes and data output to ensure all nutritional information was accounted for. Due to the self-reporting nature of the present study some of the nutritional values maybe limited. This was again addressed, and athletes were reminded to send daily pictures and updates of their food records to researchers to keep them accountable for recording their data. The IOC do not highlight specific recommendations for team sports, instead categorize them within moderate to high intensity sports. Due to the descriptions of the IOC recommendations, all athletes were compared to the same recommendations as athletes were in season and training up to 20 hours per week of high intensity sessions.

Application and Further Recommendations

The study highlights the differences in nutritional uptake between a variety of female sports and shows where athletes are lacking in their macronutrient uptake. Recommendations differ for each sport, and therefore differences in nutritional intake are expected between sports. However, within the current study all sports were shown to have insufficient intakes of at least a macronutrient or their overall energy intakes. This study therefore highlights female athletes are still consistently consuming insufficient macronutrient and overall energy intakes daily. Previous research nutritional interventions including education on nutrition and behavior have shown to enhance athlete nutritional knowledge and help to promote healthier and improved intakes of macronutrients (Abood et al., 2004; Stickler et al., 2019; Lagowska et al., 2014; Lagowska et al., 2014). This suggests more nutritional interventions maybe needed within collegiate sports not only to aid athletes within their performance but to also enhance their health. Łagowska et al., (2014) demonstrated that through increased nutritional education within female athletes they were able to upregulate menstrual regulating hormones, including luteinizing hormone, follicular stimulating hormone, estrogen, and progesterone. It may seem apparent that supplying each collegiate school with a qualified dietician may aid in reducing these risks, however many NCAA schools do not have the funds to sustain this. Further, the universities selected for this study are shown to have registered dieticians working at the schools. Although this is the case each NCAA school has roughly over 170 female athletes alone within it. As most schools only employ one dietician, this dietician must often seek to inform and educate over 380 students alone. It has been indicated that increases in coaches, athletes, and athletic trainer's knowledge of nutrition can help the athlete make better nutritional choices and reduce work for the registered dietician. It would be recommended to conduct further research examining the macronutrient intake of female athletes within a larger cohort, and to include a wider range of sports to examine whether other collegiate sports also demonstrate low caloric intakes. Furthermore, research into whether this macronutrient intake or changes in macronutrient intake truly alter athlete performance, and whether increase nutritional knowledge could help to correlate with an increase in athletic performance.

Conclusion

The current study is one of the only studies to examine and compare macronutrient intakes within cross-country, soccer, basketball, and volleyball players. The study demonstrates that there are significant differences in macronutrient intakes between sports which equate to differences in body composition. The study also shows female athletes still lack sufficient nutrient intakes and overall caloric intake. Although nutrient intakes were shown to be statistically lower than the average, body fat percentage was shown to be higher in all athletes compared to previous research. However, this increase in body fat has been associated with reduced risks in RED-S, although it can lead to some detriments to overall performance. For future research, a larger cohort would be recommended to assess all regions of the US along with assessments on athletic performance throughout the season.

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APPENDIX A

MACRONUTRIENT RECOMMENDATIONS SET BY THE IOC, ACSM AND ISSN

Table A1 *Table of IOC, ACSM and ISSN macronutrient recommendations for different discipline areas within sport*

	International Olympic Committee	American Colleges of Sports Medicine	International Society of Sports Nutrition
Carbohydrate (g/kg)	Strength: 4-7k/kg Endurance: 6-10g/kg	Strength and Endurance: 6-10g/kg	Moderate - high intensity: 5-8g/kg High-volume: 8-10g/kg
Carbohydrate (%)			
Protein (g/kg)	1.3 – 1.8g/kg/day	Strength and endurance: 1.2-1.7 g/kg/day	Moderate: 1.0-1.5g/kg/day High volume: 1.5-2.0g/kg/day
Protein (%)			
Fat (g/kg)			0.5—1.0g/kg/day
Fat (%)	15-20%	20-35%	30%

APPENDIX B

IRB EMAIL OF APPROVAL

Ethical approval was given for this study by the IRB of Mississippi State University: # IRB-19-248, as seen from the following email:

Protocol ID: IRB-19-248

Principal Investigator: JohnEric Smith

Protocol Title: Macronutrient intake of college aged active females and division I female collegiate athletes

Review Type: EXPEDITED

Approval Date: October 25, 2019

Expiration Date:May 30, 2024

**This is a system-generated email. Please DO NOT REPLY to this email. If you have questions, please contact your HRPP administrator directly. **

The above referenced study has been approved. *For Expedited and Full Board approved studies, you are REQUIRED to use the current, stamped versions of your approved consent, assent, parental permission and recruitment documents. *

To access your approval documents, log into myProtocol and click on the protocol number to open the approved study. Your official approval letter can be found under the Event History section. All stamped documents (e.g., consent, recruitment) can be found in the Attachment section and are labelled accordingly.

If you have any questions that the HRPP can assist you in answering, please do not hesitate to contact us at irb@research.msstate.edu or 662.325.3994.