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SPORTS NUTRITION FOR BASKETBALL

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CHAPTER 1

INTRODUCTION: THE GAME OF BASKETBALL

INTRODUCTION: THE GAME OF BASKETBALL

JK Davis PhD, CSCS*D
Gatorade Sports Science Institute

Lauren Link, MS, RD, CSSD
Assistant Athletics Director,
Director of Sports Nutrition at Purdue University

Jen Ketterly MS, RD, CSSD, LDN
Charlotte Hornets; Duke Sports Sciences Institute;
Department of Orthopedics, Duke School of Medicine

INTRODUCTION

The game of basketball is a high-intensity sport that requires a high level of skill, power, speed, agility, and endurance (Gottlieb, Shalom, & Calleja-Gonzalez, 2021). A basketball game ranges from 32-48 min of total playing time (Table 1), which varies depending on the level of play (McInnes, Carlson, Jones, & McKenna, 1995; Stojanović et al., 2018). Basketball is one of the most popular sports in the world. It has been estimated by the International Basketball Federation that more than 450 million people play basketball across 213 countries (Calleja-González et al., 2016; FIBA, 2020) with the number of players rising dramatically since 1992 (FIBA, 2020). The game has also gained considerably more interest from a research perspective with the number of publications produced each year. A total of 33 basketball publications occurred in 1990 with over 600 publications appearing both in 2021 and 2022. The number of nutrition publications with specific regards to basketball players has also increased rapidly in last 15 years with 48 publications alone in 2022. Due to the vast popularity of the sport and the increased research attention, there is a need to understand how to implement science backed recommendations into practical applications with basketball players. Further, with the high-intensity nature of the sport and substantial energy demands of the game, players should be encouraged to establish good hydration and fueling habits not only during the season but in the off-season as well. These habits can benefit any athlete no matter their level of play and should be developed and maintained throughout the year. This will not only help the player to prepare for competition but perform at their best on the court and recover after the game.

	AGE RANGE (YR)	GAME DURATION (MIN)	GAME STRUCTURE	HALFTIME DURATION (MIN)	CONSIDERATIONS RELATED TO FUELING OPPORTUNITIES
High School	14-18	32	8-min quarters	10	25-35 regular season games Practice and games times vary School rules related to food intake during the day Parent and coach schedules Other sports
College (Women's Basketball)	18-22	40	10-min quarters	15	25-35 regular season games Class schedule varies from semester to semester Food is often provided, but not always Travel (air and bus); depends upon division (I, II, III, NAIA) Late-night studying / activities
College (Men's Basketball)	18-22	40	20-min halves	15	
Professional (NBA)	19-36	48	12-min quarters	15	The game is their job Considerable air travel, long series on the road NBA: 82 regular season games with additional 16 wins to claim championship WNBA: 40 regular season games with add`itional 8 wins to claim a championship
Professional (WNBA)	22-36	40	10-min quarters	15	

Table 1: Comparison of High School, College and Professional Basketball Structure

The purpose of this chapter is to provide an introduction at each competitive level including high-school, college, and professional basketball players. Both the competitive season and off-season will be described in relation to practice and game schedules with needs and opportunities to provide sports nutrition recommendations to the basketball player at various competitive levels. This chapter will help ground the reader to understand the game at each level, which will act as a foundational component to other chapters. Further, the goal of the book is to provide a practical approach for influencers working with basketball players to help fuel their performance on the court and help players recover off-the court.

PART I: HIGH SCHOOL BASKETBALL

Introduction

High school basketball players typically range from 14-18 years of age but can have a wide range in height and weight depending on growth and maturation. Players face a lot of demands during this time period with learning how to balance school, athletics, social life, and preparing for college. High school provides a critical time in a basketball player's career in which they start taking steps to improve and sharpen their skills. It is important to note that the majority of high-school basketball players will not go on to play college basketball; as the National Collegiate Athletic Association reports that only 3-4% of high-school basketball players play in college (NCAA, 2015). This period also creates a key opportunity for educating players in how to incorporate good habits and behaviors for nutrition, sleep, and recovery techniques. This will not only be important for performance in high school but for players going on to play in college. Further this will be important for players who are not able to play at the next level to understand good nutrition and sleep behaviors for the rest of their life for overall health and wellness. Coaches will have a key role in this area as they will be one of the main sources of education in the high-school setting. Although some high schools may have a full-time athletic trainer(s) and a strength coach on staff, other schools will only have a part-time athletic trainer available at practices with the coaches taking the role of leading strength and conditioning. Therefore, the majority of high schools in the United States will likely rely on the coaching staff and athletic trainer for education.

The Competitive Season

The high-school basketball game consists of four quarters of play with each quarter lasting 8 min and a 10 min halftime period (Table 1). Basketball teams will typically play 2-3 games per week and 25-35 games per season. There could be more games depending upon the number of tournaments played during the season and the success of games during tournament play and post-season playoffs. Teams will typically practice 4-5 times per week for 1.5-2 h. Practices will vary greatly among coaches but typically consist of moderate to high-intensity skills, drills, and conditioning while working on various sets and schemes for offense and defense. The day prior to the game teams will usually prepare for their upcoming opponent by going over the scouting report and walk through offensive plays and defensive sets and schemes. Players will also get in additional shooting during this time and most practices will vary from low to moderate intensity. The structure of game day can also vary with high schools as well. Some coaches may have a walk-through practice, going over key items for the game that night and include a shoot around during practice. Team practices may occur either in the morning before school or right after school for weekday games. Some coaches will also hold film sessions before practices 1–2 times per week to review previous games. Also, players will typically perform 1-2 strength and conditioning sessions per week for 20-30 min. The strength and conditioning session will typically be led by one of the coaches on staff since the large majority of high schools in the United States will not have a full-time strength and conditioning coach.

The style of the game can vary greatly among high schools depending upon the coach and their philosophy. Some may prefer to play a full-court game that is high intensity, high tempo, and push the pace of the game. While other schools might prefer to play a half-court game depending on philosophy, team personnel, and may prefer to slow the pace of the game. Due to the high-intensity nature of the game this provides an excellent opportunity to help educate players with their nutrition to perform at their best on the court. Chapter 2 will discuss further details of the energy system demands of the game while chapters 4, 5, and 6 will discuss practical applications on fueling players performance, recovery, and hydration. Regarding fueling basketball players, some coaches may have coordinated meals planned before games. These meals may be coordinated by the booster club members (parents and volunteers helping with the program). Other schools may leave pre-game meals up to individual players or parents to provide on their own. During the game players should have access to fluids and have an opportunity to further fuel during half-time of the game with snacks and fluids. High-school players will need help in navigating not only what foods to fuel their performance but also for recovery. It is also important to educate players on when to eat during the school day, meals and snacks before the game, and the post-game meal. Chapters 4 and 12 will provide practical applications for incorporating meals and snacks for home and away games.

The Off-Season

The high-school basketball season will typically end in February for most schools with playoffs extending into March. The nature of the off-season will depend on whether the athlete is a multi-sport athlete or playing basketball year around. For the multi-sport athlete, they will either transition into their respective spring sport (e.g., baseball or softball) or start training and preparing for a fall sport (e.g., American football, soccer). For the athlete playing year around basketball most will transition into their AAU basketball season at this time. This period provides an opportunity for players to work further on improving and developing their basketball skills with a continued focus on showcasing their talents with AAU travel teams. However, there are a number of articles investigating the health consequences of sport specialization at a young age (Jayanthi, Post, Laury, & Fabricant, 2019; McGuine et al., 2017). Recently a few studies have noted that almost half of adolescent athletes participated on club teams in addition to their school-teams (McGuine et al., 2017; Post et al., 2017). The concern raised for position statements have been related to psychological burnout and overuse injuries for sport specialization at a young age (Brenner, 2016; DiFiori et al., 2014). Regardless of whether the athlete is specializing in basketball year around or multi-sport athlete, it is beneficial for players to continually participate in a strength and conditioning program year around. This is not only beneficial for players gaining strength and continuing to improve conditioning but with a focus on injury prevention as well. Further, the off-season for high-school basketball presents a great opportunity to develop behaviors focused on proper nutrition, hydration, and adequate sleep. Athletes from all levels and ages would benefit from continued education from their coaches for developing behaviors around sports nutrition and recovery.

PART II: COLLEGE BASKETBALL

Introduction

Collegiate basketball athletes are a unique cohort, in that despite having a tight age window of 18-22 years, maturity levels can vary significantly, as can the exposure and education they have had around training and nutrition. While many collegiate basketball athletes come to their university with a heavy focus on basketball, it is important to remember that they are college students too. In addition to the increased level of training and

conditioning, they are also balancing class and a social life as a young adult in a completely new environment, not to mention the intense travel schedule that they endure in-season. One of the more challenging aspects of working with this population is helping them navigate the transition to this new environment and becoming an adult. In addition to helping athletes fuel appropriately for high-level training amidst a busy schedule, it is also important to educate around healthy sleep habits, smart supplement use (that is compliant with NCAA rules), and how to budget effectively for meals and snacks. While some athletes at the collegiate level may be reaping the rewards of the new Name, Image, Likeness legislation and have very few financial worries, other athletes may not, and especially if they are not receiving financial aid through a scholarship and come from a lower socioeconomic status household, they may need serious assistance in how to make their meals come together.

The Competitive Season

College basketball games are uniquely structured as the only level of competitive basketball that does not play quarters. This applies specifically to men's college basketball players where they play two 20-min halves with a 15 min halftime (Table 1). While women's college basketball players play four 10 min quarters with a 15 min halftime, which replicates the Women's National Basketball Association (WNBA) and International Basketball Federation (FIBA). Many collegiate teams will play between 25–35 games per season, depending on the level (NCAA Division I, II, III, NAIA, or NJCAA) and if/how far they make it during tournament play and post-season playoffs. Most teams have the opportunity to be involved in both a conference and national tournament, which could add up to an additional 10 games if you make it all the way to the NCAA championship game. Collegiate teams must follow guidelines set by the NCAA. During the competitive season, teams are allowed up to 20 h of required team activities per week, with no more than 4 h occurring in one day. These team-related activities can include practice, film, strength training and conditioning, games and any other activity directed or supervised by a member of the coaching or support staff. Most programs will practice 4–6 days per week, depending on the game schedule, and practices may be up to 3 h of high-intensity exercise. In addition to the time that they spend on the court, athletes are expected to attend film sessions, spend time in the weight room, and tend to injuries in the athletic training room when needed. Overall, the time commitment tends to be significantly greater than when they were a high school athlete.

The travel requirement during the competitive season is one of the most challenging aspects of playing at this level. Depending on the level of program, travel may range from bus trips to commercial or even private chartered flights. Depending on the schedule and the resources available, teams could be on the road for just a couple days, or for multiple nights if traveling farther or participating in multiple games on one trip. The ever-expanding TV schedule for games has also created a scenario where teams may play on practically any night of the week, and sometimes will not tip off until late at night. All of these considerations can add to the stress levels of the athletes trying to perform at a high level and keep up with school work. Meals and snacks on the road will also vary per institution. Most Division I, Power 5 schools have full time sports dietitians on staff for consultation and education, but even at the Division I level, the size and scope of the dietitian staff varies greatly between schools. Many athletic departments provide team meals and snacks through the week or a “training table,” which is a cafeteria with menus curated specifically for athletes. At other schools, athletes may rely on their campus meal plans, and the budget can be limited when providing meals and snacks on the road. Overall, these increased demands can make it challenging to ensure that they are appropriately fueling and getting enough rest.

The Off–Season

The majority of collegiate basketball players are one-sport athletes and dedicate the off-season to improving their game and potentially their body composition and fitness levels, although multi-sport athletes are found at every level of competition. Most collegiate basketball players will be given a short time off after the competitive season, usually 2–4 weeks, to rest and recharge their bodies as necessary before starting back with skill work and strength and conditioning workouts.

Basketball commitments during the off-season tend to vary depending on the level and coaching demands. This tends to be an important time for the strength and conditioning program to ramp up to work toward the specific goals set for each athlete. During the summer, athletes at lower division colleges are more often at home and may need to balance an off-season training program provided by their coach with a summer job. At many Division I schools, the athletes are usually on campus for summer school and summer workouts. These workouts include strength and conditioning sessions 3–5 days per week and on-court workouts with the coaches. This can also be a prime time to work on more involved nutrition education with players, whether that be body composition/weight goals, cooking skills, grocery shopping tips, or individual hydration testing. Overall, during the off-season the NCAA allows up to 8 h of team related activity per week, 2 h of which can be direct contact with the basketball coaches on the court.

PART III: PROFESSIONAL BASKETBALL

Introduction

Professional basketball players range in ages as some will leave their college careers early to enter the draft and some players will remain in the leagues for many years as they enjoy veteran careers. These players are highly skilled and represent the best talent, skill, and potential the game has to offer. At the professional level, the athlete’s day-to-day schedule now becomes focused on their responsibilities to the team and their development as a professional. Off the court, these athletes will also transition to new responsibilities in managing finances, contracts, endorsements, entrepreneurial ventures, charity work and more. New expectations and time demands can make it challenging for professional athletes to adequately fuel, plan meals, and meet nutrient needs, especially without all access training tables, robust fueling stations and meal supplements players may be accustomed to from their collegiate programs. Many professional teams will provide some meals in the facility but most of the meal support and facilitation will come outside of their time at the facility. Given the schedule changes, demands and increasing importance of fueling and recovery many players opt to hire personal chefs or meal services to help support some of their meals. Continuing player education, no matter which meal sources are arranged remains a priority to help these athletes understand how to best support their performance fueling and recovery needs as well as mitigate risk of injury throughout perhaps a new style of play, travel stress, and in-season duration.

The Competitive Season

The National Basketball Association (NBA) regular season opens in October each fall and runs through April for approximately 82 games in addition to preseason games. Weekly schedules can often include 3-4 games per week with occasional back-to-back competitions. Post season playoffs typically begin with a play-in tournament mid to late April followed by conference final rounds in May and extending into June. The Eastern and Western conference champions play a best of 7 game series to determine the league champion. The two teams competing in the NBA Championship Final will play over 100 games that season.

The NBA G-League is the NBA's official minor league featuring 31 teams. The season structure includes two parts with a 16-game regional competition and a traditional 34-game regular season running from November to late March. Each team will play a 50-game schedule each season and will also include occasional back-to-back competitions and extensive travel.

Professional women play in the Women's National Basketball Association (WNBA) with a 40-game regular season running June to September. WNBA Playoffs feature the top 8 teams in the league. The first round of playoffs is a best of 3 game series followed by two rounds of best of 5 games to determine the league champion. The WNBA Playoffs often extend into mid-October.

Practices in the professional leagues are typically 1.0-1.5 h in duration and may be infrequent due to game and travel schedules. Travel and away games represent 50% of both regular seasons, i.e., 41 away games in the NBA and 20 away games in the WNBA. Many teams and organizations employ or retain consultant sports dietitians to help plan, educate, and facilitate nutrition related needs through the duration of the season. Gameday fueling, hydration assessments, recovery strategies, maintenance of lean body mass, injury support, biomarker monitoring, supplement strategies, and meal management are areas of top attention during a season. Meal management can be challenging given the time spent away from home environments and hydration status can be compromised by frequent air travel. Well intentioned, individualized nutrition and hydration plans are key concepts to incorporate for any professional basketball player.

The Off-Season

The off-season's primary objective is to recover from the long in-season demands, support and rehab any injuries, address players' base fitness levels and focus on skill development. Many players will move from their team's home market to personal residences and work with individual trainers and support staff. Maintaining connections, meal and nutrition support strategies, and monitoring progress and development from afar become off-season challenges. Schedules, locations, goals, and objectives all vary and are individualized during this period of time. The NBA hosts a summer league in July where many incoming and early career players participate in preparation for September training camps.

SUMMARY

Basketball players at every level of competition face numerous challenges relating to adequate hydration and nutrition. Overall, the purpose of this book is to provide an evidence-based approach to incorporating best practices for hydration, nutrition, sleep, and recovery techniques to help the basketball player perform at their best. Prior to diving into recommendations, it is fundamental to understand the physiological demands of the game along with developing a deeper understanding of the physical characteristics of the basketball player. The following chapters will highlight opportunities for helping to fuel and hydrate basketball players for home and away games, along with recommendations to promote recovery after the game. Additionally, the chapters will cover the importance of sleep, recovery techniques, and monitoring recovery for basketball players.

JK Davis is employed by the Gatorade Sports Science Institute, a division of PepsiCo R&D. The views expressed are those of the authors and do not necessarily reflect the position or policy of PepsiCo, Inc.

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CHAPTER 2

ENERGY FOR BASKETBALL PLAYERS

ENERGY FOR BASKETBALL PLAYERS

SCIENCE-BASED RECOMMENDATIONS

Lawrence L. Spriet, PhD
University Professor Emeritus
Human Health & Nutritional Sciences,
University of Guelph, Guelph, Ontario, Canada

KEY POINTS

- In stop-and-go sports like basketball, large amounts of energy are needed from the aerobic and anaerobic sources in skeletal muscles.
- The production of aerobic energy provides the majority of energy while moving around the court during play.
- Anaerobic energy produced in the glycolytic pathway and from phosphocreatine degradation fuels the quick and powerful bursting movements like jumping, sprinting and defensive slides that are needed in basketball.
- The aerobic system also helps during periods of recovery (jogging, light running on the court and stoppages in play) to replenish the phosphocreatine store and remove by-products of glycolysis (lactate and H^+).
- Carbohydrate is the fuel of choice for basketball as it is the dominant fuel for energy production during high-intensity aerobic exercise and is also the only fuel for anaerobic energy production in the glycolytic pathway.
- Proper nutrition in the days and hours before training/competition can maximize the body's store of carbohydrate (skeletal muscles and liver). Carbohydrate intake during training/competition can also provide fuel for the muscles and the brain, and help maintain mental acuity.
- Recovery nutrition right after training/competition should include ~1-1.2 g carbohydrate/kg body mass/h and 20-25 g of protein to help muscles replenish the body stores of glycogen and increase muscle protein synthesis. A proper meal should follow 1-3 hours after exercise.
- These are general nutrition guidelines for basketball players, but many factors require that players are advised on an individual basis (body size, energy and decision-making demands of position, training vs. competition, time in the season, individual variability, overtraining and health status).

INTRODUCTION

Basketball is demanding stop-and-go sport where the energy requirements of the player are constantly changing. Recent studies have measured the high internal and external loads that male and female basketball players experience during training and games (Pernigoni et al., 2021; Power et al., 2022; Scanlan et al., 2014) and stop-and-go sports in general (McLaren et al., 2018). Players could be completely stopped during time-outs, stoppages in play, and foul shots, or could be walking or jogging on the court at low exercise intensities or hustling down the court or back on defence at a fast pace or going full out in sprint-like fashion for a short period of time when driving the basket, attacking, jumping, or defending on a fast break. Large amounts of energy are needed to meet the physical demands of the stop-and-go sport of basketball and transitions are the name of the game. Skeletal muscles are most impressive in their ability to handle this wide spectrum of energy demands.

This chapter examines how skeletal muscles are able to provide the energy needed to play basketball at a high level and how nutrition plays an essential role in providing the fuels the muscles need to make sure energy provision is optimal in all situations and never runs out! The brain also benefits from proper nutrition by maintaining cognitive performance and is heavily influenced by what players eat and drink. Therefore, nutritional guidelines and goals have been established for stop-and-go sports like basketball and these give the athlete, athletic trainers, nutritionists, coaches, and other team personnel general guidelines to follow, realizing that each player is an individual and will need one-on-one attention. Several previous reports have examined nutrition for team sports including basketball (Burke, 2007; Holway & Spriet, 2011; Ryan, 2005; Williams & Rollo, 2015).

It is known that "diet significantly influences athletic performance" and that, "all athletes should adopt specific nutritional strategies before, during and after training and competition to maximize their mental and physical performance" (Maughan & Shirreffs, 2011). Another way of saying this is, a proper diet can't make an average basketball player elite, but a poor diet can make an elite basketball player average!

WHERE DO BASKETBALL PLAYERS GET THEIR ENERGY?

Skeletal muscles continually produce a compound called adenosine triphosphate (ATP) which is the immediate source of energy for all cellular metabolic functions. It is our “energy currency” (Hargreaves & Spriet, 2020). While the metabolic energy needs of skeletal muscle are low at rest, the demand for energy can increase by several hundred-fold during burst activity! The fact that skeletal muscles can rapidly respond to the needs for ATP to fuel the contractions necessary for intense movements is remarkable (Spriet, 2021). The muscles provide ATP through two main metabolic processes; 1) in the cellular compartments called mitochondria with the use of oxygen, and fat and carbohydrate as fuels. This is referred to as oxidative phosphorylation or "aerobic" energy production, 2) via pathways in the cytoplasm of muscle cells that do not need oxygen and are referred to as substrate phosphorylation or "anaerobic" energy production. The two main sources of anaerobic ATP production are in the glycolytic pathway (called anaerobic glycolysis) with the use of carbohydrate as a fuel, and through the breakdown of phosphocreatine (PCr), that is stored in the muscles (Spriet, 2006; 2022).

Aerobic Energy Production is our Default Energy Source

It is important to realize that aerobic energy production is our default energy provision system and can provide ATP for long periods of time at a reasonably high rate. The fuels for this system are carbohydrate and fat in a well-fed player (Fig. 1), but carbohydrate is the dominant fuel for the high intensity aerobic exercise needed in basketball (Hawley & Leckey, 2015). Fat is a helper fuel for lower intensities of exercise and use during stoppages in play. The rate at which ATP can be produced in the aerobic system increases by ~20-30% with exercise training in most people, as a function of an increase in the mitochondrial content in skeletal muscle (Holloway & Spriet, 2009). The carbohydrate stored in skeletal muscles as glycogen also increases in concert with exercise training (Fig. 1), but the system can still be compromised if we run out of carbohydrate due to poor pre-event nutrition or prolonged high intensity aerobic exercise uses all the fuel (Burke & Hawley, 2018).

The Aerobic System does have Limitations

The aerobic system takes some time (~60-120 s) to fully turn on at the start of exercise, or when transitioning from a lower to higher exercise intensity. So, it could be argued that this system has some limitations when playing a stop-and-go game like basketball, as it is a game of transitions where the energy demands are constantly changing. The aerobic system also has an upper limit in terms of the rate at which it can provide energy. This can be estimated by measuring the maximal rate at which oxygen can be taken up and used by the body (VO_2max). When energy is needed at a rate that is higher than VO_2max, another energy source is needed. Fortunately, energy provision from the anaerobic energy systems provides the missing energy at the onset of exercise, when moving to a higher power output, and when the need for energy is beyond what the aerobic system can provide.

Anaerobic Energy Provision Plays an Important Role in Basketball

The anaerobic systems (glycolysis and PCr) specialize in turning on very quickly (like a light switch) and producing ATP at high rates that permits the transitions that require quick energy and occur hundreds of times during a game. They also provide energy at much higher rates than the aerobic

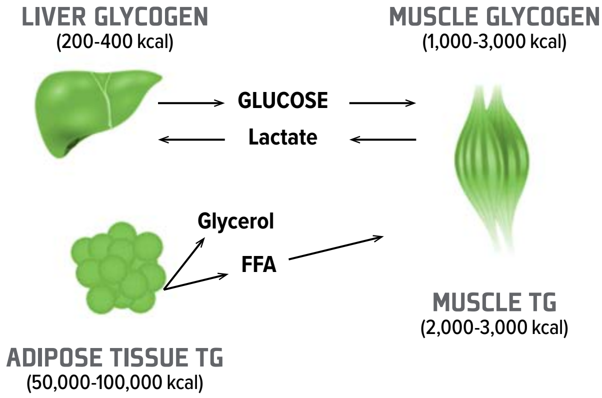

Figure 1: Major sources of carbohydrate and fat fuels and potential energy available during exercise. TG, triacylglycerol/triglyceride; FFA, free fatty acids. Redrawn from Hargreaves & Spriet, 2020.

system can provide to enable sprinting, jumping, and bursting activities in basketball, albeit for short periods of time (a few seconds). So, to be successful at basketball and meet the physical energy demands in skeletal muscle, athletes need contributions from both the aerobic system and the anaerobic systems.

The Anaerobic Systems also have Limitations

The capacity of the anaerobic systems is much less than the aerobic system, as the PCr store can run out quickly and the glycolytic energy provision is associated with fatiguing by-products including increasing acidity (H+) in the muscles (Hargreaves & Spriet, 2020). When repeated bursts of activity are needed as in a game of basketball, the depletion of skeletal muscle carbohydrate stores can also limit the glycolytic system. Both anaerobic systems can be used repeatedly in a game, but the glycolytic system is generally more susceptible to fatigue due to increasing muscle acidity or carbohydrate depletion. Muscle acidity can negatively affect performance as it makes it hard for the contracting muscles to produce energy. Muscle acidity can be minimized if the periods requiring sprinting/jumping are limited to 3-6 s, which is the case in most stop-and-go sports. While the PCr store can be depleted quickly, it is not slowed down by acidity, and can be regenerated and recover in the muscle in as little as ~90-120 s of rest or light activity (Harris et al., 1976; Greenhaff et al., 1994). During an intermittent game like basketball, PCr can be used over and over when periods of sprinting/jumping are followed by lighter activity and/or rest (Bogdanis et al., 1998).

Exercise training that incorporates some sprinting and all-out efforts can increase the capacity of the glycolytic system by about 20% (Bogdanis et al., 1996; Gaitanos et al., 1993), while, remarkably, the

capacity of the PCr system does not increase with training (MacDougall et al., 1998; Perry et al., 2008). Skeletal muscle total creatine and PCr stores can be increased by ~15-20% by consuming supplemental creatine, which may lead to improved performance in basketball. Regimens for both rapid and slower increases in muscle creatine have been outlined in previous research (Harris et al., 1992; Hultman et al., 2006). Other supplements have also been identified that may aid in anaerobic energy provision in elite athletes (Maughan et al., 2018). The reader is refereed to chapter 7 of the book for more information on dietary supplements and basketball players.

The Aerobic System also Provides Energy for Recovery

The aerobic system also plays a large role in helping basketball players quickly recover from intense activity. When our PCr is degraded, we can quickly resynthesize it when the physical activity slows to a low intensity, or we stop moving. The energy to replenish the PCr store comes from ATP produced aerobically such that the PCr store can be restored in about 90-120 s, as mentioned above. Importantly, the higher your aerobic capacity (VO max), the quicker the PCr replenishment occurs! The aerobic system also contributes to recovery in a second way by using lactate as a fuel in the muscles when we move to a lower intensity (jogging or walking the court) or stop moving. Removal of lactate from the muscles and blood helps remove the acidity that builds up in our muscles and blood when we engage in sprint, jumping, and burst activities, and this helps lessen the feeling of fatigue. The bottom line here is that fit players recover more quickly than less fit players.

Fat is a Helper Fuel and Protein is Important in Recovery

Skeletal muscles of trained people store a significant amount of fat directly in the muscles as intramuscular triacylglcyerol or triglyceride (Fig. 1). Muscles can also take up fat in the form of free fatty acids from the blood, as it is released from adipose throughout the body. However, fat only plays a significant role as a fuel at low to moderate aerobic exercise intensities and at rest and is not a fuel for anaerobic energy production (Hargreaves & Spriet, 2020). Protein can also be used as an aerobic fuel, but this does not occur to any great extent in well-fed athletes. However, protein plays major roles is assisting with carbohydrate and fat energy metabolism during exercise and stimulating muscle protein synthesis during recovery from exercise (Heaton et al., 2017).

Energy Provision Summary

To summarize, the ability to play basketball at a competitive level requires both a high aerobic capacity to produce continual amounts of oxygen-requiring energy on the court and during periods of recovery. A high capacity to produce anaerobic ATP is also needed to supplement with energy during transitions to higher intensities and when sprinting, bursting or jumping, where the energy demand is too high for the aerobic system. In most basketball situations, other than stoppages in play, both systems are working together to produce the required energy. It is not a scenario where the aerobic system works alone, or the anaerobic system works alone, as they work together in most instances when active on the court.

It is also important to mention that genetic endowment plays a large role in the capacity to produce aerobic and anaerobic energy and there is large variation between individuals. However, energy provision is not the only determinant of success, as skill, ability to focus, determination, training, proper nutrition, etc. all play a role in the ultimate success of a basketball player.

THE IMPORTANCE OF CARBOHYDRATE AS A FUEL FOR BASKETBALL PLAYERS

Carbohydrate is the fuel of choice for the aerobic system during intense exercise. At 50% of a person's VO_2max, fat and carbohydrate contribute about equally to fuel provision, but as the intensity climbs to ~80% VO_2max and beyond, carbohydrate and specifically muscle glycogen, becomes the dominant fuel (Romijn et al., 1993) (Fig. 2). This has been shown in both well trained males and females (Romijn et al., 1993, 2000; Van Loon et al., 2001).

Carbohydrate is also the fuel of choice for sprinting, jumping and bursting activity as the glycolytic pathway can only use carbohydrate as a fuel, not fat or protein. So, if a player is running the court at a high aerobic intensity and already using mainly carbohydrate as an aerobic fuel, a sudden sprint or jump will require more carbohydrate, along with some PCr, to produce the anaerobic energy to successfully complete the task.

Humans generate a lot of energy from carbohydrate when we use it for aerobic energy production (~36 mol ATP/mol carbohydrate), but considerably less when used it for anaerobic energy production (only 3 mol/mol carbohydrate) (Hargreaves & Spriet, 2020). So sprinting, bursting, and jumping “costs” a lot of carbohydrate, in exchange for the ability to produce these powerful and ballistic movements. This can be seen in Figure 3 as muscle glycogen use rises exponentially at power outputs above ~100% VO_2max. Fortunately, bursting, jumping and sprinting are normally kept short, ample carbohydrate has been stored in the body before the practice or game, and finally carbohydrate is ingested during the activity. Several studies have made direct measurements of skeletal muscle glycogen before and after soccer, rugby, Australian rules football, and ice hockey games and shown that muscle glycogen stores are significantly depleted and is the dominant fuel for these stop-and-go sports (Bradley et al., 2016; Krustrup et al., 2006; Routledge et al., 2019; Vigh-Larsen et al., 2020).

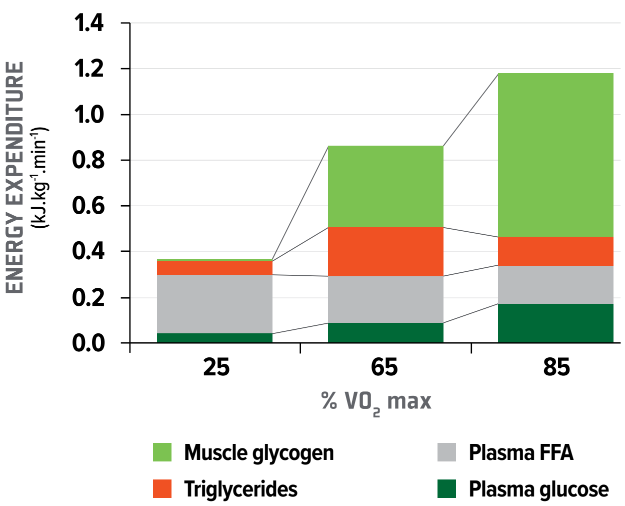

Figure 2: Schematic of energy expenditure and fuel use at varying exercise intensities. KJ, kilojoules. FFA, free fatty acids. VO_2 max, maximal oxygen uptake. Redrawn from Romijn et al., 1993.

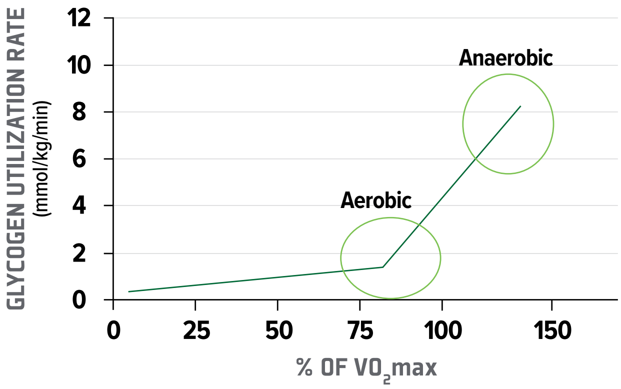

Figure 3: Estimated rate of muscle glycogen use in the aerobic (up to 100% maximal oxygen uptake, VO_2max) and anaerobic (>VO_2max) exercise intensity ranges.

NUTRITIONAL INTAKE OF CARBOHYDRATE IS NEEDED FOR BASKETBALL PLAYERS

Carbohydrate is the fuel for stop-and-go sports like basketball (Thomas et al., 2016). The IOC Consensus Conference on Sport Nutrition concluded that, "In stop-and-go team sports, performance is limited by energy, and particularly carbohydrate intake" (Maughan & Shirreffs, 2011). Because of this important role, trained players store a large amount of carbohydrate (as glycogen) in the muscles they use to play the sport. There is also a large amount of glycogen stored in the liver of a well-fed player. The liver's job is to release carbohydrate in the form of glucose into the blood to maintain a blood concentration of ~5 mM at all times (Fig. 1). During exercise the contracting muscles take up a lot of glucose from the blood and the liver has to match this by replacing the used glucose. If unsuccessful, the person's blood glucose decreases, consequently leading to feelings of nausea, light-headedness, and general whole-body weakness and fatigue, as the brain also relies mainly on glucose for fuel (Coyle et al., 1983). When exercise is intense and prolonged, athletes can assist the liver in maintaining the blood glucose level by drinking a sports drink that contains glucose or other forms of carbohydrate (Coyle et al., 1983; Podlogar & Wallis, 2022). The ingested carbohydrate quickly gets into the blood and can be used by the muscles, heart, and brain.

There is also strong evidence that the ingestion of carbohydrate during exercise stimulates the carbohydrate receptors in the mouth to activate brain motor control activity and reward centers and reduces ratings of perceived exertion (Carter et al., 2004; Chambers et al. 2009). Carbohydrate mouth rinsing has been shown to improve running performance (Rollo et al., 2008, 2010) and in some stop-and-go team sports. It improved performance in female soccer players, male lacrosse players, and male ice hockey players (Dolan et al., 2017; Nyman et al., 2022; Pribyslavská et al., 2016), but not male soccer and rugby players (Dorling & Earnest, 2013).

In summary, given the importance of carbohydrate as a fuel for basketball players, it comes as no surprise that there are general guidelines for carbohydrate intake in the days and hours leading up to a training session or game, during the activity itself, and also following the training session or game (Burke, 2007; Holway & Spriet, 2011; Thomas et al., 2016). Numerous studies using dietary recall techniques with basketball players suggest that athletes do not always reach these goals (Grandjean, 1989; Nowak et al., 1988; Short & Short, 1983). The recovery phase after exercise is also the beginning of preparation for the next session as elite players are training or playing most days and often several times a day in tournaments and camps (Heaton et al., 2017; Pernigoni et al., 2022).

The general carbohydrate and fuel intake guidelines follow:

Pre-training/competition preparation - days

- Moderate duration/low to moderate intensity training: 5-7 g carbohydrate/day/kg body mass (bm).
- Moderate to heavy basketball training or game: 7-12 g carbohydrate/day/kg bm.
- Repeated bouts of moderate to heavy basketball training/games: 10-12+ g carbohydrate/day/kg bm.

These guidelines ensure that muscles are loaded with glycogen.

Pre-training/competition preparation - hours

- Ingestion of carbohydrate-rich meal after overnight (fast) and 2-4 h before training/competition.
- Smaller amounts of carbohydrate (snacks) in the final 2 h before training/competition (~30 g carbohydrate/h to individual preference).

These guidelines ensure that liver is loaded with glycogen, muscle glycogen is topped up, and the brain stays alert.

Carbohydrate intake during basketball training and games

- Ingest fluid, electrolytes and carbohydrate in ~6% solution (60 g carbohydrate/32 oz or 6 g/100 mL or 60 g/L).
- Ingest ~17-32 oz or 500-1000 mL/h (30-60 g carbohydrate/h) as per individual need, preference, etc.
- Some team sports players prefer a ~2-3% carbohydrate solution.

These guidelines ensure provision of glucose in the blood for use by muscles and brain and stimulate the carbohydrate receptors in the mouth to activate brain motor activity and reward centers that reduce the perception of fatigue. At the present time these guidelines for carbohydrate intake before and during exercise seem appropriate for male and female athletes (see chapter 4 for more details).

Recovery following training/competition

- Ingest carbohydrate (~1 - 1.2 g carbohydrate/kg/h for first 2-3 h) immediately post-exercise to start replenishment of liver and muscle glycogen stores.
- Ingest 20-25 g of protein to increase muscle protein synthesis and put the muscle in positive protein balance (protein synthesis is greater than protein degradation).
- Eat a proper meal no later than 1-3 h after training/activity; Snacks high in carbohydrate are substituted if repeated training or games occurs on the same day.
- Eating after exercise allows the recovery of the skeletal muscles and liver to begin.

It is important to remember that these nutritional guidelines and goals for stop-and-go sports like basketball will provide the athlete, athletic trainers, nutritionists, coaches, and other team personnel with general guidelines to follow, realizing that each player is an individual and will need one-on-one attention (see chapters 4 and 5 for more fueling options).

SUMMARY

Playing basketball at a high level requires large amounts of energy provision by the skeletal muscles. Well-trained basketball players have high capacities to produce energy from both the aerobic and anaerobic energy systems. A high aerobic capacity (VO2max) also speeds up recovery during the numerous periods of jogging or walking on the court and the stoppages in play during training and games. Carbohydrate is the fuel of choice for basketball players as it serves as a fuel for both the aerobic and anaerobic energy producing systems. Fat is also used at lower intensities and during stoppages in play as an aerobic fuel. Clear guidelines are available for maximizing the availability of carbohydrate before, during, and after training and games. A small amount of protein ingestion following activity is also important for rapid muscle recovery.

The views expressed are those of the author and do not necessarily reflect the position or policy of PepsiCo, Inc.

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CHAPTER 3

PHYSIOLOGIC PROFILE OF BASKETBALL ATHLETES

PHYSIOLOGIC PROFILE OF BASKETBALL ATHLETES

Anthony Wolfe, MS
Gatorade Sports Science Institute

KEY POINTS

- Most elite basketball athletes tend to be tall, long, and lean. Most elite players are moderately powerful and exhibit relatively high aerobic capacity and anaerobic thresholds. Lower body strength may be critical at the elite level.
- Ideal body shape, size, and physiology are not sufficient for excellence in basketball.
- Female basketball athlete characteristics tend to mimic those of the male athlete. However, there is still a dearth of data, and more work should be done to understand physical and physiological profiles of elite players.
- Gameplay style and strategy may impact the physical and physiological requirements for the athlete and should not be overlooked.

INTRODUCTION

This chapter will cover the physical and physiological characteristics of basketball players at various skill levels that can be found throughout the literature as well as what is available from the National Basketball Association (NBA). In general, these athletes are tall and have a "lean" body composition. However as this chapter shows, there is considerable variability between players and anthropometrics alone do not dictate if an athlete will be or is successful (Latin et al., 1994). Because of this, "optimal" values of body fat and muscle tissue required for health and basketball specific performance are difficult to establish. Since there is no one size fits all approach for basketball performance, those factors influencing body composition (i.e., dietary requirements and/or energy balance) should be individually tailored and adjusted depending on player role and specific athlete needs (Impey et al., 2016).

HEIGHT, WEIGHT, AND BODY COMPOSITION

Most elite basketball players tend to be tall, long, and lean. For example, based on data collected year over year at the NBA Draft Combine, on average the players have been 77.69 in (197.33 cm) tall, weigh 211.29 lbs (95.82 kg) with a body fat percentage of 6.84%. Other metrics include wingspan (fingertip to fingertip, 82.47 in [209.47 cm]), hand length (8.72 in [22.15 cm]), and hand width (9.43 in [23.95 cm]). At the NBA combine body fat percentage is typically assessed via the skinfold method. The technique used relies on three regions; the pectoral, the abdomen, and the quadriceps (Cui et al., 2019). As discussed below this method does have accuracy limitations.

Various metrics (height, weight, body fat percentage, wingspan, hand length and width) from the NBA Combine are broken down by position in Table 1 (NBA, 2017-2023). In general, the guard position is typically characterized by a lower body mass, height, and body fat percentage, while centers are typically heavier and taller and have a greater body fat percentage (NBA, 2017-2023; Sallet et al., 2005; Suprs, 1997-2012). Forwards generally fit somewhere in the middle. Furthermore, there is some evidence that anthropometric indices differ between first and second-division European players (Pehar et al., 2017). For example, first-division centers were 6.5 cm (2.56 in) taller, 9 kg (19.8 lbs.) heavier, and had 3% less body fat when compared to their second-division peers (Pehar et al., 2017). First-division forwards were also taller and had a longer reach than second-division level forwards. This difference may lead to better in-game performances, particularly in jumping tasks where vertical reach is important(Sisic et al., 2015). There is also a relationship between body composition, aerobic fitness, anaerobic power, and positional roles in elite basketball (Delextrat & Cohen, 2008; Narazaki et al., 2009), as shown in Table 1 and discussed further below.

An extensive range of methods to assess body composition currently exist. The four main methods used in basketball are skin folds, air displacement plethysmography (ADP), bioelectrical impedance analysis (BIA) and dual-energy X-ray absorptiometry (DXA). For each method, a qualified and skilled practitioner is required to complete the measurements with as little error as possible.

The skinfold method has been reported as a reliable 'in the field' measurement (Ackland et al., 2012). This method is typically performed using calipers to measure skin folds at specific anatomical sites, described in full previously (Marfell-Jones et al., 2006). Athlete specific equations from skinfold, circumference measures, and age have been developed previously. However, these equations may not be effective for all athlete subgroups such as basketball and American football players (Sinning et al., 1985).

	VERTICAL HEIGHT (IN)	WEIGHT (LBS.)	BODY FAT %*	WINGSPAN (IN)	HAND LENGTH (IN)	HAND WIDTH (IN)
Guards	74.97	194.17	6.32	79.63	8.44	9.11
Forwards	79.05	217.15	6.93	83.63	8.84	9.58
Centers	81.79	244.35	8.12	87.46	9.23	9.94
Overall	77.69	211.29	6.84	82.47	8.72	9.43

	VERTICAL HEIGHT (CM)	WEIGHT (KG)	BODY FAT %	WINGSPAN (CM)	HAND LENGTH (CM)	HAND WIDTH (CM)
Guards	190.42	88.06	6.32	202.26	21.44	23.14
Forwards	200.79	98.48	6.93	212.42	22.45	24.33
Centers	207.75	110.82	8.12	222.15	23.44	25.25
Overall	197.33	95.82	6.84	209.47	22.15	23.95

n=370
** Skin fold method was used to determine body fat (%)*

Table 1: Updated NBA draft average measurements.

The BIA technique offers a non-invasive method to assess the fluid distribution and body composition of athletes. The BIA works by passing an electrical current through the player's body. The resistance to that current, due to the specific resistivity and volume of fat free mass, is measured. Total body water is also calculated, and the value can be used to estimate body fat percentage (Kushner & Schoeller, 1986).

ADP body composition is typically assessed by using a BOD POD™ (Gold Standard Model 2007A Life Measurement Instruments/COSMED). The ADP method is based on a two-compartment model of body composition (fat mass and fat-free mass) and uses the inverse relationship between pressure and volume (Boyle's law) to derive body volume (L). Once body volume is determined, the principles of densitometry are used to determine body composition. Furthermore, to reduce the potential error due to isothermal air trapped in clothing and body hair, players are asked to wear minimal tight-fitting clothing (e.g., compression shorts) and a swim cap before sitting in a chamber, limiting their movement, and breathing normally. An equation is then used to predict thoracic gas volume and determine body fat from body volume (McCrory et al., 1998).

DXA is a clinical method with the primary purpose to assess bone mineral density (Barry & Kohrt, 2008). However, this technology has become a commonly used method within sports, as it can also provide a relatively precise estimate of fat mass, bone mineral content and lean mass. Full details of DXA technology and standardization procedures have been reported previously (Nana et al., 2016). Briefly, players lie on the DXA bed while an X-ray beam passes in a posterior to anterior direction through the bone and soft tissue upward to a detector. Fat mass and fat free mass are differentiated by the ratio of X-ray beam attenuation. Consideration for using DXA in players should include the history of high levels of ionizing radiation exposure (i.e., medical treatment following injury).

Each of these methods has their pros and cons. Skinfold assessments tend to be the quickest and cheapest, however depending on the clinician training and regression equation used, accuracy may be questionable (Golja et al., 2020). BIA devices also provide a body fat assessment in a timely manner, however their accuracy may be manipulated by acutely increasing total body water via hydration (Koulmann et al., 2000). ADP tends to be accurate when compared to DXA, however values diverge at the extreme ends of the body mass index (BMI) spectrum, which may impact athletic populations (Kasper et al., 2021). ADP is also sensitive to air movement and body hair. DXA is often considered the most accurate assessment method, however it is not without limitations either. It is known that different software manufactures use different computational methods to calculate body fat percentages. Furthermore, ADP and DXA tend to be less practical as the equipment needed is expensive, large, and may require qualified technicians.

If possible, any longitudinal or tracking data should be compared to data captured with the same measurement equipment and computational model. Similarly, standardizing factors such as hydration status, food intake, physical activity, and temperature should take place as they are all known to influence body fat assessment methods (Sansone et al., 2022).

STRENGTH, POWER, AND AGILITY

Agility in sports is typically defined as the ability to accelerate, decelerate, stabilize, and quickly change directions under control to execute sport specific skills. Strength is the capacity to exert force to overcome resistance, while power is the ability to produce force at a high rate, or simply put the ability to rapidly combine strength and speed. These three concepts are important for a basketball player, as they have been reported to be predictors of basketball performance (Hoffman et al., 1996; Latin et al., 1994; Ziv & Lidor, 2009).

Lower body strength has been shown to be correlated with playing time at the NCAA Division I level (Dawes & Spiteri, 2016; Hoffman et al., 1996), which together with upper body strength is responsible for successful movement execution.

Upper body strength has been shown to be both correlated with (Dawes & Spiteri, 2016) and have no relationship with playing minutes (Lockie et al., 2020). Like body size and fat percentage, strength differs between playing positions. For example, as shown in Table 2 centers performed the most reps on the bench press test at the NBA Combine. Similarly, one investigation found a moderate effect size on bench press reps performed at 83.91 kg between front and backcourt players, although the difference was statistically insignificant (Lockie et al., 2020). However, regardless of playing position there does appear to be a steady decline in upper body strength over the past few years, as about 10% of eligible players in the NBA Pre-Draft Combine could not bench press the required 185 pounds (NBA, 2017-2023; Suprs, 1997-2012). This does not eliminate strength as a critical aspect to basketball performance, rather may suggest there are other qualities that may be more impactful on in-game performance.

Elite players have been found to have superior agility compared to average-level players (Delextrat & Cohen, 2008). For example, in one study that compared 8 players participating at a national or international level to 8 players on the university second team and found that the national or international level performed better on an agility T-test (Delextrat & Cohen, 2008). There have also been investigations that have noted significant correlations between agility tests and in-game

	VERTICAL LEAP (IN)	RUN VERTICAL JUMP (IN)	BOX AGILITY (SEC)	BENCH PRESS REPS* (185 LBS.)
Guards	30.18	36.92	11.04	8.54
Forwards	29.44	35.58	11.39	8.75
Centers	28.16	33.13	11.90	9.50
Overall	29.75	35.80	11.31	8.78

	VERTICAL LEAP (CM)	RUN VERTICAL JUMP (CM)	BOX AGILITY (SEC)	BENCH PRESS REPS (~84 KG)
Guards	76.66	93.78	11.04	8.54
Forwards	74.78	90.37	11.39	8.75
Centers	71.53	84.15	11.90	9.50
Overall	75.57	90.93	11.31	8.78

n=308
** Stopped after 2019-2020 combine*

Table 2: Updated NBA draft average assessments by position.

performance outcomes. Gomes et al. (Gomes et al., 2017) saw correlations between the agility T-test and successful two-point field-goals (r = -0.65), free throws (r = -0.61), and steals (r = -0.62) in Brazilian national team members. While Hoffman et al. (Hoffman et al., 1996) also found moderate correlations between playing time and sprint outcomes in 29 Division I NCAA players. Similarly, in 14 major American university players McGill et al. (McGill et al., 2012) found correlations between lane agility drill time and minutes played (r = -0.59), points (r = -0.60), assists (r = -0.74), and steals (r = -0.69). However, these relationships do not seem to be universal as investigations have also observed no significant correlations between any NBA combine tests and total minutes played (Dawes & Spiteri, 2016; Lockie et al., 2020), minutes per game (Dawes & Spiteri, 2016; Lockie et al., 2020), or total games played (Lockie et al., 2020) in both NCAA Division I and II players.

Mixed results has been found with respect to sport specific power producing movements (Delextrat & Cohen, 2008; Köklü et al., 2011). For example, there were differences in vertical jump height and peak torque of the knee extensors between first and second division players, but none for the Wingate anaerobic test (Delextrat & Cohen, 2008). Similarly in a study utilizing magnitude-based inferences, there were ‘possibly small’ differences between Division I and II players in force produced during a counter movement jump (CMJ) (Ferioli et al., 2018). When comparing players within the same level, most studies report no statistically significant differences between the various positions (Köklü et al., 2011; Ostojic et al., 2006; Pehar et al., 2017). However, this is not a universal finding, as at the NCAA level Lockie et al. found a difference in vertical jump and approach vertical jump between front and backcourt players (Lockie et al., 2020). Studies with Division I basketball players have indicated significant correlations between playing time and vertical jump height (r = 0.68, r = 0.39) (Dawes & Spiteri, 2016; Hoffman et al., 1996) and standing long jump and minutes played (r = 0.67), rebounds (r = 0.63), and blocks (r = 0.55) (McGill et al., 2012).

These data suggest the best players may move faster and jump higher than others (Abdelkrim et al., 2007; Ostojic et al., 2006), as there does seem to be relationships between player level and strength, agility, and power. Player position may highlight the different requirements for these characteristics. However, much like the anthropometric data, there is considerable variability between individuals. Table 2 further highlights positional differences with data collected from NBA Combine assessments (NBA, 2017-2023).

AEROBIC CAPACITY

This section will discuss general aerobic and anaerobic capacity characteristics of basketball players at various levels. The demands of the game on each energy system are described elsewhere (chapter 2) and as such will not be discussed here. Physical fitness is considered a critical part of basketball competition at any level; however, much like body composition and measures of strength, power, and agility, it may not be indicative of or accompanied by technical performance proficiency (Apostolidis et al., 2004). Maximal aerobic capacity (VO_2max) is not often assessed in stop-and-go sports like basketball. Where VO_2max has been assessed, inconsistent methods have been used, ranging from laboratory-based assessment to various field-based estimation methods (Yo-Yo test, beep test, 30-15IFT).

Boone et al. investigated Belgian first division players utilizing laboratory-based equipment and indirect calorimetry. They found significant differences between positions, with guards demonstrating the highest VO_2max followed by forwards and then centers (60.3 ± 3.7, 56.4 ± 4.1, 52.7 ± 3.4, mL/kg/min respectively) (Boone et al., 2014). Another study grouped 42 professional players into perimeter (all guards and small forwards) and post (power forwards and centers) players. Their results suggested that perimeter players have a higher aerobic capacity on average when compared to post players (52.17 and 46.23 mL/kg/min respectively) (Gocentas et al., 2011). In a large longitudinal study from 2007-2011, Boone and Bourgois investigated 144 first division Belgian players via an incremental running test on the treadmill. Their results found that point guards (57.4 ± 4.8 mL/kg/min) and shooting guards (55.3 ± 3.6 mL/kg/min) had higher VO_2peak, than power forwards (50.4 ± 5.2 mL/kg/min) and centers (50.9 ± 5.2 mL/kg/min), and the VO_2peak of point guards was also higher than that of small forwards (52.9 ± 5.6 mL/kg/min) (Boone & Bourgois, 2013). A similar mean VO_2max (57.5 ± 8.2 mL/kg/min) was reported in four NCAA Division II male players utilizing laboratory methods; however, positional differences were not specified (Narazaki et al., 2009). Finally, 13 elite level players on the Greek Junior National team (18.5 ± 0.1 years) completed an incremental intensity treadmill test and were found to have an average VO_2max of 51.7 ± 1.3 mL/kg/min (Apostolidis et al., 2004).

Field-based estimation methods are useful when attempting to understand the aerobic capacity of a large group in a short amount of time. These methods are often used in team sports and can provide a valid estimate of VO_2max depending on the population (Buttar et al., 2019; Gottlieb et al., 2022; Ramsbottom et al., 1988). The Yo-Yo test was utilized to estimate the aerobic capacity of 11 players on a professional team in Brazil and the investigators found an average of 48.5 ± 3.2 mL/kg/min at the beginning of league playoffs (Gomes et al., 2017). In another study, Tunisian senior national team members exhibited estimated VO_2max values of 59.88 ± 5.26 mL/kg/min (Abdelkrim et al., 2010). In Serbian first national league players, Ostojic et al. found that guards (52.5 ± 4.8 mL/kg/min) and forwards (50.7 ± 2.3 mL/kg/min) had a higher estimated VO_2max than centers (46.3 ± 4.9 mL/kg/min); while the average for all 60 players was 49.8 ± 4.9 mL/kg/min (Ostojic et al., 2006). In American Division II players Dawes et al. found an estimated VO_2max of 41.76 ± 3.5 mL/kg/min in participating players, but no correlation with playing time (Dawes & Spiteri, 2016).

As described above there is a large range in the maximal aerobic capacity of basketball players, and it may not have a relationship with playing time, at least not in NCAA Division II players (Dawes & Spiteri, 2016). However, there may be differences in aerobic capacity between different positions (Boone & Bourgois, 2013; Boone et al., 2014; Ostojic et al., 2006). Guards tend to have higher aerobic capacity than centers (Boone & Bourgois, 2013; Boone et al., 2014; Ostojic et al., 2006) and sometimes forwards (Boone & Bourgois, 2013). There is also evidence that players at different levels may exhibit different aerobic capacities (Abdelkrim et al., 2010; Castagna et al., 2009), however this is often confounded by age differences.

ANAEROBIC CAPACITY/THRESHOLD AND POWER

Anaerobic threshold and power are concepts that are often defined as an exercise intensity above which measurement of oxygen uptake cannot account for all of the required energy (Svedahl & MacIntosh, 2003), and is expressed as either a power output, speed, or percentage of VO_2max. Anaerobic threshold has been determined various ways, including blood sampling for lactate (L_{AnT}), Wingate test (W_{AnT}), or by ventilation (V_{AnT}). There are also differences in how the anaerobic threshold is described. When utilizing blood sampling for lactate some have suggested a threshold of 4 mmol/L is indicative of the anaerobic threshold (Heck et al., 1985), while others suggest that it is the onset of plasma lactate accumulation (Farrell et al., 1993). When utilizing ventilatory methods anaerobic threshold is determined when VCO_2 departs from linearity or when there is an increase in ventilation that is disproportional to the increase in power output or speed during an incremental test (Svedahl & MacIntosh, 2003; Wasserman et al., 1973; Yoshida et al., 1981). In addition, anaerobic capacity is often measured as it been suggested that athletes who can exercise at a higher portion of their VO_2max (anaerobic threshold) may perform better than athletes who may be physiologically limited by a lower anaerobic threshold (Coyle et al., 1988; Svedahl & MacIntosh, 2003).

Apostolidis et al. investigated both W_{AnT} and V_{AnT} in Greek Junior National team members and found what they considered to be moderate anaerobic power (10.7 ± 0.4 Watts/kg) and a relatively high V_{AnT} (77.6 ± 1.9 %) (Apostolidis et al., 2004). These results are in line with findings from a group investigating Belgian first division players (Delextrat & Cohen, 2008). Boone et al. utilized L_{AnT} when also investigating Belgian first division players and found no statistically significant differences between guards (83.3 ± 2.9 %), forwards (82.9 ± 3.4 %) or centers (83.0 ± 3.2 %) (Boone et al., 2014). However when expressed as speed, L_{AnT} in guards (13.8 ± 1.1 km/h) was higher than in forwards (12.9 ± 0.9 km/h) and centers (12.0 ± 1.2 km/h) (Boone et al., 2014). This is similar to an earlier study in the same population that found L_{AnT} differences between guards and power forwards and centers, but not small forwards (Boone & Bourgois, 2013). An investigation in Spanish national second division basketball players utilized L_{AnT} methods but expressed results in terms of speed and percent of maximal heart rate. The average speed of the players was in line with previous findings at 12.8 ± 1.0 km/h, while the percentage of maximal heart was 93.5 ± 2.8 for the group of ten players (Garcia-Tabar et al., 2015).

Overall, these results suggest that basketball players exhibit moderate to high anaerobic thresholds. This is interesting to note as a study with male NCAA Division II players found that lactate concentration was 4.2 ± 1.3 mmol/L and VO_2 was 64.7 ± 7.0% of maximum during a 4 quarter exhibition game (Narazaki et al., 2009). These values seem to be lower than player thresholds and might suggest both anaerobic and aerobic conditioning is essential to success. Furthermore, the positional differences noted above may suggest that players at different positions might need to possess different anaerobic capabilities for their sport specific tasks.

FEMALE PLAYERS

Little data exists on female basketball players, particularly when considering the professional level in North America. Likewise, a majority of the data that does exist, at any competition level, does not breakdown anthropometrics into relevant playing position. To the author's knowledge there is only one investigation that does so in Division I collegiate players, and one for the professional level. The trend follows that of professional NBA players with centers being the tallest on average (189.05 cm [74.43 in]) followed by forwards (180.28 cm [70.98 in]) and then guards (170.78 cm [67.24 in]). The same can be said for other measures such as body mass (centers 81.29 kg [179.24 lbs.]; forwards 73.46 kg [161.98 lbs.]; guards

64.13 kg [141.41 lbs.]) (Carter et al., 2005; Lamonte et al., 1999) and body fat percentage (centers 20.79 %; forwards 17.4 %; guards 14.62 %) (Lamonte et al., 1999).

When considering these female athletes as an adult group (collegiate and national level), players are 179.40 ± 5.58 cm (70.63 ± 2.20 in) tall, weigh 73.23 ± 5.54 kg (161.47 ± 12.22 lbs.), with a body fat percentage of 18.89 ± 3.58 % (Carbuhn et al., 2010; Carter et al., 2005; Garcia-Gil et al., 2018; Lamonte et al., 1999; Nunes et al., 2014). Female high school players are smaller on average with their anthropometrics reported as the following for height (166.93 ± 1.42 cm [65.35 ± 0.56 in]), weight (58.59 ± 2.36 kg [129.19 ± 5.20 lbs]) and body fat percentage (20.45 ± 4.65 %) (Greene et al., 1998; Gryko et al., 2022). Much like in men's basketball, there seems to be a wide variety of body size and composition and it may not be wholly indicative of individual athlete success.

Unlike the previously collected unpublished data from the NBA draft (Table 2), strength, power, and agility data is not often collected in female basketball players. There are some investigations that have included certain measures within their research design; however, there is a dearth of data in this area when compared to male basketball parameters. The general body size measurements follow similar trends to men (i.e., height, weight, body fat percentage) in that guards tend to be smaller and leaner than forwards, which in turn tend to be smaller and leaner than centers (Carter et al., 2005; Lamonte et al., 1999).

Female basketball players have a relatively high peak power output (W/kg); however, forwards may jump higher than their guard or center peers, albeit to an insignificant amount (Lamonte et al., 1999). Available literature suggests that elite female basketball players complete a typical T-drill test in 9.83 ± 0.56 s (Lamonte et al., 1999; Nunes et al., 2014), and have a vertical leap of 36.3 ± 2.46 cm (14.17 ± 0.97 in) (Lamonte et al., 1999; Nunes et al., 2014; Ziv & Lidor, 2010); however, the number of studies are limited. Furthermore, Garcia-Gil et al. observed correlations in agility T-drills to basketball performance outcomes (performance index rating and team rank) in players from first division Spanish league teams (Garcia-Gil et al., 2018). Much like data on body size, there seems to be large variability in strength, power, and agility in female players.

Aerobic capacity in female players (50.3 ± 5.9 mL/kg/min) is lower than their male counterparts at least at the NCAA Division II level; however, they tend to use a similar proportion of it during live gameplay (66.7 ±7.5%) (Narazaki et al., 2009). A similar investigation involving professional players from the Slovenian (n = 12) and Serbian (n = 12) national teams utilized a field-based estimation method to determine player aerobic capacity and stratify by position. The average for the overall group was (47.6 ± 9.7 mL/kg/min), with guards exhibiting the highest VO2peak (53.1 ± 9.1 mL/kg/min) followed by forwards (46.9 ± 9.6 mL/kg/min), and then centers (42.7 ± 8.3 mL/kg/min); however, the positions were not statistically different (Štrumbelj et al., 2015). A more recent study involving female players from the National Croatian League also investigated aerobic capacity according to playing role and position via graded fitness test in a laboratory setting. They found that backcourt players (guards) had higher VO_2max than their frontcourt (forwards and center) teammates (48.1 ± 3.8 and 43.0 ± 3.3 mL/kg/min respectively) (Scanlan et al., 2021). Similarly, those players who were starters exhibited better aerobic capacity than those who were bench players (47.4 ± 5.2 and 44.7 ± 3.5 mL/kg/min respectively) (Scanlan et al., 2021). This group of investigators was also able to validate a field-based aerobic capacity estimation test (30-15 IFT) in female players (Scanlan et al., 2021).

SUMMARY

There does not appear to be a 'one size fits all' physiological or anthropomorphic profile of a basketball player. It seems clear that "ideal" physique and physiology are not sufficient on their own to excel in basketball (Latin et al., 1994). Basketball players demonstrate a moderate level of anaerobic power with a high anaerobic threshold and aerobic capacity. Strength, power, and agility may predict success (playing time) in elite basketball; however, there is considerable variability between both positions and players. It may be that the position of the player is most related to body composition and/or physical characteristics. There is still limited data available in female basketball players, particularly at the elite level; however, trends seem to mirror those of male counterparts. Game and strategic changes in playing style may impact physical and physiological requirements for gameplay and should not be overlooked (Hoffman, 2003).

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CHAPTER 4

FUELING THE BASKETBALL ATHLETE

FUELING THE BASKETBALL ATHLETE

A PRACTITIONER'S APPROACH

Kris Osterberg, PhD, RD, CSSD
Gatorade Sports Science Institute

KEY POINTS

- Carbohydrate is the body's preferred fuel during basketball practices and games.
- Dietary carbohydrate is stored as glycogen in the liver and muscle and becomes depleted after 90-100 minutes of high-intensity exercise. Eating a diet rich in carbohydrate (5-10 g/kg body mass) and consuming carbohydrate during play helps maintain blood glucose and prevent depletion of glycogen stores.
- Carbohydrate rich foods include fruits and vegetables as well as whole grain products (e.g., bread, pasta, and rice).
- Protein is important to build and repair muscle. Basketball players should get 1.4 – 1.7 g/kg body mass per day. However, an athlete eating adequate amount of food usually consumes plenty of protein without the need for supplementation.
- Pregame meals should be high in carbohydrate and low in fat and fiber with the goal of providing energy, eliminating hunger, and reducing the risk of gastrointestinal distress. Pregame meals should always be practiced, as each athlete's gastrointestinal system may respond differently to certain foods and beverages.
- During practices and games, athletes should consume 30-60 g of carbohydrate per hour.
- If an athlete has less than 24 hours between training sessions or games, he/she should place a high priority on recovery nutrition. Carbohydrate intake of 1.0-1.2 g/kg and about 20 g of protein after exercise helps restore muscle glycogen and supplies amino acids for muscle protein synthesis, respectively.
- Tournament play is marked by high-intensity games and short recovery time. Prioritizing recovery and proper fueling before and during the games will help ensure each athlete has the energy to play at their best each time they step on the court.

INTRODUCTION

Basketball players come in all shapes and sizes ranging from a 5’4” 120-lb female high school point guard to a 7’2” 250-lb male college center. Though the playing time and relative intensity may be similar between the two athletes, they will have vastly different caloric needs. Choosing foods that will provide the energy and nutrients to support competition and training is essential and can also be quite challenging. This chapter will provide dietary guidelines for all players using examples of meals and snacks that are accessible and budget friendly.

ENERGY AND NUTRIENTS

The energy requirements of basketball players can be considerable. Energy expenditure in elite high-school-aged female and male basketball players during the season was measured to be over 3,500 and 4,600 kcals/day, respectively (Silva et al., 2012). Meeting these energy needs can be challenging for young athletes. A study in elite junior male basketball players found that 32% had protein intakes under 1.4 g/kg and 56% had carbohydrate intakes under 6 g/kg with inadequate intakes of vitamin A, zinc, and calcium (Nikic et al., 2014). Additionally, a recent study in collegiate female players found inadequate intakes of energy, protein, and carbohydrate over the course of the season (Zanders et al., 2021). Educating athletes to select the proper foods in adequate quantities can ensure they meet their energy, macro- and micronutrient needs.

Carbohydrate

The muscle’s preferred fuel during high-intensity activities such as basketball is carbohydrate. The body stores carbohydrate as glycogen in the liver (75-100 g) and skeletal muscle (300-400 g). Liver glycogen maintains blood glucose at rest and during exercise (Wasserman, 2009). An overnight fast substantially lowers liver glycogen which is why it is so important for athletes to eat prior to a morning practice (Sunzel, 1963). Training can nearly double the amount of glycogen the muscle can store (Roedde et al., 1986) which is advantageous because higher muscle glycogen increases the amount of time an athlete can continue to play at a high intensity. When muscle glycogen stores are full, most athletes have enough to fuel 90–100 min of moderate to high-intensity activity (Hermansen et al., 1967). While it’s unlikely that individual basketball practices or games will deplete muscle glycogen, inadequate carbohydrate intake coupled with daily training can critically lower muscle glycogen over the course of several days. This leaves a player fatigued or with a feeling of “heavy legs”. A study in male basketball players found that 4-weeks of a low carbohydrate diet (10% carbohydrate) significantly lowered total work capacity assessed via a Wingate test compared to a conventional diet (54% carbohydrate) or high carbohydrate diet (75% carbohydrate) (Michalczyk et al., 2019).

Basketball players should consume a high-carbohydrate diet from foods such as fruits, vegetables, whole grains, and legumes. Most sports dietitians recommend carbohydrate intake based on body mass to ensure adequate intake. The range of carbohydrate consumption suggested for basketball players is 5–7 g/kg body mass but may be higher or lower depending upon playing time (Karpinski & Rankin, 2017). Athletes who play most of the game and multiple games per week may need to consume 8-10 g/kg while those who are injured or play very few minutes may need 5 g/kg or less (See Table 1). Tracking perceived exertion by asking “How hard did practice feel for you today on a scale of 1-10”? may help identify players who may be under consuming carbohydrate. Subjective ratings of practice at the upper end of the scale for multiple days in a row (especially if their teammates consistently give lower ratings), may signal low glycogen stores. For those players with high carbohydrate needs, eating carbohydrate at regular intervals in the form of high-carbohydrate snacks (fruits, sports bars, smoothies) while including fruits, vegetables and whole grains

BODY WEIGHT	5 G CARBOHYDRATE/DAY	7 G CARBOHYDRATE/DAY	10 G CARBOHYDRATE/DAY
60 kg (132 lbs)	300 g	420 g	600 g
81 kg (178 lbs)	405 g	567 g	810 g
100 kg (220 lbs)	500 g	700 g	1,000 g

Table 1: Range of carbohydrate recommendations for select body weights.

at meals can help ensure they get the energy and carbohydrate required. Conversely, if an athlete isn't getting much playing time and is gaining weight, an adjustment in energy intake may be necessary.

Protein

Protein is important for building and maintaining lean body mass. Although many athletes take supplements and make efforts to increase dietary protein to build muscle mass, this can usually be met by eating a well-balanced diet with sufficient energy and protein spread throughout the day. Consuming 20-30 g every 3-4 h with meals or snacks is sufficient for most players to promote muscle protein synthesis. However, supplementation should be considered if time or resource constraints limit access to high-protein food. Research shows that protein intake of 1.8 g/kg body mass is the upper limit for muscle protein synthesis assuming the athlete is consuming adequate calories (Phillips & Van Loon, 2011). For a 55 kg (120 lb) player, that is about 98 g of protein. A player that weighs 82 kg (180 lb) may need up to 150 g. As shown in the sample menu, this is easily met with adequate energy intake. While eating excess protein is not harmful for healthy people, it often displaces energy from carbohydrate, which, as discussed above, is the muscle's preferred fuel. The recommendation for daily protein intake for basketball players during the competitive season is 1.4–1.7 g/kg of body mass during the season (Macedonio, 2017).

Fat

Dietary fats are important for the synthesis of hormones and cell membranes, as well as proper immune function. Athletes should strive to eat heart-healthy fats such as mono-unsaturated fats (olive oil, avocado) as well as omega-3 fats (salmon, flaxseed) and avoid saturated fats (beef fat, lard) and trans fats (margarine and processed foods). Recent research reported that professional basketball players were not consuming adequate omega-3, as indicated by self-reported intake of fatty fish and omega 3 supplements and confirmed by low blood concentrations of omega 3 index (Davis et al., 2021; Davis et al., 2022). Energy intake from fat should make up the remainder of calories after protein and carbohydrate recommendations are met.

Micronutrients

Though micronutrients do not contribute energy to the diet, they are essential for a multitude of functions including red blood cell formation, oxygen carrying capacity, bone mineralization, antioxidant status, and metabolism. Vitamin D is a micronutrient that has gained attention in recent years specific to baskeball players. As basketball is primarily an indoor sport, players should be mindful of their vitamin D status since vitamin D is synthesized through the skin's exposure to sunlight. Recent studies have found that over 70% basketball players have inadequate blood concentrations of vitamin D (Stojanović et al., 2021; Grieshober et al., 2018). Athletes with darker skin pigmentation may be at an increased risk of vitamin D insufficiency (Fields et al., 2019). This is because UVB rays from the sun penetrate into the skin transforming 7-dehydrocholesterol into previtamin D3. Dark pigmentation of the skin acts as sunscreen absorbing the UVB rays and effectively blocking the activation of 7-dehydrocholesterol (Holick et al., 2007). Despite having lower concentrations of 25-hydroxyvitamin D (the primary form measured in the blood) African Americans generally have higher bone mineral density and lower fracture risk (Shieh & Aloia, 2017). Vitamin D plays an important role in bone health but is also vital for proper immune and neuromuscular function. A recent study found that when female basketball players were supplemented with 4,000 IU/day of vitamin D for 6 weeks, markers of bone resorption and muscle damage decreased (Stojanović et al., 2021).

Vitamin D can be consumed by eating fatty fish (e.g., salmon, herring, and sardines) or through fortified products (e.g., milk or orange juice). Currently, supplementation is advised if blood concentrations of total 25[OH]D levels are < 80 nmoL/L or 32 ng/ml (Alshahrani & Aljohani, 2013). However, a recent review has suggested that measuring free 25[OH]D as opposed to total 25[OH]D is a better indicator of status (Sempos et al., 2022); the major drawback being the cost and accessibility of this assay. The daily requirement for vitamin D for adults aged 19-50 is 600 IU/day with a maximum of 4000 IU/day for everyone over 8 years old (Holnick et al., 2011). While supplementation may be warranted, over supplementation of vitamin D can lead to toxicity the symptoms of which include nausea, vomiting, gastrointestinal disorders, irregular heartbeat, and renal damage (Alshahrani & Aljohani, 2013). Testing throughout the season to ensure vitamin D sufficiency is prudent.

FOOD	SERVING SIZE	CARBOHYDRATE (G)
Animal Crackers	14	25
Apple	Medium	25
Banana	Medium	25
Fuit Gummies	2 pouches	34
Fruit Leather	1 oz	24
Gatorade Thirst Quencher	20 oz	35
Graham Crackers	2 sheets	24
Grapes	1 cup	27
Pretzels	1 oz	25
Quaker Chewy Granola Bar	2 bars	33
Raisins	1/2 cup	30
Trail Mix	1/2 cup	28

Table 2: Carbohydrate content of select foods.

Pregame Meals

The goal for any pre-competition meal is to provide energy (e.g., top off liver glycogen) while eliminating the distraction of hunger. Appropriate meals or foods should be high in carbohydrate and low in fat and fiber to facilitate gastric emptying (See Table 2 for examples of high carbohydrate snacks). A good rule of thumb for determining appropriate pre-game carbohydrate intake is the following equation:

(body mass in kilograms) x (hours prior to competition) = grams of carbohydrate

For example, a player weighing 68 kg (150 lb) and eating 3 h prior to the game could eat: 68 kg x 3 h = 204 g of carbohydrate. This would be equivalent to a small meal including a turkey sandwich, an ounce of pretzels, a granola bar, and 1 L (33 oz) of Gatorade® Thirst Quencher. On the other hand, if this player is eating 1 h prior to the game, only about 70 g of carbohydrate should be consumed. An appropriate snack may be 1 liter (33 oz) of Gatorade® Thirst Quencher and an ounce of pretzels. It is very important that each player find what combinations of foods and beverages work best by experimenting before and during practices.

Fueling During Games

Consuming carbohydrate during the game is important for maintaining sprint speed (Baker et al., 2015). Although it is unlikely that a player will deplete his glycogen stores, supplementing with carbohydrate during the game may help maintain performance in the fourth quarter (Welsh et al., 2002). The recommended amount of carbohydrate to consume during exercise is 30–60 g/h. Athletes who are playing the majority of the game or who begin the game inadequately fueled should aim for 60 g/h. This could be achieved through drinking a sports drink, or through supplements (gels, chews) or foods (banana, bars). Sports drinks, such as Gatorade, contain 60 g of carbohydrate/L while helping replace fluid and electrolyte losses. Many sport supplement products such as gels and chews contain 25-30 g of carbohydrate per serving and are quick sources of energy. These products should be consumed with water to expedite gastric emptying and absorption into the body. Replacing sweat losses while meeting carbohydrate needs can be accomplished in a variety of ways. A personalized fueling plans allows individuals to meet their needs in a way that works best for them.

Recovery

Recovery nutrition is very important when players have less than 24 h between games or training sessions. In the period immediately after training, muscle is especially sensitive to amino acids and glucose in the blood and can use them for muscle protein synthesis and glycogen restoration, respectively. Eating a meal or drinking a recovery shake immediately post-exercise allows the muscle to recover its glycogen stores more quickly than the same meal eaten multiple hours after exercise (Ivy et al., 1988). Recommended carbohydrate intake is 1.0–1.2 g of carbohydrate/kg body mass and about 20-30 g protein (Thomas et al., 2016). For a 68 kg (150 lb) person, this would be about 82 g carbohydrate (328 kcal). Some players prefer liquid meals for recovery, as they may not have an appetite for solid food following competition. Many commercial recovery products are available; however, chocolate milk and other foods are also appropriate (See Table 3). In most cases, however, basketball athletes will have more than 24-h to recover between games and training sessions. Players should be encouraged and provided the opportunity to eat regular, nutrient-dense meals to ensure they meet their energy and nutrient needs.

Tournament Play

The principles of pregame meals and recovery should be followed for teams entering tournament play. Some Amateur Athletic Union (AAU) teams may play 3-5 games over a weekend or, in the case of collegiate tournaments, may play back-to-back games with less than 24-h to recover. In this scenario, it becomes essential that players are provided with foods that supply carbohydrate to restore their muscle glycogen reserves, protein to help with muscle protein synthesis, and fluid to rehydrate. Teams that must play more than one game per day or play in the evening and again in the morning should consume pregame meals that are high in carbohydrate. Breakfasts may include toast or bagels with jam, a small stack of pancakes with syrup, or ready-to-eat cereal with low-fat cow's or plant-based milk. Lunches or dinners may consist of pasta with marinara sauce, a low-fat sandwich or wrap, or soup with bread.

SUMMARY

Developing the skills needed to become a great basketball player requires endless hours of time spent shooting, passing, ball-handling, and conditioning. Ignoring proper nutrition is like building a high- performance sports car and putting the wrong gas in the tank; it cannot operate optimally unless its engine is given high-grade fuel. Such is the case with athletes. Although the body can function on low-grade fuel, it will not perform as well as it could when given the proper types of food in the correct amounts at the optimal times. Eating a variety of whole grains, fruits and vegetables, lean sources of protein, and healthy fats will provide high-quality fuel for the best possible performance.

Kris Osterberg is employed by the Gatorade Sports Science Institute, a division of PepsiCo R&D. The views expressed are those of the author and do not necessarily reflect the position or policy of PepsiCo, Inc.

FOOD	SERVING SIZE	CARBOHYDRATE (G)	PROTEIN (G)
Gatorade Recovery Protein Shake	1 Bottle	45	20
Low-Fat Chocolate Milk	24 oz	72	22
Bagels with Turkey Breast	2 Medium bagels with 3 oz of turkey breast	76	31
Quaker Oatmeal Squares with Skim Milk	1/5 cups cereal + 16 oz skim milk	90	25
Strawberry Banana Smoothie	8 oz milk, 5 oz Greek yogurt, 1.5 cups strawberries, 1 banana	72	24

Table 3: Recovery "meals".

Sample Menus

55 kg (120 pound) player

Breakfast: oatmeal (1 cup cooked), banana, low fat milk 300 ml (10 oz)

Snack: apple with peanut butter (2 TBS), Quaker chewy granola bar

Lunch: turkey wrap (4 oz turkey breast, lettuce, tomato, mayo on whole wheat wrap), baby carrots (8), baked chips (1 oz)

Snack (pre-practice): Gatorade 600 ml (20 oz), pretzels (1 oz)

Dinner: spaghetti with marinara (2 cups), tossed salad with dressing (small), garlic toast (2 pieces)

Totals: 2,428 kcal; 6.5 g carbohydrate / kg body mass; 1.5 g protein / kg body mass

68 kg (150 pound) player

Breakfast: oatmeal (1 cup cooked), banana, low fat milk 360 ml (12 oz), orange juice 360 ml (12 oz)

Snack: apple with peanut butter (1 TBS), Quaker chewy granola bar

Lunch: turkey wrap (4 oz turkey breast, lettuce, tomato, 2 oz Swiss cheese and mayo on whole wheat wrap), baby carrots (8), baked chips (1 oz)

Snack (pre-practice): Gatorade 900 ml (32 oz), pretzels (1 oz)

Dinner: spaghetti with marinara (3 cups), tossed salad with dressing (small), garlic toast (2 pieces)

Totals: 3,187 kcal; 7.0 g carbohydrate / kg body mass; 1.5 g protein / kg body mass

82 kg (180 pound) player

Breakfast: oatmeal (1 cup cooked), banana and raisins (1/4 cup), low fat milk 360 ml (12 oz), orange juice 360 ml (12 oz)

Snack: apple with peanut butter (2 TBS), Quaker chewy granola bar

Lunch: turkey wrap (2 wraps each with 3 oz turkey breast, lettuce, tomato, 1 oz Swiss cheese, mayo on whole wheat wrap), baby carrots (8), baked chips (2 oz)

Snack (pre-practice): Gatorade 900 ml (32 oz), pretzels (2 oz)

Dinner: spaghetti with marinara (3 cups), tossed salad with dressing (small), garlic toast (2 pieces)

Totals: 3,667 kcal; 6.7 g carbohydrate / kg body mass; 1.6 g protein / kg body mass

96 kg (210 pound) player

Breakfast: oatmeal (1.5 cup cooked), banana and raisins (1/4 cup), low fat milk 300 ml (10 oz), orange juice 360 ml (12 oz)

Snack: apple with peanut butter (2 TBS), Quaker chewy granola bar

Lunch: turkey wrap (2 wraps each with 3 oz turkey breast, lettuce, tomato, 1 oz Swiss cheese and mayo on whole wheat wrap), baby carrots (8), baked chips (2 oz)

Snack (pre-practice): Gatorade 900 ml (32 oz), pretzels (2 oz)

Dinner: spaghetti with marinara (3.5 cups), tossed salad with dressing (small), garlic toast (2 pieces)

Evening Snack: mixed berry smoothie (2 cups fruit, 1 cup yogurt)

Totals: 4,419 kcal; 7.0 g carbohydrate / kg body mass; 1.6 g protein / kg body mass

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CHAPTER 5

RECOVERY NUTRITION FOR THE BASKETBALL ATHLETE

RECOVERY NUTRITION FOR THE BASKETBALL ATHLETE

Sara Y. Oikawa, PhD
Gatorade Sports Science Institute

Keith Baar, PhD, FACSM
University of California Davis

KEY POINTS

- Proper nutrition is the key to maintaining muscle mass and strength throughout a basketball season.
- Nutrition may also help prevent or treat musculoskeletal injuries that are common to basketball players such as patellar tendinopathy (jumper's knee).
- Adequate protein (0.24-0.31 g/kg) should be consumed per eating occasion and following training to maximize muscle protein synthesis and support recovery.
- Athletes should consider the addition of 15-20 g of dietary collagen + 50 mg of Vitamin C to support connective tissue recovery and enhance performance.

BACKGROUND

Strength, speed, and power are dependent on a players' muscle mass, their muscle type (fast vs. slow), their neuromuscular recruitment, and the stiffness of the connective tissue that transmits to force generated in muscle to bone. When basketball players train, they experience three types of fatigue: 1) metabolic fatigue resulting from the breakdown of fuels (fats and carbohydrates) to play the sport; 2) mechanical fatigue within the musculoskeletal system as a result of the combination of eccentric (braking), isometric (planting), and concentric loading (propulsive acceleration) (Spiteri et al., 2014) involved in basketball; and 3) neurological fatigue as a result of the need to rapidly process and read the game while maintaining the concentration needed to execute the skills necessary to excel at the sport. For information on fueling recovery as a result of the metabolic fatigue of basketball, please see chapters 4 and 9. This chapter will introduce how nutrition can be leveraged to improve recovery from mechanical fatigue within the musculoskeletal system in response to basketball training, with a specific focus on enhancing muscle protein synthesis and connective tissue health. For additional information on this topic, the reader is referred to a more thorough review paper (Davis et al., 2022).

MAINTAINING AND GROWING MUSCLE

The goal of recovery nutrition, in the context of this chapter, is to help overcome the mechanical fatigue of playing basketball. When optimized, the stress of playing basketball together with sufficient rest and nutrition can grow muscle and support connective tissue adaptations; allowing athletes to get bigger, stronger, and to perform better. However, when the load of practice and game time is too great and/or recovery or nutrition is suboptimal, this is when muscle mass and strength can decline, injuries occur at a greater rate, and performance suffers. In fact, without the proper nutrition, strength training is likely insufficient to increase mass and strength (Phillips, Tipton, Aarsland, Wolf, & Wolfe, 1997). It would be difficult to build muscle mass and strength in very tall athletes who are practicing for long hours at a high intensity with insufficient nutrition (Hickson, 1980). As a result, it is not uncommon for an athlete to lose weight during a season because of the imbalance between training/competition and recovery/nutrition.

An athletes' muscle mass is determined by the balance between how much muscle protein they make and how much muscle protein they breakdown. Both protein ingestion and exercise can increase rates of muscle building, or muscle protein synthesis. However, a combination of both stimuli can increase rates of muscle protein synthesis more than either stimuli independently (Tipton, Ferrando, Phillips, Doyle, & Wolfe, 1999). This can result in a shift in balance so that athletes can begin to add muscle mass with training over time. In recovery from training, both muscle protein synthesis and breakdown increase. When provided with sufficient amounts of high quality protein, (an easily digestible food that provides all of the essential amino acids and is rich in leucine, as will be discussed below) (Tipton et al., 1999) the body can use the provided amino acids to build the new muscle proteins needed to recover from the mechanical fatigue of training and possibly grow stronger. This repair and remodeling are critical to all athletes, regardless of whether they are intending to increase muscle mass.

Nutrition in recovery from training can improve muscle growth and aid in the remodeling and rebuilding of muscle following exercise, but what type of protein should athletes eat? As suggested above, an easily digestible protein source that contains all the essential amino acids is important. Essential amino acids are those that cannot be produced by the body and therefore need to be consumed in the diet. Ensuring adequate consumption of foods with high levels of the essential amino acids and in particular, the branched chain amino acid leucine (at ~1-3 g per meal/snack), will aid in the muscle recovery process. This process is crucial to skeletal muscle rebuilding and remodeling to meet the high demands of basketball training. Milk proteins (whey and casein), and most other animal-based proteins (eggs, meat, fish, etc.) are richer in the essential amino acids, including leucine, than soy and other plant-based proteins (Phillips, 2017). Consuming whey protein after training has been shown to stimulate muscle building to a greater extent than soy protein isolate when provided at the same absolute amount (Tang, Moore, Kujbida, Tarnopolsky, & Phillips, 2009). However, this does not mean that plant-based protein sources cannot benefit muscle recovery. Since plant sources of protein are lower in the essential amino acids and leucine, a consideration would be to consume a greater total amount of protein from a plant source compared to an animal sourced protein (for example, 30 g soy protein isolate instead of 20 g of whey) to ensure that adequate amounts of essential amino acids are available for muscle rebuilding, remodeling, and repair.

It is also important that the protein source consumed following training is easy to absorb. For example, a steak has all the essential amino acids but is difficult to digest and absorb. Simply grinding the steak into hamburger makes it easier to digest and absorb and therefore more of the amino acids from the meat are used to build muscle. In a similar way, the two protein components of milk (whey and casein protein) are absorbed at different rates. Casein is more slowly absorbed because it clumps when mixed with stomach acid, whereas whey is rapidly absorbed once ingested. Plant-based sources of protein are typically harder to digest and lower in EAAs and are sometimes very low in other essential amino acids (Gorissen et al., 2018). However, athletes using plant-based sources to meet daily protein recommendations can still achieve the recommended daily intake of all the essential amino acids through either increasing their total protein intake as mentioned above, or from consuming plant proteins from a variety of sources, termed complementary proteins. For example, legumes are often low in the essential amino acid methionine, while grains are often low in the essential amino acids lysine, tryptophan, and threonine. However, consuming a combination of legumes and grains (ex. rice and beans) can overcome these deficiencies and provide adequate amounts of all essential amino acids (Young & Pellett, 1994).

Given the high amount of training undertaken by basketball players, a greater amount of dietary protein is recommended to support the repair and remodeling of muscle and other tissues. For a basketball player, 1.2-2.0 g/kg/day would likely better support skeletal muscle recovery than the 0.8 g/kg/day recommended for the general population (Thomas, Erdman, & Burke, 2016). To achieve this elevated protein recommendation, athletes should aim to consume 0.24-0.31 g of protein per kg of body mass after training and at each meal, approximately every 3-4 h throughout the day. This recommendation benefits both muscle remodeling and contributes to daily protein needs but also encourages athletes to consume food and meals in sufficient frequency to support of their total caloric requirements, the latter of which is a documented challenge for high performance athletes (Logue et al., 2020). For example, a 250 lb (113 kg) athlete may aim to consume ~35 g, a 175 lb (~80 kg) athlete may aim to consume ~25 g, and a smaller 130 lb (~60 kg) athlete may aim to consume ~15 g of protein following training and at each meal. An example of protein containing meals and snacks can be found in Table 1.

It is important to remember that recovery from mechanical fatigue does not end in the few hours following training. In fact, after strength training, muscles are more sensitive to protein feeding for at least 24 h (Burd et al., 2011). That means that every time an athlete eats protein for a full day following strength training, they benefit from higher rates of protein synthesis as a result of their training.

An often-missed opportunity to optimize protein intake to benefit muscle health and recovery is consuming protein prior to sleep. Given that protein and exercise are two of the most influential stimuli to increase muscle protein, sleep represents a prolonged period where neither protein ingestion, nor muscle contraction occurs; resulting in over-all negative net protein balance (Res et al., 2012). Research examining muscle protein synthesis during the overnight period after training has shown that when 40 g of protein (in this case, casein protein) is consumed prior to sleep, rates of muscle building were higher than with a placebo. This means that the extra protein taken before sleep was successfully incorporated into new muscle proteins during sleep (Res et al., 2012). Thus, protein ingestion prior to sleep may serve as an effective strategy for athletes who are looking to maximize recovery.

It is important to acknowledge that the literature used to form protein recommendations for athletes is almost exclusively derived from data in men. However, it is understood that there is minimal difference in the rate of muscle protein synthesis between young (18-30 years) men and women at rest

(Fujita, Rasmussen, Bell, Cadenas, & Volpi, 2007), in response to amino acid ingestion (Smith et al., 2009), following resistance exercise (West et al., 2012), or in response to amino acids and exercise combined (Dreyer et al., 2010). This is despite significant differences in circulating hormone concentrations between males and females (West et al., 2012). Similarly, there does not appear to be significant differences in the ability of women to build muscle during different phases of the menstrual cycle (Miller et al., 2006). Notably, a recent review suggested that total daily protein recommendations for male and female athletes is similar at ~2.0 g/kg/day for both resistance and endurance trained athletes (Mercer et al., 2020); however, to date studies have not assessed the optimal per meal/dose of protein in trained female athletes or in basketball athletes specifically. Thus, current recommendations for protein ingestion to improve muscle building and repair in athletes are independent of sex. Notably, sex differences do exist in other aspects of physiology that impact performance such as the potential for sex-hormones to influence connective tissue, as will be discussed below.

Lastly, nutrients other than proteins have been shown to benefit the muscle building response and therefore may act together with protein ingestion to improve recovery following basketball training. Specifically, supplementation with n-3 fatty acids (n-3PUFAs) has been shown to benefit muscle recovery following exercise. Athletes ingest n-3PUFA supplements in pursuit of a wide variety of reported performance and health benefits including reduced inflammation, improved recovery following injury, enhanced immunity, and in some cases, in an effort to increase skeletal muscle metabolic efficiency (Philpott, Witard, & Galloway, 2019; Wall, Morton, & van Loon, 2015). Dietary sources of n-3PUFAs include oily fish (ex. mackerel, salmon, sardines), egg yolks, walnuts, and chia seeds. Though the optimum dose of n-3PUFAs (and the optimum ratio) remains unknown, benefits to muscle strength, size, and muscle protein synthesis have been observed with doses between 2-5 g/day (Philpott et al., 2019).

Dietary supplementation with n-3PUFAs has been shown to sensitize muscle to the anabolic effects of protein ingestion through altering the skeletal muscle phospholipid membrane (Calder, Yaqoob, Harvey, Watts, & Newsholme, 1994). The increase in polyunsaturated fatty acids into the muscle membrane improves the transport of nutrients, such as amino acids, into muscle, increasing rates of muscle building (Lewis, Daniels, Calder, Castell, & Pedlar, 2020) and therefore may impact training adaptations and exercise recovery over time. Supplementation will likely need to occur for at least 4 weeks before the maximal incorporation of n-3PUFAs into muscle is reached (McGlory et al., 2014). An additional benefit to athletes is the finding that n-3PUFAs may reduce muscle soreness following exercise. Though not measured in basketball athletes, in competitive soccer players, muscle soreness was significantly lower 3 days following intense exercise in the group consuming 1.1 g of n-3PUFAs combined with protein and carbohydrates compared to ingesting protein and carbohydrate alone (Philpott et al., 2018). This improvement was attributed to a reduction in muscle damage, with a 39% reduction in markers of muscle damage, in the n-3PUFA group (Philpott et al., 2018). Consuming n-3PUFAs may also help during periods of more prolonged recovery such as following injury, surgery, or illness. A recent study showed that consuming 5 g of n-3PUFA per day for 4 weeks prior to complete knee immobilization (similar to following injury, or ACL reconstruction), reduced the loss of muscle mass loss in healthy active females compared to the muscle mass lost in females consuming a placebo oil (McGlory et al., 2019). Therefore, n-3PUFA supplementation may be a therapeutic recovery strategy from injuries in sport. For a thorough assessment of the literature on n-3PUFAs, please see the review by Philpott, Witard, & Galloway (Philpott et al., 2019).

IMPROVING CONNECTIVE TISSUE HEALTH AND FUNCTION

Another component of strength, speed, and power is the stiffness of an athlete's connective tissue. Connective tissues include not only an athlete's tendons and ligaments, but also the collagen within a muscle that transfers the force made by the muscle to the tendon and bone, and the collagen within important load-bearing tissues like bone and cartilage. Athletes and their coaches normally only think of connective tissues when they have an injury. However, connective tissue is also important for performance. Stiffer connective tissues allow an athlete to jump higher and play faster. Therefore, to play their best an athlete needs to have stiff connective tissues, but stiff connective tissues can make the athlete more prone to certain injuries.

Connective tissue injuries comprise ~70% of all missed training or games. In basketball, ~50% of youth and up to 70% of professional players suffer from "jumper's knee" or patellar tendinopathy. Other common connective tissue injuries include ankle sprains, Achilles tendinopathy/rupture, muscle pulls, and ruptured anterior cruciate ligaments (ACL). Each of these injuries will need extensive rehabilitation that may benefit from targeted nutrition. Importantly, the incidence of ACL rupture is 4-6-times higher in female basketball players compared with their male counterparts (Arendt & Dick, 1995), whereas muscle pulls are 80% lower in women. This is in part because the hormone estrogen makes connective tissue less stiff. By contrast, testosterone increases connective tissue stiffness. This is one of the reasons that men can (on average) jump higher than women. More importantly, these hormonal differences mean that where stiffness decreases injury rate (ligaments), women suffer more injuries and where stiffness increases injury rate (muscle pulls) women suffer fewer injuries.

	60 KG (130 LBS) ATHLETE ~15 G PRO/MEAL INCLUDING MEAT	60 KG (130 LBS) ATHLETE ~15 G PRO/MEAL VEGETARIAN (INCLUDING DAIRY)	80 KG (175 LBS) ATHLETE ~25 G PRO/MEAL INCLUDING MEAT	80 KG (175 LBS) ATHLETE ~25 G PRO/MEAL VEGETARIAN (INCLUDING DAIRY)	113 KG (250 LBS) ATHLETE ~35 G PRO/MEAL INCLUDING MEAT	113 KG (250 LBS) ATHLETE ~35 G PRO/MEAL VEGETARIAN (INCLUDING DAIRY)
Breakfast/ Post training	1 cup cooked oatmeal (6 g protein) ¼ scoop whey protein isolate (7 g protein) 100 g yogurt (4 g protein)	1 cup cooked oatmeal (6 g protein) ½ scoop (15 g) pea protein isolate (12 g protein)	1 cup cooked oatmeal (6 g protein) ½ scoop whey protein isolate (15 g protein) 100 g yogurt (4 g protein)	1 cup cooked oatmeal (6 g protein) 1 scoop (30 g) pea protein isolate (24 g protein)	2 eggs (12 g protein) 2 slices whole grain bread (7 g protein) ½ cup low fat cottage cheese (14 g protein)	1 cup scrambled tofu (11 g protein) 2 slices whole grain bread (7 g protein) ½ cup low fat cottage cheese (14 g protein)
Morning snack	½ cup low fat cottage cheese (14 g protein) with fresh fruit	½ cup low fat cottage cheese (14 g protein) with fresh fruit	1 cup low fat cottage cheese (28 g protein) with fresh fruit	1 cup low fat cottage cheese (28 g protein) with fresh fruit	1 scoop (30 g) whey protein isolate (24 g protein) ¼ cup Greek yogurt (5 g protein) 10 roasted almonds (6 g protein)	1.5 scoops (45 g) pea protein isolate (30 g protein) 10 roasted almonds (6 g protein)
Lunch	50 g turkey breast (7 g protein) 2 slices whole grain bread (7 g protein)	1 whole wheat tortilla (4 g protein) ¼ cup black beans (3.5 g protein) ¼ cup seitan (8 g protein)	100 g turkey breast (15 g protein) 2 slices whole grain bread (7 g protein)	1 whole wheat tortilla (4 g protein) ¼ cup black beans (3.5 g protein) ½ cup seitan (16 g protein)	100 g turkey breast (15 g protein) 2 slices whole grain bread (7 g protein) 1.5 cups 1% milk (13 g protein)	1 whole wheat tortilla (4 g protein) 1/4 cup black beans (3.5 g protein) 1 cup seitan (32 g protein)
Dinner/ Post training	2 oz chicken breast (16 g protein)	½ cup cooked tempeh (16 g protein)	3 oz chicken breast (24 g protein)	½ cup cooked tempeh (16 g protein) 1 cup cooked quinoa (7 g protein)	4 oz chicken breast (32 g protein) ½ cup cooked quinoa (3.5 g protein)	1 cup cooked tempeh (32 g protein) ½ cup cooked quinoa (3.5 g protein)
Pre-sleep	40 g casein protein shake	40 g casein protein shake	40 g casein protein shake	40 g casein protein shake	40 g casein protein shake	40 g casein protein shake

Table 1: Examples of protein sources and serving sizes at varying meal occasions for athletes weighing 60 kg (130 lbs), 80 kg (175 lbs), and 113 kg (250 lbs). Servings are relative to body mass (0.24-0.31 g/kg of protein/serve) with options for omnivorous diets and lacto-ovo vegetarian diets.

As mentioned above, there is a direct relationship between muscle-tendon stiffness and jump height (Foure, Nordez, Guette, & Cornu, 2009). The best way to increase muscle-tendon stiffness and jump performance is to perform rapid plyometric exercises (jumps, sprints, bounds, or playing basketball). However, even though this is good for performance, greater tendon stiffness is associated with an increased incidence of muscle injury (McHugh et al., 1999), so exercise caution with a lot of plyometric activities especially early in training. Reversing muscle-tendon stiffness is as easy as doing the same movements with a heavy weight at a slower speed or concentrating on very slow negative, or lengthening, movements (i.e. the lowering phase of a toe raise; Mahieu et al., 2008). Therefore, performing heavy slow movements in training can decrease tendon stiffness (and likelihood of a muscle injury).

The issue of connective tissue function is especially important for young athletes for three reasons. First, the rate of ACL rupture is highest in girls between 13 and 18 years of age. Second, the proteins at the core of tendons like the Achilles are not thought to change after the age of 18 (Heinemeier, Schjerling, Heinemeier, Magnusson, & Kjaer, 2013). Therefore, what young basketball players do during this critical window will shape their tendons for the rest of their lives. The third reason that connective tissue function is important for young basketball players is that early specialization and high training loads with insufficient rest is associated with 3-times more injuries than those training less or allowing greater recovery (Post, Rosenthal, Root, & Rauh, 2021).

Clearly, there is a balance between performance and injury when it comes to connective tissue. Lots of fast plyometric movements increase stiffness and improve performance, whereas slow movements decrease stiffness and lower injury rates. What is less clear is how these processes can be enhanced with nutrition. First, unlike muscle, connective tissue has limited blood flow. Tendons and ligaments have few blood vessels and instead get nutrients by squeezing fluids through the tissue. When stretched or loaded, fluid is squeezed out of the tendon, and when relaxed new fluid is sucked in. This suggests that nutrients that improve tendon and ligament function might work better if they are in the blood stream before exercise.

Using this framework, Shaw et al. (2017) performed a simple study feeding people gelatin and vitamin C every 6 h for three days. An hour after they drank the placebo, 5, or 15 g of gelatin each subject jumped rope for 6 min to stimulate collagen synthesis. Interestingly, when the subjects drank 15 g of gelatin, they showed a 2-fold greater rate of collagen synthesis than when they drank the placebo control (Shaw, Lee-Barthel, Ross, Wang, & Baar, 2017). Further work has shown that hydrolyzed collagen works as well as gelatin and importantly consuming 20 g of collagen improves performance during heavy strength training (Lis et al., 2022). However, this work has recently been questioned in a study that showed no effect of hydrolyzed collagen on collagen synthesis after jumping rope (Hilkens et al., 2023).

As for the role of dietary collagen in injury prevention and repair, 10 g of hydrolyzed collagen daily increased cartilage thickness (McAlindon et al., 2011) and decreased knee pain in athletes (Clark et al., 2008), and in runners with Achilles tendon injuries adding collagen to rehabilitation doubled the rate of return to play (Praet et al., 2019). These data suggest that dietary collagen can improve performance and recovery in jumping athletes. Most importantly for basketball players, a structured program performed 2-3 times a week comprised of heavy isometric squats and leg extensions 30-60 min after drinking 15 g collagen and 50 mg of vitamin C was able to completely reverse patellar tendinopathy in a professional basketball player (Baar, 2019). These data suggest that dietary collagen may decrease injury and improve performance in basketball athletes.

SUMMARY

Differences in strength, speed, and power separate skilled basketball players from the elite. Building strength, speed and power requires the proper training, rest, and nutrition. To increase muscle mass and strength through a basketball season an athlete should consume 0.24-0.31 g of leucine rich protein per kilogram of body weight every 3-4 h and as soon as possible after training. Proteins such as milk, whey, eggs, and meat are ideal for this purpose. Not only is muscle important for strength, but we are also learning that connective tissue plays an important role in both performance and injury rate. Taking 15-20g of dietary collagen 30-60 min before training may decrease injury and improve performance.

PRACTICAL APPLICATIONS

1. The primary goal of any training program is to decrease injuries. The secondary goal is to improve performance. Proper training and nutrition facilitate both goals.
2. Protein is a key component to proper nutrition. However, rather than simply consuming excess protein, consuming small protein-rich meals evenly spaced throughout the day provides greater benefits.
3. Eating a meal rich in amino acids, specifically leucine, as soon as possible after training augments the effects of training by improving muscle protein synthesis.
4. Proteins such as whey or milk that result in a rapid and prolonged increase in leucine in the blood maximize the increase in muscle protein synthesis and strength.
5. There is currently no evidence to suggest differences in protein recommendations (either type, or amount) between male and female athletes.
6. Connective tissue is also essential to the health and performance of basketball players.
7. Rapid plyometric movements increase stiffness and performance but also increase the risk of muscle injury. Heavy slow movements decrease stiffness and the risk of injury.
8. Eating 15-20 g of dietary collagen with 50mg of vitamin C before training may help minimize injuries and improve performance (ensuring that supplements are third-party tested).

The views expressed are those of the authors and do not necessarily reflect the position or policy of PepsiCo, Inc.

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CHAPTER 6

HYDRATION SCIENCE AND STRATEGIES FOR BASKETBALL

HYDRATION SCIENCE AND STRATEGIES FOR BASKETBALL

Lindsay B. Baker, PhD, FACSM
Gatorade Sports Science Institute

KEY POINTS

- Research indicates that ≥ 2% dehydration may impair performance of basketball-specific skills (field-goal shooting) and basketball-specific movements (on-court sprinting and agility).
- Multiple indices should be used and interpreted collectively to obtain an estimate of hydration status. Practical assessment techniques, such as monitoring urine (color, concentration, and frequency), changes in body weight, and thirst sensation can be useful in guiding fluid intake needs before, during, and after training or competition.
- The descriptive literature indicates that relatively low levels of dehydration accrue in most players during basketball practice/games if drink breaks are provided. However, it seems that off-court hydration may be inadequate in some players. Rehydration strategies should be individualized and consider the volume, rate, and composition of fluid intake, especially in situations involving congested schedules and travel between practices/games.

INTRODUCTION

Body water loss through sweating occurs during exercise to dissipate body heat and, therefore, prevent sharp rises in body core temperature. Thermoregulatory sweat losses can be large, particularly during high-intensity and/or prolonged activity such as a ~1.5-2 h basketball practice or game. When fluid intake is less than sweat loss, a body water deficit, or dehydration, occurs. The purpose of this chapter is to: 1) provide an overview of the effect of dehydration on basketball performance, 2) discuss what is currently known about off-court and on-court hydration practices of basketball players to determine the most common hydration issues that need to be addressed, and 3) recommend hydration strategies that can be implemented by coaches and practitioners to ensure players are well-hydrated before, during, and after practice/competition. Throughout this chapter, dehydration will be expressed as a percentage of body weight deficit (e.g., 2% dehydration is equivalent to 2% loss of body weight, which is 3 lb. in a 150 lb. player). The term euhydration will be used to denote “normal” body water content or maintenance of baseline body weight by ingesting fluid to completely replace sweat losses incurred during a workout.

EFFECT OF DEHYDRATION ON PERFORMANCE

Success in the game of basketball is dependent upon both aerobic and anaerobic performance as well as sprinting, strength, and jumping ability. Research suggests that some, but not all, of these components of the game may be impacted by hydration status. Dehydration (> 2% body weight deficit) has been found to consistently impair aerobic performance (Cheuvront & Kenefick, 2014; Sawka et al., 2007). In addition, hypohydration may be associated with decrements in muscle endurance, muscle strength, and anaerobic power, but has no effect on anaerobic capacity and vertical jumping ability (Savoie et al., 2015). The game of basketball also involves the execution of complex sport- specific skills, which are dependent upon motor skill and cognitive function. There is evidence from studies in the general population and with athletes that dehydration (>2%) impairs mood and cognitive performance, especially for tasks involving attention, executive function, and motor coordination (Sawka et al., 2007; Wittbrodt & Millard-Stafford, 2018). Cognitive performance research specific to basketball is limited; however, one study has found that dehydration (1-4%) impairs attention (resulting in more errors made during a test) in male high school and college basketball players (Baker, Conroy, et al., 2007).

A few studies have also tested the impact of dehydration on basketball-specific skills during a simulated game. Dougherty et al. (2006) compared the effect of 2% dehydration vs. fluid replacement to maintain euhydration on skill performance of 12 to 15-year-old competitive male basketball players. Performance was assessed during four quarters of basketball drills designed to incorporate various aspects of the game, including field-goal and free-throw shooting, repeated sprints, vertical jumps, and defensive slides. Compared with the players’ performance during the euhydration trials, 2% dehydration resulted in significantly slower total sprinting and lateral movement times as well as a lower shooting percentage over the course of the entire simulated game (Dougherty et al., 2006). In a follow up study, Baker et al. (2007) employed a similar basketball protocol to investigate the effect of progressive (1% to 4%) dehydration vs. euhydration on performance in 17 to 28-year-old male basketball players. In this study, the players experienced a progressive deterioration in sprint times and the number of shots made as dehydration progressed from 1 to 4%. The level of dehydration at which overall performance was significantly impaired compared with euhydration was 2% body weight deficit (Baker, Dougherty, et al., 2007).

In another basketball performance study, ten male players completed a 40-min simulated “2 on 2 full court” game with or without drinking (Hoffman et al., 1995). During the fluid-restricted trial, players accrued 1.9% dehydration throughout the simulated game, whereas euhydration was maintained with water during the fluid-ingestion trial. No statistically significant differences in field-goal or free-throw shooting performance were observed between trials. However, during the fluid-restricted trial, players experienced an 8.1% decrease in field-goal percentage between the first and second half of the simulated game. By contrast, field-goal percentage increased by 1.6% in the fluid-ingestion trial (Hoffman et al., 1995). Although this difference did not reach statistical significance, a net 9.7% difference in shooting performance could be of practical significance in a game. In another study, Carvalho et al. (2011) found no effects of 2.5% dehydration on performance of basketball drills in 14 to 15-year-old male players after a 90-min training session. It is important to note, however, that players accrued 1.0% body weight deficit in the control trial, thus there was a smaller difference in body weight loss between dehydration and control trials in this study (Carvalho et al., 2011) compared with the literature finding detrimental effects on skill performance. Studies with female basketball players have found that 2.1% and 2.3% dehydration were associated with lower field goal percentage (Brandenburg & Gaetz, 2012) and impaired lower body reactive agility (Hoffman et al., 2012), respectively, compared with euhydration.

The aspects of basketball performance that are negatively impacted by dehydration are illustrated in Figure 1. Although more basketball-specific research is needed, the balance of evidence to date suggests that ≥2% dehydration may impair sprinting, agility, field goal shooting, and certain aspects of cognition (attention) in basketball players. In addition, ≥2% dehydration is associated with increased ratings of fatigue (Baker, Conroy, et al., 2007; Dougherty et al.,

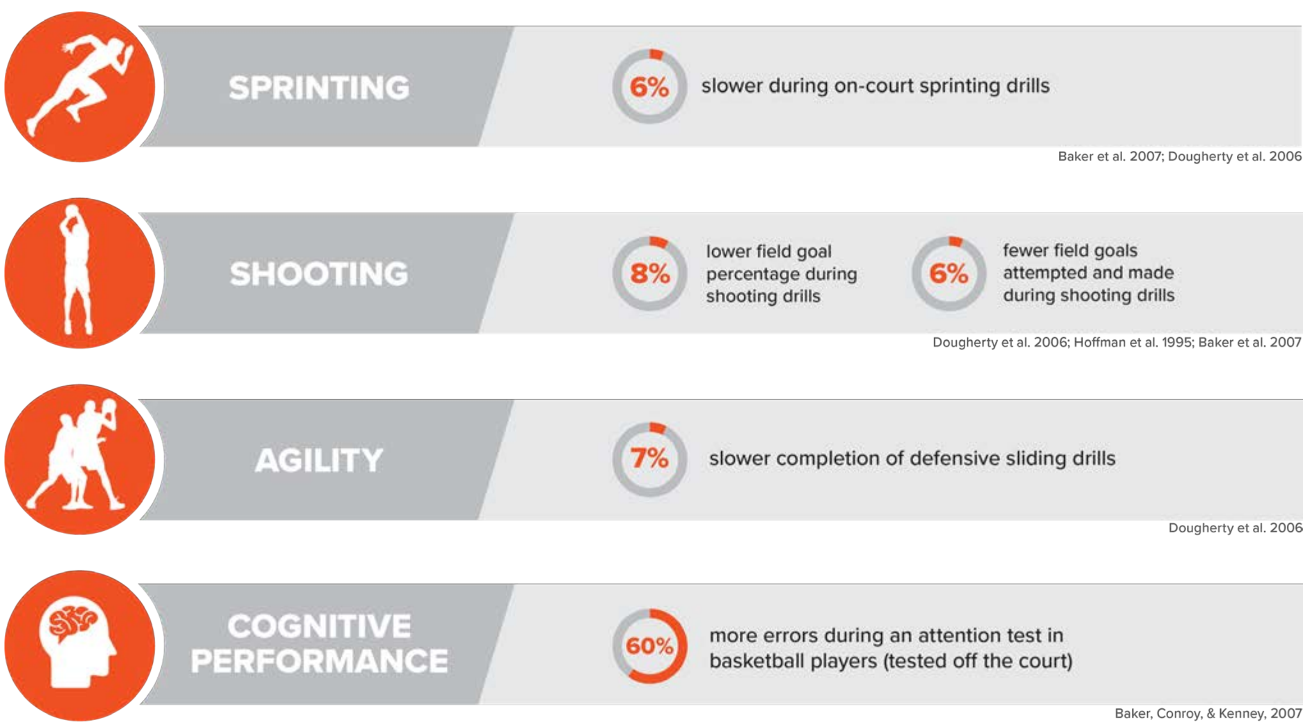

Figure 1: Aspects of basketball performance impaired by ≥ 2% dehydration.

ORIGINAL BODY WEIGHT (LBS)	NET FLUID LOSS IF 2% HYPOHYDRATED (LBS)	BODY WEIGHT WHEN 2% HYPOHYDRATED (LBS)
150	3.0	147.0
160	3.2	156.8
170	3.4	166.6
180	3.6	176.4
190	3.8	186.2
200	4.0	196.0
210	4.2	205.8
220	4.4	215.6
230	4.6	225.4
240	4.8	235.2
250	5.0	245.0

Table 1: Body weight loss equivalent to 2% dehydration.

2006). Table 1 shows the body weight loss equivalent to 2% dehydration for basketball players of various body weights (in 10-lb increments).

FLUID BALANCE IN BASKETBALL PLAYERS

Off-Court Hydration

Fluid intake habits off the court are important in determining how well-hydrated an athlete is at the start of a training session or game. Observational studies (Table 2) suggest that it is common for basketball athletes to begin practice or competition with urine concentrations that may be indicative of dehydration (urine specific gravity, USG ≥ 1.020) (Brandenburg & Gaetz, 2012; Hamouti, Del Coso, Estevez, et al., 2010; Heishman et al., 2021; Osterberg et al., 2009; Sawka et al., 2007; Thigpen et al., 2014). For example, Heishman et al. (2021) found that 55–66% of pre-exercise urine samples had USG > 1.020 across multiple years of NCAA men's preseason and competitive basketball seasons. In this study USG was significantly higher during the competitive season versus preseason (Heishman et al., 2021). In another study, 79% of NCAA basketball players' samples had USG > 1.020 before offseason conditioning and preseason practices, with no significant differences between men and women (Thigpen et al., 2014). However, Brandenburg & Gaetz (2012) found that female Canadian national-level players were well-hydrated prior to games. Given the inconsistent results between studies more research may be needed to understand off-court hydration habits of female players.

Although USG is a practical measure, interpretation of spot measurements (pre-exercise) can be difficult because of confounding factors. Experts suggest that USG is most useful and accurate as a hydration assessment technique when collected upon waking in the morning (Cheuvront et al., 2015; McDermott et al., 2017; Thomas et al., 2016). Interestingly one study in Table 2 collected first morning voids and all 11 European professional basketball players had a USG > 1.020, thus providing support to the notion that most athletes begin exercise in a hypohydrated state (Hamouti, Del Coso, Estevez, et al., 2010). However, future studies should report the percentage of athletes with USG >1.025 (as well as >1.020) since false positives may occur with values between 1.021-1.025, especially in larger athletes (Hamouti, Del Coso, Avila, et al., 2010).

On-Court Hydration

Shortly after beginning physical activity fluid losses start to occur from thermoregulatory sweating. Therefore, fluid intake is needed to prevent dehydration during training or competition. Sweating rates can vary considerably among players (and even from day-to- day within players) because of differences in body size, exercise-intensity, and environmental conditions, among other factors. Based on normative data developed by the Gatorade Sports Science Institute (GSSI) (Figure 2) the mean sweating rate across 196 basketball players (92 ± 18 kg) was 950 ml/h, but ranged from ~0.2 L/h up to 2.5 L/h (Barnes et al., 2019). Sweat sodium losses were ~10 mmol/h to 150 mmol/h (or 230 mg/h to 3,450 mg/h). Similar results have been reported for sweating rate (see Nuccio et al., 2017 for review) and sodium losses (Hamouti, Del Coso, Estevez, et al., 2010) in other observational studies with basketball athletes. For example, one study observed 16 to 18-year-old basketball players training at the Australian Institute of Sport (Broad et al., 1996) and found that sweating rates were higher during games (male: 1587±362 ml; female: 976±254 ml) than practices (male: 1039±169 ml; female: 687±114 ml) and higher in practices than the weightlifting sessions (male: 377±120 ml; female: 246±133 ml) during the winter season. This finding may be explained by differences in absolute exercise intensity among session types, but this is speculative since energy expenditure data were not collected in this study (Broad et al., 1996).

Despite the large sweat losses incurred during training and competition, the descriptive literature suggests that most basketball players drink enough fluid to prevent significant fluid deficits

REFERENCE	PARTICIPANTS	SEASON	TIMING OF URINE COLLECTION	USG RESULTS
Heishman et al., 2021	15 male NCAA Division I players	Preseason and competitive seasons across two years	Pre-practice	55–66% >1.020
Thigpen et al., 2014	11 male and 11 female NCAA Division II players	Offseason conditioning and preseason practice	Pre-practice	68% 1.020-1.030 and 14% >1.030 (men) 55% 1.020-1.030 and 20% >1.030 (women)
Hamouti et al., 2010	11 male European professional players	Competitive season	First morning void (3 h before practice)	100% 1.021-1.030
Osterberg et al., 2009	29 players from 5 NBA teams	Summer league competition	Pre-game	52% > 1.020
Brandenburg & Gaetz, 2012	17 female Canadian national-level players	Exhibition game during training camp	Pre-game	6% > 1.020

Table 2: Summary of studies assessing urine specific gravity before basketball practices and games.

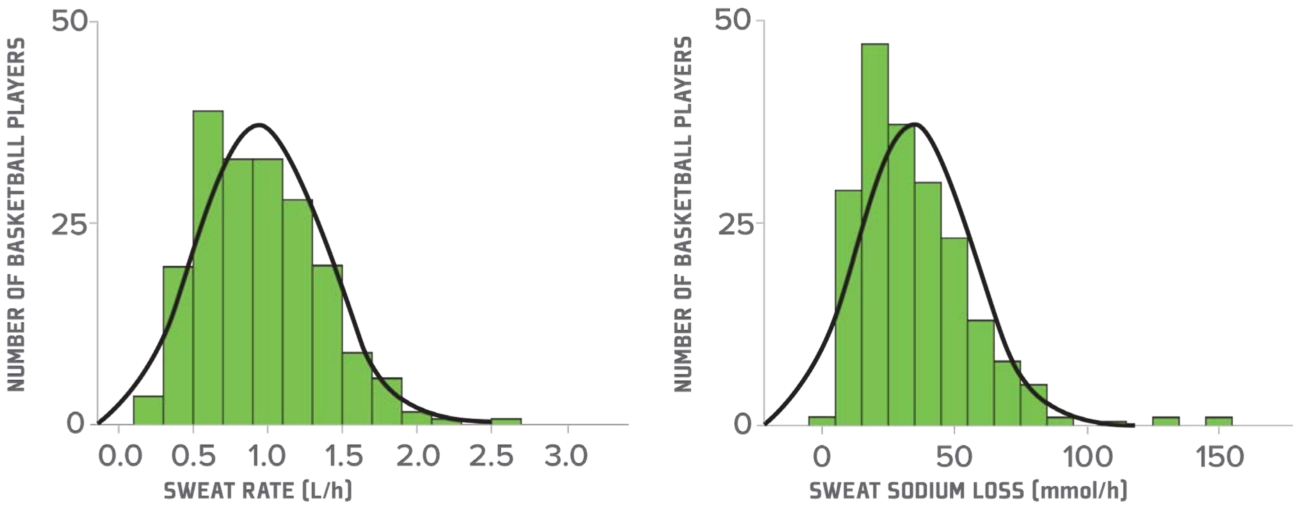

Figure 2: Frequency histograms showing whole body sweating rate and sweat sodium loss of 196 basketball players tested by the Gatorade Sports Science Institute. Reproduced from Barnes et al. 2019, with permission.

(≥2% body weight deficit). For example, Broad et al. (1996) found that less than 10% of the 16 to 18-year-old basketball players accrued ≥ 2% dehydration throughout a training session or game and most players (~50-70%) accrued < 1% dehydration. Similarly, GSSI has found that only 12% of professional basketball players developed >2% hypohydrated during pre-season practices (Figure 3) (Baker et al., 2022). Similar findings have been reported in other observational studies with male and female adolescent (Carvalho et al., 2011; Minehan et al., 2002), male and female collegiate (Thigpen et al., 2014), and male professional basketball players (Hamouti, Del Coso, Estevez, et al., 2010; Osterberg et al., 2009). These results may be somewhat surprising given that most basketball players underestimate their sweat losses during training (Thigpen et al., 2014). However, the volume of *ad libitum* fluid consumed by an athlete during exercise is largely dependent upon fluid availability (Passe, 2001). Thus, the lack of significant in-game dehydration found in basketball is likely related to the structure of the game, which is conducive to frequent stoppage of play, allowing opportunity for fluid intake during time-outs, player substitutions, and halftime (Belval et al., 2019). It is important to note, however, that the possibility of the Hawthorne effect (alteration of behavior – i.e., consuming more fluids than usual - due to their awareness of being observed) cannot be ruled out either.

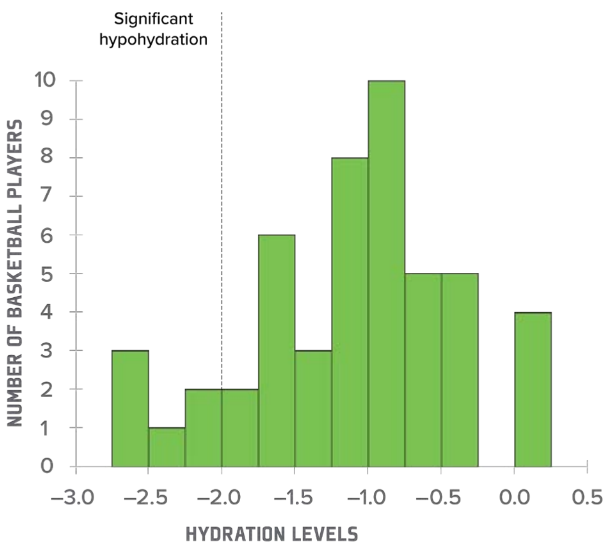

Figure 3: Frequency histograms showing fluid balance of 49 professional basketball players after 98 ± 30 min of a coach-led pre-season practice. Reproduced from Baker et al. 2022, with permission.

HYDRATION STRATEGIES

Hydration Assessment Techniques

Practical indices of hydration status include body weight (e.g., fluctuation in morning body weight or change from before to after exercise), urine (e.g., color, USG, and frequency), and thirst. Although each of these indices is somewhat limited in their precision and accuracy (compared to more- expensive or controlled laboratory-based techniques), they can still be effective in estimating fluid intake needs, especially when used collectively and interpreted in the proper context (Sawka et al., 2007). For example, first morning nude body weight can be a useful indicator of hydration status. For a euhydrated individual who is in “energy balance,” morning body weight (after voiding) is stable and not expected to deviate by > 1% (Armstrong, 2007). Thus, when a first morning nude body weight deviates from “normal” morning body weight (established by regular measurements over a period of several days) by > 1%, the individual may be dehydrated, especially if accompanied by dark/concentrated urine and thirst.

This concept is illustrated in the Venn diagram in Figure 4 (Cheuvront & Sawka, 2005). “WUT” is a simple memory tool to help determine if a player is dehydrated based on their body weight, urine color,

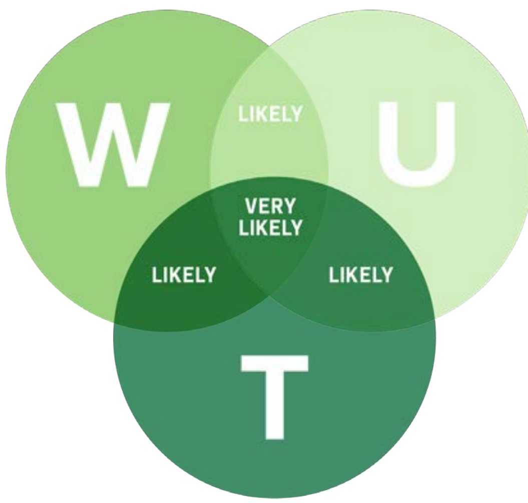

Figure 4: WUT Venn diagram to monitor day-to-day hydration status. There are three questions that can be assessed based on simple markers to determine if an athlete is dehydrated: 1) Is the player thirsty? 2) Is their morning urine dark yellow? 3) Is their morning body weight noticeably lower when compared to yesterday morning? If the answer to any one of these questions is “Yes,” the athlete may be dehydrated. If the answer to any two of these questions is “Yes,” it is likely that the athlete is dehydrated. If the answer to all three of these questions is “Yes,” it is very likely that the athlete is dehydrated. Reproduced from Cheuvront and Sawka 2005, with permission.

and thirst. When two or more markers are present, dehydration is likely. If all three markers are present, dehydration is very likely. The "WUT" technique is most appropriate for day-to-day hydration assessment, whereas acute changes in body weight are best for monitoring fluid losses and hydration needs during/after exercise. Another simple assessment is urine frequency, with ≥ 5-7 voids per day considered "optimally" hydrated (Perrier et al., 2021).

Sweat Testing

As discussed above, it is well known that sweat profiles (i.e., sweating rate and sweat sodium concentration) vary considerably among athletes. Thus, sweat testing is recommended to determine sweat profiles of each individual player. This information can be helpful in developing personalized hydration strategies – i.e., how much water and sodium are needed to replace sweat losses and restore euhydration.

The simplest and most accurate way to assess sweat loss is by measuring the athlete's body weight over time. Acute body weight change (e.g., from pre- to post-exercise of a < 3 h workout) (Sawka et al., 2007) represents ~16 oz. of sweat loss per 1 lb. of body weight loss (Armstrong, 2007). However, non-sweat sources of body mass change (especially fluid/food intake and urine/stool output) should also be measured and accounted for, when applicable.

Objective assessments are important because athletes tend to poorly conceptualize their sweat losses during exercise (O'Neal et al., 2020). For example, Thigpen et al. (2014) found that the error in self-estimating sweat losses was high (~71%) among male and female NCAA Division II basketball players.

Sweat is comprised mostly of water and salt (sodium chloride). While sweat contains a variety of other electrolytes, minerals, and metabolites, sodium and chloride are by far the most abundant constituents. In particular, sodium plays an important role in fluid balance in the body. Sodium (and chloride) concentrations in sweat range from 10-90 mmol/L (230-2070 mg/L sodium and 355-3191 mg/L chloride), whereas potassium is ~2-8 mmol/L (78-312 mg/L), while calcium (0.2- 2 mmol/L or 8-80 mg/L) and magnesium (<0.5 mmol/L or < 12 mg/L) are even lower. Sweat composition is typically determined from the standard absorbent patch technique. With this method patches are placed on the skin (typically the forearm) to collect sweat during exercise. The sweat samples are subsequently analyzed using ion chromatography in a biochemistry laboratory to determine the athlete's sweat electrolyte concentrations (Baker, 2017).

Recently, a microfluidic wearable device (Gx Sweat Patch) has been developed by GSSI to provide a more practical alternative to determine sweating rate and sweat sodium/chloride losses. In a validation

PRE GAME
4 h before game: Drink 14-19 oz of fluid
2 h before game: Player has dark urine and USG=1.021. Therefore, drink 8-14 oz of fluid.

DURING GAME
Drink at least 24 oz but no more than 80 oz.
e.g., depending on tolerance, could aim for 30 oz (or 1 full Gatorade squeeze bottle) per half

POST GAME
Body weight deficit of 1.25 lbs after the game
Drink 30 oz of fluid with post game salty snack or a meal

Additional Considerations:

Sweat Profile – based on previous sweat tests this player typically loses about ~5 lb during a game.

Schedule – the player has another game tomorrow.

Figure 5: Example game-day fluid intake volumes required for a 180-lb player based on pre, during, and post-exercise recommendations.

study with G-League basketball players, the Gx Sweat Patch provided similar sweat sodium/chloride concentrations and whole body sweating rate results during moderate-intensity practices compared with standard methods (Baker et al., 2022).

Recommendations

Table 3 contains detailed hydration strategies to aid proper hydration before, during, and after training/competition. Example game-day fluid volumes required for a 180-lb player based on these recommendations can be found in Figure 5. Because of the deleterious effects of dehydration on basketball performance, it is recommended that athletes start practice well-hydrated, drink enough fluid to prevent ≥ 2% body weight deficit during a practice session or game, and rehydrate to replace any remaining body fluid deficit after a workout. Beginning practice or competition in a well-hydrated state is important because fluid intake during exercise may not be sufficient to compensate for poor pre-exercise hydration status; as studies with professional basketball players have shown that there is no relation between pregame USG and the volume of fluid consumed during competition (Hamouti, Del Coso, Estevez, et al., 2010; Osterberg et al., 2009).

To ensure players begin training/competition well-hydrated, fluids should be readily available throughout the day. For example, athletes could be encouraged to carry a water bottle if possible or drink during passing periods in school. The use of a fluid tracking smart bottle/application may also help remind athletes to sip fluid throughout the day. For basketball teams that may travel via air before/after games, players should be encouraged to drink fluids while in flight since the dry air in the cabin results in greater insensible (respiratory and transcutaneous) fluid loss (Zubac et al., 2020). Consuming beverages that promote fluid retention (e.g., electrolytes) can reduce the need to urinate (topic discussed in more detail below).

Rapid and complete rehydration after exercise is important if the athlete is participating in a practice session or game within the same day or in <24 h (Sawka et al., 2007; Shirreffs & Sawka, 2011). In this case, it is recommended that athletes drink 24 oz for each 1 lb (i.e., 150%) of body weight deficit. The additional volume compensates for the urine loss stimulated by rapid consumption of large volumes of fluid. Consuming fluid with sodium and/or at a more gradual rate over time also helps maximize fluid retention. When there is ≥ 24 h between sessions, adequate fluid can usually be consumed with normal eating and drinking practices (i.e., ad libitum). However, congested schedules and travel, particularly to warmer areas, may make it difficult to drink appropriately throughout the day. With these considerations in mind, fluid intake strategies after exercise should be based on individual needs (as determined by assessments described above and in Table 3). In addition, adequate all-around fluid intake before and during practices/games lessens the need for aggressive post-exercise rehydration,

OCCASION AROUND TRAINING/ COMPETITION	HYDRATION ASSESSMENT TECHNIQUE	DEFINITION	RECOMMENDATIONS
Before	Morning body weight Urine specific gravity Urine color Urine frequency Thirst	• In a euhydrated individual who is in "energy balance," morning body weight (after voiding) is stable and not expected to deviate by >1%. • Determine "normal" (euhydrated) baseline body weight by taking daily measurements (over a period of ≥3 days). • Specific gravity is a measure of urine concentration. A urine sample < 1.020 is indicative of euhydration. This technique requires an instrument called a refractometer. • Light yellow (like lemonade) is indicative of euhydration. • Dark yellow or brown (like apple juice) is indicative of dehydration. • Clear urine is indicative of overhydration. • As a general assessment, urine frequency ≥ 5-7 x per day may be considered well hydrated. • Thirst can be determined with a simple yes/no question.	• Use the "WUT" diagram (Figure 5) to determine if a player is dehydrated based on body **w**eight, **u**rine color, and **t**hirst. When two or more markers are present, dehydration is likely. If all three markers are present, dehydration is very likely. • If morning body weight has dropped by >1% from "normal," then drink fluid to reestablish baseline body weight. • Slowly drink fluids (e.g., ~5–7 mL/kg or 0.077-0.108 oz/lb) at least 4 h before the practice or game. If no urine is produced, or urine is dark or highly concentrated, slowly drink more fluid (e.g., another ~3–5 mL/kg or 0.046-0.077oz/lb) about 2 h before the event. • Consuming beverages with sodium (110-270 mg/8 oz) and/or small amounts of salted snacks or sodium-containing foods will help retain the consumed fluids.
During	Change in body weight	• Measure pre- and post-workout body weight to determine expected sweat loss during training and games of various intensities, durations, and environmental conditions. • Body weight should be taken with minimal dry clothing or nude, if possible.	• Avoid significant body weight deficit (i.e., ≥2%). Also, avoid any body weight gain. • Drink up to 16 oz of fluid for each 1 lb of sweat lost during the course of a workout. • Consuming a beverage with sodium (110-160 mg/8 oz) helps replace sweat sodium losses and stimulate thirst.
After	Change in body weight	• Compare post-workout body weight to pre-workout body weight. Body weight should be taken with minimal dry clothing or nude, if possible.	• Drink ~24 oz of fluid for each 1 lb of body weight deficit. This is especially important if the next practice or game is in <24 h. In most other situations, fluid can be consumed with normal eating and drinking practices. • Consuming a beverage with sodium (110-270 mg/8 oz) and/or small amounts of salted snacks or sodium-containing foods helps replace sweat sodium losses, stimulate thirst, and retain the ingested fluids.

Table 3: Hydration strategies before, during and after training/competition.

which allows athletes to focus their attention on other nutrition needs or recovery modalities between training sessions/games (Davis et al., 2022).

Strategies for adequate hydration after exercise should consider the composition as well as the volume of fluid ingested between games/training (Evans et al., 2017). Some of these considerations are described in Table 3. For example, the inclusion of sodium in a drink stimulates renal water reabsorption, which helps to restore plasma volume and promotes better fluid retention after exercise-induced dehydration than electrolyte-free fluids (Shirreffs et al., 1996). Fluid retention can also be enhanced by increasing energy density (e.g., inclusion of protein and/or ≥ 10–12% carbohydrate), which slows fluid delivery to the circulation, thereby delaying urine losses after fluid ingestion. For example, the increased energy density as well as the clotting of casein in milk-based products delays gastric emptying (James et al., 2011).

Practitioners should consider the duration between training bouts when deciding the most appropriate composition of a fluid replacement beverage. Milk or other energy-dense carbohydrate/protein-based drinks are effective for rehydration when there are several hours between exercise bouts. However, when more rapid fluid replacement is needed, energy dense fluids such as milk may not be suitable since the delay in gastric emptying could cause gastrointestinal distress. In these situations, athletes should drink up to ~1.5 L (51 oz) of a sodium-containing fluid (with relatively low energy density, i.e., 2-6% carbohydrate) for each kilogram (2.2 lbs) of body fluid deficit to promote fluid retention without delaying fluid delivery to the circulation. Providing a chilled beverage with the addition of flavor and sweetness can also improve beverage palatability and voluntary fluid intake (Sawka et al., 2007). Further, regarding the rehydration efficacy of other common beverage components consumed throughout the day, moderate caffeine (up to 400 mg) does not impact fluid balance (Maughan et al., 2019), but drinks with > 2% alcohol can impair rehydration by stimulating urine loss (Evans et al., 2017).

On a final note, although female sex hormones alter certain aspects of body fluid regulation, there are minimal effects of sex or menstrual cycle phase on hydration outcomes. Direct comparisons have not been made in basketball athletes, but in general sweat loss, fluid balance, and post-exercise rehydration are not significantly influenced by sex per se and do not differ significantly within women across the menstrual cycle. Instead, factors such as body size, absolute workload, aerobic fitness, heat-acclimatization status, and behavioral differences generally play a larger role in determining sweat loss and fluid balance. The reader is referred to review papers for more information on this topic (Baker, 2023; Rodriguez-Giustiniani et al., 2022).

SUMMARY

Dehydration by ≥ 2% of body weight has been found to impair basketball skill performance, and greater levels of dehydration can further degrade performance. Observational studies suggest that a relatively small percentage of athletes (~10-15%) experience significant body weight loss from pre- to post-training/competition, likely because of easy access to fluids and frequent opportunities to rehydrate. However, players with heavy sweating rates and who receive minimal substitution breaks can accrue ≥ 2% body weight loss during practice and competitions. Thus, sweat testing is recommended to identify the 10-15% of players with significant risk for dehydration and inform hydration strategies on and off the court. Moreover, most (≥ 50%) basketball players begin practice or competition with urine concentrations that may be indicative of dehydration, suggesting that off- court (i.e., pre-training or pre-game) hydration habits may be inadequate. Furthermore, fluid intake during a game may not compensate for poor pre-game hydration status. Therefore, strategies to ensure that a player begins training or competition in a well-hydrated state should be considered just as important as in-game hydration strategies.

Lindsay Baker is employed by the Gatorade Sports Science Institute, a division of PepsiCo R&D. The views expressed are those of the author and do not necessarily reflect the position or policy of PepsiCo, Inc.


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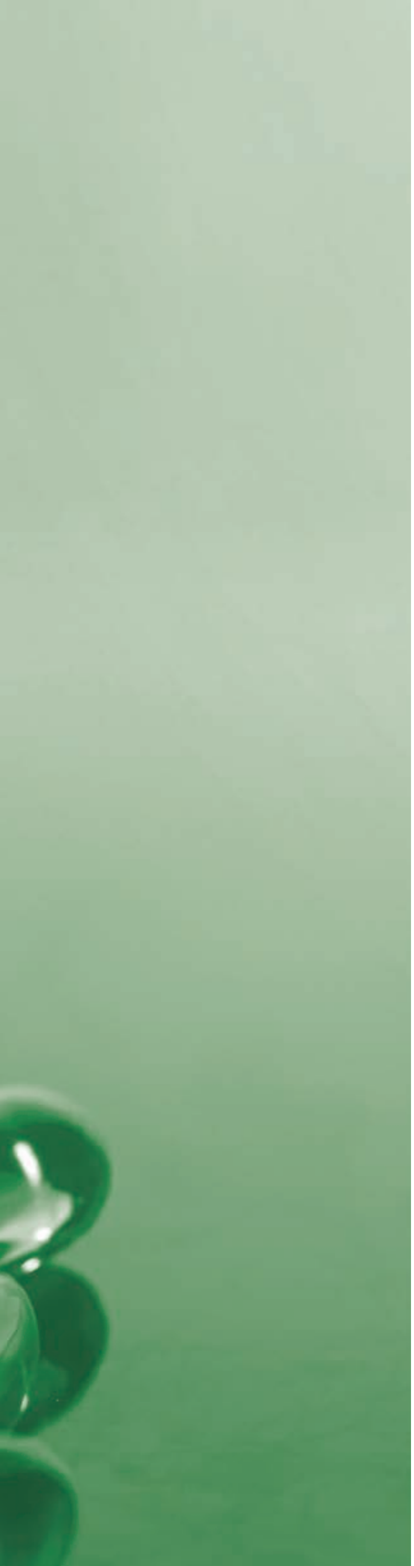
CHAPTER 7

DIETARY SUPPLEMENTATION FOR BASKETBALL



DIETARY SUPPLEMENTATION FOR BASKETBALL

Steven Basham, MS
Gatorade Sports Science Institute

KEY POINTS

- Supplements may be defined as a food, food component, nutrient, or nonfood compound that is purposefully ingested in addition to the habitually consumed diet, with the aim of achieving a specific health and/or performance benefit.
- Supplements such as caffeine, beta-alanine, nitrates, and creatine may boost high-intensity exercise and thus basketball performance.
- Supplements such as omega-3s, vitamin D and antioxidants may improve overall health and recovery following exercise.
- Caution should be taken when using supplements as some may cause adverse reactions. As such, before using any supplements, it is recommended to conduct a cost/benefit analysis as well as consult with a healthcare provider.

INTRODUCTION

A dietary supplement may be defined as "A food, food component, nutrient, or nonfood compound that is purposefully ingested in addition to the habitually consumed diet, with the aim of achieving a specific health and/or performance benefit" (Maughan, Burke et al. 2018). This definition from the International Olympic Committee consensus statement, suggests supplements should be consumed to complement adequate nutrition and training and not as a replacement. As such, players should advise his or her healthcare provider and/or certified dietitian/ performance staff before beginning any dietary supplement routine, as well as perform a cost/benefit analysis (Maughan & Sheriffs 2018). Furthermore, with the lack of proactive regulatory policies for dietary supplements, athletes and practitioners should seek out credible independent third-party certifications to help mitigate safety and/or contamination risks. One example of a third-party certification is NSF Certified for Sport®, among others (e.g., Informed Sport). Mindful of the aforementioned considerations for dietary supplements, there are several dietary supplements that may aid performance and recovery in the context of basketball. For this chapter, supplements that have scientific efficacy and relevance to basketball will be reviewed.

CAFFEINE

Caffeine is commonly found in coffee, tea, and chocolate. As a stimulant, caffeine exerts its ergogenic (i.e., enhances performance) effects through several mechanisms of action as an adenosine receptor antagonist and neuromuscular modulator, among others (Maughan et al., 2018). Indeed, caffeine's effect on the central nervous system may be the most influential for performance given that even low doses (e.g., ~ 3 mg/kg) improve indices of performance. Since caffeine crosses the blood-brain barrier and acts as an adenosine receptor antagonist aspects of cognition are also augmented (Spriet, 2014).

The ergogenic effects of caffeine are reported across aerobic endurance and muscular endurance, strength, and power (Guest et al., 2021). Compared with endurance and resistance exercise, there are few studies investigating caffeine effects on team sports performance. A systematic review and meta-analysis reported caffeine ingestion improved jump height, repeated sprint velocity, along with distance covered and number of sprints completed during games in team sports athletes aged 15 to 28 years (Salinero et al., 2019). Evidence for a caffeine effect on surrogate markers of performance and skill-based assessments in basketball players is limited.

Two recent systematic reviews indicated caffeine improved counter movement jumps, agility, sprint times, and power output, but had no effect on skill-based performance (e.g., shooting accuracy, ball-dribbling speed, free throw accuracy) in national youth to elite level basketball players (Lazić et al., 2022; Tan et al., 2021). The lack of effectiveness of caffeine on skill-based performance could be due to the small number of studies investigating these measures. One study, however, examined caffeine intake (3 mg/kg) in 20 professional and semi-professional basketball players. Caffeine enhanced physical performance (i.e., vertical jump), and skill-based performance (e.g., total rebounds and total free throws made), which improved performance index ratings during a 20-min simulated basketball game (Puente et al., 2017). To the author's knowledge, no study has shown a detrimental effect of caffeine on basketball performance. Therefore, caffeine ingestion may be a pragmatic approach for those seeking to improve his or her basketball performance.

Practical Recommendations

The half-life (i.e., time required for a substance to decrease by half) of caffeine has been reported to be ~3-5 h, with peak plasma concentration reached 40-80 min after intake (Spriet, 2014). Caffeine ingestion may be ideal to consume before tipoff with effects lasting the length of the basketball game. In addition, caffeine may be advantageous to consume during the off-season combined with training sessions that are aimed to improve endurance and muscular strength. The most common dose where caffeine is reported to exert ergogenic effects is 3-6 mg/kg (Guest et al., 2021). Furthermore, a recent review suggests that doses lower than 3 mg·kg-1 may be rendered moot for improving team sport performance (Salinero et al., 2019). However, lower levels of caffeine (e.g., < 3 mg/kg) have been shown to improve performance in endurance-related activities and some cognitive tasks (Spriet, 2014). Moreover, caffeine is associated with side-effects such as insomnia, jitteriness, headaches, and tachycardia especially with large doses (i.e., > 9 mg/kg) and these effects tend to increase in a linear fashion with dose (Guest et al., 2021; Maughan et al., 2018). One must be aware of caffeine consumed across the day in various foods (e.g., dark chocolate) and beverages (e.g., energy drinks), as this will add to the overall total amount caffeine consumed, leading to higher risks of symptoms associated with large doses.

Variations in caffeine metabolism among individuals may also influence the effectiveness of caffeine on performance and side-effects associated with caffeine (Guest et al., 2021). Thus, an individualized approach should be implemented when considering caffeine as an ergogenic aid for basketball. Lastly, when considering caffeine and adolescents, the American College of Pediatrics strongly discourages the use of caffeine in adolescents and children (Schneider, Benjamin 2011).

BETA-ALANINE

Beta-alanine is an amino acid, and when combined with L-histidine in the muscle produces carnosine. Carnosine acts as an intracellular buffer for hydrogen ions to maintain muscle pH levels. The maintenance of pH is important as this may mitigate the early onset of fatigue. This may be particularly relevant in basketball as the demands of the game often require high-intensity, repeated sprinting and jumping, where most intensities are above lactate threshold (Stojanović et al., 2018).

The majority of literature support beta-alanine supplementation for exercise lasting from 60 to 240 s (Saunders et al., 2017). Scientific evidence also suggests that supplementation may positively influence exercise lasting as little as 30 s and as long as 600 s (i.e., 10 min) (Hobson et al., 2012). However, there are limited data investigating beta-alanine supplementation in team sport athletes, particularly in stop-and-go sports such as basketball. Evidence may be translated from other sports with similar demands such as soccer, where beta-alanine supplementation was beneficial for performance (Saunders et al., 2012). However, these results are not fully corroborated with the few studies examining beta-alanine supplementation in basketball players. For instance, Milioni and colleagues examined beta-alanine supplementation in young elite basketball players. Following six weeks of supplementation at 6.4 g/day, beta-alanine had no effect on repeated sprint ability and countermovement jumps (CMJ). However, lactate concentrations following the Yo-Yo test were lower in the beta-alanine group compared to placebo (Milioni et al., 2017). In a more recent study, basketball players ingested 6.4 g/day of beta-alanine for eight weeks and measures of anaerobic (e.g., sprint test, CMJ) and aerobic (e.g., VO2max) performance were assessed. Although beta-alanine did not improve all aspects performance, specific measures such as peak power from the running-based anaerobic sprint test and VO2max were enhanced (Turcu et al., 2022). In the same study the authors reported reduced concentrations of surrogate markers of whole-body inflammation (e.g., CRP, IL-6). Although these measures are not specific to performance, these results do open new areas of research for beta-alanine and recovery. Lastly, a recent study examined performance and recovery effects of beta-alanine supplementation in female basketball players. Four weeks of beta-alanine supplementation (6.4 g/day) led to lower blood lactate concentrations after an exhaustive exercise test, but did not improve Yo-Yo test and CMJ performance (Gholami et al., 2022). Given the somewhat underwhelming results from these studies on surrogate markers of basketball performance, it is difficult to conclude how this would translate to on-the-court performance. Future studies should investigate in-game performance measures to better understand beta alanine's efficacy in basketball. Nevertheless, beta-alanine supplementation is advantageous for off-the-court performance for improving training adaptations needed to perform at elite levels in team sports.

Practical Recommendations

Although there is limited to no data in basketball regarding beta-alanine supplementation during the season, supplementation may still be advantageous based on underlying mechanisms for improving exercise capacity. However, more research is needed to determine beta-alanine's effect on in-game basketball performance during the season. In addition to in-season supplementation, beta-alanine may confer training adaptations during the off-season. For instance, in other sports such as college football, beta-alanine improved work capacity and reduced subjective muscle fatigue during training (Hoffman et al., 2008). These results suggest performance can be enhanced in elite athletes during off-season training where adaptations are most relevant.

Regarding the amount and duration of supplementation, most studies used a daily dose of 3.2 - 6.4 g/day or a relative dose of 65 mg/kg, split into several small doses throughout the day for an extended period of time (i.e., 10-12 weeks) (Maughan et al., 2018; Saunders et al., 2017). Stellingwerff et al. (2012) observed four weeks of 3.2 g/day significantly increased muscle carnosine concentrations to a greater extent when compared to 1.6 g/day (Stellingwerff et al., 2012). Additionally, these researchers found that a dose of 1.6 g/day, following the 4-week supplementation of 3.2 g/day, further increased muscle carnosine concentrations (Stellingwerff et al., 2012). However, it is important to note that high levels of beta-alanine (typically > 10 mg/kg) may be associated with adverse effects, such as flushing of skin and a tingling sensation. Therefore, lower doses, ingested over a longer duration, may be suitable if adverse effects are experienced.

NITRATES

Inorganic nitrates (NO_3^-) are mostly found in foods such as dark leafy green vegetables and roots, such as spinach and beetroot, respectively. Once ingested, NO_3^- , can be further metabolized into nitric oxide (NO). Through increasing nitrate stores, NO bioavailability is augmented and has been linked to several physiological effects leading to improved muscle function. (Jones, 2014a, 2014b; Jones et al., 2021). As a result, studies have focused on beetroot juice concentrated with nitrates. Indeed, an early investigation reported improvements in performance during low and high intensity exercises following beetroot juice (0.5 L ~11 mmol nitrate) supplementation (Bailey et al., 2009). Since then, extensive evidence has established the ergogenic effect of nitrate supplementation (Hlinský et al., 2020; Tan et al., 2022).

Regarding team sports, one study demonstrated increased sprint split times and total distance covered in team-sport athletes following 5 days of nitrate supplementation (6.4 mmol) (Thompson et al., 2016). Likewise, another study demonstrated nitrate supplementation (~800 mg·day-1 for 6 days) enhanced Yo-Yo performance in young male soccer players (Nyakayiru et al., 2017). Similar results have been observed following acute beetroot juice supplementation (30 h before), where a 4% increase in performance in the Yo-Yo IR1 was reported (Wylie, Mohr, et al., 2013). Only recently has nitrates been investigated in basketball players. One study provided 140 mL of beetroot juice (~12.8 mmol of NO_3^-) to 10 competitive male basketball players (age 15-16 yr) 3 h before a battery of performance tests (i.e., CMJ, 10/20 m sprints, agility T-test and simulated game) in a randomized, placebo-controlled crossover fashion (López-Samanes et al., 2020). Compared to placebo, beetroot juice supplementation failed to improve basketball performance. This finding is in contrast with a recent review that suggests nitrate supplementation may improve explosive exercise performance (Tan et al., 2022). Nonetheless, underlying physiological mechanisms for nitrate supplementation may preferentially be more effective in type II muscle fibers, which are responsible for explosive, high-intensity movement (Jones et al., 2016). This may be particularly relevant for basketball players since success is dependent upon high-intensity and explosive movements. However, more studies are needed to understand the effectiveness of nitrate supplementation on basketball performance.

Practical Recommendations

NO_3^- supplementation may provide some benefit for basketball players to enhance game day performance. The optimal strategy for NO_3^- supplementation in elite team sports athletes is still largely unknown. Nevertheless, it appears that for acute (2.5 h prior to exercise) ingestion of NO_3^- containing 8.4 mmol is just as effective at improving exercise capacity as 16.8 mmol (Wylie, Kelly, et al., 2013). Regarding the time course of supplementation, a 2-day pre-load of nitrates, plus an additional dose ~2 h prior to the start of a game, is recommended. For highly trained athletes, performance gains may be harder to attain and as such, a longer supplementation period (e.g., > 3 days) may be advantageous to enhance potential ergogenic effects (Maughan et al., 2018). Additionally, one may want to avoid using antibacterial mouthwash and/or chewing gum since it has been shown to reduce the rate limiting enzyme in the oral cavity that is responsible for the bioactivity of NO (Jones et al., 2021).

CREATINE

Creatine is one of the most widely researched supplements and its ergogenic benefits range from performance to recovery (Wax et al., 2021). Creatine is mainly stored in the muscle as phosphocreatine (PCr) and acts to resynthesize adenosine triphosphate (ATP) from adenosine diphosphate (ADP) (Rawson & Persky, 2007). During high-intensity exercise, this breakdown from ATP to ADP happens at an increased rate, thus depleting PCr stores. Creatine supplementation may increase PCr stores in the muscle by ~20% (Hultman et al., 1996) aiding in ATP resynthesis between exercise bouts. This is important for basketball players given the repeated high-intensity nature of the game.

Most studies investigating creatine and performance have reported improvement in high-intensity exercise capacity (Kreider et al., 2017). Similarly, creatine supplementation augments muscle strength and resistance training performance (Lanhers et al., 2017; Lanhers et al., 2015; Rawson & Volek, 2003). Limited data on creatine supplementation in team sports such as soccer suggests creatine may improve anaerobic performance (Mielgo-Ayuso et al., 2019). These results may be translated to basketball players. For example, in an open-label, randomized, placebo-control trial, 23 male U16 basketball players ingested 0.1 g/kg/day (~ 6.5 g/d) of creatine for eight weeks while following a strength training protocol. Creatine supplementation resulted in improved jump performance (e.g., abalakov jump power test) and points scored per game (Vargas-Molina et al., 2022). These results are in line with the widely accepted notion that when combined with resistance/strength training, creatine supplementation enhances muscular adaptation and subsequent performance (Rawson et al., 2018).

Creatine is also reported to promote athlete recovery. Muscle glycogen resynthesis may be augmented with the co-ingestion of creatine and carbohydrate (Kreider et al., 2017). This is critical for basketball players since the number of games played in a short period limits recovery opportunities. During these times, adequate muscle glycogen is crucial to sustain subsequent performance (Heaton et al. 2017). Furthermore, empirical evidence points to creatine's role for modulating favorable inflammatory (e.g., TNF-α, C-reactive protein) and muscle damage (e.g., creatine kinase, LDH) responses following exercise-induced muscle damaging (EIMD) exercise (Jiaming & Rahimi, 2021; Wax et al., 2021).

Practical Recommendations

To increase skeletal muscle creatine and PCr stores, creatine supplementation may involve a "loading phase", consisting of 20 g/day (divided in 4 equal daily doses of 5 g) for the first 5-7 days, followed by a "maintenance phase" of 3-5 g/day (Harris et al., 1992; Hultman et al., 1996). However, sufficient muscle creatine concentrations can also be attained, without a "loading phase", if smaller doses (about 3 g) are taken for a longer period of time (Hultman et al., 1996). Creatine supplementation timing is equivocal, thus, pre/post training or throughout the day are all effective strategies for enhancing muscle creatine stores (Stecker et al., 2019). Also, co-ingesting other macronutrients such as protein and carbohydrates may further enhance intramuscular creatine stores (Steenge et al., 2000). The most studied and effective form of creatine is creatine monohydrate and therefore should be the form athletes utilize to aid performance (Kreider et al., 2022). Furthermore, creatine supplementation should be strategically planned at specific times during the year (i.e., in-season, off-season) to maximize the benefits, and individualized based on specific athlete needs such as performance, training adaptations, or recovery.

OMEGA-3 POLYUNSATURATED FATTY ACIDS

Omega-3 polyunsaturated fatty acids are essential fatty acids and must be consumed in the diet. The main dietary sources of Omega-3 fatty acids include, but not limited to, oily fish (such as tuna, mackerel and salmon) flax seeds, chia seeds and nuts. The most bioavailable sources of Omega-3s are eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). Cardiovascular health benefits are most common with Omega-3 ingestion; however, benefits span beyond health and into athlete performance and recovery (Heaton et al., 2017; Rawson et al., 2018). For this section, Omega-3 will be discussed from a muscle recovery perspective, focusing on the muscle damage response. The reader is referred to chapter 5 for the role of Omega-3s and muscle protein synthesis.

The biological roles of Omega-3s in recovery are primarily related to their incorporation in cell membranes (Calder et al., 1994) and anti-inflammatory actions (Calder, 2017). With respect to EIMD, studies demonstrate Omega-3 supplementation may improve markers of muscle damage and soreness in team sport athletes (Philpott et al., 2018) as well as soreness and inflammation in recreational athletes (Kyriakidou et al., 2021). For example, a recent study demonstrated reduced muscle soreness and mitigated performance decrements following five weeks of Omega-3 (1.5 g/day) supplementation in elite Rugby Union players (Black et al., 2018). Lastly, evidence suggests Omega-3 supplementation may aid in injury recover through mitigated muscle loss during limb immobilization after suffering from an injury (Witard and Davis SSE #211).

Practical Recommendations

The evidence above, along with a recent study from our group that demonstrated low fish consumption and Omega-3 index in professional basketball players (Davis et al., 2021), suggests players could benefit from Omega-3 supplementation and/or increasing fish consumption in their diet. If assessing Omega-3 index is not feasible, a combination of

other non-invasive, cost-effective screening methods such as medical history and dietary assessments, may be pragmatic for determining individualized supplementation needs. More research is needed to identify the optimal dose for Omega-3 on recovery indices as the available research has utilized a wide range (1.8-3 g/day). Furthermore, the duration of Omega-3 supplementation needed for recovery benefits has yet to be determined. Lastly, when evaluating Omega-3 products, disparities must be made between non-concentrate and concentrate forms, where the latter often provides higher levels of EPA/DHA typically in a 2:1 EPA/DHA ratio (Ritz and Rockwell SSE #212). Nonetheless, evidence suggests that at least two weeks is needed for an increase in the incorporation of Omega-3 in the muscle (Philpott et al., 2019).

VITAMIN D

Vitamin D is a fat-soluble vitamin and precursors may be obtained through sun exposure or diet. However, the amount of vitamin D obtained from the sun is highly variable with a variety of factors influencing the degree of absorption (e.g., environment, skin pigmentation and clothing) (Owens et al., 2018). Nonetheless, vitamin D plays significant roles in various physiological systems throughout the body such as a modulatory signal for immune, bone and skeletal muscle function (Caballero-García et al., 2021; Charoenngam & Holick, 2020). Furthermore, emerging evidence suggest vitamin D may positively influence aspects of performance and recovery (de la Puente Yagüe et al., 2020; Owens et al., 2018).

Importantly, reports have indicated that high percentages of elite or professional athletes may have insufficient vitamin D (< 75 nmol/L) status based on blood 25 hydroxyvitamin D concentrations (Rawson et al., 2018). Similarly, another review indicated various athletes across sports are vitamin D deficient or insufficient as defined by the United States Institute of Medicine (de la Puente Yagüe et al., 2020). More specifically, a recent systematic review and meta-analysis including 14 studies, analyzed vitamin D concentrations of 527 basketball players at various skill levels including amateur, collegiate and/or elite basketball players. Following analysis, 77% of basketball players were characterized as having inadequate (< 80 nmol/L) vitamin D concentrations (Stojanović et al., 2022). However, vitamin D supplementation in insufficient basketball players does not seem to impact performance (e.g., vertical jump, sprints, agility drills) (Stojanović et al., 2022). No studies to date have investigated effects of vitamin D supplementation on recovery. Further research is needed to elucidate the effects of vitamin D supplementation on performance and recovery in basketball players.

Practical Recommendations

The available evidence suggests the potential need for vitamin D3 supplementation for basketball players for overall health and wellness. The recommended daily allowance for vitamin D is 600 IU/day. It has been debated that the RDA may be too low, but optimal doses for the general population and athletes are still unknown (de la Puente Yagüe et al., 2020; Heaton et al., 2017). The reader is referred to Sports Science Exchange article 191 for an excellent diagram to help determine if/when and how much vitamin D should be supplemented for an athlete(s) (Close, Allison, Owens SSE #191) (Owens et al., 2018). To summarize, adequate baseline testing and individual needs must be considered to effectively supplement with vitamin D.

ANTIOXIDANTS

Antioxidants are molecules with properties that aid in scavenging free radicals and promote a favorable redox environment and may enhance recovery (Canals-Garzón et al., 2022). Polyphenols are a class of antioxidants that are found in dark colored fruits and roots/spices. These foods include, but are not limited to, curcumin and tart cherry, which are often termed “functional foods”. Curcumin and tart cherry are associated with improved exercise recovery (Fernández-Lázaro et al., 2020; Hill et al., 2021) and will be the focus of this section. The reader is referred to other sources for a review on several other functional foods (i.e., beetroot, pomegranate) that also support recovery (Canals-Garzón et al., 2022).

Curcumin, the bioactive in the spice, turmeric, has been shown to reduce inflammation, ameliorate muscle damage, mitigate oxidative stress, and alleviate delayed onset of muscle soreness (Campbell et al., 2021; Fernández-Lázaro et al., 2020). Moreover, evidence also suggests that curcumin supplementation may mitigate the decline in performance. For example, one study supplemented 27 trained subjects with 500 mg of curcumin before an intense lower body resistance training protocol (Mallard et al., 2021). Results indicated the treatment group was able to maintain power during subsequent resistance training sets while simultaneously decreasing post-exercise muscle pain compared to the placebo group (Mallard et al., 2021). Similarly, other studies have reported improved maximal voluntary contractions (Tanabe, Chino, Ohnishi, et al., 2019; Tanabe et al., 2015), and range of motion (Tanabe, Chino, Sagayama, et al., 2019) following maximal eccentric muscle actions, as well as sustained vertical jump performance following plyometric exercise (Hillman et al., 2022). Regarding team sport athletes, only one study has investigated curcumin. Delecroix and colleagues (2017) investigated the effects of curcumin supplementation in ten elite rugby players for markers of recovery (e.g., creatine kinase, soreness) and performance (e.g., CMJ, MVC, single-leg sprint). Curcumin mitigated the decline in power output via single-leg sprints, and although not statistically different, tended to reduce muscle damage following the exercise bout (Delecroix et al., 2017). Altogether, the evidence suggests that curcumin may improve recovery as well as minimize performance decrements following exercise.

Tart cherries contain polyphenols such as anthocyanins and phenolic acids. The first study that investigated cherries reported reduced symptoms of muscle soreness following an EIMD protocol (Connolly et al., 2006). Since this initial discovery, a number of studies have corroborated the efficacy of tart cherry on recovery indices (Hill et al., 2021). The recovery effects are wide ranging and include, but are not limited to, markers of muscle damage/soreness, inflammation, and strength-recovery across resistance and endurance type exercise (Bell et al., 2014; Gao & Chilibeck, 2020; Hill et al., 2021). However, these findings are primarily limited to recreational athletes. Studies in team sport athletes are few and results do not align with previous findings. For instance, tart cherry supplementation had no effect on markers of recovery in rugby-league/union (Kupusarevic et al., 2019; Morehen et

DIETARY SUPPLEMENT/INGREDIENT	PURPORTED IMPACTS	DOSE & TIMING
Caffeine	High-intensity, endurance, strength/power exercise; cognition and mood	3-6 mg/kg ~ 60 min before exercise
Beta-alanine	High-intensity and intermittent exercise	3.2-6.4 g/d (~65 mg/kg) for ≥ 4 wks
Nitrate	High-intensity intermittent and endurance exercise	~8 mmol/day ≥ 2 d prior and 2 hours before exercise
Creatine	High-intensity exercise and strength; muscle glycogen resynthesis	20 g/day (4 x 5 g) for 5-7 d followed by maintenance dose of 5 g/d
Omega-3 Fatty acids	Recovery from exercise	1.5 g-3 g/d for ≥ 2 wks
Vitamin D	Immune and muscle function	N/A (dosing should reflect individual needs determined by vitamin D status). See text for details.
Antioxidants		
Curcumin	Recovery from exercise	N/A (dose depends available commercial formula) Recommend bioavailable formulas
Tart Cherry	Recovery from exercise	Juice: ~230 ml – 360 ml 2x/d; days leading up to and following exercise Concentrate: ~30 ml 2x/d; days leading up to and following exercise

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al., 2021) and professional soccer players (Abbott et al., 2020). Nonetheless, more research is needed to confirm these results. In other areas of recovery, tart cherry may be beneficial for sleep in athletes due to its antioxidant properties and melatonin concentrations (Doherty et al., 2019). For example, a recent study demonstrated short-term tart cherry supplementation may improve sleep quality in elite field hockey players (Chung et al., 2022).

Practical Recommendations

Dietary antioxidants may be effective for supporting basketball recovery. However, caution should be used when implementing and should be strategically periodized to confer optimal in-season and out-of-season adaptations (antioxidants supplementation may hinder training adaptations). Furthermore, the form and dosing strategy of the antioxidants discussed should be considered, given the wide range of bioavailable formulations and various dosing protocols leading up to and following exercise. For curcumin, bioavailability is a common barrier impeding effectiveness (Dei Cas & Ghidoni, 2019; Jamwal, 2018). Therefore, when considering supplementation with curcumin, an optimized form of curcumin that enhances the bioavailability and thus bioactivity, is recommended. As for tart cherry, the recommended amount is dictated largely on the form of tart cherry (i.e., juice vs. concentrate vs. powder). The most common forms of supplementation are tart cherry juice (237-355 ml (~100 cherries total/2 servings)) and concentrate (30 ml (~180 cherries total/2 servings)) supplemented twice per day for several days leading up to and following exercise (McHugh, 2022).

SUMMARY

In summary, professional basketball players must meet the demands of the repeated, high-intensity nature of a basketball game throughout a long and grueling schedule. First and foremost, basketball players must ensure that daily energy intake is sufficient in both macro- and micronutrient quantities, to support off-season training adaptations, and maintain in-season performance and recovery. Evidence suggests that some supplements, reviewed herein, may be beneficial for basketball players. However, most of the evidence is derived from lab-based, recreationally trained individuals opposed to basketball specific activity and players. Therefore, there is an obvious need for further research utilizing highly trained basketball players and employing basketball specific exercise protocols and in-game performance testing. When deciding if a player should take a supplement, a cost-benefit analysis must occur, and players should experiment with supplement strategies in training or simulated games first before implementing during games. Players should work closely with their team's performance staff and/or sports dietitian to ensure supplements consumed are safe, reliable, and allowed within the sports' governing body. One step to assessing the latter (i.e., safety/reliability) is to always seek out supplements that are independently, third-party certified.

The views expressed are those of the author and do not necessarily reflect the position or policy of PepsiCo, Inc.

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CHAPTER 8

NUTRITIONAL SUPPORT FOR BASKETBALL INJURIES

NUTRITIONAL SUPPORT FOR BASKETBALL INJURIES

Kimberly Stein, PhD
Gatorade Sports Science Institute

KEY POINTS

- Adequate calories are necessary to promote healing. Practitioners can determine the appropriate intake for athletes by measuring or estimating resting metabolic rate and then adjusting by the level of activity and stress factor related to the specific injury.
- Elevated protein consumption at regular intervals is an effective countermeasure for atrophy and anabolic resistance that accompanies reduced activity and immobilization. Creatine, HMB, fish oil and vitamin D supplementation may help support muscle mass during injury recovery.
- Gelatin or collagen with vitamin C may promote healing of injury to tendons and ligaments.
- While more research is needed, some data suggest that creatine and fish oils may support recovery from concussion.

INTRODUCTION

Injury is an inevitable part of sport, particularly for a high contact, fast paced game such as basketball. According to data published in the Journal of Athletic Training from online injury surveillance programs for high school and collegiate players (Clifton et al., 2018a & b), the most common injuries for male and female basketball players are ligament sprains, muscle and tendon strains and concussion. The majority of these injuries affect the ankle, knee and head/face. In the NBA, ankle sprains are reported as the most common injury. However, patellofemoral inflammation, resulting in pain around the kneecap, has been reported as the most significant injury in terms of competition days lost (Drakos et al., 2010). Similarly, in the WNBA lower-extremity injuries, especially ankle sprains, are the most common type of injury. Like men, knee injury also results in the greatest number of games missed in women, but in this case the type of knee injury is a torn anterior cruciate ligament (ACL) (Baker et al., 2020). For each of these types of injuries, inclusion of nutritional interventions in the rehabilitation program may help accelerate a return to the court.

ENERGY REQUIREMENTS DURING RECOVERY

Adequate energy intake is critical to support healing. However, it is common practice for injured athletes to restrict calories in an effort to avoid weight gain during a period of reduced activity. While it may be appropriate to adjust calorie intake to training load, severe restriction is problematic. Resting metabolic rate (RMR) can increase 15-50% depending on the injury (Tipton, 2015) and use of crutches can further increase energy expenditure 2-3 times (Tipton, 2015).

Researchers published a case study of their work with a professional male soccer player from the English Premier League who suffered an ACL injury. During the six weeks post-injury, energy expenditure was quantified using doubly labeled water, and energy intake via food photography. Average daily energy intake was 2765 ± 474 kcal/d and energy expenditure 3178 kcal/d. As expected, body mass decreased by 1.9 kg during this time of energy deficit. Loss of fat free mass, as measured by dual energy X-ray absorptiometry (DEXA), was 0.9 and 0.6 kg in the injured and non-injured limb, respectively. The athlete was able to regain these losses over the following 22 weeks of rehabilitation, but these data illustrate the need to avoid excessive energy restriction even when activity is reduced post-injury to help limit loss of muscle mass (Anderson et al., 2019).

To determine the appropriate calorie intake for an injured athlete, RMR should be measured via indirect calorimetry or calculated using the Harris-Benedict prediction equation. The RMR is then adjusted based on the athlete's activity level and stress factor based on the type of injury. Daily calorie needs are equal to the RMR x activity factor x stress factor (Smith-Ryan et al., 2020). See next page for equations and values.

Another method to monitor and ensure adequate calorie intake is to track body mass and watch for any significant changes. However, this can be a sensitive issue for many athletes, particularly female players, and must be handled appropriately. Helping the athlete understand his/her energy needs and consume the appropriate calorie load for his/her injury and rehabilitation program will help the healing process and maximize the results of the return to play program. Daily calorie needs will need to be adjusted as the athlete progresses through the rehabilitation program and activity level ramps back up prior to a full return to the court.

MUSCLE TISSUE

In a healthy, non-injured muscle, the tissue is active and regularly cycles between protein breakdown and synthesis of new muscle proteins. This process is influenced by the mechanical load on the muscle and the amino acids consumed from food. In general, turnover in healthy muscle tissue is about 1-2% per day, or 300-600 g/d of tissue broken down and resynthesized (Wall et al., 2015). When a muscle is injured, especially if immobilized, the mechanical load is reduced or removed, and the process of muscle breakdown/resynthesis is interrupted. Sensitivity to ingested amino acids is also reduced, leading to anabolic resistance and together resulting in loss of muscle tissue (Wall et al., 2015). During 1-2 weeks of immobilization, healthy inactive muscle atrophies at a rate of about 0.5% per day, which can result in the loss of about 150-400 g/d of muscle mass (Wall et al., 2015). In addition, strength decreases at about 3x the rate that muscle mass is lost (Wall et al., 2015). For an in-depth discussion on the metabolic and functional consequences of immobilization following an exercise-induced injury, please see Sport Science Exchange article 169 (Tipton, 2017).

DETERMINING CALORIE NEEDS DURING REHABILITATION

(Smith-Ryan 2020)

Step 1 Determine Resting Metabolic Rate (RMR)

Indirect Calorimetry to measure **RMR**

OR

Harris Benedict Equation

RMR (Men) = 66 + (13.7 x wt [kg]) + (5 x ht [cm]) – 6.8 x age [y])

RMR (Women) = 655 + (9.6 x wt [kg]) + (1.8 x ht [cm]) – 64.7 x age [y])

Step 2 Activity Factor

Sedentary = **1.2** (little or no exercise)

Lightly active = **1.375** (light exercise 1-3 days/wk)

Moderately active = **1.55** (moderate exercise 6-7 days/wk)

Very active = **1.725** (hard exercise 2x per day)

Extra active = **1.9** ((hard exercise 2x per day or training for long endurance event)

Step 3 Stress Factor

Minor injury (eg: ankle sprain), minor surgery, clean wound, bone fracture = **1.2**

Infected wound, major trauma (eg: ACL surgery), severe burn = **1.5**

= Daily Calorie Intake = RMR x Activity Factor x Stress Factor

Recommended protein intake during rehabilitation is 1.6–2.5 g/kg body mass per day

Divided into servings of about 20–40 g every 3–4 hours, to be most effective

(Wall et al., 2015)

With such a rapid decline in muscle mass and strength when an athlete is injured, particularly for an injury requiring immobilization, there is an immediate need to address atrophy. Since in most cases there is little to no exercise right after the injury to provide mechanical stimulus to the muscle, nutrition can be a non-exercise strategy to help combat anabolic resistance. Specifically, protein intake consumed in the right amount and pattern is a nutritional countermeasure to maintain the stimulus and help manage anabolic resistance. Accordingly, the recommended total amount of protein during immobilization is higher than generally recommended for a basketball athlete (1.6-2.5 g/kg body mass per day) (Wall et al., 2015) to account for the resistance of the muscle to use the amino acids. To be most effective, the total amount should be divided into servings of about 20-40 g every 3-4 h to maintain a regular stimulus to the muscle, rather than eating one or two large protein containing meals (Wall et al., 2015). That pattern includes eating protein before sleep to provide some anabolic stimulus prior to a long period of fasting. The best type of protein to choose is one rich in the amino acid leucine, which is a substrate as well as a signal to start muscle protein synthesis (Phillips et al., 2013). The best sources of leucine are whey and milk proteins, followed by animal protein meats. Plant proteins typically provide less leucine than animal sources, but soy and legumes are options for vegetarian athletes. Consuming high quality, leucine rich proteins regularly throughout the day is important to help maintain muscle mass, especially since calorie intake is likely reduced (Wall et al., 2015). Once the athlete begins more active rehabilitation protocols, this protein pattern should remain, including following each training session.

Holm et al. (2006) examined the impact of post-exercise protein intake in 26 men and women (18-35 yr) participating in a 12 week ACL injury rehabilitation program. Study participants entered the program on average ~18 months post-surgery and completed 36 total training sessions. In a parallel study design, participants consumed 10 g protein (skim milk and soy blend) with carbohydrate, carbohydrate alone (isocaloric with protein + carbohydrate group), or placebo. Participants that consumed protein improved cross-sectional area of the quadriceps and peak torque compared with the energy matched carbohydrate alone and placebo groups. This study was conducted prior to current guidelines for

protein intake and showed even a small amount of post-exercise protein may be beneficial during rehabilitation exercise for improved muscle outcomes.

Beyond protein, dietary supplements, specifically creatine, HMB (beta-hydroxyl-beta-methylburyrate), fish oil and vitamin D, may also help maintain muscle mass during reduced activity and immobilization (Rawson et al., 2018, Smith-Ryan et al., 2020). There is insufficient data to definitively recommend taking these supplements to combat anabolic resistance, but there is some evidence to suggest they may support recovery.

It is well known that creatine has beneficial effects on muscle with training and it may also have beneficial effects in stemming atrophy. For example, in one study with upper arm immobilization, 20 g/day creatine supplementation over 2 weeks slowed the loss of muscle and strength in young men (Johnston et al., 2009). However, a similar study (20 g/day for 2 weeks) with leg immobilization found no benefit (Backx et al., 2017). In this study creatine intake was continued during a 12 week rehabilitation program with a reduced dose (15 g/d weeks 1-3 followed by 5 g/d) and found to promote the recovery of muscle mass. While more research is needed, a recent review concluded creatine supplementation is possibly effective to stem atrophy during immobilization (Harmon et al., 2021), and the benefit of creatine to promote muscle gain with subsequent exercise is well-established. Recommended intake of creatine monohydrate following immobilization is 20 g/day split into 4 individual doses for 5 days, followed by a 5 g per day maintenance dose. For individuals who cannot tolerate 20 g/day, a 5 g/day dose is effective but takes longer to accumulate in the muscle (Rawson et al., 2018, Smith-Ryan et al., 2020).

HMB is a metabolite of leucine and may help increase muscle protein synthesis and decrease breakdown. More research is needed with athletes during a period of injury recovery, however HMB supplementation of 3 g/day (divided into 1.5 g doses) may help preserve muscle during immobilization and promote muscle mass gain during rehabilitation exercise (Smith-Ryan et al., 2020).

Fish oil has been reported to have potential anabolic benefits by increasing the sensitivity of the muscle to ingested amino acids. Therefore, supplementation may help decrease muscle loss during reduced activity and immobilization combined with appropriate protein intake. High doses up to 5 g/day may have a benefit after ~2 weeks of consumption, but the evidence is not consistent and the benefit speculative (Close et al., 2019). Since it is not known when an injury will occur, it could be suggested that athletes consume a fish oil supplement on a regular basis given the other potential benefits (see the section on concussion on the following page) (Close et al., 2019).

As an indoor sport, insufficient vitamin D concentrations are commonly found in basketball athletes who are not actively supplementing (Fishman et al., 2016). Vitamin D is a steroid hormone with receptors found in the skeletal muscle and adequate status supports skeletal muscle regeneration. Therefore, low vitamin D status may impair recovery from muscle injury. Vitamin D status should be assessed via a blood test at the time of injury, with deficiency defined as <75 nmol/L 25(OH) D. An optimal dose of vitamin D has not been defined. The RDA is currently 600 IU/day, although controversy exists on whether or not this is too conservative. The optimal dose may be closer to 4000 IU per day, but the best course is to work with medical staff to determine the correct dosing for the individual athlete (Close et al., 2019, Rawson et al., 2018, Smith-Ryan et al., 2020).

Lastly, alcohol consumption impairs muscle protein synthesis both at rest and in response to an anabolic stimulus such as nutrition (Steiner et al., 2015). A limitation of this research is reliance on animal models as clinical work in humans is difficult However, Parr et al. (2014) published a study which investigated the effect of alcohol intake following resistance exercise and high intensity cycling on muscle protein synthesis in 8 healthy males. In a cross-over design, following the exercise bout subjects consumed 25 g whey protein, 25 g whey protein plus 1.5 g/kg alcohol or energy matched carbohydrate plus alcohol. Muscle protein synthesis, as determined by muscle biopsy, was significantly reduced in both alcohol groups compared to the protein only control. While this study was conducted in healthy men, and the amount of alcohol consumed was quite high, it is prudent for athletes to limit or ideally avoid alcohol during injury rehabilitation.

TENDONS AND LIGAMENTS

Injury to tendons and ligaments are some of the most common for basketball players and, similar to muscle injury, nutrition may help improve recovery outcomes. Supplementation with gelatin or hydrolyzed collagen plus vitamin C has been shown to increase collagen synthesis (Lis et al., 2019). In a pilot study of 20 patients with chronic mid-portion Achilles tendinopathy, consumption of collagen peptides during 3 months of a structured calf-strengthening program improved the clinical outcomes compared to placebo, as assessed by the Victorian Institute of Sports Assessment Achilles questionnaire (Praet et al., 2019).

The recommended supplementation amount is 5-15 g of gelatin with 50 mg vitamin C (Rawson et al., 2018). While current data suggest a possible benefit of collagen and vitamin C supplementation for increased collagen synthesis and decreased pain, evidence for direct improvement in recovery from injury or functional outcomes is not available (Khatri et al., 2021, Rawson et al., 2018).

CONCUSSION (MILD TRAUMATIC BRAIN INJURY)

A sports-related concussion results in an "energy crisis" in the brain via increased energy demand, decreased energy supply and alterations in substrate metabolism. Following a concussion event, the brain briefly enters a hypermetabolic phase (minutes to hours) followed by a hypometabolic phase for several days. Athletes may self-select to increase energy intake after suffering a concussion and return to an isocaloric state upon recovery, and this appears to be a good thing to promote healing (Walton et al., 2020, 2021). If an athlete is nauseated and does not have the appetite to eat, consider encouraging soft or liquid foods or caloric beverages to help meet the energy demands of the brain during this time.

As part of the altered metabolic state, brain creatine also decreases post-concussion. Creatine supplementation may help balance adenosine triphosphate (ATP) stores, thereby reducing the negative effects on energy status. In animal studies, creatine supplementation prior to injury decreased damage to the brain up to 50% (Sullivan et al., 2000), and in humans, data indicate improved cognitive processing (Turner et al., 2015). In children, creatine supplementation for 6 months post-concussion decreased headaches, dizziness, fatigue, and improved cognitive function (Sakellaris et al., 2006, 2008). If athletes are already ingesting creatine for benefits to the muscle, they may also receive benefits should a concussion occur. However, more research is needed to confirm these benefits. Nonetheless, the typical protocol of 5 g/day, with or without a loading phase is a safe dose (Forbes et al., 2022, Rawson et al., 2018, Smith-Ryan et al., 2020).

Similar to creatine, regular intake of omega-3 fatty acids, particularly docosahexaenoic acid (DHA), prior to a concussive event may protect the brain by lessening the severity of structural damage and improve functional outcomes. In animals, omega-3 supplementation following injury decreased inflammation, cellular death, and damage to axons. Studies in humans are limited but data are promising (Barrett et al., 2014, Smith-Ryan et al, 2020). It may be advisable for athletes in sports such as basketball with high potential of concussion to regularly incorporate omega-3 fatty acids into their diet. The Institute of Medicine recommends an adequate intake of 1.0-1.6 g/d of omega-3 fatty acids, preferably from fatty fish.

BONE

While bone injuries are not the most common injury in basketball, they do occur, including both stress fracture from overuse and contact fractures. The micronutrients to focus on during recovery of injury to the bone are the same as for general bone health: calcium, vitamin D, magnesium, phosphorus, potassium and fluoride (Close et al., 2019). While there is no need to go above the RDA for any micronutrient, particular attention should be paid to calcium and vitamin D. The RDA for calcium is 1000 mg/d for adults. This amount should be spread throughout the day, with no more than about 600 mg at one time to promote adequate absorption. Vitamin D supplementation is also suggested for individuals with low blood concentrations, as outlined in the section on muscle previously in this chapter (Sale et al., 2020).

Of greater concern for athletes than micronutrient status may be low energy availability, which as discussed earlier is not uncommon during a time of injury (Close et al., 2019, Sale et al., 2020). Energy availability is defined as energy intake minus exercise energy expenditure adjusted for muscle mass. While total daily energy expenditure is decreased during injury, it is critical to consume adequate calories to support bone healing (Sale et al., 2020).

A NOTE ON INFLAMMATION

Acute inflammation post-injury is an essential part of the healing process and therefore nutritional interventions related to controlling inflammation are not recommended. However, chronic inflammation impairs recovery and using nutrition in this instance can be beneficial to return to the court. Nutritional supplements with anti-inflammatory benefits are curcumin (a component of the spice turmeric, 5 g/day), tart cherry juice (8-12 oz, twice per day for several days), omega-3 fatty acids (~2 g/day) and vitamin D (RDA 600 IU per day, work with physician based on blood levels) (Rawson at al., 2018, Smith-Ryan et al., 2020). In addition to seeking anti-inflammatory nutrients, athletes should also limit foods that promote inflammation, such as those high in saturated fats, trans-fats and refined sugars. Lastly, it is prudent to advise athletes to avoid alcohol during recovery from injury as it also has a pro-inflammatory impact on the body (Wang et al., 2010).

POST-SURGERY

For injuries requiring surgery, the right nutrition can support post-operative wound healing. As discussed, adequate calories are essential to support the energy demands of healing. The key micronutrients to focus on during this time are the Vitamins A, C and E and the minerals zinc and iron. Ideally these nutrients are consumed from whole foods as part of overall energy intake, fortified with a multivitamin if the athlete does not meet recommendations from foods (Smith-Ryan et al., 2020, Barchitta et al., 2019).

THE REHABILITATION TEAM

It is not always common to include nutrition as part of a rehabilitation plan, but given the importance as discussed in this paper the inclusion of a dietitian on the care team is critical. It is the collaborative work of a rehabilitation team which includes the physician, athletic trainer, sports dietitian and in some cases a physical therapist and psychologist that will result in the best return-to-play outcomes.

PRACTICAL APPLICATIONS

- Lower extremity injuries are the most common in basketball and result in immobilization or significant reductions in activity.
- Use the guide provided in Table 1 to determine appropriate calorie goals for your athlete to balance the reduction in activity with the energy cost of healing. Follow that up by paying attention to any drastic changes in body mass.
- Immediately upon injury adjust protein intake to help minimize atrophy and anabolic resistance. Aim for 1.6-2.5 g/kg body mass per day consumed every 3-4 h including prior to sleep. The pattern of intake is important to supply a regular anabolic stimulus to the muscle.
- Some data suggest creatine, HMB, vitamin D, and maybe fish oil supplementation can help slow atrophy during injury.
- 15 g of gelatin with 50 mg vitamin C may increase collagen synthesis and decrease joint pain.
- A concussed athlete may benefit from creatine monohydrate (5 g/day with or without a 20 g/day loading phase) and up to 2 g/day of fish oil.
- Athletes should avoid alcohol during recovery from injury since it leads to increased inflammation that would have a detrimental effect on muscle protein synthesis.
- The collaborative care of a sports dietitian with the physician, athletic trainer, physical therapist and psychologist can result in the best return-to-play outcomes.

SUMMARY

Basketball injuries often involve the lower extremities and result in a period of significantly reduced activity. Nutritional approaches should be considered as a rehabilitation modality to prevent excessive loss of muscle mass and promote regain of muscle mass and strength, as well as support overall healing. Ingestion of the right nutrients during recovery from musculoskeletal injury and concussion can help accelerate return to play.

Kim Stein is employed by the Gatorade Sports Science Institute, a division of PepsiCo R&D. The views expressed are those of the author and do not necessarily reflect the position or policy of PepsiCo, Inc.

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CHAPTER 9

MONITORING LOAD & RECOVERY IN BASKETBALL

MONITORING LOAD & RECOVERY IN BASKETBALL

Aaron Heishman, PhD, CSCS*D
Head of Sport Science and Reconditioning,
Vegas Golden Knights

KEY POINTS

- Implementing athlete monitoring systems should start with identifying the needs and key questions of the primary stakeholders, which then direct the selection of tools that provide valid, reliable, and relevant measures that generate actionable decision-making.
- There are a multitude of athlete monitoring strategies available for use in basketball, which can provide value in athlete profiling, evaluating the athlete's response to imposed training/competition demands, and guiding return-to-play protocols following injury.
- External training load refers to the biomechanical or locomotive demands an athlete experiences during training or competition and is utilized to quantify in training prescription, while internal load represents the relative psychobiological response to stressors imposed on the athlete during training or competition.
- There is increasing evidence suggesting the need to evaluate and monitor mental fatigue, as well as employ sport-specific assessments that incorporate basketball skill to examine changes in readiness and performance.

INTRODUCTION

Athletes perform meticulous, year-round training regimens designed to improve performance and maximize success in competitions. Training regimens are designed to impose acute stress that will accumulate into long-term adaptations and improvements in performance capabilities. The adaptive responses to training are thought to follow the general adaptation syndrome (GAS) model outlined by Hans Selye in the early 1950s, which describes an organism's adaptation process when confronted with stress or perceived harmful stimuli (Selye, 1950). In accordance with the GAS model and dependent upon the phase of training, athlete training programs are designed to enhance performance by progressively applying overload, causing the athlete to adapt. As presented in Figure 1, generally adaptations are thought to occur in a dose-response relationship, where too light of a training stimulus may limit the magnitude of positive adaptation, restricting the maximization of performance improvements, while too large of a stimulus overburdens the athlete, requiring more time for the recovery-adaptation response and may not allow for the desired enhancements in performance capacities to be realized. As a result, athlete monitoring strategies have emerged as an essential piece in applied sports performance to supervise the delicate balance between applying adequate training stress, while also allowing appropriate recovery for regeneration and adaptation.

Athlete monitoring strategies provide the ability to characterize the physical demands of the game, help generate individualized player profiles, and provide critical information used to guide return-to-play and return-to-performance protocols following injury. Such strategies can also be used to quantify, and prescribe training loads as well as assess the athlete's fatigue and recovery response as they cope with the training or the rigorous demands of a competition in season. Therefore, athlete monitoring can serve as a method to oversee and manage the training process, by quantifying sport-specific demands in the dynamic basketball environment. Therefore, the purpose of this chapter is to discuss contemporary athlete monitoring strategies used to optimize performance and mitigate injury risk in basketball athletes.

A number of athlete monitoring strategies are available to supervise the training process of basketball athletes. However, before discussing the details of specific strategies, it is important to conceptualize the underlying framework that an effective athlete monitoring system is built upon. First, implementing athlete monitoring systems should start with identifying the needs and key questions of the primary stakeholders (e.g., sport coaches, athletes, strength and conditioning coaches, athletic trainers, sports dietitians, sport psychologist, etc.) within the performance system. The identified needs and questions should then drive the overall purpose of

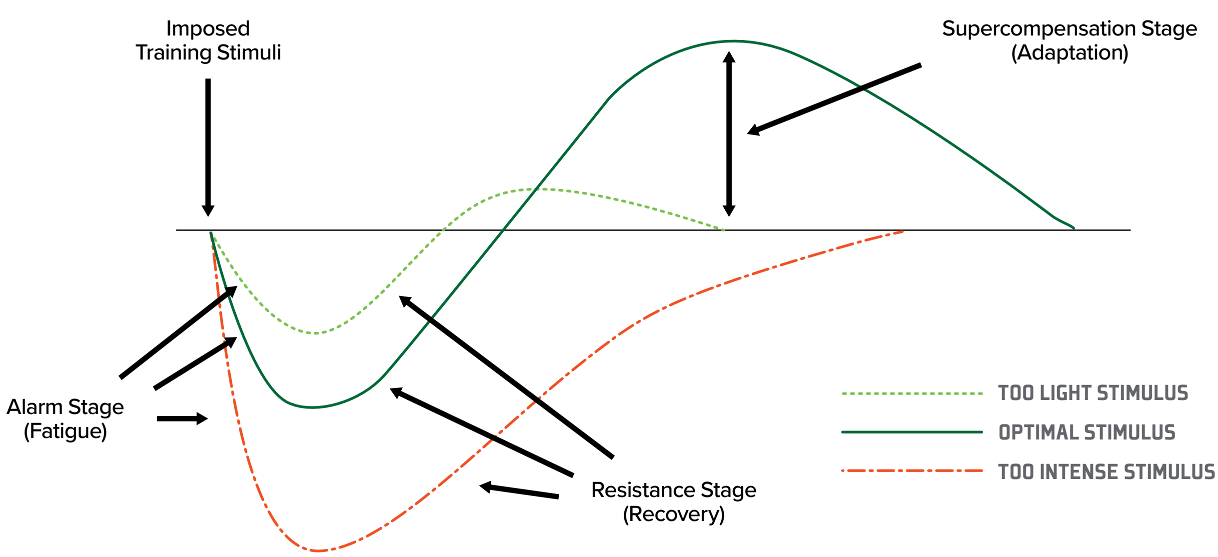

Figure 1: General Adaptation Syndrome (GAS) Model. In the GAS model, an imposed stress, such as a training exposure, initiates the alarm stage, characterized by disruption in the organism's homeostasis, resulting in acute fatigue and a suppression in their physiological state. Sufficient recovery following the initial stimuli allows the organism to enter the resistance stage, where homeostasis is restored, and positive adaptations develop to ensure exposure to a similar stimulus in the future induces less homeostatic disruption. Ideally, if appropriate stimuli are applied, the organism can experience supercompensation, or the enhancement in adaptation above homeostasis, which leads to increases in performance capacities. Conversely, the exhaustion stage can occur if the magnitude or frequency of the stimuli surpasses the adaptive reserve of the organism, ultimately contributing to maladaptation and diminished performance.

the athlete monitoring system and direct the selection of tools that provide valid, reliable, and relevant measures that can allow for actionable decision-making. Monitoring strategies also should be selected with considerations of the financial and logistical constraints of your specific team environment, such as budget allowances, athlete compliance, and coach's buy-in. Additionally, it is important to have adequate staff with the skillset and time availability to frequently collect, analyze, visualize, and most importantly, communicate findings back to the key stakeholders. Finally, athlete monitoring strategies can be a useful component supporting an evidence-guided athlete performance model, steering the decision-making processes of athlete performance and care; however, these methods are meant to enhance, not replace, the practical and clinical expertise of the primary stakeholders.

EXTERNAL LOAD

External training load (eTL) refers to the biomechanical or locomotive work completed by the athlete, independent of the athlete's internal characteristics (Fox, Scanlan, & Stanton, 2017; Halson, 2014; Heishman et al., 2018; Russell, McLean, Impellizzeri, Strack, & Coutts, 2021). External training load is often associated with training prescription, including loads accrued during both practice and competition. Although measures of eTL during basketball may appear as a relatively new construct, the desire to objectify training loads during basketball play can be traced back to the late 1930s when Lloyd Messersmith developed an electrical pursuit with a scaled replicate of the court area. Positioned above the area of play, the researcher would trace an athlete's movement throughout the game, ultimately quantifying the distance the athlete traveled over the course of the game (Messersmith & Bucher, 1939). Current sport science practices have evolved to use a variety of technologies to quantify eTL with the purpose of characterizing the demands of the game, providing insights into tactical periodization, and establishing key reference data for return-to-play scenarios. Practically, eTL is useful in enhancing the precision of on-court team and individual training prescriptions, which allows for manipulation of practice training load patterns, reducing training monotony and optimizing physical readiness leading into competition. In addition, eTL characteristics captured during training and competition can guide the prescription of training volume, intensity, and density throughout the return-to-play process to ensure an athlete is adequately prepared for the specific demands they will experience once back into competition.

Outdoor team sports rely on the satellite-based navigational device, global positioning system (GPS) with the capability to measure the position, distance, and speed of player movements to track eTL. However, signal interference precludes the use of GPS to measure eTL of indoor sports, leading to the innovation of alternative solutions to quantify eTL. In basketball, the three most common tools used to quantify eTL are Inertial Measurement Units (IMUs), Local Positioning Systems (LPS), and Optical Tracking Systems (Fox et al., 2017; Russell et al., 2021).

IMUs are perhaps the most common tool used to measure eTL in basketball. IMUs are microsensors containing an accelerometer to measure linear acceleration, a gyroscope to measure angular velocity, and a magnetometer to provide orientation to magnetic north. Manufacturers of the commercially available microsensor technologies have developed supportive software that applies specific algorithms to transform the input of raw inertial data captured during athlete movement, into meaningful and standardized output variables used to quantitate the movement experienced. Further, each unit incorporates a built-in microprocessor onboard to allow "live" automatic, real-time feedback via telemetry (Fox et al., 2017; Heishman et al., 2018).

IMU devices often attempt to quantify the total workload performed by the athlete using a metric called PlayerLoad™ (which may also be referred to as "BodyLoad" or "Accumulation Load" depending upon the manufacturer). PlayerLoad™ (PL) is a valid and reliable measure in quantitating the movement demands of team-sport play and often used a measure of training volume, as measures of PL have been shown to positively correlate with distance traveled (Barrett et al., 2014; Heishman et al., 2020). In addition, PL is often divided by the session duration to characterize the intensity of the training session (PL/Minute). Moreover, increases in PL (meaning increases in training volume) have been associated with subsequent changes in neuromuscular performance (decreases in jump height and explosiveness), further endorsing the metrics as a valuable tool in quantifying eTL (Heishman et al., 2018; Heishman, Daub, Miller, Freitas, & Bemben, 2020). While the details are outside the scope of this chapter, it should be noted that the use of IMUs is expanding, which may provide more detailed information particularly useful during return-to-play following injury (Burland, Outerleys, Lattermann, & Davis, 2021).

Local position systems (LPS), also referred to as indoor positioning systems, operate similarly as GPS technology, allowing real-time positional information in an indoor environment (Fox et al., 2017; A. Heishman et al., 2020). These technologies employ radio frequency identification and ultra-wideband systems that allow large volumes of data to be transmitted. LPS may have the potential to provide more precise information associated with instantaneous speed and acceleration, critical components of basketball play. In a preliminary analysis including a cohort of 13 men's collegiate basketball players, Heishman et al. (2020) observed a strong positive correlation between the distance traveled measured via LPS and PL measured via IMU over the course of three practices. Although the use of these devices is increasingly common, more work is needed establishing the validity and reliability of these tools, specifically focusing on outcomes of acceleration, deceleration, and change-of-direction activities of varying intensity.

Optical tracking systems use the coordination of multiple cameras to automatically track the 2-demensional movement of athletes and the ball during play (Russell et al., 2021). Optical tracking technology offers an advantage as an unobtrusive method to capture eTL, especially in leagues that prohibit wearable technology during competition. However, the validity and reliability of optical tracking technology have yet to established in the literature. In addition, the cost and lack of portability, among other factors have limited the widespread growth in use of optical tracking systems. Nevertheless, optical tracking systems show high potential in athlete monitoring and could become more common as the technology continues to evolve, but more research is needed.

INTERNAL LOAD

Internal Training Load represents an athlete's response to the training stimuli during training or competition (Halson, 2014; Heishman et al., 2018; Russell et al., 2021). Factors such as the recovery time required, an athlete's fitness level, and capacity to tolerate the prescribed training loads all impact the athlete's response. A variety of methods have been utilized to assess internal load in basketball athletes including blood lactate responses, heart rate, and rating of perceived exertion (RPE) (Berkelmans et al., 2018; Russell et al., 2021).

Heart rate information can be collected continuously and noninvasively which allows for frequent monitoring. The intermittent structure of basketball play creates undulations in heart rate that may not be captured through measures of average and peak heart rate, alone. To accommodate the variations in heart rate during the intermittent nature of play, Training Impulse (TRIMP) models are often used to characterize the physiological responses to training and competition. As demonstrated in Figure 2, TRIMP is a cumulative score designed to mimic the increase in blood lactate concentration that increase curvilinearly with increases in exercise intensity (Heishman et al., 2018). Although TRIMP can be calculated by various methods (Manzi et al., 2010), generally, TRIMP models attempt to account for the increase metabolic stress at higher heart rates by stratifying heart intensities into various zones, with higher intensity zones contributing greater arbitrary units into the cumulative score.

Although heart rate measures during training offer a noninvasive method to continuously capture exercise intensity during play, there are some limitations should be considered when implementing these tools in the applied setting. Numerous factors affect heart rate responses during exercise, including hydration, nutrition, emotional stimuli, and other environmental factors. Additionally, many TRIMP algorithms require accurate measurements of resting and maximal heart rate to appropriately stratify heart rate zones. Therefore, obtaining valid measures of both resting and maximal heart rate are critical for data quality. Nonetheless, monitoring heart rate is a viable option to capture the general response an athlete experiences to the demands of both training and competition.

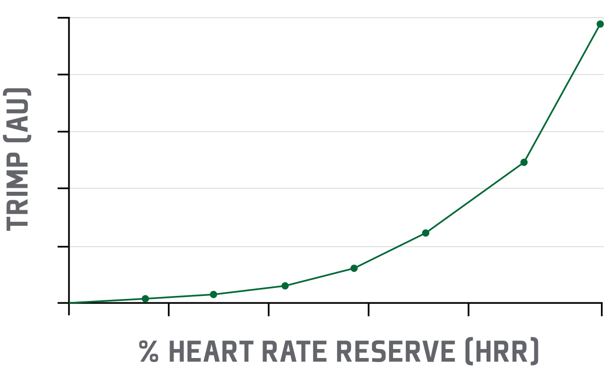

Figure 2: Training Impulse (TRIMP)-The cumulative score designed to mimic the increase in blood lactate concentration that increase curvilinearly with increases in exercise intensity.

Heart Rate Recovery

In addition to continuous heart rate monitoring during a session, measures of heart rate recovery (HRR), or the decline in heart rate at the termination of exercise, can be an insightful measure reflecting autonomic function. Meaning the balance between the athlete's state of "fight or flight" and "rest in digest", as well as signifying an athlete's fitness level (Daanen, Lamberts, Kallen, Jin, & Van Meeteren, 2012). Measures of HHR are commonly calculated by obtaining the heart rate at the cessation of exercise subtracted by the heart rate at 60 s following exercise. This measure provides insight into the ability of the autonomic nervous systems to shift from the sympathetic drive stimulated with the onset of exercise to parasympathetic activity reflecting recovery, where a greater decrease in beats per minute reflect positively on the athlete's fitness. In other words, well-conditioned athletes with high levels of fitness can quickly shift from the excited "fight or flight" response generated with exercise to the calmer "rest and digest" state needed during the recovery process, which is represented by bringing their heart rate down from the high rates experienced during exercise back to lower resting levels. Practically, measurement of HRR can be useful to determine athletes' fitness levels across training phases, but also valuable during a return-to-play protocol, as it provides a common measure for comparing changes in fitness across the various phases of rehabilitation, when exercise restrictions and the type of activities permitted will vary.

Heart Rate Variability

Heart Rate Variability (HRV) refers to the normal instantaneous variation of time intervals between heart beats (R-R Interval) (Pagaduan, Chen, Fell, & Xuan Wu, 2021; Pumprla et al., 2002). HRV serves as a proxy measure representing the continuous interplay between the parasympathetic nervous system (PNS) and sympathetic nervous system (SNS) branches of the autonomic nervous system (ANS) in regulating heart rate. HRV provides biofeedback through the indirect assessment of fluctuations in ANS function, where high PNS or low SNS activity is associated with increases in HRV thought to reflect homeostatic balance, adequate adaptability, and resilience to stress (Pagaduan et al., 2021; Pumprla et al., 2002). Conversely, depressed HRV is believed to represent high SNS or reduced PNS activity, which is associated with stress, limited adaptive reserve, and even physiologic malfunction (Pagaduan et al., 2021;

Pumprla et al., 2002). However, it is important to note that measures of HRV are highly individualized and require frequent collection to establish individual norms prior to interpreting these data points. Nonetheless, previous data has highlighted the sensitivity of HRV to alterations in training load and performance, as well as an effective parameter used to guide training prescription. However, the positive utility of HRV has predominantly been reported in non-team sport athletes (Pichot et al., 2000). Unfortunately, less evidence exists verifying the utility of HRV measures in the team sport environment. Evidence suggests that training guided by daily HRV measures rather than a pre-determined training program in individual athletes resulted in greater improvement in performance (Düking, Zinner, Reed, Holmberg, & Sperlich, 2020).This approach may be possible for basketball athletes during the off-season training phase when strength and conditioning training programs should increase in their individualization to optimize player development. However, this strategy may become logistically challenging during the competitive season when the primary stress is generated from playing the sport and team practices that include all squad members, making individual modification to the training plan challenging.

Historically, the challenges with HRV assessment in the team setting have revolved around the logistics of the frequency of data collection and capturing quality resting measurements. Previous work has established the reliability of short period HRV assessment (~60 s) and determined a minimum of 3 assessments per week are required to effectively monitor responses to training (Plews et al., 2014). However, advancements in wearable technology are quickly evolving, which expands the practicality of HRV monitoring. Modern smart rings and watches employ photoplethysmography allowing the collection of consistent HR and HRV measures throughout the day and night (Miller, Sargent, & Roach, 2022). Moreover, the ability to collect nocturnal measures of HRV may increase compliance and applicability while also enhancing the degree of standardization in data collection. Additionally, increases in accessibility and adoption of these devices will likely generate a better understanding of the true value of these measurement in team sports, which is currently lacking.

Session Rating of Perceived Exertion

As proposed by Enoka and Duchateau, fatigue during human performance can be classified into two categories, i) *performance fatigue*, defined as a decline in an objective measure of performance over a discrete period and ii) *perceived fatigability*, described as changes in the sensations that regulate the integrity of the athlete (Enoka & Duchateau, 2016). To that effect, gathering perceptual information associated with training may offer an enhanced understanding or provide information of the athlete's internal response. In addition, previous literature suggests a mismatch between the intended prescribed load of the coach and the perceived load of the player (Brink, Frencken, Jordet, & Lemmink, 2014). The estimation of perceptual responses during basketball play are commonly captured using session rating of perceived exertion (sRPE). As exampled in Figure 3, sRPE represents the global rating of intensity across an entire training session and is calculated by multiplying the athlete's RPE (on a scale of 1-10) by the duration of the session in minutes. The relationship between sRPE measures and physiologic constructs supports the use of sRPE as a surrogate measure in assessing internal load, especially when resources for quantitative measures are unavailable (Scanlan, Wen, Tucker, & Dalbo, 2014). In other words, sRPE is a simple low-cost tool to monitor the training intensity when on a budget or more sophisticated measurements tools are impractical for your setting. However, it is likely sRPE is best implemented in addition to other quantitative

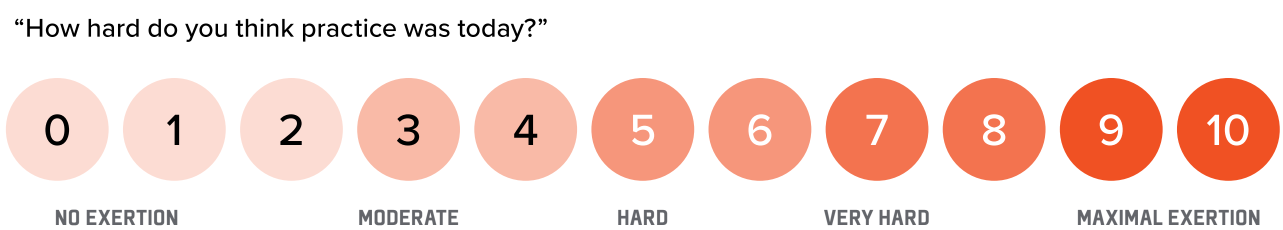

Figure 3: Rating of Perceived Exertion (RPE) question and scale, which can then be multiplied by exercise duration to determine the Session-RPE for the practice, game, or training exposure.

measures. Furthermore, considering the established relationship with objective physiological measures of internal load, coaches and practitioners should also consider the mismatch of quantitative measures and subjective perceived measures, which should initiate a conversation to check-in on an athlete's well-being.

The simplicity, cost effectiveness, and ease of implementation makes the utilization of sRPE an attractive method to monitor training loads in athletes of all levels. However, key methodological elements should be considered to preserve the validity and reliability of the sRPE measurement. Practitioners should use a standardized instrument that includes previously validated verbal anchors, while not modifying the tool with the addition of colors or images, such as facial expressions, to symbolize each level of effort, as these factors are likely to influence responses. In addition, data collection should occur 30 min after exercise cessation to mitigate acute influences on sRPE scores by allowing a more global reflection and response to the session (Foster et al., 2001). For example, if a practice ends on a hard, high intensity drill, asking an athlete's subjective sRPE too soon following the conclusion of the practice may overestimate their overall perceived intensity of the practice with the last drill dominating their sRPE score. Finally, in the applied setting, a variety of administration modes are utilized when collecting sRPE (e.g., paper questionnaire, face-to-face, electronic, etc.), which may inadvertently affect outcomes. New evidence has observed an inflation in sRPE scores when collected in a group setting compared to when collecting individual written responses (Minett, Fels-Camilleri, Bon, Impellizzeri, & Borg, 2022). Their findings suggest the presence of athletes or coaches appear to influence sRPE scores. Importantly, practitioners should recognize the potential influence of contextual psychosocial factors on sRPE outcomes and establish standardized collection procedures around the measurement mode and environment to safeguard data quality.

In line with the value of obtaining perceptual responses to training, questionnaires and surveys are often utilized to gather feedback related the athlete's perceived muscle soreness, fatigue, and overall well-being. Often referred to as *athlete-reported outcome measures*, common assessments include Profile of Mood State (POMS), Daily Analyses of Life Demands of Athletes (DALDA), and Recovery Stress Questionnaire for Athletes (RESTQ) (Kellmann, 2010; Kenttä & Hassmén, 1998). These instruments serve as a simple, inexpensive method to gather subjective information linked to an athlete's response to training and competition. From a practical perspective, many teams employ app-based recovery questionnaires which allow the athlete to independently respond to questions associated with their recovery. These methods often include a digital body map to allow the athlete to indicate the area of muscle soreness or concern. Completion of the app-based digital questionnaires prior to arrival at the training facility allows the performance and medical staffs to be proactive in delivering the appropriate care upon the athlete's arrival. Although the theoretical premises of acquiring wellness responses are sound, clear evidence establishing their reliability and validity is lacking. Furthermore, the subjective nature of self-reported information can be easily manipulated. Practitioners should be strategic in their use of these instruments as the length of the survey, combined with the frequency of administration can become monotonous, cumbersome, and time-consuming to the athlete, ultimately affecting data quality. In addition, anecdotal evidence from many coaches suggests one of the most valuable ways to obtain wellness information, especially with relatively small teams like basketball, is by building relationships with players and having open conversations daily related to their readiness and recovery.

Neuromuscular Fatigue and Performance

In exercise science, fatigue has traditionally been defined as the inability to maintain the required or expected force (power) output (Edwards, Hill, Jones, & Merton, 1977). Fatigue is a multifactorial, task specific phenomenon that manifests due to a plethora of physiologic mechanisms along the motor pathways, which often occur simultaneously. However, researchers often categorize fatigue into central or peripheral mechanisms based upon the primary site emerging as the limiting factor in force production. Central fatigue transpires proximal to the neuromuscular junction and reflects the reduction in voluntary activation of the muscle, also referred to as a decrease in motor drive or the inability of the central nervous system to drive motor neurons activation (Gandevia, 2001). Peripheral fatigue refers to the alteration in function at or distal to the neuromuscular junction, which leads to the inability of skeletal muscle to respond to adequate central activation, ultimately resulting in reduced force-generating capacities (Gandevia, 2001; Kent-Braun, Fitts, & Christie, 2012). In other words, central fatigue

results from alteration in the brain and spinal cord that result in decrease force production, whereas peripheral fatigue occurs at the local muscular level which result in a decrease ability to produce force. As it relates to team sports such as basketball, low frequency fatigue (LFF) has been speculated as a primary factor underlying fatigue thought to be particularly challenging due to its long-lasting effects that may persistent even once metabolic disruptions have resolved (Mooney, Cormack, O'Brien, Morgan, & McGuigan, 2013). LFF is a form of peripheral fatigue characterized as the disproportionate loss of force and low firing frequencies compared to high firing frequencies (Fowles, 2006). LFF is thought to develop during activities of high intensity and moderate-to- high force, as well as activities that include repetitive eccentric contractions or frequent stretch-shortening activities. While the definitive mechanisms of LFF have yet to be fully understood, evidence of LFF has been identified in soccer (Rampinini et al., 2011). Understanding the different origins of fatigue can allow practitioners to facilitate improved strategies to optimize recovery and allow the fatigue to dissipate, as the origin of fatigue appears to influence the rate of recovery (Thomas, Dent, Howatson, & Goodall, 2017).

The countermovement jump (CMJ) is seemingly the most common field assessment used to monitor changes in neuromuscular readiness, fatigue, and recovery in response to training (Claudino et al., 2017). The CMJ is particularly attractive in team sports as numerous athletes can be tested in a time efficient manner without adding undue stress or fatigue. In addition, the CMJ utilizes dynamic muscle action known as stretch-shortening cycle (SSC) (Nicol, Avela, & Komi, 2006). Beyond the obvious sport specificity of the jumping movement, the CMJ also employs the slow SSC (<250 ms) which has been associated with the longer ground contact times of sprint acceleration, which is a key physical component of basketball, due to the smaller size of the playing area and intermittent nature of play (Cronin & Hansen, 2005). Importantly, previous work has identified the intra- and intersession reliability of the CMJ, with a growing body of evidence regarding the sensitivity of the CMJ to detect alteration in neuromuscular performance (Gathercole, Sporer, Stellingwerff, & Sleivert, 2015; Heishman et al., 2020). Indeed, decreases in CMJ jump height (JH) have been reported within the 24- to 48-h timeframe following a bout of basketball activity (Chatzinikolaou et al., 2014; Pliauga et al., 2015). Moreover, Heishman et al. observed increases in training stimuli were associated with significant decreases in CMJ JH 24-h after the training session, further connecting the dose-response relationship between external training load and subsequent neuromuscular performance (Heishman et al., 2018).

Although the CMJ movement incorporates the SSC that requires both concentric and eccentric muscle action, classic CMJ analyses have focused on changes in components of the concentric phase or gross output measures (e.g., force, power, JH) (Heishman et al., 2020). Increased accessibility and affordability of force platform systems and the associated analysis software has made the detailed analysis of the CMJ force-time curve mainstream. As presented in Figure 4, Phase specific analyses of the CMJ are now commonplace, with evidence suggesting alteration in the force-time signature may provide greater information associated with the athlete's neuromuscular performance status. For example, growing evidence suggests alternative measures such as Flight Time:Contraction Time (or Reactive strength Index-Modified) may be more sensitive to changes in neuromuscular performance, as the athlete will attempt to modify their jump strategy to maintain the desired outcome of preserving jump height (Gathercole et al., 2015; Heishman et al., 2020). Furthermore, many contemporary force platforms utilize dual cells which also the examination of inter-limb asymmetries, which may be useful in return-to-play scenarios (Jordan et al., 2020).

Practically, the CMJ is utilized for athlete profiling, monitor acute readiness, as well as evaluate neuromuscular performance following injuries during a RTP protocol. When the CMJ is implemented to monitor acute readiness and changes in neuromuscular performance, it is typically performed with the athlete's hands kept on their hips due to improved reliability and to isolate lower extremity force production (Heishman, 2020). However, when using the CMJ to evaluate changes in performance across a training phase, its common to also incorporate the CMJ with the arm swing, which has a greater degree of sport specificity, as well as enhanced overall performance (Hara, Shibayama, Takeshita, Hay, & Fukashiro, 2008). In addition, when using the CMJ for athlete profiling, it is common to test at the beginning and end of each training phase to understand adaptations to training. When using the CMJ for acute readiness and athlete monitoring, more frequent measurements are taken, sometimes including multiple tests per week. However, coaches should be cautious of testing too frequently, as it may lead to testing fatigue resulting in athlete not giving maximal effort during each jump trial.

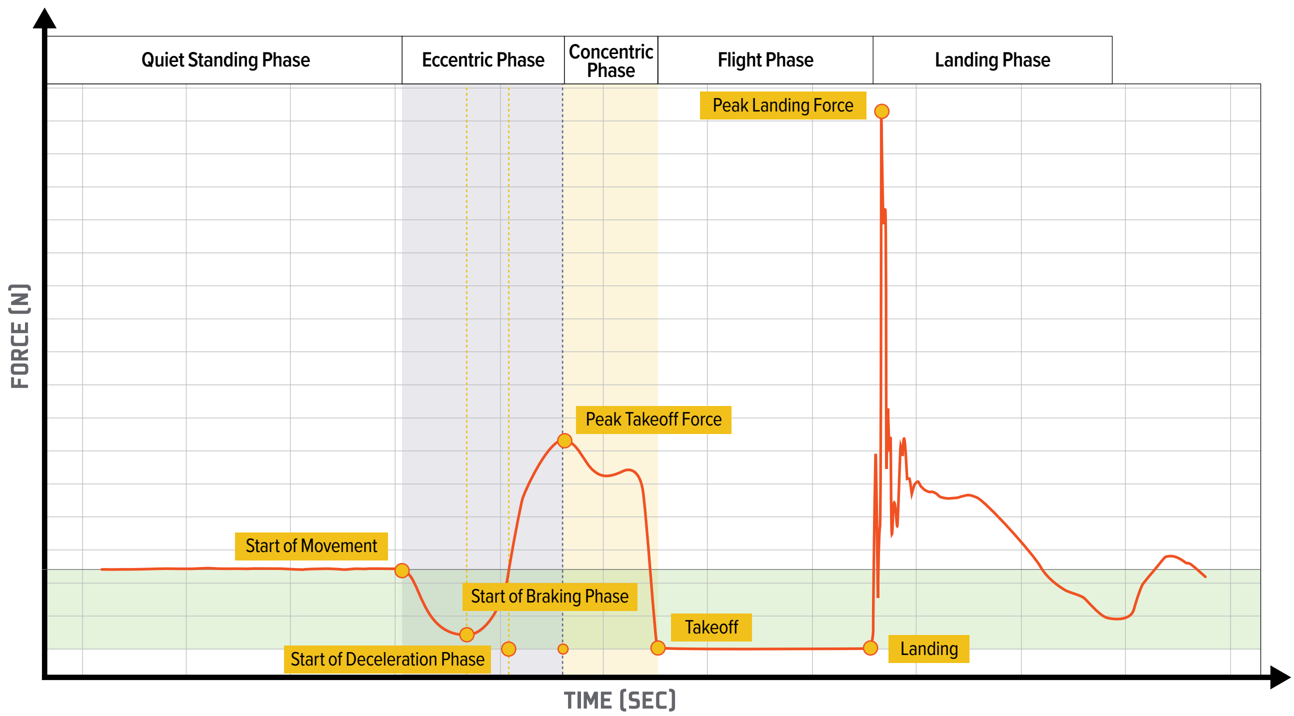

Figure 4: The Countermovement Force-Time signature depicting the Quiet Standing Phase, the Eccentric Phase, the Concentric Phase, Flight Phase, and the Landing Phase.

Biochemical Markers

Given the pivotal role of the endocrine system during the recovery and adaptation process, monitoring biochemical and hormonal responses to training has been proposed as a beneficial method identifying an athlete's position on the recovery-adaptation continuum. The invasive assessment of biochemical markers via blood collections has been utilized to assess acute and chronic responses to training. For example, serum levels of creatine kinase have been measured in basketball (Montgomery et al., 2008) and other team sports (Coutts, Reaburn, Piva, & Murphy, 2007) reflecting acute exercise induced muscle damage following activity. However, utilization of invasive assessment of biochemical markers requiring blood collection are often only utilized for initial screening of athletes or research purposes rather than for a routine monitoring strategy.

The use of noninvasive assessment of biomarkers through salivary techniques are often preferred as they are more conducive for collection in the applied setting. The most common biochemical markers evaluated in response to training are testosterone and cortisol. Testosterone is an anabolic hormone associated with increases in protein synthesis and decrease in protein degradation, as well as exerting indirect anabolic action by stimulating the secretion of other anabolic hormones (Kraemer & Ratamess, 2005). Cortisol is the primary catabolic hormone which is thought to increase with stress and has been associated with decreases in protein synthesis, increases in protein degradation, the stimulation of lipolysis in adipose tissue, as well as the inhibition of inflammation and immune processes (Papacosta & Nassis, 2011). Therefore, cortisol is thought to be a key indicator for assessing gross stress as it pertains to athlete training and competition. Furthermore, testosterone and cortisol are often monitored and interpreted in conjunction via the testosterone:cortisol ratio (T:C Ratio) to reflect the balance of anabolic to catabolic balance.

Most studies specifically examining testosterone, cortisol, and T:C Ratio responses in basketball players have focused on longitudinal changes over a season. Hoffman et al. (1999) measured testosterone, cortisol, and T:C ratio over a 4-week pre-season training period in a cohort of 10 professional basketball players, reporting increases in blood cortisol as the pre-season progressed while observing no changes in testosterone or T:C ratio. Similarly, Schelling et al. reported more consistent cortisol levels when observing 20 male European professional basketball players across a training phase, while noting testosterone levels and T:C ratio were significantly lower during the later stages of data collection (Schelling, Calleja-González, Torres-Ronda, & Terrados, 2015). Andre et al. captured weekly salivary samples in a cohort of 12 NCAA Division I basketball players over a 7-week pre-season and 23-week competitive season and observed increases in cortisol during the pre-season, with no change in testosterone, or T:C Ratio. Furthermore, a taper employed to decrease training loads during the transition from pre-season to the competitive season resulted in an increased T:C ratio. A significant negative correlation between playing time and T:C ratio was documented, suggesting increases in playing time were related to the suppression of T:C ratio, although this is not necessarily a direct causal relationship (Andre & Fry, 2018). Ultimately, the theoretical premise for monitoring changes in testosterone, cortisol, and T:C ratio is sound, however routine monitoring may be cost prohibitive.

MENTAL FATIGUE

Historically, athlete monitoring strategies have mostly focused on evaluating alterations in physical fatigue and performance; however, recent efforts have directed considerable attention to the influence of mental fatigue on sports performance (Cao et al., 2022). Mental fatigue (MF) is defined as a psychobiological state that may occur during or after bouts of prolonged cognitive exertion and is characterized by feelings of tiredness and exhaustion (Van Cutsem et al., 2017). The physiological mechanisms underlying MF have yet to be fully understood, but existing hypotheses speculate that it may be related to elevated adenosine levels in the brain, which inhibits presynaptic neurotransmitter releases and neuronal firing, as well as alterations in dopamine release and receptor affinity (Martin, Meeusen, Thompson, Keegan, & Rattray, 2018). The practical manifestations of MF have been observed through sensations of tiredness and lethargy, reductions in reaction time and accuracy of task completion, and alteration in brain activity, which have been stratified in three major categories of behavioral, subjective, and physiologic, respectively. The deleterious effects of MF have been observed on both cognitive and physical performance, as well as sport-specific skill performance (Sun, Soh, Roslan, Wazir, & Soh, 2021; Van Cutsem et al., 2017).

As it relates to basketball, recent work has demonstrated the negative impact of MF on sport-specific performance. For example, in a cohort of youth players participating in a small-sided game, there were increases in turnovers accompanied by alteration in neuroendocrine and autonomic responses when players were mentally fatigued (Moreira et al., 2018). Similarly, previous work has demonstrated the negative effects of MF on basketball skill expression, with induced MF resulting in impaired free throw shooting accuracy (Filipas, Ferioli, Banfi, Torre, & Vitale, 2021). Given the mounting evidence demonstrating the negative impact of MF on sport performance, key sources of mental fatigue should be considered. Interestingly, film sessions, which are commonly used in basketball to teach technical and tactical strategies, appear to be a potential source of MF. Preliminary evidence suggests a significant reduction in shooting performance following a Stroop task commonly used in research interventions to induce mental fatigue, but also the negative effect of a film session on shooting performance (Daub, McLean, Heishman, Peak, & Coutts, 2023). In addition, unlike physical fatigue generated primarily from training, mental fatigue may be initiated by sources outside of the sport training environment, such as screentime and academic load in college athletes (Fortes et al., 2020). Interestingly, recent work has identified reduction in basketball shooting performance with increases in MF emanating from academic workloads, which appear to manifest independent of physical training loads (Daub et al., 2023). Although more research is needed to enhance our understanding of the dose-response relationship and longitudinal implications of MF on performance, preliminary evidence suggests understanding the influence of MF could provide valuable insights for performance and should be included in athlete monitoring strategies. In conjunction with assessments of physical fatigue previously discussed, coach and practitioner may consider using a simple visual analogue scale (VAS) to track mental fatigue of their athletes (Smith, Chai, Nguyen, Marcora, & Coutts, 2019).

Sport-Specific Monitoring Tools

Basketball success requires the combination of complex technical, tactical, physical, and psychological components at both the individual and team level. Although the multidimensionality may be recognized, athlete monitoring strategies have predominantly focused on examining changes in physical qualities (e.g., eTL demands, HR; CMJ performance; etc.) to assess acute fatigue and readiness. Lately, a growing interest has been directed at the use of sport-specific assessments that incorporate basketball skill to examine changes in readiness and performance. Recently, Daub et al. (2022) developed a standardized shooting task (SST) used to assess sport-specific shooting performance in college basketball players. The SST is comprised of 60 free throw attempts followed by a timed 4-min period of spot-to-spot shooting. The newly develop SST demonstrated adequate intersession reliability, significant construct validity in sorting the best shooters, as well as acute sensitivity to the sport-specific fatigue of a basketball practice (Daub et al., 2022). Importantly, the practical and ecological validity of the SST creates a distinct advantage over other athlete monitoring strategies, as it allows for seamlessly integration of the test into sport practice, which may subsequently provide insight as a covert monitoring tool to track acute changes in readiness, as well as chronic alteration in performance overtime. Due to the task specificity of fatigue, the pinnacle of athlete monitoring strategies arguably lies in the evaluation of sport-specific tasks, with ensuing evaluations used to discern the underpinning mechanisms responsible for changes in performance. Although currently sport-specific skill tests are limited in their use as a fatigue monitoring tool, it is likely future research will look to integrate readiness assessment with sport-specific tasks. Furthermore, as these methods evolve, the value of implementing standardized skill-based assessments could expand beyond assessing acute fatigue and readiness, but also deliver aid in talent identification processes and may even be used to appraise the efficacy of long-term player development programs through the evaluation of sport-specific skill.


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PRACTICAL APPLICATIONS

- Athlete monitoring strategies that capture the dose-response relationship of the training process can be valuable tools used to optimize player health and performance.
- External load should be monitored to understand the physical demands prescribed to the players from both practice and games, which can be tracked by simple methods, such as the duration of practice and minutes played in game, or more sophisticated approaches including the use of inertial measurement units or positioning systems to understand the athlete's movement signature during play.
- Internal load should be monitored to understand how players are handling the demands of training and competitions. Tracking internal load responses can be as simple session-rating of perceived exertion or more complex strategies such as heart rate monitoring.
- Mental fatigue is a growing area of interests that could affect player performance, especially among student-athletes, and should be taken into consideration to optimize player health and performance.
- Coaches should consider including sport-specific assessments, such as the Standardized Shooting Task, to evaluate short- and long-term changes in player performance.
- Coaches and practitioners should start by identifying the potential methods based upon their specific environment and select tools that provide valid, reliable, and relevant measures that generate actionable decision-making.

SUMMARY

There are a variety of athlete monitoring strategies available to effectively track both internal and external training loads in basketball athletes. Furthermore, it is clear new methods will continue to emerge in parallel with the continual technologic innovation and advancements. Sport scientist and practitioners should remember that the most value from an athlete monitoring system allows for the collection of reliable and relevant data that can lead to actionable decision-making. Therefore, effective athlete monitoring systems start with identifying the most important and relevant questions for the environment and progress by implementing the best tools necessary in answering those questions. Oftentimes, a common pitfall when establishing athlete monitoring systems occurs when the primary focus gets placed on acquiring the latest technology without a clear direction in the use or relevance of the data gathered, ultimately leading to sport scientist and practitioners overwhelmed with data and a lack of direction for its use. Additionally, successful athlete monitoring systems combine applied sport science with the art of coaching, which creates buy-in from both athletes and coaches alike, ultimately leading to an integration that allows for positive change.

The views expressed are those of the author and do not necessarily reflect the position or policy of PepsiCo, Inc.

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CHAPTER 10

SLEEP IN BASKETBALL PLAYERS

SLEEP IN BASKETBALL PLAYERS

Shona L. Halson, PhD
School of Behavioural and Health Sciences, Australian Catholic University, Brisbane, QLD, Australia

Sports Performance, Recovery, Injury and New Technologies (SPRINT) Research Centre, Australian Catholic University, Brisbane, QLD, Australia

KEY POINTS

- Sleep is important for basketball players, both for preparing for, and recovering from, training and competition and should be considered as a priority for performance.
- Sleep disturbances can occur during training periods and prior to or following competition.
- There are numerous ways to monitor sleep and specific options will likely vary depending on resources and available expertise.
- Strategies that can be implemented to optimize athletes' sleep include education, sleep screening, napping, a good pre-sleep routine, and banking sleep.

BACKGROUND

Sleep plays an important role in performance, cognitive function, energy metabolism, muscle repair, mood and illness prevention (Halson, 2019). In high intensity intermittent team sports, such as basketball, where recovery may be limited due to congested schedules, protecting and improving sleep where needed is crucial. Optimizing sleep is often regarded as the best recovery strategy available to athletes (Walsh et al., 2020).

Although the function of sleep is not fully understood, it is generally accepted that it serves to provide recovery from previous wakefulness and/or prepare for functioning in the subsequent wake period. An individual's recent sleep history therefore has a marked impact on their daytime functioning. Restricting sleep to less than 6 h per night for four or more consecutive nights has been shown to impair cognitive performance and mood (Belenky et al., 2003), disturb glucose metabolism (Spiegel et al., 1999), appetite regulation (Spiegel et al., 2004) and immune function (Krueger et al., 2011). This type of evidence has led to the recommendation that adults should obtain 8 h of sleep per night to prevent neurobehavioual deficits (Van Dongen et al., 2003).

Sleep in Basketball Athletes

While published data on sleep characteristics in the highest levels of professional basketball is limited, research in sub-elite or development athletes as well as other team sport research can provide insight into many of the challenges associated with sleep in basketball players.

Leeder et al. (2012) compared the sleep habits of 47 elite athletes from Olympic Sports using actigraphy over a four-day period to that of age and sex-matched non-sporting controls. The athlete group had a total time in bed of 8:36 ± 0:53 h:min, compared to 8:07 ± 0:20 h:min in the control group. Despite the longer time in bed, the athlete group had a longer sleep latency (time to fall asleep) (18.2 ± 16.5 min vs. 5.0 ± 2.5 min), a lower sleep efficiency (estimate of sleep quality) than controls (80.6 ± 6.4 % vs. 88.7 ± 3.6 %), resulting in a similar time asleep (6:55 ± 0:43 vs. 7:11 ± 0:25 h:min).

In a recent assessment of the sleep need of elite athletes, it was reported that elite male and female athletes subjectively report they require 8.3 h ±0.9 h of sleep to feel rested (Sargent et al., 2021). However, a majority of athletes (71%) fail to meet this need on most nights, with an average sleep duration of 6.7±0.8 h per night. This results in a sleep deficit index of 96.0±60.6 min. When comparing across various sports, basketball athletes had the latest wake times and the longest sleep durations.

PERFORMANCE EFFECTS OF SLEEP DEPRIVATION AND SLEEP EXTENSION

Sleep Deprivation

There are a limited number of studies which have examined the effects of sleep deprivation on athletic performance. From the available data it appears that several phenomena exist. Firstly, the sleep deprivation must be greater than 30 h (one complete night of no sleep and remaining awake into the afternoon) to have an impact on anaerobic performance (Skein et al., 2011). Secondly, aerobic performance may be decreased after only 24 h (Oliver et al., 2009) and thirdly, sustained or repeated bouts of exercise are affected to a greater degree than one-off maximal efforts (Blumert et al., 2007; Reilly & Edwards, 2007). For example, peak power has been shown to be unchanged after 24 h of wake however, they were impaired after 36 h without sleep (Souissi et al., 2003). Isokinetic performance has also been shown to decrease significantly following 30 h of sleep deprivation (Bulbulian et al., 1996). Skein et al. (2011) reported significant decreases in mean and total sprint time following 30 h of sleep deprivation in ten male team sport athletes. Blumert et al. (2007) examined the effects of 24 h of sleep deprivation in nine US college-level weightlifters in a randomised counter-balanced design. There were no differences in any of the performance tasks (snatch, clean and jerk, front squat and total volume load and training intensity) following 24 h of sleep deprivation when compared to no sleep deprivation (Blumert et al., 2007). However, mood state as assessed by the Profile of Mood States was significantly altered, with confusion, vigour, fatigue and total mood disturbance all negatively affected by sleep deprivation. While much of the research has focussed on anaerobic performance, reductions in endurance running performance have been observed following 24 h of sleep deprivation (Oliver et al., 2009). Interestingly, this occurred without any changes in physiological parameters and pacing.

The mechanism behind the reduced performance following prolonged sustained sleep deprivation is not clear, however it has been suggested that an increased perception of effort is one potential cause. While the above studies provide some insight into the relationship between sleep deprivation and performance, most athletes are more likely to experience acute bouts of partial sleep deprivation where sleep is reduced for several hours on consecutive nights.

Partial Sleep Deprivation

A small number of studies have examined the effect of partial sleep deprivation on athletic performance. Reilly and Deykin (1983) reported decrements in a range of psychomotor functions after only one night of restricted sleep, however gross motor function such as muscle strength, lung power and endurance running were unaffected. Reilly and Hales (1988) reported similar effects in females following partial sleep deprivation, with gross motor functions being less affected by sleep loss than tasks requiring fast reaction times.

The effect of 2.5 h of sleep per night over 4 nights was measured in eight swimmers (Sinnerton & Reilly, 1992). No effect of sleep loss was observed when investigating back and grip strength, lung function or swimming performance. However, mood state was significantly altered with increases in depression, tension, confusion, fatigue and anger and decreases in vigour.

Reilly and Piercy (1994) found a significant effect of sleep loss on maximal bench press, leg press and dead lifts, but not maximal bicep curl. Sub-maximal performance however, was significantly affected on all four tasks and to a greater degree than maximal efforts. The greatest impairments were found later in the protocol, suggesting an accumulative effect of fatigue from sleep loss (Reilly & Piercy, 1994).

From the available research it appears that sub-maximal prolonged tasks may be more affected than maximal efforts particularly after the first two nights of partial sleep deprivation (Reilly & Piercy, 1994).

Effects of Sleep Extension

Another means of examining the effect of sleep on performance is to extend the amount of sleep an athlete receives and determine the effects on subsequent performance. Sleep extension involves accumulating additional sleep by spending more time in bed with the intention to sleep or by adding daytime naps. Mah et al. (2007) instructed six Division I college basketball players to obtain as much extra sleep as possible following 2 weeks of normal sleep habits. Faster sprint times and increased free-throw accuracy were observed at the end of the sleep extension period. Athletes obtained on average 1.8 h of additional sleep per night as measured by activity monitoring Mood was also significantly improved, with increased vigour and decreased fatigue (Mah et al., 2011). The same research group also increased the sleep time of swimmers to 10 h per night for 6-7 weeks and reported that 15 m sprint, reaction time, turn time and mood all improved.

Eleven endurance cyclists and triathletes completed 3 nights of sleep extension (approximately 1.5 h) which resulted in significantly faster time trial performance on day 4 of sleep extension when compared to normal sleep (Roberts et al., 2019).

The authors concluded that accumulated sleep time appears to influence performance by reducing perceived exhaustion at a given exercise intensity. The data from this small number of studies suggests that increasing the amount of sleep an athlete receives may significantly enhance performance.

Effects of Napping

Athletes suffering from some degree of sleep loss may benefit from a brief nap, particularly if a training session is to be completed in the afternoon or evening (Waterhouse et al., 2007). There is limited research on napping in athletes, however, the effects of a lunchtime nap on sprint performance following partial sleep deprivation (4 h of sleep) has been investigated (Postolache et al., 2005). Following a 30 min nap, 20 m sprint performance was increased (compared to no nap), alertness was increased, and sleepiness was decreased. In terms of cognitive performance, sleep supplementation in the form of napping has been shown to have a positive influence on cognitive tasks (Postolache et al., 2005). Naps can markedly reduce sleepiness and can be beneficial when learning skills, strategy or tactics in sleep deprived individuals (Postolache et al., 2005).

Napping may be beneficial for athletes who have to routinely wake early for training or competition and for athletes who are experiencing sleep deprivation (Waterhouse et al., 2007).

In a recent systematic analysis (Lastella et al., 2021), it was found that napping is common practice among athletic populations. While napping presents athletes with the opportunity to supplement their night-time sleep, evidence also indicates that napping may be beneficial for a range of measures such as physical performance, cognitive performance and mood in athletes (see Figure 1). Data from the review suggests that athletes should aim to nap for between 20–90 min in duration and between 13:00 and 16:00 h. Finally, athletes should allow 30 min to reduce sleep inertia prior to training or competition to obtain better performance outcomes.

What Disturbs Sleep in Athletes

There are many contributary factors of sleep disturbance in athletes including both non-sport factors and sport-specific factors, see Figure 2 (Walsh et al., 2020).

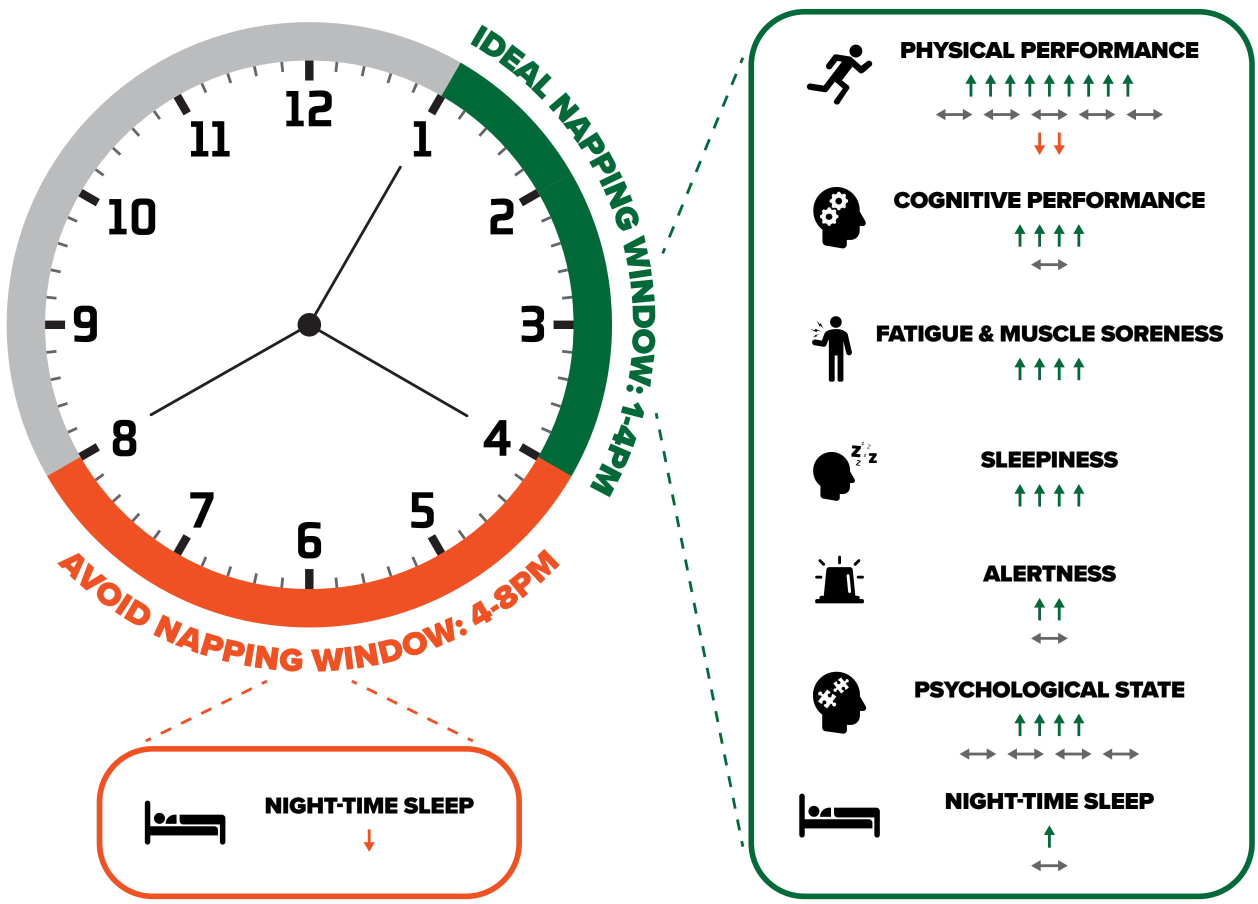

Figure 1: Overview of the evidence examining the impact of napping on various measures of athletic performance.
↑ indicates improvement, ↓ indicates decrease, ↔ no change in variable assessed

Contributory Factors for SLEEP DISTURBANCE IN ATHLETES

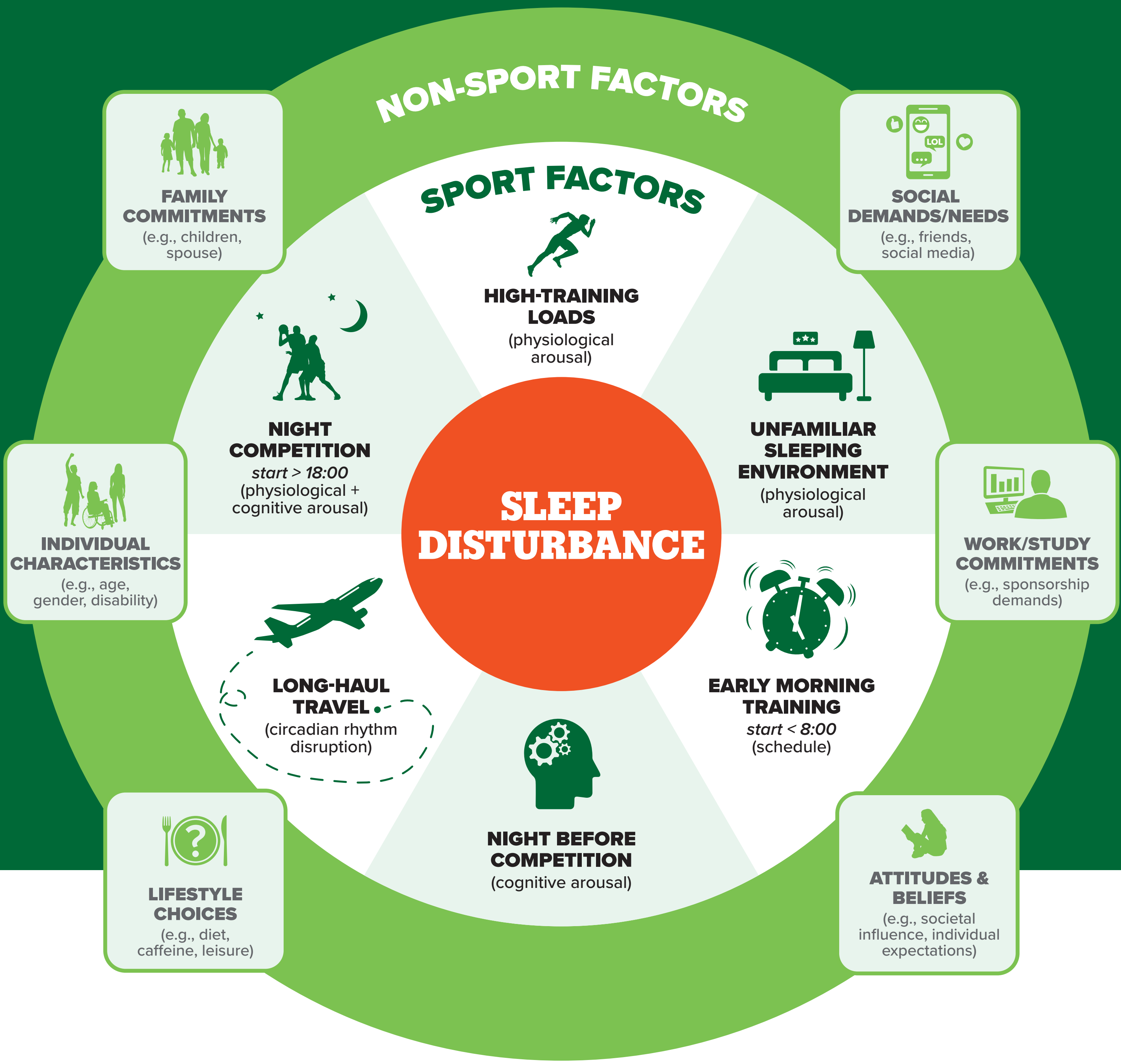

Figure 2: Contributory factors of sleep disturbance in athletes (Walsh et al., 2020).

Basketball presents some specific challenges that may result in disturbed sleep, including: frequent late-night matches, congested schedules, travel across multiple time zones and caffeine consumption. Erlacher et al. (2011) administered a questionnaire to 632 German athletes to assess possible sleep disturbances prior to competition. Of these athletes, 66% (416) reported that they slept worse than normal at least once prior to an important competition. Of these 416 athletes, 80% reported problems falling asleep, 43% reported waking up early in the morning and 32% reported waking up at night. Factors such as thoughts about competition (77%), nervousness about competition (60%), unusual surroundings (29%) and noise in the room (17%) were identified as reasons for poor sleep (Erlacher et al., 2011).

Many elite team sport athletes complain of poor sleep after games, in particular night games, which may be compounded when subjected to congested schedules. Seventeen elite Australian female basketball players had their sleep assessed, using activity monitors, over two seasons, totalling 30 weeks (Staunton et al., 2017). Match schedule influenced total sleep time, with double-headers resulting in players experiencing an 11% reduction in total sleep time when compared to the regular match schedule (one game per round). Elevated adrenaline and noradrenaline concentrations have been found before and after night games, when compared to a rest-day, in elite netball players (Juliff et al., 2018). Further, athletes who had a tendency towards a high trait arousal were more susceptible to sleep complaints following a night-game (Juliff et al., 2018).

Workload during training and competition may also influence sleep characteristics. Fox et al. (2020) examined the impact of workload during training and competition on subsequent sleep duration and sleep quality in seven semi-professional male basketball players. Sleep onset time was significantly later following medium and high training and competition workloads compared with control nights. Time in bed and sleep duration were also significantly shorter following high training and competition workloads compared with control nights (Fox et al., 2020). Similar results were found in 38 elite Australian Rules Football players where high maximal running speeds and player loads during training were negatively associated with objective sleep markers (Lalor et al., 2020). However, sleep/wake behaviors were not influenced by training load in 11 elite female adolescent basketball players (Lastella et al., 2020). In this study players did not obtain the recommended 8-10 h of sleep per night on training days. However, sleep onset and offset times were later on rest days than training days, while time in bed and total sleep time were greater on rest days compared to training days. Recent data in elite team sport athletes suggest that high regularity in bed and wake times may be associated with higher sleep quality and less wake after sleep onset (Halson et al., 2022). Therefore, the scheduling of training sessions should be as consistent as possible.

Training sessions should also not be scheduled too early in the morning so that training encroaches on players total sleep time available. Early morning training sessions have been shown to reduce total sleep time in elite swimmers (Sargent et al., 2014), in rugby players (Dunican et al., 2019) and in elite team sport athletes (Halson et al., 2022). This can be particularly challenging with multiple games per week and the potential associated travel. However, avoiding unnecessarily early training sessions is likely of benefit to the players.

Therefore, it appears that sleep disturbances in athletes can occur at various time points: 1) prior to games, 2) after games and 3) during normal training. This sleep disruption during normal training may be due to a poor routine as a consequence of early training sessions, poor sleep behaviours, nocturnal waking to use the bathroom, caffeine use, and excessive thinking/worrying/planning.

Assessing Sleep

A range of methods to assess sleep exist including polysomnography (PSG), activity monitoring, wearables, sleep diaries and questionnaires. However, there are currently no guidelines or recommendations for best practice regarding monitoring of sleep-in athletes. There are numerous advantages and disadvantages of available methods to measure sleep in athletes (for reviews, please see (Halson, 2019; Walsh et al., 2020)) and it is important that there is an understanding of the limitations and benefits of methods to ensure appropriate data interpretation and feedback.

Polysomnography

PSG is considered by many to be the gold standard for measuring sleep and typically includes an assessment of eye movement, brain activity, heart rate, muscle activity, oxygen saturation, breathing rate and body movement (Roomkham et al., 2018). PSG allows for the determination of sleep stages (rapid eye movement (REM) and non-rapid eye movement (NREM)). PSG is typically only utilised to assess specific sleep disorders as it is an expensive, obtrusive and complex technique, requiring expertise in setting up the individual to be monitored and manually scoring the sleep data. Further, PSG typically occurs in a laboratory and therefore is impractical for longitudinal monitoring.

Activity Monitoring/Actigraphy

Activity monitors are small, wearable devices which record movement as a function of time (Quante et al., 2015), with most utilising a 3-axis accelerometer to determine sleep/wake based on a specific algorithm (Kolla et al., 2016). Research-grade activity monitors have been validated against PSG and the algorithms utilised to quantify sleep and wake are reported and have been validated in an athlete population (Fuller et al., 2017; Sargent et al., 2016). Actigraphy allows for longitudinal monitoring (beneficial for assessment of sleep/wake times across numerous days) and are popular devices in both research and practice. However, typically these devices perform poorer in individuals with fragmented sleep who have higher amounts of wake during sleep (Quante et al., 2015). Further, research quality devices can be expensive and some expertise is required to ensure accuracy of the data provided and to consolidate this data into a usable sleep report.

Wearables

As highlighted above, current tools for assessing sleep require some level of expertise and/or significant costs. Many companies have leveraged the popularity of sleep monitoring to create inexpensive and user-friendly monitoring devices that are available to the general public. While wearables have some advantages in terms of cost and ease of use, information regarding accuracy and reliability for some devices are limited. However, many devices compare favourably to activity monitoring in terms of validity and research and technology in this space is advancing rapidly.

Sleep Diaries and Questionnaires

The use of a sleep diary can represent a simple and cost-effective means of assessing sleep. Recommended minimum variables to include in the diary are: bed and wake time, lights out time, daytime napping, ratings of sleepiness and alertness, caffeine and alcohol intake, exercise and light emitting device use (Anderson, 2018) for a duration of at least one week. However, biases with diary use may exist due to recall and social desirability and expectation (Quante et al., 2015) and it is often recommended that diaries are completed in conjunction with activity monitoring. Sleep questionnaires are often utilised as the first diagnostic test due to their ease of administration and low cost. There are a variety of questionnaires available to assess sleep disorders, which may have limited usefulness in athletes. Recently, questionnaires designed to specifically examine sleep in athletes have been developed (Athlete Sleep Screening Questionnaire (Bender et al., 2018; Samuels et al., 2016) and Athlete Sleep Behaviour Questionnaire (Driller et al., 2018) and provide useful resources for the elite athlete.

The majority of concerns regarding the collection and interpretation of sleep information are related to having ready access to daily information regarding sleep over long periods of time. This may cause unnecessary stress and anxiety in some individuals and may actually disturb sleep and exacerbate a poor perception of sleep.

Many individuals assume that data collected objectively are accurate and of more value than subjective data, but this may not be the case with sleep monitoring devices. Practitioners should be aware of the differences between devices and understand how to interpret the data or explain to the individual the reasons not to place excessive importance on aspects of their data. What is clear is that devices may facilitate interaction with a professional and encourage healthy sleep behaviours, but they should not replace a clinical evaluation when required (Choi et al., 2018).

Managing Sleep in Athletes

To optimize and improve sleep, basketball players may benefit from sleep monitoring, feedback and education (Halson, 2019). Avoiding excessive screen time (Jones et al., 2019), inappropriate caffeine intake (Dunican et al., 2018) and providing education regarding general good sleep behaviors may help protect sleep in a sport where optimal sleep may be somewhat challenging given certain schedules. Monitoring and education have been shown to be useful in the short-term, however consistent and persistent messaging to athletes is likely important (Caia et al., 2018).

PRACTICAL APPLICATIONS

- Provide sleep education for athletes—Sleep education sessions for athletes have been shown to improve sleep. Sleep education could cover topics related to sleep quantity, quality, timing, and sleep monitors. Education should focus on how sleep relates to performance in their sport to create buy-in for further sleep interventions.
- Screen athletes for sleep problems—Start with a questionnaire-based tool (Athlete Sleep Screening Questionnaire (Bender et al., 2018; Samuels et al., 2016) and Athlete Sleep Behaviour Questionnaire (Driller et al., 2018)) so individuals with issues can be quickly identified and seek help from a sleep specialist in a timely manner.
- Encourage naps—With late or early training times, travel and balancing life outside of sport, athletes may not have enough sleep opportunity at night so supplementing with a nap is key. Even short naps of <30 min can enhance mood, alertness and cognitive performance in those who get sufficient night-time sleep. Time naps from 13:00 to 16:00 h when there is a dip in alertness (the ‘post-lunch dip’).
- Have a good pre-sleep routine – With late night matches under the lights being a common occurrence, having a good pre-sleep routine whether at home or on the road can be beneficial. Putting away electronic devices and substituting with relaxing activities can help prepare the mind and body for sleep. Taking a warm bath or shower, writing a to-do list, reading a paper book, stretching, and breathing techniques are supported by research to reduce the time to fall asleep and improve sleep quality.
- Caffeine- While individual responses to caffeine intake is highly variable, athletes should observe their caffeine use and potential effects on night-time sleep. Caffeine intake should ideally cease prior to 2pm, however observing effects on time taken to fall asleep is a priority.
- Sleep and training times- Ideally bed and wake times should be kept as consistent as possible throughout the week. Consistent training times (including minimising very early training start times), may assist with both consistency and duration of sleep opportunity.

SUMMARY

Sleep is extremely important for numerous biological functions and sleep deprivation can have significant effects on athletic performance, especially sub-maximal, prolonged exercise. From the available evidence it appears that athletes may be obtaining less than 8 h of sleep per night and that increasing sleep (sleep extension) or napping may be useful to increase the total number of hours of sleep and thereby enhance performance, mood, alertness and cognitive function.

The views expressed are those of the author and do not necessarily reflect the position or policy of PepsiCo, Inc.

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CHAPTER 11

RECOVERY MODALITIES

RECOVERY MODALITIES

Shane O'Riordan PhD, ESSAM, AES, AspS1, CSCS
Institute for Health and Sport (iHeS), Victoria University, Melbourne, VIC, Australia

Jessica Stephens, PhD, AES, ASpS2
Queensland Academy of Sport, Nathan, Australia

Research Institute for Sport and Exercise (UCRISE), University of Canberra, Canberra, ACT, Australia

KEY POINTS

- Recovery modalities are important to maximize athletic performance.
- Practitioners should carefully consider the phase of the season when implementing recovery modalities.
- Individual athlete goals and preferences are key to maximizing adherence and benefit.
- Develop a recovery plan for athletes, especially when travelling or in tournaments.

INTRODUCTION

Optimal recovery after basketball training and games is a multifaceted process that involves both physical and psychological restoration (Calleja-González et al., 2021). It is crucial for staff to manage players recovery during periods of intensified load, such as during pre-season training, in-season and over multi-day tournaments to avoid poor performance and reduce the risk of illness and injury from occurring (Doeven et al., 2020). The implementation of various post-exercise recovery modalities in basketball has been the focus of several recent review papers (Calleja-González et al., 2021; Davis et al., 2022; Huyghe et al., 2020; Pernigoni et al., 2022), providing a sufficient evidence base to enable staff to make informed decisions regarding the use of recovery modalities in basketball.

RECOVERY MODALITIES

Some of the most utilized recovery strategies in basketball include sleep, nutrition, hydrotherapy, compression, active recovery, stretching, massage and foam rolling (Calleja-González et al., 2021; Pernigoni et al., 2022). Sleep and nutrition are often considered the most important recovery strategies as they can have the greatest impact on athletic performance (Stephens & Halson, 2022). Chapters 4 and 10 cover these topics in greater detail, but it is important to acknowledge that sleep and nutrition interventions should be considered as part of an overall recovery plan.

Hydrotherapy

The use of hydrotherapy to enhance athletic recovery has been common practice for many years. Hydrotherapy is thought to induce a number of physiological changes due to the impact of water temperature and hydrostatic pressure which lead to changes in blood flow and body temperature (Stephens et al., 2017). There are three main types of hydrotherapy methods typically utilized by athletes, these are cold water immersion (CWI), contrast water therapy (CWT) and hot water immersion (HWI). In a basketball context CWI has been found to be the most utilized hydrotherapy modality (Pernigoni et al., 2022) and it is the only hydrotherapy modality that has multiple basketball-specific intervention studies to support its use (Davis et al., 2022).

CWI is thought to work by reducing core, skin and muscle temperature and blood flow which can lead to a reduction in swelling, inflammation, and pain (Davis et al., 2022). CWI has been found to be effective in enhancing recovery in multiple basketball scenarios such as following a training session (Sánchez-Ureña et al., 2017), post-game (Delextrat et al., 2013), during a multi-day tournament (Montgomery, Pyne, Cox, et al., 2008; Montgomery, Pyne, Hopkins, et al., 2008) and when routinely utilized over a season (Seco-Calvo et al., 2020). Protocol selection for CWI has varied across studies, with the optimal combination of temperature, duration, depth and mode (continuous vs. intermittent) remaining unknown (Stephens et al., 2017). Both continuous (12 min) and intermittent (4-5 x 1-2 min) CWI protocols have been found to be effective for enhancing the recovery of basketball athletes, as have water temperatures

between 10°C and 12°C (50°F and 53.6°F) (Davis et al., 2022). CWI protocols should be individualized where possible, as factors such as body composition, gender, and age have all been found to impact athlete responses (Stephens et al., 2017). It has been suggested that athletes who have lower body fat and/or lower muscle mass as well as females and youth and masters' athletes may need less intense protocols (e.g., warmer temperature, shorter duration or less body area exposed) to reduce the risk of overcooling and discomfort (Stephens et al., 2017). The individualization of CWI protocols in a team environment can be most easily achieved by altering the immersion duration as changing water temperature between athletes is often not practical.

Though not utilized as frequently as CWI, CWT has been perceived as useful for enhancing recovery and is regularly utilized in basketball (Pernigoni et al., 2022). CWT is thought to work by causing peripheral vasoconstriction and vasodilation as athletes move between cold and hot water temperatures (Huyghe et al., 2020), which enhances blood flow to remove metabolic waste and reduce inflammation (Davis et al., 2022). Despite reports of regular usage, there remains no basketball-specific research examining CWT. Protocol selection for CWT is less evidence driven than CWI; however, research findings from other sports suggest that 3 to 7 rotations of 1-2 min and an equal ratio of hot to cold is recommended (Versey et al., 2011).

HWI is reported to be the least utilized hydrotherapy modality for basketball (Pernigoni et al., 2022) and appears to be the least researched hydrotherapy modality across all sports. HWI may ease muscle tension and increase blood flow, which is thought to enhance removal of waste products and delivery of nutrients to and from the cells (Davis et al., 2022). Protocols for HWI recommend one continuous immersion for at least 10 min in a water temperature of at least 36°C.

One of the key considerations when choosing to implement any hydrotherapy modality is the facilities available, many sporting stadiums now have purpose-built recovery pools making post-game and training access easy. However, this is not always the case in all levels of basketball, and often teams will need to travel with their own portable pools. Whilst logistically challenging at times, inflatable pools or large plastic tubs can provide a good option when travelling. The use of showers has also been suggested to be an effective option when facilities are limited. Using showers for CWT has been equally effective as pools for perceptual recovery (Juliff et al., 2014). Hydrotherapy is possible in any environment as long as some forward planning is done.

Compression

The use of compression garments and intermittent pneumatic compression (IPC) devices as a strategy for exercise recovery originate from the medical sector and have been used to treat lymphedema, posttraumatic edema, and blood flow pathologies (e.g., deep vein thrombosis, peripheral arterial disease) (Byrne, 2001; Greenall & Davis, 2020). The underlying mechanisms attributed to the benefits of compression garments and IPC use include improved arterial and venous blood flow (O'Riordan et al., 2021, 2022; Zuj et al., 2021). Furthermore, considering the positive relationship between increased blood flow and exercise performance recovery (Borne et al., 2017), compression garments and IPC are now commonly used by athletes to aid recovery.

Compression Garments

Compression garments are designed to provide external pressure to the covered limb, with the type (e.g., sock, tights, arm sleeve) dictated by the sport or activity demands (i.e., muscle group used). Research on compression garment use in basketball settings has produced mixed findings. For example, post-basketball games, compression garments did not reduce muscle damage (Montgomery, Pyne, Cox, et al., 2008) or enhance exercise performance recovery (Atkins et al., 2020; Montgomery, Pyne, Hopkins, et al., 2008). However, perceived muscle soreness and fatigue were positively influenced by compression garments in basketball athletes (Atkins et al., 2020; Montgomery, Pyne, Hopkins, et al., 2008). A limitation of compression research, and a potential reason for the lack of effect in some studies, is insufficient pressure applied by compression garments (Weakley et al., 2021). Current evidence suggests garments should cover as much of the limb as possible (i.e., entire lower-limb). The garment should exert a minimum pressure of 14 mmHg and athletes should wear garments for as long as possible post-exercise (Davis et al., 2022); but the garments should not negatively influence sleep. From a practical perspective, compression garments are relatively low in cost compared to other strategies and can be used while travelling post-game or training.

Intermittent Pneumatic Compression

Intermittent pneumatic compression devices mimic the rhythmic skeletal muscle squeezing action during limb movement by inflating and deflating specific pressures to the limb. Research has explored the efficacy of IPC as an exercise performance recovery strategy after various forms of exercise, including plyometric jumps (Blumkaitis et al., 2022; Wiecha et al., 2021), resistance exercise (Chase et al., 2020; Chleboun et al., 1995; Cochrane et al., 2013; Cranston & Driller, 2022), Wingate cycling test (Hanson et al., 2013; Martin et al., 2015), sprinting (Sharma et al., 2016), incremental running (Khan et al., 2021; Rahman et al., 2022) and cycling time trial (Overmayer et al., 2018). However, the use of IPC post-exercise has been shown to improve measures of exercise recovery (e.g., subsequent jump performance, blood lactate, muscle soreness, muscle swelling) in some (Blumkaitis et al., 2022; Cranston & Driller, 2022; Hanson et al., 2013; Heapy et al., 2018; Martin et al., 2015; Sharma et al., 2016), but not all studies (Chase et al., 2020; Cochrane et al., 2013; O'Donnell & Driller, 2015; Overmayer et al., 2018; Wiecha et al., 2021). The difference in IPC prescription details is a potential explanation for these contrasting findings. For example, the IPC duration and pressure post-exercise range from 15 to 60 min (Blumkaitis et al., 2022; Chase et al., 2020; Rahman et al., 2022) and 60 to 110 mmHg (Blumkaitis et al., 2022; Chase et al., 2020; Cranston & Driller, 2022; Hanson et al., 2013), respectively. As such, there is not yet clear evidence for prescribing IPC duration and/or pressure for post-exercise recovery.

Active Recovery

Active recovery, the task of performing low to moderate intensity exercise (e.g., jogging, cycling, swimming) within 1 hr of practice or competition (Van Hooren & Peake, 2018), is perceived as the most useful recovery strategy among basketball players (Pernigoni et al., 2022). Active recovery aims to decrease musculotendinous stiffness, lessen muscle soreness, enhance the removal of metabolic by-products (e.g., lactate, creatine kinase), accelerate muscle repair, and promote the faster recovery of heart rate (Ortiz Jr et al., 2018; Takahashi et al., 2001; Tessitore et al., 2007; Van Hooren & Peake, 2018). Research has shown the benefits of active recovery when performed after team sports activities (Hamlin, 2007; Rey, Lago-Peñas, et al., 2012; Tessitore et al., 2007; West et al., 2013), but other studies show no benefits for performance recovery (Andersson et al., 2008; King & Duffield, 2009; Rey, Lago-Penas, et al., 2012). Despite these mixed results, active recovery is widely reported to positively influence an athlete's psychological perception of recovery (Ortiz Jr et al., 2018). Other benefits reported include relaxation, socializing, and an opportunity to reflect on practice or match (Van Hooren & Peake, 2018). Active recovery protocols should be 6 to 10 min in duration (Huyghe et al., 2020; Ortiz Jr et al., 2018), prioritize exercises that are low to moderate in intensity, provide low mechanical impact (e.g., cycling, swimming) to minimize further muscular damage (King & Duffield, 2009), and involve the same muscle as the previous activity (Mika et al., 2016).

Stretching

Stretching is a popular recovery strategy in basketball (Pernigoni et al., 2022) and involves applying force to the musculotendinous structures to enhance range of motion, restore strength, and reduce muscle stiffness and soreness (Sands et al., 2013). Various stretching methods exist, including passive, active, dynamic and proprioceptive neuromuscular facilitation (PNF) (Afonso et al., 2021). However, the benefits appear anecdotal, as there is no substantial evidence to suggest any method of stretching is beneficial for post-exercise recovery (Afonso et al., 2021; Dupuy et al., 2018; Herbert et al., 2011). If stretching is included post-exercise, practitioners are encouraged to promote the static stretching of major muscle groups and that the stretch is low in intensity (i.e., pain-free), coordinated (Sands et al., 2013) and held for 60 s in duration (Apostolopoulos et al., 2017). Additionally, the prescription of stretching should be carefully considered as an excessive stretch (i.e., painful) may increase muscle soreness (Smith et al., 1993).

Massage

Massage involves the rhythmical application of mechanical pressure to the body tissues. It is achieved by either a trained therapist (i.e., manual massage) or through self-massage techniques (e.g., foam rolling, massage ball, percussion devices). These strategies aim to increase blood and lymphatic flow (Weerapong et al., 2005), reduce tissue adhesion (Gasibat & Suwehli, 2017), lessen muscle oedema (Bakar et al., 2015) and increase a sense of well-being (Weerapong et al., 2005).

Manual Massage

The benefits of manual massage have been reported in basketball players (Delextrat et al., 2014; Mancinelli

et al., 2006). However, the effectiveness of manual massage for muscle recovery has limited scientific evidence due to considerable heterogeneity in research studies (e.g., type of massage, duration, exercise intervention) (Weerapong et al., 2005). Nonetheless, many psychological benefits are reported in basketball players, including a lower perceptual rating of fatigue (Delextrat et al., 2014) and muscle soreness (Mancinelli et al., 2006). As such, massage may promote psychological recovery (Davis et al., 2022) and is ranked second in perceived usefulness for recovery amongst basketball players (Pernigoni et al., 2022). The current recommendation for utilising massage for exercise recovery is between 5-12 min and implemented immediately post-exercise (Poppendieck et al., 2016).

Self-Massage

Self-massage is achieved by rolling and compressing soft tissues by either using body weight (e.g., foam rollers, massage balls) or applying pressure using upper body strength (e.g., roller massager) (Ferreira et al., 2022). The technique involves applying pressure to the tissue in slight back-and-forth undulations, gradually moving from the proximal to the distal portion of the muscle or vice versa (Shalfawi et al., 2019). Foam rolling is basketball players' most used recovery strategy (Pernigoni et al., 2022), likely due to its ease of use and affordability (Alonso-Calvete et al., 2022; Kalichman & Ben David, 2017). Also, there is strong evidence for the benefit of foam rolling in attenuating decreases in exercise performance (Alonso-Calvete et al., 2022; Wiewelhove et al., 2019), perceived muscle soreness (Behm et al., 2020; Wiewelhove et al., 2019) and fatigue (Alonso-Calvete et al., 2022). Furthermore, adding vibration to self-massage devices appears to have the potential to increase their benefits (Alonso-Calvete et al., 2022), but further research is required. Athletes are encouraged to self-massage for 90-120 s per muscle group, apply pressure up to 50% of maximum discomfort (i.e., avoid pain), and hold pressure on any tender areas in the muscle (Ferreira et al., 2022; Hughes & Ramer, 2019; Shalfawi et al., 2019).

Percussion therapy guns are another type of self-massage that has become popular with athletes, non-athletes, and sports medicine professionals (Cheatham et al., 2021; Chen et al., 2021). These electric or battery-powered devices provide localised compressive force to the muscle tissue, similar to the action of a small jackhammer (Cheatham et al., 2021; Chen et al., 2021). However, despite its increased popularity (García-Sillero et al., 2021), the evidence to support its use for improving exercise recovery is lacking. Therefore, until further research is conducted, athletes should practice caution and seek advice from qualified personnel on how to use them correctly and minimise potential complications (e.g., increased muscle damage) (Chen et al., 2021).

Cryotherapy

Cryotherapy is still an emerging recovery modality, and its use is typically limited to top level athletes due to the expense and specialized equipment required. Cryotherapy is typically performed using Cryochambers or Cryosaunas/Cryocabins. The main difference between the two is that cryochambers are a whole-body exposure whereas in cryosaunas/

cryocabins the athletes head and neck are not exposed to the cold. Cryotherapy works in a similar way to CWI by reducing body temperatures and blood flow which decrease swelling and inflammation and perception of pain (Stephens & Halson, 2022).

Cryotherapy is rarely used for recovery in basketball (Pernigoni et al., 2022) and there remains minimal research examining cryotherapy for athletic recovery. To date only one study has examined cryotherapy use post-game in basketball (Bouzigon et al., 2018). However, the effects of cryotherapy on performance recovery in basketball remains unknown as Bouzigon et al. (2018) only examined perceptual measures. Protocols for cryotherapy involve exposure to air below -110°C for 2 to 5 min. While 3 min exposures at -130°C were found to be well tolerated by basketball athletes, consideration should be given to individual differences as gender and body composition may impact responses (Bouzigon et al., 2018).

Facility access is often a significant limiting factor for utilizing cryotherapy. It is rare for stadiums to have cryotherapy chambers or cryosaunas and finding commercial facilities when travelling can be challenging and often expensive. Nevertheless, if access is possible, cryotherapy can be a time effective way to use cold temperature exposure to enhance recovery. Implementing cryotherapy must be done in a safe way with particular attention to protocols and safety consideration as overexposure may result in hypothermia, skin damage caused by cold burn, hypertension, and reduced blood flow in fingers and toes (Stephens & Halson, 2022).

Sauna

The use of sauna for recovery in basketball is one of the least popular recovery modalities (Calleja-González et al., 2021) and there is very little research examining the effect of sauna on performance recovery (Skorski et al., 2019; Mero et al., 2015). Much like HWI, saunas are a form of passive heat therapy which are thought to relax the muscles, increase blood flow and activate the sympathetic nervous system (Skorski et al., 2019). Traditional Finnish Saunas typically operate between 10-20% relative humidity and 80-100°C (176-212°F) (Skorski et al., 2019) whilst Far Infrared Sauna (FIRS) cabins typically operate at similar humidities but lower temperatures of 40-60°C (104-140°F) (Mero et al., 2015). The limited research available on saunas makes informed decisions around protocol choice impossible. Finnish Saunas have been found to have a negative impact on acute performance in swimming and were recommended to only be used on rest days (Skorski et al., 2019). Mental recovery has been shown to be improved following finish sauna use with enhanced neural relaxation and increased cognitive processing (Cernych et al., 2018). FIRS have been found to enhance neuromuscular recovery following an endurance training session but not following a strength training session (Mero et al., 2015). With limited evidence behind the use of both types of saunas, basketball staff may choose to take a similar approach to that recommended by Skorski et al. (2019) whereby saunas are only used on rest days for relaxation and perceptual recovery purposes. If using saunas on rest days staff should be mindful of the impact on athlete hydration as the increased sweat rate from sauna use may impact fluid loss.

Mental Recovery

Most of the recovery modalities discussed in this chapter focus on physical and physiological recovery; however, it is important not to overlook an athlete's mental and psychological recovery. Relaxation and psychological recovery have been reported to be well used in basketball (Pernigoni et al., 2022). There is no basketball specific research examining mental recovery; however, strategies such as relaxation, mindfulness, yoga, progressive muscle relaxation (PMR), breathing techniques, mental imagery, debriefing, mental detachment, biofeedback, neurofeedback, and music have all been suggested to have a beneficial effect on psychological recovery in elite athletes (Huyghe et al., 2020; Stephens & Halson, 2022). PMR in particular has been shown to improve the amount of slow wave sleep achieved during a day-time nap (Simon et al., 2022) as well as reduce sleep onset latency in elite dancers (McCloughan et al., 2016). Therefore, PMR should be recommended as a strategy for athletes to assist with enhancing both mental recovery and sleep. Access to the aforementioned mental recovery strategies is easily achieved through various commercially available apps, this enables athletes to have these on their own devices to use at any time.

Athlete education has been suggested to be vital, as the ability to self-recognize when they need to recover will ensure athletes are better able to manage their performances and avoid burnout (Calleja-González et al., 2016).

PRACTICAL APPLICATIONS

The use of recovery modalities should be specific to the athlete's recovery needs (Stephens & Halson, 2022). The below examples provide specific practical applications of how recovery modalities can be applied during different phases of a basketball season.

Preseason

Recovery strategies utilized during this period can be beneficial to reduce the high levels of fatigue and inflammation and allow for greater quality and quantity of training.

However, as fatigue and inflammation are necessary for training adaptations to occur, the prescription of recovery methods during the preseason period should carefully consider the following four points:

1. Consider the level of acceptable fatigue and goal for the next training session (e.g., non-fatigued state for high quality or high skill training).
2. Limit recovery modality use to maximize training adaptation.
3. Avoid cooling strategies after resistance training.
4. Consider athlete's individual goals (e.g., endurance or strength).

In Competition

Effective use of recovery strategies over a prolonged season (e.g., NBA) or during a shorter multi-day tournament (e.g., Olympics) can limit the effects of fatigue on performance. Having a plan for how and when you will implement recovery with the team is crucial particularly when travelling, as you may need to book facilities or bring your own equipment.

- Immediately post-game, teams can begin their recovery plan with an active recovery and stretching performed on court.
- Begin nutrition and hydration protocols during the active recovery and continue this during hydrotherapy.
- CWI is an effective hydrotherapy strategy during tournaments and where possible CWI should be performed within 30 min of the game ending, as immediate CWI use has been found to be more beneficial then delayed.
- In tournaments where multiple games are played on the same day CWI may not be appropriate when the turnaround time between games is short (≤60 min), as cooling the muscles may reduce strength and power performance if there is not sufficient time re warm-up.
- Intermittent CWI is effective in team scenarios and can be more time efficient then continuous immersion as athletes can alternate with time in and out of the water.
- When time between games is short athletes should focus on completing an active recovery and stretching as well as attending to their nutrition and hydration needs.
- Following water immersion athletes should be advised to put on their compression garments (e.g., tights, socks, etc.) and wear these for as long as is comfortable, including during sleep so long as they do not impact sleep quality.
- Pneumatic compression could also be used immediately following water immersion when athletes are feeling particularly sore.
- Sleep should be prioritized, and teams may choose to implement group relaxation or stretching sessions prior to bed when travelling to assist athletes to unwind and prepare for sleep.
- During rest days or down time, there should be scheduled opportunities for athletes to nap or access massage.

SUMMARY

Recovery is complex and multifactorial, and time should be taken to consider the athlete's physical and psychological needs. A planned and considered approach that is situation specific and periodized based on the training phase and individual goals of the player, is the best way to ensure both performance and adaptation are maximized.

The views expressed are those of the author and do not necessarily reflect the position or policy of PepsiCo, Inc.

RECOVERY MODALITY	RECOMMENDATIONS
Cold Water Immersion (CWI)	• Protocols 10-12 min at 10-12°C for continuous immersions or 4-5 x 1-2 min at 10-12°C for intermittent immersions. • Whole body immersions are best where possible, legs only still effective. • Immersion should be completed 30-60 min post-game/training. • Best used when body temperatures are high or muscle damage/doms.
Hot Water Immersion (HWI)	• Protocol 10-20 min at 36-40°C. • Avoid using if the athlete has recent soft tissue injuries or elevated body temperature post exercise. • Best used on rest days for relaxation.
Contrast Water Therapy (CWT)	• Protocols 3-7 x 1-2 min alternating between HWI and CWI. • Finish on CWI. • Best used when athletes are feeling flat or fatigued (Pernigoni et al., 2022).
Compression Garments (CG)	• Cover entire limb, need to exert a minimum pressure of 14 mmHg and wear for as long as possible post-exercise.
Intermittent Pneumatic Compression (IPC)	• Not enough evidence to suggest optimal protocol, however a minimum of 20 min and medium to high levels (80-110 mmHg) of pressure are typically used.
Active Recovery	• 6-10 min in duration, involve same muscle as previous activity, low impact and low to moderate intensity.
Stretching	• Stretch major muscle groups, for 60s and should be pain free.
Manual Massage	• 5-12 min in duration and ideally immediately post exercise.
Self-Massage	• Foam rolling – 90-120s per muscle group, 50% of maximum discomfort and hold pressure on tender areas. • Percussion therapy – As evidence is lacking, athletes should practice caution and seek advice from qualified personnel.
Cryotherapy	• Not enough evidence to suggest optimal protocols however 3 min at -130°C has been well tolerated by basketball athletes in the past.
Sauna	• Not enough evidence to suggest an optimal protocol. 3 x 8 min at 80-85°C was tolerated by swimming athletes in the past (Skorski et al., 2019). • Consider only using on rest days for relaxation and mental recovery.
Mental Recovery	• Progressive muscle relaxation can be used to improve sleep onset before naps (Simon et al., 2022). • There are a number of apps avaliable for athletes to utilise on their personal devices.

Table 1: Protocol recommendations.

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CHAPTER 12

TRAVEL NUTRITION FOR BASKETBALL

TRAVEL NUTRITION FOR BASKETBALL

Lisa Heaton, MS, RD, CSSD, LDN
Gatorade Sports Science Institute

KEY POINTS

- Different modes of travel pose unique challenges for athletes in terms of food availability, portability and convenience, all of which can influence an athlete's hydration and nutrition.
- Air travel and travel across time-zones can negatively impact performance. Hydration and nutrition strategies may be able to offset some of the negative impact.
- Practitioners should work with local arena, hotel, restaurants and/or catering to provide athletes with food, snack and hydration options to support athlete fueling, hydration and recovery needs.

INTRODUCTION

Whether at the high school, collegiate or professional level, travel is a reality that male and female competitive basketball athletes face. The overall performance and recovery nutrition needs of the basketball athlete are similar regardless of a home or away game (chapters 4 and 5), but the ability of the athlete to maintain their typical habits and performance nutrition plan can be challenging when on the road. It is important to consider many factors when helping the individual athlete or team develop a travel nutrition plan. These include but are not limited to the distance traveled, mode of transportation, duration of the travel, hotel accommodations and ease of access to food.

It is also important to consider the volume of travel required for a basketball team over the course of a season. Back-to-back away games, particularly when crossing multiple times zones, presents unique challenges for athletes. Half of the regular season NBA games are away games, with travel of up to 2 weeks across multiple cities. Depending on the level of play, regular season basketball games take players on the road for 30-50% of games, and they could be away for 4-5 days in the middle of the school year (Davis et al., 2022). For high school, road games are typically within driving distance and do not require an overnight stay. Depending on whether the school is located in a more urban, suburban or rural area, some teams may travel >2 h each way on a bus (Nichols, 2018). Each of these scenarios create unique nutritional challenges for the athlete and practitioner.

Mode of transportation, duration of travel, and days away from home can all impact player health and performance. In NBA players traveling for half of the regular season, the accumulation of travel fatigue and chronic desynchronization of circadian rhythms negatively impacts sleep and recovery (Charest et al., 2021). Without adequate recovery throughout the season, players will not be at their peak performance at the end of the season or when entering the playoffs. Jet lag and travel fatigue result in a variety of issues including, but not limited to, disruption to sleep and gastrointestinal disturbances which in turn can impact overall health and wellness (Jans van Rensburg et al., 2021). Illness and injury impact playing time and performance on the court and nutritional support should be provided to keep players as healthy as possible. Tailored sleep and recovery strategies need to be developed and adapted throughout the season to overcome the challenges involved with travel (Charest et al., 2021). Nutrition is one acutely modifiable component of these strategies. This chapter will cover considerations for domestic travel within North America, with no greater than a 3 time-zone difference, and how athletes can develop nutrition strategies to overcome challenges that occur throughout the course of a season.

RESEARCH REVIEW

The impact of long-haul travel across multiple time zones is easily recognizable, but shorter duration flights may also negatively impact performance and recovery. In a study conducted in soccer players, short-haul air travel may acutely increase perceptual fatigue but is not likely to affect game performance (Fowler et al., 2014). In a narrative review of travel in NBA players, it was reported that short-haul flights increased injury risk, impeded performance, and that frequent air travel resulted in travel fatigue (Huyghe et al., 2018). Nutrition is one piece of an athletes' strategy at home and away and there are opportunities and limitations that must be addressed.

When athletes travel, particularly if they are traveling to different regions, the athlete may not have access to foods they feel comfortable eating. In this scenario, they may rely on familiar fast food restaurants or quick options that do not provide the best nutrition

(Halson et al., 2019). Changes to usual food habits can have an impact on GI health, influencing how the player subsequently feels and performs on court. Providing familiar foods and teaching players the importance of good hygiene (e.g. handwashing) is important for keeping them healthy on the road (Halson et al., 2019).

The relative humidity in the airplane cabin is kept at 10-20%, which is lower than the athlete's typical environment. This combined with reduced oxygen partial pressure (low O_2 pressure) may result in increased insensible water loss through evaporation of water at the skin surface (Greenleaf et al., 2004) and respiratory water losses through increased respiration (Brown et al., 2001). Recommendations from the European College of Sports Science in 2007 suggested increasing water intake by 15-20 ml/h (0.5-0.67 fl oz/h) of the flight (Reilly et al., 2007). A later publication by Zubac et al. (2020) suggested intake of 100-300 ml/h (3.3-10.1 fl oz/h) of flight in order to combat these additional fluid losses. It is important to emphasize the intake of fluids in flight, particularly to players who may attempt to limit fluid intake to avoid using the cramped plane bathrooms. Pairing electrolytes with fluid sources may be beneficial in terms of fluid retention/reduced urine production in flight (Greenleaf et al., 1998).

There is limited evidence to support specific nutritional recommendations to reduce symptoms of jet lag with air travel. However, travel over multiple time zones, such as from East to West coast in the United States, can negatively impact power, agility, speed and reaction time in athletes (Kraemer et al., 2016, Reilly et al., 2001, Chapman et al., 2012). These negative effects can last for up to 24 h post-flight. In a study with professional athletes, including NBA players, those that traveled from the East coast to the West coast had the greatest impairment. It has been theorized that performance is negatively impacted from traveling East to West because many games are scheduled in the evening, during a time when players would likely be resting or preparing to sleep. (Roy et al., 2018).

Meal timing has been explored as a method for adjusting the peripheral circadian clock, taking advantage of the feeding and fasting cues. In a study with military personnel a diet that involved specific meal timing and fasting was used to reduce or avoid symptoms of jet lag (Reynolds & Montgomery, 2002). Fasting of this nature is not a realistic strategy for basketball players as it does not support their fueling needs for performance. It is also worth noting that in this study the military personnel were traveling over 9-time zones, significantly greater than air travel for basketball players in North America. In a subsequent meta-analysis of meal timing and jet lag, insufficient evidence was found to support the use of specific meal timing and fasting to reduce or avoid jet lag (Herxheimer, 2014).

Caffeine has been shown to reduce daytime sleepiness and potentially help reduce symptoms of jet lag in athletes after travel across multiple time zones (Choy et al., 2011, Janse van Rensburg et al., 2020, Janse van Resnburg et al., 2021). If players choose to consume caffeine before the game, the minimally effective dose recommended is 3 mg/kg (Spriet, 2014). Timing of caffeine intake in relation to sleep is also important. The half life of caffeine is approximately 5-6 h and taking caffeine too close to bed time may negatively impact sleep and recovery.

Exogenous melatonin supplementation has been suggested as a mechanism to combat jet lag. Melatonin is a hormone that is naturally produced in the human body and helps to regulate the circadian clock, with increase melatonin production in the evenings. In a systematic review, exogenous melatonin consumption has been linked to decrease subjective rating of jet lag in athletes on eastward and westward flights (Herxheimer, 2014). The majority of studies utilized a dose of 2-8 mg of melatonin (Choy & Salbu, 2011) and timing of intake should also be considered. In the United States, melatonin is regulated as an over-the-counter dietary supplement. As with all supplements, athletes should use caution and look for a product that has been 3rd party tested.

PRACTICAL CONSIDERATIONS

Single-day Travel Considerations

During single day travel, the athlete will generally be transported to the away game location via car, school bus or charter bus depending on competition level. If the athlete is a student athlete, they may be traveling directly from school, without first going home to pick up food. This requires some level of pre-planning, especially if there is no capability to provide a training table meal to the athlete. It is important to understand when the high-school student athlete eats lunch. For athletes with early lunch times, a larger pre-game snack may be necessary to prepare for competition.

	RECOMMENDATIONS (THOMAS ET AL 2016)	FOOD/BEVERAGE
Carbohydrate	1-4 g/kg in the 1-4 h pre-game ~30 g in the h before the game	Granola bars or fruit bars Individually packaged cereal Fig bars Fresh fruit* Dried fruit/trail mix Sandwich or wrap – limit protein and fiber Sandwich crackers Sports gels or dried fruit rolls Pretzel twists
Fluids	5-7 ml/kg 3-4 h pre-game 3-5 ml/kg 1-2 h pre-game if urine is dark or not produced	Water Sports drink Low-calorie sports drink Tea/coffee** Juice

** Choose fresh fruit that will transport easily or store fruit in a container to avoid spoiling or bruising.*
*** Consider avoiding caffeine if the game is at night or if the athlete is not a habitual caffeine user.*

Table 1: Pre-game non-perishable snack options for travel via car/bus/van.

Pre-game

Providing the athlete with portable and non-perishable pre-game snacks and fluids that can be consumed while traveling is recommended. These snacks should be rich in carbohydrate to support subsequent performance on the court. The recommended amount and timing of carbohydrate intake is consistent whether the athlete is traveling or playing at a home game. Similarly, fluid intake should be based on the individual athlete's needs. Pre-training and game recommendations for fluid and carbohydrate can be found in chapter 4 and chapter 6, respectively. Table 1 provides practical examples of foods and fluids that are easily transportable and can be mixed and matched to meet the athletes' carbohydrate and fluid needs.

Team Meals

At the collegiate and professional level, if the players will be arriving >2 h prior to game time, it may be necessary to work with arena managers and/or catering to set up team meals on-site. Alternatively, the practitioner could bring additional snacks to make available in the locker room. This gives the athletes the opportunity to take in additional fuel on-site prior to the game. Several considerations must be made when determining if organizing a training table is necessary or beneficial.

- What time will players arrive at the court? If several hours before game time, a training table with a light meal or a snack is appropriate.
- What are the food options?
    - Arena catering can vary from location to location. Review the arena catering menu for appropriate choices that are rich in carbohydrate but limit fat, fiber and protein.
    - If food is provided by concession stands, appropriate food options may be difficult to find. Options such as hot pretzels, popcorn or even candy would provide carbohydrate prior to the game. If players have >1 h before the game, a hamburger would be a reasonable option to provide protein and carbohydrate to support fueling needs as well as satiety.
    - Catering from a restaurant or grocery store should be considered. Review catering menus for appropriate choices that are rich in carbohydrate but limit fat, fiber and protein.
    - 3rd party meal delivery services or grocery store pickup could be utilized to provide meals or snacks for the team.

- If the team arrives <1 h prior to the game, provide ~30 g of an easily digestible form of carbohydrate for players to consume in the hour before the game starts. Fluids with electrolytes should also be readily available for athletes to consume ad libitum.

During-game

The practitioner should determine what equipment and facilities will be available on-site during the game when preparing the sports nutrition plan for the team.

- Will the home team supply coolers, cups/bottles, water or sports drinks? If yes, are the beverages familiar to the athletes (e.g., products they consume at home)?
- Will any foods or other sports products be available during the game?
- Are there any restrictions around types of beverages or foods allowed on the court?

All of these factors must be considered when determining what equipment and supplies to bring. If the home team provides sports products that are not familiar to your players, the best strategy may be to bring your own fueling and hydration products. Consuming unfamiliar products may lead to GI distress and impact performance on the court.

Post-game

Similar to the pre-game strategy, portable and non-perishable recovery foods and beverages are likely the most beneficial choices on game day unless the team will be stopping for food at a restaurant or service station. Table 2 details portable snack options that can be mixed and matched to meet carbohydrate, protein and hydration recovery needs.

If coolers are available and can be kept at a safe temperature, the athlete has additional options for recovery foods. The cooler could be stocked with perishable items like Greek yogurt, string cheese, flavored milk, deli sandwiches, etc.

In some instances, the team or athlete may have the opportunity to stop at a sit down or fast-food restaurant, the athlete should be equipped with how to make good choices post-game. Athlete education related to high quality protein and good sources of carbohydrate is important. The athlete should also be made aware of the importance of limiting saturated fats/cholesterol and what food choices still provide the nutrients needed but limit these less healthy options. There are many different fast food and sit down restaurants available depending on where the team is traveling. Providing options for common chain restaurants and then educating on how to adapt those choices for similar restaurants is an easy way to educate athletes on the types of choices you would recommend.

	RECOMMENDATIONS (THOMAS ET AL 2016)	FOOD/BEVERAGE
Carbohydrate	1-1.2 g/kg if competing or training within 8 h As needed if >8 h	Granola bars Individually packaged cereal Fig bars Fresh fruit* Trail mix – nuts, dried fruit, chocolate Sandwich or wrap Crackers
Protein	0.25-0.3 g/kg	Shelf stable white or flavored milk Shelf stable protein shake Protein bar Sandwich or wrap Beef jerky
Fluids	20-24 oz/lb lost	Sports drink Low or zero sugar sports drinks Water 100% juice

** Choose fresh fruit that will transport easily or store fruit in a container to avoid spoiling or bruising.*

Table 2: Post-game non-perishable snack options for travel via car/bus/van.

Multi-day Travel Considerations

Fueling and Recovering in Flight

Depending on the level of play, athletes may fly commercial in economy, first class or on a chartered jet. The food options available to the players in flight will vary based upon the level of accommodation. Players flying in economy may only be offered a small package of pretzels or biscuits compared to a meal in first class. When flying economy, encouraging the athlete to pack high quality snacks or making a good meal choice at an airport restaurant is recommended. If the team or player are flying in first class, a meal will likely be offered. As the practitioner, you can contact the airline to determine what meals may be offered. For a basketball player, this meal may not be large enough to support the players caloric and macronutrient needs. In this case, the practitioner and/or player should also bring appropriate snacks on board. Providing and encouraging players to consume snacks or small meals will support their overall fueling and recovery needs.

If the team will be traveling in a chartered plane, consider catering a meal that the players can serve themselves as they board. The players can then eat while they wait for takeoff. The practitioner can also work with the airline stewardess to provide good snack options to the players enroute. If returning from an away game or traveling to an additional location, foods that promote recovery and are anti-inflammatory like tart cherries should be included.

The practitioner may also want to consider packing a case with easy fuel sources to bring to the arena. To save space, packing powdered sports drinks vs. liquids is recommended. Bars, gels, gummies or other fuel sources can also be packed in the case. If traveling to an area with unfamiliar or limited cuisine, familiar snacks for the players could be added to ensure they are taking in adequate calories and fuel (Halson et al 2019).

Hydration in Flight

Players should bring an empty reusable water bottle and fill the bottle before boarding the plane. It is important that the players hydrate in flight. It is important to encourage fluid intake in flight and allow the athletes to drink a beverage of his or her choice (excluding alcohol). Encouraging the player to consume the beverages with a source of sodium will help with fluid retention and distribution as well. The practitioner should include ongoing education around the importance of electrolytes, primarily sodium, in beverages to support hydration in flight as well as on the court.

Hotel Catering or Room Service

Utilizing resources at the team's hotel can simplify the logistical challenges that can come with planning meals for the team. If the hotel offers room service, review menus in advance and provide food guides for players on the most appropriate choices based on when they will be eating meals relative to the game. Options for pre-game and post-game are recommended.

Assuming the team has a budget, discuss potential catering option with the hotel. Reserving a large banquet or meeting room is necessary to accommodate the team and staff. Buffet style hotel catering menus can be reviewed for appropriate food choices for the players. Menus should be developed with the catering lead and focus on high carbohydrate and high protein foods, fruits and vegetables as well as fluids. Any food allergies/intolerances and cultural


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or religious restrictions should be accounted for when developing the menus. Depending on the reason for the restriction, the special needs options could either be incorporated into the broader menu or prepared individually for the athlete. Athletes with severe food allergies or religious restrictions may feel more comfortable with foods that are prepared separately. Nutrition cards can also be developed to identify what the foods are, what nutrients they provide and any potential allergens that are included within the foods.

Due to the large volume of travel that basketball players face throughout the season, menu fatigue can become a reality. If traveling frequently, try to vary menu options from hotel to hotel to avoid monotony and encourage players to attend the meals. This could be as simple as rotating breakfast bread options, pancakes, waffles, French toast, etc. to including a regional dish based on where the team has traveled to. It is important to make sure the players have access to familiar safe foods but to also provide some variety.

If hotel catering is unavailable, reserve an additional large bedroom, banquet room or meeting room and cater from nearby restaurants or local grocery store chains. Ensure that there are plates and cutlery available if you order from an external source. It is also important to determine if the location will deliver or if time needs to be added in for picking up and returning with the food.

If players have access to a refrigerator in the hotel, snacks can be purchased at the destination and delivered to their rooms to store at an appropriate temperature. This allows the athlete to have easy access to nutrition to support overall daily performance and recovery nutrition needs.

Arena Catering/Locker Room Team Meals

If players will arrive to the arena 2+ h before the game or coordinating a pre-game meal at the hotel is not an option, consider working with the arena catering or a local restaurant to provide food options for the players that are rich in carbohydrate but low in fat, fiber and protein. This gives players the opportunity to top off fuel stores and to take in additional calories. Also provide ~30 g of an easily digestible form of carbohydrate for players to consume in the h before the game starts. This option can also be made available to players at halftime to provide fuel to start the second half of the game. Ensure fluids are readily available for players to grab and drink to support hydration needs based on the individual players' hydration plan.

During game

As mentioned previously, the practitioner needs to do a significant amount of preparation work to provide the players with the right equipment and products to meet their hydration and fueling needs. Having products, the athlete is familiar with will help him or her to follow an individualized hydration and nutrition plan to support performance on the court.

Post game

Ensure that there are easily accessible, protein rich recovery options as well as rehydration beverages available to players at the arena. Players should also be encouraged to take in these options during the cool down or while the coach is talking to the team after the game. There may be a large gap in time between leaving the arena and arriving at a restaurant or the hotel, so having these options available on-site is critical to begin recovery.

Players should be encouraged to eat a meal or a snack as soon as they are comfortable after they have left the arena. This could be a catered meal at the hotel, room service or dining out. Provide the players with "best choice" options for a variety of restaurants to ensure they make choices that will support recovery. If providing a meal post-game, choose foods that are familiar and enjoyable to the athletes to encourage consumption post-game. If immediately traveling to the airport, ensure snacks are available.

SUMMARY

Whether the athlete is embarking on a short road trip or a long-distance flight, the practitioners should ensure the athlete has access to appropriate fluids and foods to fuel and recover. The sports nutrition recommendations do not change whether the athlete is playing away or at home; but the logistics do. The practitioner likely needs to do a significant amount of planning before travel begins to coordinate food and fluid availability enroute and on site. Content related to international or long-haul travel was beyond the scope of this chapter. The articles by Halson et al. (2019) and van Rensburg et al. (2021) provide insights into additional strategies for long-haul travel.

Lisa Heaton is employed by the Gatorade Sports Science Institute, a division of PepsiCo R&D. The views expressed are those of the author and do not necessarily reflect the position or policy of PepsiCo, Inc.

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AUTHOR & EDITOR BIOGRAPHY

Chief Editors

Jon-Kyle Davis, PhD, CSCS*D

Jon-Kyle Davis is an Associate Principal Scientist at the GSSI satellite Lab at Baylor, Scott and White Sports Performance Center in Frisco, Texas. His main responsibilities include leading GSSI's Performance Monitoring Program as part of the Elite Recovery Sciences Program. He co-leads GSSI Technology program, contributes to research, and helps manage GSSI Frisco operations. Prior to joining GSSI he was an Assistant Professor at the University of Montevallo and Texas A&M University-Commerce. During his time in academia he taught various courses in the areas of nutrition, applied and clinical physiology. He has conducted research in the areas of thermoregulation, hydration, and caffeine. Originally from Hopkinsville, Kentucky, Jon-Kyle earned his Bachelor's and Master's from Western Kentucky University in Exercise Science. During his time at Western Kentucky he worked in the area of strength & conditioning with a variety of individual and team sport athletes. In 2009 he graduated with his PhD from the University of Alabama in Human Performance. He is certified by the National Strength and Conditioning Association (CSCS) and by the American College of Sports Medicine.

Lindsay Baker, PhD, FACSM

Dr. Lindsay Baker is a Director at the Gatorade Sports Science Institute (GSSI) and a PepsiCo R&D Fellow. Since joining GSSI in 2007, Lindsay's primary role has been designing and conducting sports nutrition and hydration studies for the GSSI research program. With the transition of GSSI's Clinical Research Hub from Barrington IL to Valhalla NY in 2022, Lindsay took on the site lead role and oversees the new facility and expanded team in New York. Lindsay also holds Chief Editor responsibilities for the PepsiCo R&D Publication and Presentation Review Process. Originally from Saxton, Pennsylvania, Lindsay came to GSSI from The Pennsylvania State University where she earned a doctorate in Kinesiology. While at Penn State, she conducted hydration and thermoregulation research at Noll Laboratory under the mentorship of Dr. W. Larry Kenney. Lindsay has over 50 publications in sports hydration and nutrition, including peer-reviewed manuscripts and invited reviews and book chapters. She is a Fellow of the American College of Sports Medicine and is on the Scientific Advisory Board for the Korey Stringer Institute.

Jen Ketterly, MS, RDN, CSSD, LDN

Jennifer Ketterly is the Associate Director of Sports Performance for the Duke Sports Sciences Institute and faculty member in the Department of Orthopedics and Sports Medicine at Duke University in Durham, NC. She also serves as the sports dietitian for the NBA's Charlotte Hornets organization. She is a board-certified specialist in sports dietetics with over 20 years of practice across collegiate & professional sports, athletic medicine, and the food & beverage industries.

Prior to her current work, Jen was most recently the Director of Performance Nutrition at the UNC Human Performance Center and an Assistant Professor in the department of Family Medicine, School of Medicine at the University of North Carolina at Chapel Hill. She was the founding director of the sports nutrition departments at the Universities of Georgia and North Carolina at Chapel Hill, where she established full time, integrated nutrition service lines into the sports medicine and athletic departments. Jen began her career at the University of Connecticut coordinating nutrition and wellness services for campus and assisting with athletic care.

Lauren Link, MS, RD, CSSD

Lauren Link is a Registered Dietitian and Board Certified Specialist in Sports Dietetics. She is an Assistant Athletics Director and the Director of Sports Nutrition at Purdue University, where she played women's soccer as a team captain and was part of the 2007 Big Ten Tournament championship team. As an undergrad, she completed a dual degree in Dietetics and in Nutrition, Fitness and Health, and would later complete her Masters from Purdue in Health and Kinesiology. Lauren began her professional career as a clinical dietitian with St. Vincent's Hospital before returning to her alma mater in 2014 as the program's first full-time sports dietitian. As the director of sports nutrition at Purdue she oversees all sports nutrition operations and staff, and works directly with football, men's basketball, soccer and volleyball.

In addition to fueling her athletes for success on the field, she is also passionate about helping athletes successfully navigate the transition into the real world. She has led multiple initiatives to this end, founding the Purdue student-athlete community garden, spearheading a program called BLAST—for Boiler Life After Sport—designed to help address key components of athletes' transition to "normal human" status, and in 2017 published her first book on the subject: The Healthy Former Athlete. She is a member of AND, SHPN and currently the Vice President for the Collegiate and Professional Sports Dietitians Association (CPSDA).

Authors

Keith Baar, PhD, FACSM

Dr. Keith Baar is the head of the Functional Molecular Biology Laboratory in the Department of Neurobiology, Physiology, and Behavior at the University of California, Davis. He is a renowned scientist in the emerging field of molecular exercise physiology and is leading a team of researchers attempting to develop ways to improve muscle, tendon, and ligament function. The goal of his laboratory is to understand the molecular determinants of musculoskeletal development and the role of exercise in improving health and performance. To achieve this goal, he and his team work on muscle, tendon, and ligaments from 2- and 3-dimensional tissue culture, in vivo wild type and genetically modified animals, and humans.

Steven Basham, MS

Steven received a master's degree in exercise physiology at Mississippi State University, where he worked as a graduate teaching assistant and taught courses in exercise physiology. During his graduate studies, he conducted nutritional and antioxidant supplementation research focusing on optimizing health, exercise performance, and recovery in tactical occupations (e.g. firefighters) and recreational athletes. His research focus remains on improving health and enhancing recovery after training. Steven was a scientist at the Gatorade Sports Science Institute from 2018-2023, supporting the satellite laboratory in Frisco, Texas.

Shona Halson, PhD

Professor Shona Halson is the Deputy Director of the SPRINT Research Centre at ACU's School of Behavioural and Health Sciences. Prior to this she was the Head Recovery Physiologist at the Australian Institute of Sport for over 15 years and has led the Recovery team at three Olympic campaigns with the Australian Olympic Committee. Her research focuses on sleep, recovery and fatigue and she has published over 160 peer-reviewed articles and multiple book chapters. Shona provides consultancy services to the Australian Open Tennis Tournament and Nike as well as a number of national and international professional sporting teams.

Lisa Heaton, MS, RD, CSSD

Lisa has worked in the sports nutrition realm since 2007 and is a Board Certified Specialist in Sports Dietetics (CSSD) with interests in sports nutrition, recovery, hydration and performance. As a sports dietitian at the Gatorade Sports Science Institute (GSSI), Lisa works with nutrition related education and translation of research, as well as supports the athlete testing program. She also served as the Sports Dietitian for the Chicago Bulls for the 2015-2016 and 2016-2017 seasons. Lisa joined GSSI in February 2011 after working as the sports dietitian for the National Institute for Athletic Health & Performance in Sioux Falls, SD (Now Sanford Sports Science Institute). Lisa completed her undergraduate work at Bradley University where she earned a Bachelor's Degree in Foods, Nutrition and Dietetics. She completed her dietetic internship with the University of Houston and continued within the University to earn her Master's Degree in Exercise Science. In July of 2009, Lisa earned the CSSD credential through the Commission on Dietetic Registration (CDR), the premier credential for sports dietitians.

Aaron Heishman, PhD, CSCS*D

Dr. Aaron Heishman is the Head of Sport Science and Reconditioning for the Vegas Golden Knights of the NHL, where he leads the organization's sport science initiatives, while also maintaining an active coaching role primarily through implementing re-conditioning programs for athletes returning from injury. Prior to VGK, Aaron served as the Assistant Director of Basketball Performance and Sport Scientist at the University of Oklahoma. In 2020 he graduated with his PhD from the University of Oklahoma in Exercise Physiology focusing on the use of athlete monitoring strategies, as well as neuromuscular fatigue and performance. Aaron received his Bachelor's degree in 2014 from Virginia Tech and graduated in 2016 from the University of Virginia with Master's in Exercise Physiology while also serving as the graduate assistant for Basketball Strength and Performance.

Sara Oikawa, PhD

Sara Oikawa earned her Honours Bachelor of Science in Kinesiology, Masters of Science in Kinesiology, and her Ph.D. in Kinesiology at McMaster University in Hamilton, Canada. Sara has worked with a wide variety of populations including healthy young and older adults, pregnant women, cardiovascular rehabilitation patients, and elite athletes. She has also studied several physical activity models such as resistance exercise, inactivity and HIIT, to investigate skeletal muscle protein metabolism. Specifically, Sara is interested in the impact of dietary protein quality on muscle protein synthesis through alterations in physical activity. Sara was a scientist at the Gatorade Sports Science Institute from 2020-2023.

Shane O’Riordan, PhD, CSCS, AES, ASpS1

Shane is currently a researcher at Victoria University, Australia. Shane earned his bachelor’s degree in sports and exercise science from the University of Limerick, Ireland before completing his master’s degree in exercise physiology from Central Michigan University, USA. In 2021 he completed his PhD studies in sports and exercise recovery at Victoria University and the Australian Institute of Sport. Shane has applied experience with collegiate women’s soccer, NBA academy players and the Australian Open tennis grand slam. Shane is also a certified strength and conditioning specialist (CSCS) with NSCA and an accredited exercise scientist and sports scientist with Exercise and Sports Science Australia. He continues to conduct research in areas of human performance and provides research support to the Australian Institute of Sport.

Kris Osterberg, PhD, RD, CSSD

Kris Osterberg is a Principal Scientist at the Gatorade Sports Science Institute (GSSI) in Bradenton, FL. Kris recently rejoined the team and will lead the research efforts at the GSSI satellite location located at IMG Academy. Originally from Florence, Wisconsin, Kris attended Colorado State University on a basketball scholarship and received her BS degree in Exercise and Sport Science. While obtaining her MS degree in Human Nutrition, she worked in Dr. Chris Melby’s Nutrition and Metabolic Fitness laboratory where she conducted research on the effects of resistance exercise on resting metabolic rate in women, and the impact of caloric intake during exercise on post-exercise food consumption. Following eight years at GSSI, she attended Virginia Tech University and received her PhD. Her dissertation research focused on the impact of probiotics and diet on metabolic health. In her spare time, Kris enjoys spending time with her husband and three dogs, traveling, and playing outdoors.

Lawrence Spriet, PhD

Dr. Lawrence Spriet is a University Professor Emeritus at the University of Guelph in Canada. His research examines how skeletal muscle generates the large amounts of energy needed to exercise and perform in work and sport situations. Lawrence is recognized as one of the leaders in the field of exercise metabolism and has published extensively on this topic. In addition to his fundamental research, his applied research examines whether compounds that are purported to be “ergogenic” or “work enhancing” agents, actually improve muscle metabolism and/or human performance. He also conducts hydration/sweat testing and practical research aimed at counteracting the effects of dehydration in athletes engaging in stop-and-go sports like ice hockey, basketball, rugby, and soccer. Dr. Spriet has had a long history with GSSI, first coming on board in 1990, helping establish the Canadian GSSI Branch in 2005 and acting as Chair of XP since 2012. He is an active ice (real) hockey player in the winters and road cyclist in the summers.

Kim Stein, PhD

Dr. Kimberly Stein is a scientist with a background in exercise physiology and sports nutrition. Kim's previous research focused on vitamin D, dairy foods and recovery, and in her current position, she oversees programming in the translation of scientific information for influencers as well as athlete/team testing. Kim earned her bachelor's degree at Beloit College (WI) in Chemistry and Sociology, where she also played basketball and softball, and her master's degree in Organic Chemistry from the University of Notre Dame. In 2005 Kim earned her doctorate at Purdue University from the department of Health and Kinesiology while training in the Interdepartmental Nutrition Program. Prior to arriving at GSSI, Kim worked as an Assistant Professor of Exercise Physiology and Sports Nutrition at Carroll College (WI), and coached basketball for 10 years. Kim is passionate about sports nutrition and enjoys helping athletes understand why proper fueling is so important for their performance.

Jessica Stephens, PhD, AES, ASpS2

Jessica is currently a Performance Scientist at the Queensland Academy of Sport in Brisbane, Australia. Her role is predominantly servicing focused, however she maintains her research interest in recovery and holds an adjunct appointment at the University of Canberra. She has completed a PhD in Optimizing Cold Water Immersion Protocols through the University of the Sunshine Coast while based at the Australian Institute of Sport in Canberra. Jessica has over 10 years of experience working in high performance sporting environments across a variety of sports (Rowing, Cycling, Swimming, Triathlon, Netball and Basketball), with athletes ranging from Pathways/Development level to Olympic and Paralympic representatives. She was a Recovery Physiologist for the Australian Olympic Team at the Tokyo 2020 games and has also provided recovery support during the Australian Open Tennis Grand Slam. She has numerous published peer-reviewed articles and has authored multiple book chapters on recovery.

Anthony Wolfe, MS

Anthony is an exercise scientist at the Gatorade Sports Science Institute's satellite laboratory at the Baylor, Scott, and White Sports Performance Center in Frisco, Texas. His interests lie in exercise physiology, sports nutrition, and human performance and recovery in team sports. Anthony earned his Bachelor's Degree from Hamline University where he competed in NCAA ice hockey while finding an interest in research. He then moved on the Human Performance Laboratory at the University of Texas at Austin where he obtained his Master's Degree under the guidance of Edward Coyle, PhD. Anthony's research background has ranged from carbohydrate and protein supplementation to postprandial metabolic assessment and intervention in physical inactivity. In his free time he enjoys playing recreational ice hockey, weightlifting, and spending time with family.

For more information about the authors of this book and the wider GSSI team visit:
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