

Effects of an active halftime rewarm-up, with
carbohydrate supplementation, on players' blood glucose
and second half performance during a collegiate soccer match

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ABSTRACT

BACKGROUND: The half-time (HT) period of a soccer match is viewed as a period for recovery. Completely inactive and passive HT has implications on metabolic responses and subsequent performance during the initial phases of the second half. **PURPOSE:** Determine the effects of an active rewarm-up, compared to a passive period, at halftime on various measures of performance during the first 15-minutes of the second half using global positioning system (GPS) units. Identify the effects of the active versus passive HT period, with CHO beverage supplementation, on blood parameters. **METHODS:** Crossover design study, twenty collegiate male soccer players participated in two 90-minute soccer matches with passive rest (CON) or a moderate-intensity rewarm-up (RWU) during HT with CHO supplementation. Subjects received five fingerstick blood samples throughout the match (BG) and four subjects had serum insulin/BG taken three times during the match. **RESULTS:** RWU had significantly ($p < 0.05$) higher measures for total distance, average speed, speed exertion, accelerations, HMP distance, decelerations, and EE during TI-4 half when compared to CON. No subjects experienced hypoglycemia. However, CON did have a significant drop in BG after HT and the lowest mean BG taken at 60-minutes. Tendency for CON and RWU to have HT insulin levels that were elevated and reduced, respectively. **CONCLUSION:** A passive HT period is not optimal, given its causal role in temporary physical performance deficits in the second half of soccer matches. The results provide a strong rationale for collegiate soccer players and teams to incorporate the 8-minute RWU into the HT regime to optimize second half performance.

General Audience Abstract

The half-time (HT) period of a soccer match is commonly viewed as a period of rest and recovery. A completely inactive HT period has metabolic and performance implications during the initial phases of the second half. A transient reduction in blood glucose (BG) concentrations could contribute to the second half performance decrement. The purpose of this study was to determine the effects of an active rewarm-up, compared to a passive period, at halftime on various measures of performance using global positioning system (GPS) units. Additionally, identify the effects of the active versus passive half-time period, with carbohydrate (CHO) beverage supplementation, on blood parameters. In a crossover design study, twenty collegiate male soccer players participated in two 90-minute soccer matches that included a passive rest (CON) or a moderate-intensity rewarm-up (RWU) during the 15-minute HT period with the consumption of a CHO beverage. Each subject received five finger stick blood samples throughout the match to monitor plasma blood glucose and a subset of four subjects had serum insulin taken three times during the match. The study found that an active HT, compared to passive, mixed with CHO supplementation significantly improved physical performance at the start of the second half. A passive HT period is not advised or optimal, given its causal role in temporary physical performance deficits in the second half of soccer matches. The results from this study provide a strong rationale for collegiate soccer players and teams to incorporate the 8-minute moderate-intensity into the HT regime in order to optimize second half performance.

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Chapter 1:
Introduction

Introduction

The game of soccer, commonly referred to as football or futbol outside of the United States, is a moderate to high-intensity sport embedded with various intermittent movements [Bangsbo, 1994b]. Higher-level soccer matches, such as collegiate and professional, are characterized by a game that is 90-minutes in duration. The 90-minute match period is separated into two equivalent 45-minute halves that are interceded by a 15-minute half-time period [FIFA, 2015]. A soccer match is played between two teams. The two teams field eleven players each resulting in a soccer game that is played eleven versus eleven (11 v. 11). The eleven players on the field consist of ten field players, made up of defenders, midfielders, and forwards, and then one goalkeeper [FIFA, 2015]. The ultimate objective of the game is to defeat the opposing team by scoring more goals. Numerous studies have highlighted both the physical demands and the metabolic response a player endures throughout a soccer match [Krustrup, 2006b; Bangsbo, 2006; Bangsbo, 1994b; Stolen, 2005; Osgnach, 2010; Bangsbo, 2007]. Studies employ various match-analysis systems to point out the multifaceted demands players experience throughout a soccer match [Buchheit, 2014; Carling, 2008; Mackenzie, 2013; Wehbe, 2014; Akenhead, 2016].

Performance is a complex variable that is influenced by a variety of factors during a soccer match [Currell, 2008; Lago-Penas, 2012; Bradley, 2013]. Performance, both physical and technical, is subjective to variables [Ali, 2011; Carling, 2011; Currell, 2008]. The majority of studies use simulated soccer matches or soccer-specific exercise protocols to control variables, but at the same time these methods lack the same stimuli experienced in an actual soccer match [Mackenzie, 2013]. In recent years, researchers have used match-analysis systems to measure the impact these variables have on performance in actual match play [Buchheit, 2014; Castellano, 2014]. Researchers are now able to quantify physical performance and physiological responses

as the technology advances within the field. The physical measures, such as speed, distance, and work-rate only highlight one aspect of soccer performance, but these measures can impact other performance measures such as technical and psychological [Alghannam, 2012; Backhouse, 2007; Rampinini, 2011; Reilly, 2008]. Many studies have reported reductions in various soccer performance measures during the second half, specifically in the initial stages of the second half [Mohr, 2003; Bradley, 2009; Weston, 2011].

The effect of carbohydrate [CHO] supplementation on running and skill performance in soccer players has been studied extensively over the years [Ali, 2009; Phillips, 2011; Russell, 2012a; Nicholas 2000; Foskett, 2008; Funnell, 2017; Harper, 2017]. A myriad of factors can influence soccer performance, which makes it difficult to draw specific conclusions. However, marginal differences throughout a match could potentially influence the outcome. CHO supplementation has shown to improve physical performance measures and soccer-specific skill measures [Kingsley, 2014; Ali, 2007; Winnick, 2005; Northcott, 1999; Russell, 2012a]. CHO supplementation is a common practice amongst soccer players given the recommendations set forth by accredited researchers [Thomas, 2016; Burke, 2011; Williams, 2015]. Nutrition, before and during a soccer match, can greatly impact an individual's performance [Beck, 2015; Russell 2014b; Williams, 2015].

In recent years, the 15-minute half-time period of a soccer match has received a lot of attention due to its placement directly between two intense bouts of exercise [Russell, 2014b; Lovell, 2013b; Edholm, 2014; Russell, 2015b]. Half time is a crucial period of time that can be used to maximize second half performance in soccer players. Half-time is typically viewed as a period meant for recovery, rest, and tactical adjustments [Towlson, 2013]. Studies have shown that a completely passive, or inactive, half time period can negatively affect second half

performance [Mohr, 2004; Edholm, 2014; Zois, 2013; Lovell, 2007; Lovell, 2013b]. The reasons for these negative impacts are still studied, analyzed, and speculated. However, some studies have shown potentially detrimental metabolic changes in soccer players following an inactive half time [Edholm, 2014; Russell, 2014a; Krstrup, 2006b]. These metabolic changes, such as a drop in blood glucose concentrations or increase in serum insulin levels, could be key factors in decreased second half performance. Studies have some that as soon as exercise stops, or a passive rest period take place, insulin levels rise and catecholamine's drop [Nalbandian, 2017; Soria, 2015; Wahren, 1973; Harper, 2016] There is also evidence of a transient drop in blood glucose concentrations during the half time period, with the lowest concentrations recorded 15-minutes into the second half [Russell, 2014a; Russell, 2011; Kingsley, 2014; Harper 2017]. The transient reduction in blood glucose is unknown and could result in hypoglycemia levels that could impair soccer performance, specifically cognitive [Bandelow, 2010; Phillips, 2011]. Some researchers have tested the effects of CHO supplementation at halftime on this transient reduction, but the reduction still occurred suggesting the reduction is “exercise-induced” [Russell, 2014a; Kingsley, 2014; Harper, 2016; Harper 2017]. Since the CHO recommendations for sport are common practice, and regularly utilized given their positive impact on performance measures, it's important to investigate the potential benefit of incorporating an active rewarm-up during the halftime period while supplemented with carbohydrates.

The review of the following studies and pertinent information help show the importance of this proposed research idea: the effects of an active halftime rewarm-up, with carbohydrate supplementation, on player's blood glucose and second half performance during a collegiate soccer match. Several specific aims were employed by this study. First, determine the effects of an active rewarm-up at halftime, compared to a passive period, on various measures of

performance during the first 15-minutes of the second half using GPSports SPI HPU units. Next, identify the effects of an active versus passive half-time period, with carbohydrate beverage supplementation, on plasma blood glucose, serum blood glucose, and serum insulin concentrations. Lastly, determine if an active rewarm-up attenuates the drop in performance measures and blood glucose concentrations commonly seen during the initial portion of the second half. The goal is to Highlight the importance of various half-time strategies and determine the best method to maximize second half performance. A crossover study design was used to highlight the effects of the rewarm-up on physical performance (via GPS) and blood measures throughout the match, specifically during halftime and the second half. It's hypothesized that the active rewarm-up (RWU) at halftime, paired with CHO supplementation, will improve performance measures when compared to the passive (CON) group. It's suspected that the RWU will have higher BG concentrations than the CON group. Literature considered, an active rewarm-up during the halftime portion should keep blood glucose levels elevated and attenuate the physical performance decrement at the start of the second half. The CHO beverage should supply the active RWU subjects with a benefit that passive subjects won't experience. The passive subjects receive the CHO beverage, but the passive exercise state may cause reduced BG concentrations during the second half due to metabolic changes (i.e. increases in insulin) at halftime. It's hypothesized that the CON group will contribute lower performance measures during the initial portion (15-min) of the second half and have lower BG concentrations that border hypoglycemia before the second half and 15-minutes into the second half. Lastly, it's hypothesized that the RWU will display significantly lower insulin concentrations than the CON at half-time, but not before or after the match.

Specific Aims:

Aim 1: Determine the effects of an active rewarm-up, compared to a passive period, at halftime on various measures of performance during the first 15-minutes of the second half using GPSports SPI HPU units.

Hypothesis: An active rewarm-up will result in improved measures of performance, such as distance, speed, acceleration, and work-rate, during the first 15-minutes of the second half when compared to the passive HT period.

Objective: Equip each subject with a GPSports SPI HPU unit and utilize a crossover design to highlight the effects of the passive and active periods at HT.

Aim 2: Identify the effects of an active versus passive half-time period, with carbohydrate beverage supplementation, on plasma blood glucose, serum blood glucose, and serum insulin concentrations

Hypothesis: The CHO beverage supplementation will cause the passive CON group to have lower plasma and serum blood glucose concentrations during HT and the second half, but higher concentrations of serum insulin at HT, when compared to the active RWU group.

Objective: To all subjects: Provide a CHO beverage at HT and perform five fingerstick blood samples throughout the match (subset of four subjects for blood draws ~ serum BG & insulin).

Aim 3: Determine if an active rewarm-up attenuates the drop in performance measures and blood glucose concentrations commonly seen during the initial portion of the second half.

Hypothesis: An active RWU will attenuate the drops commonly seen in performance measures, and BG concentrations, during the initial portion of the second half.

Objective: Analyze GPS device data: determine statistically significant differences and interactions between time-intervals and conditions (RWU vs. CON) for measured performance variables.

Aim 4: Highlight the importance of various half-time strategies and determine the best method to maximize second half performance

Hypothesis: The importance of an 8-minute, moderate-intensity RWU at HT, supplemented with a CHO beverage, will be revealed and prove to maximize second half performance ready.

Objective: Analyze and summarize the results to emphasize significant findings that can lead to future evidence-based recommendations and practices.

Chapter 2:
Literature Review

Physical Demands of Soccer

Distance

The demands and responses to a 90-minute soccer match have been studied by a variety of researchers. Throughout a soccer game, a player expends a great deal of energy. Studies show that elite soccer field players cover a distance around 9-14 kilometers [km] per game [Bangsbo, 1991; Carling, 2010; Rampinini, 2011; Wehbe, 2014; Burgess, 2006; Chmura, 2017]. In 1986, a study used hand notation to track the distance covered by professional soccer players in Sweden and Germany [Ekblom, 1986]. The study discovered that players typically covered 9.8km (Germany) and 10.1km (Sweden) during a 90-minute match [Ekblom, 1986]. Since then, many studies have used time-motion analysis to examine activity patterns and physical aspects of soccer. Bangsbo is one of the first researchers to study the energy demands and activity profile of competitive soccer using video analysis. He reported that an elite male soccer player covers a total distance of about 11km each game [Bangsbo, 1991; Bangsbo, 1994b]. Helgerud found elite junior players in Norway covered 9.1km a game [Helgerud, 2001]. Burgess studied the movements of thirty-six professional soccer players in Australia and found the players covered an average of 10.1 km a game [Burgess, 2006]. Andrzejewski found that professional male soccer players, in Europe, covered an average distance of 11.28 km in a match [Andrzejewski, 2012]. The distances covered throughout the studies, using a video analysis system, are generally similar. The integration of the global position system (GPS) method, to monitor distance covered, found similar distances covered in a soccer match. A study, performed by Anderson, found a mean total distance of 8-14km was covered each match [Anderson, 2017]. Wehbe and Varley discovered that players covered a mean distance of 9-11km and 11 km, respectively, throughout the matches [Wehbe, 2014; Varley, 2013]. Relative discrepancies exist in the

literature for the distance covered by players in soccer matches. The distance covered during a match depends on a variety of factors, such as a players training experience, fitness, and position [Andrzejewski, 2012; Barros, 2007; Di Salvo, 2007; Mohr, 2003; Rampinini, 2007]. The variations in work-rate profiles can be ascribed to differences in positional roles [Di Salvo, 2007], environmental conditions [Armstrong, 2006] style of play [Rampinini, 2007] and playing formation [Tierney, 2016]. However, it was consistently observed via video time-motion analysis and GPS that the distances covered in contemporary elite soccer to be around 9-12km.

None of the research, pertaining to physiological demands in soccer, highlights the effects on male collegiate soccer players in the United States. Therefore, the various physical demands of a soccer match will be from research studies that used junior, semi-professional, professional, and elite soccer subjects across the world in various age groups. In a study, Chmura analyzed the players in all of the 2014 World Cup matches [Chmura, 2017]. The study found that the mean distance covered by players, in all matches, was 10.07 km a game [Chmura 2017]. Numerous factors influence the distance covered in a game, one of these being a player's position. Collectively, midfield players cover a greater distance than any other position within the team. The progression of distance covered, from most to least, in these studies went midfielders, forwards, and defenders [Bradley, 2009; Dellal, 2011; Mohr, 2003; Bangsbo, 1991; Bangsbo, 2006; Reilly, 1997; Stolen, 2005; Di Salvo, 2007; Rampinini, 2007; Mallo, 2015; Wehbe, 2014; Burgess, 2006]. The amount of running and repetition of certain movements depends on the position being played. One study analyzed the activity profiles, using a multi-camera computerized tracking system, of elite soccer players playing at different positions [Bradley, 2009]. During a typical match, wide midfielders covered a greater distance in high-intensity running than all other playing positions (central midfielders, full-backs, attackers, and

central defenders]) [Bradley, 2009]. Another study found that midfielders (10.1 km) covered more distance than forwards (9.9 km) and defenders (8.8 km) [Burgess, 2006]. Di Salvo analyzed the movements of three hundred elite field players, in thirty 90-minute matches, to quantify work-rate profiles by position [Di Salvo, 2007]. The average distance covered, independent of position, was 11.39km ranging from 5.7-13.76km throughout the match. The study found that midfield players covered the greatest distance when compared to forwards and defenders [Di Salvo, 2007]. The activity profile and demands on a player will continue to be dictated by their positional role on the team. Mohr studied top-class players and found that central defenders covered less total distance and engaged in less high-intensity running than players in the other positions, which is probably closely linked to their tactical roles and their lower physical capacity [Bangsbo, 1994; Mohr, 2003; Krustrup, 2003].

Movements at various intensities

Soccer is characterized as an intermittent sport in which short-duration maximum-intensity activities, such as sprints, are intertwined with activities of low and moderate intensity that are scattered with pauses. The sport is predominately aerobic and interspersed with periods of high-intensity activities [Krustrup, 2005; Stolen, 2005]. The low and moderate intensity activities include various acts in the form of walking or jogging. Temporary pauses, where the player stands, occur throughout a soccer game due to fouls, ball traveling out of bounds, and set pieces [Barros, 2007; Di Salvo, 2007; Mohr, 2003; Rampinini, 2007]. This is in addition to the requirements of the soccer specific skill such as passing, dribbling, tackling, heading, shooting and controlling the ball [Stolen, 2005; Rampinini, 2009]. Players will also regularly engage in physical contact with the opposition. It is often required that the soccer specific skills are performed at the highest physical intensity. The combination of the multi-dimensional physical

activity and soccer specific skills requires the players to have the physical qualities such as a high level of aerobic and anaerobic endurance, agility, sprinting ability, jumping and kicking power [Reilly, 1997].

The distance covered at low speeds typically makes up 75-80% during a soccer match, leading to the conclusion that movement demands in soccer are predominately aerobic in nature [Bangsbo, 1991; Bradley, 2009; Carling, 2010; Di Salvo, 2007; Mohr, 2003]. However, the remaining movements consist mainly of high-intensity efforts such as high-speed running, jumping, changes-of direction, sprinting, accelerations and decelerations. High-intensity movements require anaerobic metabolism, discussed later, for significant energy contribution [Bangsbo, 1991; Bradley, 2009; Mohr, 2003; Reilly, 2008]. High intensity and physically demanding tasks are considered to be critical in an individual and teams performance outcomes [Reilly, 2000]. As such, large portions of the literature have concentrated on quantifying these movements in competition and these studies will be covered in the performance section [Bradley, 2013; Bradley, 2013; Bradley, 2009; Di Salvo, 2007; Di Salvo, 2009].

The frequent alterations of activities, numerous accelerations and decelerations, changes of direction, unorthodox movement patterns and the execution of various technical skills significantly contribute to energy expenditure [Bangsbo, 1997; Reilly, 1994]. The time spent, throughout an entire match, performing such movements has been highlighted by various research studies [Mohr, 2003; Wehbe, 2014; Russell, 2016] Mohr analyzed the percent time spent performing certain movements during a match [Mohr, 2003]. Mohr found top-class level Danish soccer players stood 19.5%, walked 41.8%, jogged 16.7%, ran 16.8%, sprinted 1.4%, and other 3.7%. In the same study, moderate level players stood 18.4%, walked 43.6%, jogged 19.1%, ran 15.1%, sprinted 0.9%, and other 2.9% [Mohr, 2003]. The next study found that 58-

64% of match-time was spent standing or walking, 32-38% spent jogging or running, and 2% spent high-speed running or sprinting [Wehbe, 2014]. Russell found 37% of the match was spent walking, 5% sprinting, 47% jogging and striding 11% [Russell, 2016]. He broke those actions up into various intensities of moderate intensity (jog and stride ~58%), low-intensity (standing and walking ~38%), and high intensity (sprint ~5%) [Russell, 2016]. Andrzejewski found that players spent 62% of the match standing or walking, 15% jogging, 21% in various forms of running, and 2% sprinting [Andrzejewski, 2012]. Lastly, one of the first studies to analyze percent time spent in various movements, saw players stood for 17% and walked for 40.4% of the match [Bangsbo, 1991]. Whereas 35.1% of the match consisted of low intensity movements, which consisted of jogging (16.7%), low speed running (17.1%), and backward running (1.3%). High intensity movements accounted for 8.1% of movement and it consisted of moderate speed running (5.3%), high-speed running (2.1%), and sprinting (0.7%) [Bangsbo, 1991]. The intermittent activity pattern during a soccer match, seen in the above studies, is highlighted by long periods of low-moderate intensity movements and brief bouts of high-intensity movements.

Research studies highlighted that players typically complete 1,179 and 1,431 changes in activity patterns across a 90-minute match [Bangsbo, 1991; Rienzi, 2000; Lago-Penas, 2010; Barros, 2007]. Even though overall distance is a good indicator of individual player work rate. The high intensity activity is a constant characteristic, of great importance and another measure of physical performance [Carling, 2008]. High intensity movements are typically defined as sprinting (greater than 7.0 m.s⁻¹) and high speed running (greater than 5.5m.s⁻¹) [Randers, 2010]. Throughout a match a player will run at high speed once every minute and sprint at maximum velocity every four seconds [Di Salvo, 2007]. Players sprint on average for four seconds covering a distance of 20 meters [Stolen, 2005]. Due to the short duration of the sprint

distance the player's acceleration, in order to reach the ball first or to pass an opponent, may be of greater importance than maximal speed. The players overall work rate and high intensity activity is reduced when competition commences in an environment with a higher ambient temperature [Ekblom, 1986]. Additionally it has been shown that heat stress impairs a players the ability to repeatedly perform anaerobic components of the game [Mohr, 2013].

Acceleration and Deceleration

The ability to accelerate a, change direction, and reach maximal speeds quickly is an essential component of game-deciding situations in soccer. Russell noted that approximately 300 acceleration and deceleration efforts are performed per half [Russell, 2016]. Akenhead found that ~18% of the total distance covered during a soccer match is done so through accelerations and decelerations [Akenhead, 2013]. The following studies all used GPS, with built in accelerometers, to track and define the acceleration and decelerations performed in the 90-minute matches by their respective subjects [Russell, 2016; Akenhead, 2013; Wehbe, 2014; Tierney, 2016].

The Wehbe study classified accelerations (Acc) into four categories defined as medium accelerations (2.5-4.0 m/s), high accelerations (> 4.0 m/s), medium decelerations (-2.5 to -4.0 m/s), and high decelerations (<-4.0 m/s). The accelerations were defined as lasting at least 0.5 seconds [Wehbe, 2014]. The average number of medium and higher accelerations, across all positions, were 101.4 and 6.7 each match. The average number of medium and high decelerations was higher at 119.4 and 24 a game. The midfielders executed the highest number of accelerations and decelerations (Dec) when compared to defenders and forwards [Wehbe, 2014].

The Tierney study focuses on the high-speed [> 3.0 m/s] accelerations and decelerations performed by players throughout a match, specifically how the Acc and Dec compared between team playing formations and positions [Tierney, 2016]. The mean Acc and Dec was taken in games for five different formations and five different positions. The mean Acc for formations and positions ranged from 28-38 and 27-38, respectively. The mean Dec for formations and positions ranged from 49-61 and 45-56, respectively [Tierney, 2016].

The next study, was one of the first to examine the influence of actual soccer match-play on the number of accelerations and decelerations performed by soccer players (under 21 years old: u21) in an applied setting [Russell, 2016]. Accelerations and decelerations were defined as an increase or decrease in speed for at least 0.5 seconds (s) that exceeds a maximum acceleration or deceleration for at least 0.5 meters/second (> 0.5 m/s). The number of acceleration and deceleration efforts declined in the latter stages of match play. The means for accelerations and maximum accelerations, executed in a game, were 656 and 35, respectively. The means for decelerations and maximum decelerations, executed in a game, were 613 and 44, respectively [Russell, 2016].

The next study defined accelerations slightly different. Accelerations and decelerations were defined into four categories of total (> 1.0 m/s), low (1-2m/s), medium (2-3m/s), and high (> 3 m/s) Acc/Dec [Akenhead, 2013]. Instead of defining each Acc and Dec as a separate movement, it defined the distance covered by each respective Acc and Dec. 18% of the total distance covered by the players was done so whilst accelerating or decelerating [Akenhead, 2013]. Further, the time spent in low, medium, or high Acc and Dec. was 7.5%, 4.3%, and 3.3%, respectively [Akenhead, 2013] Similar to the Russell study, Akenhead identified transient changes in the distances covered at specific acceleration and deceleration thresholds in a

comparable population of professional reserve team soccer players [Akenhead, 2013; Russell, 2016]. The studies found similar data in regards to Acc. and Dec. in match play. Players executed the higher speeds of accelerations the least amounts of times. These studies showed how data is classified or defined can dictate the numbers of Acc. and Dec. performed by players.

Influential factors

As mentioned earlier, the physiological measures of a soccer match are highly susceptible to change based on variables such as position, formation, level of play, level of competition, and training level. Rampinini examined the effects the factors that could influence the movements performed throughout a match and found that high-intensity running and total distance covered were greater against better opponents [Rampinini, 2007]. The Tierney study examined the influence of tactical formations on match performance and found that formations influence the work-rate of players [Tierney, 2016]. Since my study subjects and teams will play in the same formation, it will cancel the extra workload that some of the formations carry [Tierney, 2016]. In regards to adaptations and training, a study found that aerobic endurance training increased total distance covered, number of sprints, number of involvements with the ball, and work intensity in soccer players [Helgerud, 2001]. The study highlighted that a training regime can influence fluctuations in match performance measures, which stresses the need to use members from the same team, with the same training regime and schedule, to help cancel the training variable [Helgerud, 2001]. Bradley performed a study to quantify match-running performance [Bradley, 2013b]. He aimed to highlight whether the match running performance fluctuations were indicative of fatigue, pacing strategies, or situational influences. Bradley wanted to analyze the factors that could impact high-intensity running such as score and match importance. The players were analyzed with a computerized tracking system. The findings suggest that high-intensity is

influenced by score-line but not match importance [Bradley, 2013b]. Another 2013 study by Bradley, compared the match performance of players in the top three competitive standards of English football [Bradley, 2013a]. The study found that players in the second and third league categories performed more high-speed running (>19 km/hr) than those in the first/top League (803, 881 and 681 m, respectively), which was also the case for sprinting (308, 360 and 248 m, respectively) [Bradley, 2013a]. The differences may be related to playing style, with Premier League teams utilizing possession tactics rather than the long ball tactic typically used at lower standards, demonstrating the major influence of tactics on physical performance. Studies need to make sure player's are the same-level and that data isn't strictly compared to other levels of play. In addition, players' cover more ground with high-intensity running when playing against a higher quality opponent when compared to a lower quality [Castellano, 2011; Di Salvo, 2013; Rampinini, 2007]. Playing against strong opponents has been found to be associated with lower ball possession [Bloomfield, 2007; Lago, 2009], and it is possible that lower-standard players have to cover greater distances in an attempt to close in on players and regain possession. The following research studies reveal the several differences that exist between competition levels. Overall, these studies conclude that players of more successful teams covered greater total distances with the ball [Rampinini, 2009], completed more very high-intensity runs [Rampinini, 2009], higher average of goals for shots on goal [Lago-penas 2010], higher number of passes, tackles, dribbling, and shots on target when compared to the less successful teams [Rampinini, 2009]. Nationality differences are illustrated in a study that analyzed 5,938 players in the Spanish La Liga or English FA Premier League [Dellal, 2011]. The study revealed that high-intensity running (21–24 km/hr) accounted for 3.9% of the total distance covered and sprinting (>24 km/hr) 5.3%, with the FA Premier League players covering a longer distance at high speeds than

the Spanish players [Dellal, 2011]. However, this is likely due to the style of play and not the ethnicity of players. All of the differences seen between comparable groups in these studies will be elevated in my study, for the same gender, age, team, nationalities, talent/skill, formation, and positions will be dispersed evenly.

Heart Rate (HR)

A player's movements and heart rate are two measures that are going to greatly influence the energy expenditure during a game. During the course of a game, heart rate (HR) values fluctuate between 60-75% of maximal HR (HRmax) to upwards of 80-90% HRmax [Ekblom 1986; Ali, 1991; Krustup, 2005]. Before wearable HR monitors, tracking HR of players was rather difficult. Multiple studies include the mean HR for players and translate it into a percent of HRmax. The average HR values in the following studies fall in the range of 157–176 b/min. The age of a player will likely influence their heart rate, but these studies used adult subjects who played semiprofessionally or professionally. The average HR values in the following studies fall in the range of 157–176 b/min [Mohr, 2003; Mohr, 2012; Mallo, 2015; Souglis, 2015; Bangsbo, 1994; Mohr, 2004; Ali, 1991; Russell, 2011a]. During the Mallo study, the mean HR during the match was 165+/-11 beats/min which corresponded to 84.7+/-5.1% of the individuals HRmax [Mallo, 2015]. In the Souglis study, the average HR for male players during the match was 173 beats/min, which corresponded to 86.9% of HRmax [Souglis, 2015]. Ali tested the heart rates of twenty-seven male soccer players, who played semi-pro, university, or recreational levels, in Scotland. The average HR in a 90-minute match was 172, 167, and 168 beats/min, respectively [Ali, 1991]. Regardless of the players' nationality and talent level, the mean HR was generally consistent.

Sprints

Sprinting is one of the most important activities in soccer, although it only constitutes less than 10% of the mean total distance covered in a game. [Andrzejewski, 2012; Casamichana, 2012; Mohr, 2003; Wehbe, 2014; Russell, 2016; Bangsbo 1991]. Distance covered at high-intensities has been identified as a key performance indicator of physical match performance [Mohr, 2003]. Match analyses show that elite soccer players vary their running pace between 1.4 m/s and 10 m/s (5.04 km/hr and 36 km/hr), 800 – 1,000 times during a match [Bangsbo, 2006; Bloomfield, 2007]. Mohr found that moderate level and top-level players, through sprinting, covered 410m and 650m in a match, respectively [Mohr, 2003]. These recordings of high intensity running do not include a number of energy demanding activities such as short accelerations, tackling or jumping. In example, the number of tackles and jumps depends on the individual playing style and position in the team and at a top-level have shown to vary between 3-27 (tackles) and 1-36 (jumps), respectively [Mohr, 2003]. Numerous studies have measured the total sprint distance covered by player's throughout an entire match and found values between 200 and 800m [Osgnach, 2010; Bradley, 2013; Bradley, 2010; Mohr, 2003; Burgess, 2006; Mallo 2015]. The Mallo study found all players, on average, covered 75% on their distance walking (0.7-7.1 km/hr) and jogging (7.2-14 km/hr). This translated to a sprint distance of 202-505 m, depending on playing position, over the course of a game [Mallo, 2015]. The total number of sprints fluctuated between studies as well. Chmura found that the mean number of sprints performed, throughout the 2014 World Cup, was 33.25 a game. Also, the mean percent of total distance covered by players, at high-intensity speeds, was 8.83% [Chmura, 2017]. Drust found a mean number of 19 sprints within match play, which occurred every 4-5 minutes [Drust, 2000] and another study observed an average changes in activity every 3.5-seconds, high-intensity activity every 60-seconds, and maximal effort every 4-minutes [Strudwick, 2002].

Average Speed

The average speed of a player, over the course of a match, was found in a couple of studies. The average speed of players in the Burgess study was 6.7 km/hr [Burgess, 2006]. A study by Yamanaka reported the average speed was 5.7 km/hr for players in South America, 5.8 km/hr for players in England, and 7.6 km/hr for players in Asia [Yamanaka, 1988]. The next study assessed how the score and position changed a player's speed [Wehbe, 2014]. The average speeds were 6.66 km/hr, 6.42 km/hr, and 6.42 km/hr when the player was drawing, winning, and losing, respectively. The average speed of midfielders, defenders, and forwards was 6.95, 6.28, and 6.71 km/hr, respectively [Wehbe, 2014]. These averages speed makes sense, because they translate to a low intensity and the majority of a soccer game is spent in a low-intensity state. Osgnach found in his study that most of the distance covered, and time spent, was in the 0-8 km/hr range [Osgnach, 2010]. Similar, a study found that over 70% of match time was spent standing (0 km/hr), walking (6 km/hr), and jogging (8 km/hr) [Mohr 2003]. Casamichana, in a study assessing male semi-professional players in Spain, found that players spent over 60% of the match in the 0-6.9km/hr speed zone. [Casamichana, 2012]. Another study, the longest distance covered, and most time spent (62%), was in the 0 – 11 km/hr intensity range [Andrzejewski, 2012]. On average, a player's mean speed during a match is going to fall in a lower-intensity speed zone and most likely in the range of 5.7 to 7.6km/hr.

Energy Expenditure (EE)

It is well recognized that the ability to repeat sprints is important for physical performance in soccer [Barbero-alvarez, 2010; Dellal, 2011; Rampinini, 2007]. The harder a player works in a match, for example the amount of high-intensity movements performed, equates to the amount of energy the player expends. Bangsbo reports that the energy expenditure

(EE) of a single athlete during a match is around 1,360 kcal per game [Bangsbo, 1994a] For professional Brazilian soccer players during official matches, it was reported that the average energy expenditure is around 11.34 kcal/min (1,020.6 kcal) varying from 6.49 to 16.87kcal/min (584 kcal to 1,518.3 kcal) [Garcia, 2005]. Coelho found U-20 soccer players, during official matches of a competition, expended 17.11 ± 1.45 kcal/min, which corresponded to a total average expenditure of 1539.86 ± 130.07 kcal per game [Coelho, 2010]. The study used the players' HR and VO₂ max scores to determine the energy expenditure [Coelho, 2010]. Osgnach's study, which used a video match analysis device to assess the EE of elite soccer players, found that a player expended roughly 4,633 kJ/game (1,107 kcal/game) [Osgnach, 2010]. A study by Briggs, using an accelerometer, assessed the energy intake and expenditure of adolescent male soccer players [Briggs, 2015]. On match day, the players expended nearly 2,800 kcal a day. However, the study didn't provide a detailed representation of the match or how much energy each player expended [Briggs, 2015]. A recent study used doubly labeled water (DLW) to assess the energy expenditure of professional soccer players over a week. However, the EE was the mean of the entire week, a week that included training days, rest days, and match days [Anderson, 2017]. The study also provided the meals and analyzed the player's energy intake. The study is one of the first to utilize DLW to track energy expenditure and the energy difference across the week, but it wasn't possible to get insight into how much the players expended during the match. [Anderson, 2017]. Overall, energy expenditure for players should increase during times of an increased work-rate, distance covered, and high-intensity movements. Players are going to expend a different amount of energy depending of their fitness, weight, height, diet, metabolism, and work intensity. However, EE can provide an insight into a

players work-rate and physical performance measures during a game and this data can't be used to make internal comparisons.

Physical Demand Analysis

Laboratory and field based testing have been widely used, in the game of soccer, to understand the physiological and movement demands involved. In-game analysis and data collection have been used to better understand their involvement [Buchheit, 2014]. The technical and tactical nature of soccer has shown that the physical characteristics are multifactorial [Bradley, 2013a]. The methods used to analyze and assess soccer-match data has progressed greatly over the years. First, the use of semi-automatic computerized player tracking technologies replaced hand notation and single video-camera systems. Now it's the global positioning system (GPS) tracking the movements of all players during a match, helping to build a performance profile database to analyze relevant physical performance indicators. GPS technology, which represents a portable and economic procedure of monitoring workloads [Witte, 2004; MacLeod, 2009], is now commonly used to monitor soccer game demands [Mallo, 2015; Suarez-Arrones, 2015; Russell, 2016; Tierney, 2016; Anderson, 2017; Torreno, 2016]. The technology has led to detailed analyses of many aspects of the game, such as the importance of team tactics and the style of play of the opponent and their impact on physical demands [Castellano, 2014; Mallo, 2015; Russell, 2016; Tierney, 2016]. This information has provided a more detailed and nuanced picture of the demands on players, but the outline of fundamental requirements for players has not changed.

Summary

There is going to be a slight variation in performance measures, after reviewing much of the literature pertaining to the physical demands of soccer. The general consensus is that a player

will cover anywhere from 9 – 14 kilometers throughout the 90-minute match. The midfield players will likely cover more distance than the forwards and defenders. The mean heart rate of players during a match will likely range between 157-176 beats/min, but this number is subjective to gender, age, and fitness level. There are a variety of variables that influence physical movements during the game and it's important to control these in future studies such as tactical formation and position. Accelerations and decelerations performed throughout a game have been more recently studied, suggesting their crucial role in match performance. The majority of movements in the match will be executed in a low to moderate intensity state with high-intensity movements scattered/dispersed amongst the game. A player's average speed will likely fall in the range of 5.7-7.6 km/hr based upon the literature. Players will likely expend 500 – 1,500 kilocalories a game, but energy expenditure is a measure greatly influenced by work rate and the specific individual. It is important to evaluate match play demands in soccer, for each position within different playing formations, in order to better guide coaches and staff to the individual demands involved during soccer match play. The varying data suggests that there is a fluctuation when different analyzing systems used. [Buchheit, 2014]. Due to the different strategies used by different research teams, it becomes difficult to extrapolate data and findings. However, the study I will perform will be focused how a specific intervention changes the physical measures within a team and individual. The physical data found, via the GPS units, will be compared between the trial subjects, teams, and similar study groups that used the same analysis system. The physical demands of a soccer game significantly influence the physiological and metabolic response. A variety of changes occur throughout a match and these changes have potential implications on performance

Metabolic Demands of Soccer

The physical demands of soccer, with the majority of activity spent in aerobic states with brief periods of high-intensity anaerobic activities, influence the metabolic demands and responses [Kang, 2012; Bangsbo, 2007; Bangsbo, 1994a; Stolen, 2005; Foskett, 2008; Ekblom, 1986]. The bodies aerobic and anaerobic energy systems contribute the most energy to supply these demands [Bangsbo, 2006; McArdle, 2007; Maughan, 2007]. Soccer is an activity of long duration played at an average intensity of 70-80% VO₂max, with an average respiratory exchange ratio (RER) of 0.88 [Bangsbo, 1994a]. This value indicates a heavy reliance on muscle and liver glycogen to supply the energy needed to meet the demands of soccer [Bangsbo, 1994a; Jeukendrup, 2004, Cermak, 2013].

Energy Systems

The aerobic energy system, which requires the presence of oxygen, provides the greatest yield of energy (ATP) during a match. The long 90-minute duration of a match, with extended periods of low and moderate intensity movements, indicate the use of aerobic glycolysis for energy [Kang, 2012; Bangsbo, 2006, Cermak, 2013]. The aerobic system is very complex and takes the longest to generate ATP, but generates a much higher quantity. [Fink, 2015; Kang, 2012]

The anaerobic energy system provides energy via two pathways and utilized during the short, high-intensity efforts such as sprints [Bangsbo 2007, Kang 2012]. Energy in the anaerobic system is produced without oxygen and can be done through the use of the phosphagen or anaerobic glycolysis system. The phosphagen system provides immediate energy for very short durations, generally 6-10 seconds, because of the low energy yield and low stores in the muscle [Maughan, 2004; Bangsbo, 2006; Bangsbo, 1994a]. The phosphagen system utilizes cell stores

of ATP and creatine phosphate (CP) for energy production. Players perform roughly 200 brief, intense bouts throughout a soccer match [Bangsbo, 1994b]. CP levels drop dramatically after these intense bouts of exercise, but quickly regenerate during low-intensity exercise bouts [Bangsbo, 1994a; Bangsbo, 1994b; Krstrup, 2006b; Bendiksen, 2012]. Creatine kinase (CK) is the enzyme that catabolizes the transfer of the phosphate group off of CP to ADP in order to generate energy and form ATP. Some studies have tracked the blood CK levels following soccer matches in an effort to track muscle inflammation [Ascensao, 2008; Ispirlidis, 2008; Bishop, 2002; Nedelec, 2014; Thorpe, 2012; Schulpis, 2009].

Anaerobic glycolysis derives its energy from glycogen stored in the muscle. It works in the absence of oxygen to generate ATP and lactic acid. Lactic acid, or blood lactate, is a by-product of glycogen breakdown in the absence of oxygen. This energy pathway is predominately used for brief intense actions that last 1 to 3-minutes [Maughan, 2004; Kang, 2012; Wolinsky, 2008; Fink, 2015; Bangsbo, 2006; Bangsbo, 2007]. Several studies have analyzed blood and muscle lactate levels during a soccer match or simulated match play [Bangsbo, 1994a; Bangsbo, 1994b; Krstrup, 2006b; Ekblom, 1986; Page, 2015; Harper, 2016; Schulpis, 2009; Russell, 2014a].

Substrate Utilization

Each energy system, except the phosphagen system, involves a metabolic pathway to supply the energy. Systems will either break down molecules, catabolism, to release energy and by-products or use the energy, anabolism, to assemble complex molecules [Fink, 2015; Kang, 2012, Maughan, 2004; Wolinsky, 2008]. The aerobic system can use a variety of substrates to produce energy, but during soccer matches carbohydrates (CHO) are the main source. Soccer has a heavy reliance on endogenous CHO stores (glycogen) [Krstrup, 2005; Hargreaves, 1994;

Krustrup, 2006; Saltin, 1973]. When glycogen stores deplete, muscles attempt to cover their energy needs from fat metabolism [Kang, 2012; McArdle, 2007] Unfortunately, because fat cannot supply energy at as rapid a rate as carbohydrates, an athlete is forced to slow down their rate of work to the level at which energy expenditure and energy synthesis are matched further emphasizing the importance of glycogen availability [Holway, 2011; Kang, 2012; McArdle, 2007; Bangsbo, 1994a; Bangsbo, 2006; Burke, 2011].

CHO metabolism is suggested to supply ~55% of the energetic requirements of match play and therefore other substrates must be taken into account [Bangsbo, 1994b]. The additional contribution (~40%) comes from lipid, or fat, metabolism, especially from free fatty acids released from adipose tissue [Bangsbo, 1994b]. The frequent rest and low-intensity periods during a match allows for significant blood flow to adipose tissue, resulting in lipolysis which breaks down triglycerides into free fatty acids (FFA) and glycerol [Kang, 2012; McArdle, 2007; Wolinsky, 2008]. Fat is readily available, but it's breakdown into ATP is complex and slow. In order for the body to utilize lipids for fuel, via beta-oxidation, oxygen must be readily available. Therefore low-intensity periods are the ideal time for fat to be used as fuel [Maughan, 2004]. It's suggested that during a soccer match, lipid metabolism can help slow muscle glycogen and blood glucose utilization [Bangsbo, 2007; Bangsbo, 1994b]. Glycerol can be made into glucose via gluconeogenesis in the liver. However, the gluconeogenesis process is generally an effort to preserve blood glucose during extreme events, such as starvation or endurance exercise [Maughan, 2004; McArdle, 2007; Wolinsky, 2008; Kang, 2012].

When glycogen stores in the muscles are used up, blood glucose levels will drop and the liver attempts to correct this issue through glycogenolysis. Glycogenolysis is the breakdown of glycogen stores into glucose that is used by the muscles and brain for energy [Maughan, 2007;

Kang, 2012; Wolinsky, 2008]. Glycogen that is stored in the active muscles supplies almost all of the energy in the transition from rest to exercise. As a match progresses and exercise continues, muscle glycogen stores progressively deplete [Reilly, 2005; Krstrup, 2006a; Bangsbo, 2006; Mohr, 2003; Di Salvo, 2007; Krstrup 2011]. When the liver can't breakdown glycogen into glucose fast enough, to match glucose uptake needs in the muscles, blood glucose levels will drop to potentially hypoglycemic levels [Kang, 2012; Maughan, 2007; Maughan, 2004; Brun, 2001]. The normal concentration of blood glucose ranges between 4.0-5.5mmol/L (80-100 mg/dL) with the general consensus that a level below 3.9mmol/L (70mg/dL) is defined as hypoglycemia [Morales, 2014]. There are a variety of definitions for what quantifies a hypoglycemic blood glucose reading, but a value between 3.5-3.9mmol/L (63-70mg/dL) is common [Morales, 2014; Russell, 2014; DeMarco, 1999]. Hypoglycemic blood glucose levels can reduce the supply of glucose to the brain, contributing to the feeling of exhaustion and causing a decrease in technique and the ability to make correct decisions [Nybo, 2003; Wolinsky, 2008; Maughan, 2007].

Blood Glucose

Blood glucose is an important source of fuel for muscles during exercise and the uptake by the active skeletal muscle. The uptake in the muscle happens via the glucose transporter isoform 4 (GLUT-4). Insulin is generally required for glucose uptake, but levels drop during exercise and soccer matches [Wahren, 1973; Harper, 2016b; Kang, 2012; Bangsbo, 2007; Krstrup, 2006a; Ali, 2007]. However, during exercise the increased blood flow and translocation of GLUT-4 in the muscle leads to non-insulin dependent uptake of glucose by the muscles [Richter, 2013]. The primary function of glucose output by the liver is to maintain glucose homeostasis. It's regulated by insulin and glucagon, but during high-intensity exercise

the glucose output can outpace the utilization by muscle resulting in elevated blood glucose concentrations during parts of soccer matches and simulated soccer matches [Reilly, 2005; Kingsley, 2014; Russell, 2014b; Harper, 2016b; Russell, 2011a; Krstrup, 2006a; Bangsbo, 1992; Ali, 2009]. Whereas, when blood glucose is low, regulatory hormones are secreted.

Hormones

There are a variety of hormones that stimulate, regulate, and inhibit these metabolic processes such as insulin, catecholamine's, cortisol, and glucagon. Insulin is secreted by the beta cell of the islets of Langerhans in the pancreas. It's biological basis, for energy metabolism, is to inhibit lipolysis and increase the uptake of glucose from the blood by skeletal muscle and liver tissue. [Maughan, 2004; McArdle, 2007]. These regulations reduce plasma glucose concentrations, inhibit the release of glucose by the liver, promote the synthesis of glycogen in the liver and muscles, and inhibit the release of FFA [Maughan, 2004; McArdle, 2007]. As previously mentioned, levels drop during exercise and soccer matches [Wahren, 1973; Harper, 2016; Kang, 2012; Bangsbo, 2007; Krstrup, 2006a; Ali, 2007] that puts an emphasis on the non-insulin dependent uptake of glucose [Richter, 2013]. Glucagon has the opposite effects to those of insulin. Glucagon, is also secreted by the pancreas, increases the rate of glycolysis and promotes gluconeogenesis in the liver. A fall in blood glucose stimulates the release of this hormone. No soccer studies have specifically analyzed glucagon levels. However, studies have analyzed the catecholamine's epinephrine (adrenaline) and norepinephrine, which also stimulate the release of glucagon when blood glucose levels are low [Schulpis, 2009; Harper, 2016b; Bangsbo, 1994b; Bangsbo, 2007]. Aside from low blood glucose, exercise and exercise stress are the main stimuli for epinephrine and norepinephrine [Maughan, 2004]. Epinephrine (adrenaline) stimulates the breakdown of liver and muscle glycogen into glucose and the breakdown of fat

into FFA's [Kang, 2012; Wolinsky, 2008]. Exercise intensity is the main factor that increases the catecholamine response, indicating sprints and high-intensity movements maximize this response during exercise [Zouhal, 2008]. The relative exercise intensity has to be above ~50% VO₂max to significantly elevate plasma catecholamine concentrations [Maughan, 2004; McArdle, 2007] It makes sense for higher levels of adrenaline to relate to a higher use of glycogen stores in the body during exercise. The last hormone, which influences metabolism during exercise and soccer, is cortisol. Cortisol is a steroid hormone stimulated by low blood glucose and exercise stress, similar to the catecholamines. Cortisol promotes both lipolysis, resulting in FFA's in the blood, and gluconeogenesis, resulting in more glucose in the blood [Maughan, 2004; McArdle, 2007; Kang, 2012]. Some studies have analyzed the changes in cortisol levels during a match [Krustrup, 2006a; Thorpe, 2012; Harper, 2016b; Souglis, 2015].

One researcher analyzed what happens to hormones in well-trained athletes during acute stress induced by incremental exercise until exhaustion [Soria, 2015]. The exercise was performed using a cycle ergometer, with a steady increase in work-rate every three minutes until exhaustion. The study found that epinephrine, norepinephrine, and cortisol all increased as workload increased. Once the exercise was complete, both epinephrine and norepinephrine decreased while cortisol remained elevated [Soria, 2015]. The study also found that insulin levels decreased at the onset of exercise, but 3-7 minutes after exercise was complete the insulin concentrations rose to levels above baseline. The highest insulin concentrations (7.9mIU/L) were 5-minutes post exercise [Soria, 2015]. These findings further show how hormones change based upon whether someone is exercising or at rest. Many soccer studies have assessed the hormone response and profile for adolescents [Handziska, 2015; Romagnoli, 2016] or females [Haneishi, 2007; Aizawa, 2006; Casanova, 2016], but few on adult male soccer players following a match

[Krustrup, 2006a; Ascensao, 2008; Ispirlidis, 2008; Russell, 2014b; Harper, 2016b; Thorpe, 2012].

Metabolic Response & Changes during a Match

Glycogen

One of the earliest studies, to analyze the role muscle glycogen in soccer, filmed soccer players during a competitive game in Sweden [Saltin, 1973]. Each player had muscle glycogen levels taken before the game, at halftime, and after the game. The study found that players, who began the game with low glycogen stores (~200mmol/kg dry weight~d.w), had nearly depleted levels at halftime. The players, who had normal levels of glycogen stores (~400mmol/kg d.w) prior to the game, had slightly lower levels at halftime and almost completely depleted levels after the game (~50mmol/kg wet weight~w.w) [Saltin, 1973]. Jacobs performed a similar study on professional male soccer players in Sweden. This study included a diet record and input from a dietitian prior to the matches [Jacobs, 1982]. The study found nearly depleted levels of muscle glycogen at the end of the three games (~46-73mmol/kg w.w), values that were a 63% reduction of the players “filled” state prior to the games [Jacobs, 1982]. Later studies didn’t find levels as low, or depleted, as those two earlier studies [Krustrup, 2006a; Krustrup, 2011; Foskett, 2008; Bendiksen, 2012; Nicholas, 1999]. Krustrup performed a study that examined the muscle and blood metabolites during a soccer match [Krustrup, 2006a]. The subjects were adult male semi-professional soccer players in Denmark and their diets were controlled 16-hours prior to the match, The study didn’t specify the calories provided, but rather a gram total of general items such as 100g of vegetables, 200g of meat, and 300g of pasta. The players mean muscle glycogen levels were 42% lower at the end of the game (~260mmol/kg d.w), compared to their initial levels before the game (449mmol/kg d.w) [Krustrup, 2006a]. The study went a step further and

analyzed the glycogen content of individual muscle fibers. Of the fibers (slow and fast twitch), 11% were completely empty and 36% were almost empty of glycogen [Krustrup, 2006a]. However, it should be noted that the post-match glycogen stores in the Saltin study were given in “wet-weight” (w.w)[Saltin, 1973]. Whereas in the Krustrup study, as well as the next studies I review, the muscle glycogen content was given in “dry-weight” (d.w) [Krustrup, 2006a]. Krustrup did another study five years later to analysis the effects of recovery on muscle contractions, but this study still recorded muscle glycogen content before and after a 90-minute soccer match [Krustrup, 2011]. The subjects were adult male professional soccer players in Denmark and had a controlled diet five days prior to the match. Prior to the match players had a muscle glycogen level of 449mmol/kg d.w and immediately after the game the level reduced 43% to 193mmol/kg d.w [Krustrup, 2011]. The two studies found similar reductions in muscle glycogen content (42-43%) of players after the 90-minute match [Krustrup, 2006a; Krustrup 2011].

Some studies have used simulated soccer matches to analyze glycogen fluctuations [Foskett, 2008; Bendiksen, 2012; Nicholas, 1999]. Two studies used the Loughborough Intermittent Shuttle Test (LIST) exercise protocol [Foskett, 2008; Nicholas, 1999]. One study found reduced but not depleted levels of muscle glycogen after the LIST [Foskett, 2008]. The study loaded subject’s glycogen stores, with high-carbohydrate meals, two days prior to the match. This resulted in high glycogen levels prior to the match (~500mmol/kg d.w), but levels still fell post-match (~350mmol/kg d.w). After the 90-min LIST, subjects performed additional running until their fatigue. The player’s glycogen content at the point of fatigue was around 200mmol/kg d.w [Foskett 2008]. The next study, using the same LIST, saw players began the match with a mean muscle glycogen level of ~400mmol/kg d.w even after a 10-hour overnight

fast [Nicholas, 1999]. Players had roughly a 60% reduction in glycogen stores to a mean content level of about 160mmol/kg d.w at the end of the 90-minute LIST [Nicholas, 1999]. Bendiksen compared the effects of both a simulated soccer match (CST) and actual soccer match on glycogen content [Bendiksen, 2012]. The players, for both the soccer match and CST, were instructed to eat normally and had pre-match mean muscle glycogen levels above 400mmol/kg d.w [Bendiksen, 2012]. At the end of the 90-minute match and CST, the mean muscle glycogen levels were 188 and 235mmol/kg d.w, respectively. The study also analyzed the glycogen content of muscle fibers and found that after the soccer match 98-100% of fibers were empty or partly empty and after the CST, 80-84% of fiber were empty or partly empty [Bendiksen, 2012]. These levels of depletion in the muscle fibers exceed the values Krstrup found [Bendiksen, 2012; Krstrup, 2006a].

In general, the muscle glycogen content in players is going to be completely depleted [Saltin, 1973] or partially depleted [Jacobs, 1982; Krstrup, 2006a; Foskett, 2008; Nicholas, 1999; Krstrup, 2011; Bendiksen, 2012] after a 90-minute soccer match [Jacobs, 1982; Krstrup, 2011; Krstrup, 2006a] or simulated soccer match [Foskett, 2008; Nicholas, 1999; Bendiksen, 2012].

Insulin

The role of insulin during exercise has been studied for decades [Wahren, 1973; Achten, 2003; Tsintzas, 1998]. At the onset of exercise, insulin levels are going to drop and once exercise stops there is going to be resurgence in the levels of insulin [Wahren, 1973]. An early study by Wahren found that 5-minutes after exercise (40 minutes at 130 watts) stopped, there was a significant increase (2.5 times) in insulin levels from basal levels [Wahren, 1973]. The insulin response differs between activity and rest [Nalbandian, 2017]. A study found that during periods

of recovery, after high-intensity exercise, insulin levels increased when compared to subjects who remained active during the recovery period [Nalbandian, 2017].

Several studies have looked at insulin levels during a soccer match or simulated soccer match [Ali, 2007; Harper, 2016; Krstrup, 2006; Foskett, 2008; Nicholas, 1999; Clarke, 2008; Bangsbo, 1994]. A 2008 study used adult male university soccer players in England and a laboratory-based treadmill protocol to simulate a soccer match [Clarke, 2008]. Serum insulin levels decreased, from initial (~30-34mIU/L) pre-match levels, across the entire duration of the soccer-specific exercise [Clarke, 2008]. The lowest insulin levels were taken at the end of the game (~20-23mIU/L) [Clarke, 2008]. Foskett, who used the LIST, found serum insulin levels decreased across the 90-minute match, from start (~15mIU/L) to finish (~10mIU/L) [Foskett, 2008]. Whereas Nicholas, using the same LIST protocol, saw players start the test with lower insulin levels (~6mIU/L) and only a decrease from 0-60minutes (~4.0mIU/L). There was an unexplained increase back to ~6mIU/L from 60-90minutes [Nicholas, 1999]. The study required players to partake in a 10-hour overnight fast prior to the match, which is going to influence insulin levels and response [Nicholas, 1999]. However, another study that used the LIST and overnight fast (12 hours) found players [university level, male] started the LIST with a serum insulin concentration of 9.0mIU/L [Ali, 2007]. There was a significant decrease in this level across the 90-minute LIST and the players had a serum insulin level of 3.1mIU/L after the match, with no increase anywhere prior. [Ali 2007]. Finally, a study by Harper used male university soccer players, and a simulated soccer match (SMS), to analyze variables [Harper, 2016a]. There was a decrease in plasma insulin concentrations throughout the entire match when compared to pre-match levels [Harper, 2016a; Harper, 2016b]. The mean insulin concentration pre-match was 104pmol/L (14.5mIU/L), 60.1pmol/L (8.38mIU/L) after 15-minutes, 49.9pmol/L

(6.95 mIU/L) just before halftime, and 38.9pmol/L (5.42mIU/L) at the end of the game. Interestingly, insulin concentrations rose to 70.6pmol/L (9.84mIU/L) during halftime, which is roughly a 42% increase from the value taken ~15-minutes prior during exercise [Harper, 2016a]. The last study analyzed an actual soccer match to determine insulin response [Krustrup 2006]. The study found mean plasma insulin was highest at rest (15mIU/L) and decreased significantly over the match with the lowest level taken during the second half (6.0mIU/L). This study only took three insulin values and didn't take any values during the halftime recovery period [Krustrup, 2006].

Insulin levels decrease during exercise [Wahren, 1973; Achten, 2003; Tsintzas, 1998] and more specifically during simulated soccer matches [Harper, 2016a; Harper, 2016b; Ali, 2007; Nicholas, 1999; Foskett, 2008; Clarke, 2008] and soccer matches [Krustrup, 2006]. The studies differed on their approach and methodology, but the same result was evident. The mentioned studies either tested subjects in a fasted state [Ali, 2007; Nicholas, 1999], CHO loaded state [Foskett, 2008], or after standardized meals [Harper, 2016a; Harper, 2016b; Clarke, 2008]. This difference only seemed to dictate pre-match insulin levels and not the reduction trend seen across the match. The apparent increase in insulin concentrations during periods of recovery warrants further insight into how the halftime period is handled [Nalbandian, 2017; Wahren, 1973; Harper, 2016a; Soria, 2015].

Blood Glucose

The research, pertaining to soccer studies, shows similar responses of blood glucose (BG) to the physical demands of soccer. The majority of studies analyzed blood glucose concentrations during simulated soccer match protocols in an effort to examine the effects of a CHO beverage [Russell, 2012a; Kingsley, 2014; Russell, 2014b; Harper, 2016a]. In 2000, a

researcher saw an increase in BG concentrations during the LIST [Nicholas, 2000]. At rest, the players mean blood glucose levels were less than 5.0mmol/L and over the course of the LIST the mean value was 6.3-6.4mmol/L. Blood glucose reached its peak level after 30-minutes and then declined steadily as exercise continued [Nicholas, 2000]. The next soccer match simulation (SMS) was employed in numerous studies [Russell, 2011; Russell, 2012a; Kingsley, 2014; Harper, 2016a]. The first study to use the SMS to analyze match demands was in 2011 [Russell, 2011]. Subjects, who were male youth (15y.o) academy level players, took part in the SMS and an actual 90-minute soccer match to draw comparisons in data. The players had similar BG concentrations during the first 15-minutes of the SMS (~5.0mmol/L) and soccer match (~4.5mmol/L) [Russell, 2011]. The levels increased, to maximum values, during the 15-30minute game intervals of both the SMS and match. Both the SMS and match saw reductions in blood glucose (19% and 17%) at the onset of the second half and the lowest blood glucose concentrations between the 45-60minute period of play (~4.0mmol/L) [Russell, 2011]. Russell performed another study, using the same SMS, on adult (18y.o) academy soccer players a year later [Russell, 2012a]. Player's began the SMS with a mean blood glucose concentration of about ~5.2mmol/L. Similar to the 2011 study, blood samples were taken every 15-minutes [Russell, 2011; Russell, 2012a]. The player's highest mean blood glucose concentration (~6.0mmol/L) was found at the 15-minute mark of the SMS. The blood glucose levels dropped from that point until the sample taken at the 75-minute mark. The lowest blood glucose level (~4.6mmol/L) was taken at the 60-minute mark [Russell, 2012a]. The SMS was used by Kingsley to look at CHO effects on adult male recreational players [Kingsley 2014]. This study didn't find an increase of blood glucose during the SMS, but players did experience a drop at halftime and the lowest mean blood glucose concentration at the 60-minute mark (~4.1mmol/L) [Kingsley, 2014]. Player's

began the SMS with a mean blood glucose concentration of about ~5.5mmol/L, which translate to a reduction of about 25% during the initial 15-minutes of the second half [Kingsley, 2014]. The last study, to use the SMS, saw baseline mean blood glucose concentrations of 4.29mmol/L prior to the SMS and then a sharp increase to ~4.87mmol/L 15-minutes into the first half [Harper, 2016a]. The value at 15-minutes was the highest of the SMS and the mean value from 15-45minutes was between 4.69-4.87mmol/L. The players experienced a drop at halftime and their lowest blood glucose concentration at the 60-minute mark (~4.0mmol/L) [Harper, 2016a].

The next two studies utilized a soccer match to highlight blood glucose trends [Krustrup, 2006z; Russell, 2014b]. The subjects, adult male professional players in Denmark, in the Krustrup study had mean BG concentrations of 4.5mmol/L before the match [Krustrup, 2006a]. The study took six blood samples throughout the game. The BG concentrations increased during the first half (6.1mmol/L) and were the lowest prior to the second half (4.1mmol/L). The BG rose again during the second half (5.3mmol/L), but significantly different than the first half. At the end of the game the mean BG value was 4.9mmol/L [Krustrup, 2006a]. The 2014 Russell study, using similar subjects to his 2011 study (15y.o), analyzed BG concentrations during soccer match-play [Russell, 2011; Russell, 2014b]. The study took blood samples every 15-minutes throughout the 90-minute match [Russell, 2014b]. Player's began the match with BG concentrations around ~5.27mmol/L. The BG values increased, with the highest mean values taken during the 15-30minute mark (~6.4mmol/L). BG concentrations dropped after this mark with a value of 5.39mmol/L prior to halftime. The BG levels dropped at halftime (~4.0mmol/L) and were lowest during the first 15-minutes of the second half (~3.8mmol/L) [Russell, 2014b].

The mentioned studies generally found that blood glucose levels increase during the initials phases of play [Krustrup, 2006a; Russell, 2011; Russell, 2012a; Russell, 2014b;

Kingsley, 2014; Harper, 2016a], then proceed to decrease. The only study mentioned, that didn't highlight an increase was the Nicholas study [Nicholas, 2000]. The limitation to this study is that the LIST protocol used didn't have a designated "halftime", or 15-minute rest period. Instead, it integrated brief segments of rest (~3-min) during the 90-minute period [Nicholas, 2000]. The halftime period is when BG concentrations really drop, with the lowest levels during the initial 15-minutes of the second half, or 45-60 minute mark [Nicholas, 2000; Russell, 2011; Russell, 2012a; Russell, 2014b; Kingsley, 2014; Harper, 2016a; Krstrup, 2006a]. This drop is courtesy of an "exercise-induced" rebound glycemic response [Russell, 2011; Bangsbo, 2007], which could result in potentially hypoglycemic levels. These studies further highlight a potential adjustment area, to elevate BG concentrations, during the halftime period.

Blood Lactate

Several soccer studies have analyzed lactate concentrations [Krustrup, 2006a; Mohr, 2010; Russell, 2014b; Bendiksen, 2012; Page, 2015; Greig, 2006; Russell, 2012b; Harper, 2016a]. Krustrup performed one of the trademark studies of lactate production in soccer using data collected during actual soccer matches [Krustrup, 2006a]. Krustrup found mean blood lactate (BLa) values between 3.9-9.0mmol/L. The general finding was that lactate levels are elevated following short periods of high-intensity movements and drop during periods of low-intensity movements. The study attempted to relate blood and muscle lactate levels, but found no relationship because of their differing clearance rates (muscle faster than blood) [Krustrup, 2006a]. This implied high levels of blood lactate levels taken in studies might not be best representation of the anaerobic workload [Krustrup, 2006a]. The mean muscle lactate levels were over three times higher at the end of game, compared to before the game (13.0 vs. 4.2mmol/kg), and levels were highest after intense periods. The fact that blood lactate levels

were highest after intense periods, suggests a high rate of glycolysis for short periods of time during a game. Two more studies analyzed soccer matches to assess lactate responses [Mohr, 2010; Russell, 2014b]. Mohr analyzed BLa concentrations during a soccer-match, using professional adult male soccer players in Spain [Mohr, 2010]. Mean Blood lactate concentrations were 1.3mmol/L before the game and increased to 4.8mmol/L and 4.0mmol/L after the first and second halves, respectively [Mohr, 2010]. The Russell match-play study found players started the match with BLa levels around ~1.1mmol/L and those levels significantly increased to values around ~5.0mmol/L after 15-minutes of play [Russell, 2014b]. Blood lactate levels were highest during the 30-45minute phase of the match (~5.2mmol/L). BLa levels dropped slightly (~4.5mmol/L) during halftime and second half values mimicked those of the first half [Russell, 2014b].

Soccer match simulations are also used to analyze the effects of soccer exercise on blood and/or muscle lactate levels. The Copenhagen Soccer Test (CST) used by Bendiksen found that muscle lactate was 7.7mmol/kg at rest and increased fivefold, to 23.7mmol/kg, during the initial 15-minutes of the first half [Bendiksen, 2012]. The 23.7mmol/kg value wasn't much different then the values at 60 or 90-minutes. Blood lactate was 1.0mmol/L at rest and 4.6mmol/L after 15-minutes of play. The average BLa values were lower from 45-90minutes (3.2mmol/L) than 0-45minutes (3.9mmol/L), highlighting a decrease in the second half [Bendiksen, 2012]. Two researchers used a laboratory/treadmill based soccer match-play simulation to track physiological responses to soccer [Page, 2015; Greig, 2006]. Page, using adult male semi-professional soccer players as subjects, found baseline lactate values, prior to the match protocol, were 1.13mmol/L [Page, 2015]. The BLa values significantly increased during the first half (2.28-2.57mmol/L) and then returned close to baseline at halftime (1.47mmol/L). Page found blood lactate values peaked

at the end of the match (3.2mmol/L) [Page, 2015]. Greig saw a similar BLa response through the treadmill based soccer simulation, with reduced levels at halftime and peak levels at the end of exercise [Greig, 2006; Page, 2015] However, the initial values (1.1mmol/L) and peak values (1.4mmol/L) were much lower in this study [Greig, 2006]. The field based simulated soccer match (SMS) saw initial BLa values around ~1.2mmol/L [Russell, 2012b]. The study saw sharp and significant increases in BLa values during the first 15-minutes and peak values were achieved (~8.1mmol/L). The BLa values were lower in the second half [~5.6mmol/L] and halftime had a value (~2.5mmol/L) that was close to the rest value [Russell, 2012b]. Lastly, Harper used the SMS to monitor changes [Harper, 2016a]. The study found blood lactate levels increased drastically from their pre-match levels. The first half had the highest blood lactate values (~5mmol/L), with a sharp decrease during halftime (~2mmol/L), and values below the first half during the second half (~4mmol/) [Harper, 2016a].

The general consensus for muscle and blood lactate levels, during a soccer match [Krustrup, 2006a; Mohr, 2010; Russell, 2014b] or simulated soccer match [Bendiksen, 2012; Page, 2015; Greig, 2006; Russell, 2012b; Harper, 2016a], are the lowest levels come during periods of rest (initial and halftime) with a sharp increase during the initial part of the first half. The majority of studies found that there were higher lactate levels during the first half versus the second half [Mohr, 2010; Bendiksen, 2012; Russell, 2012b; Harper, 2016a]. A finding that could suggest less high-intensity movements performed during the second half. An earlier study highlighted the relationship between blood lactate concentrations and high intensity movements, more specifically the intensity of movement performed prior to the blood sample [Bangsbo, 1991]. The lactate concentrations are influenced by a variety of factors such as timing of samples, frequency of samples, and match protocol. However, it's typical to see increased levels

during match play, especially when there is a higher frequency of high-intensity movements such as sprints and accelerations.

Creatine Kinase

A number of soccer studies have looked at the enzyme creatine kinase (CK) to measure the stress and inflammation muscles experience after a soccer match [Schulpis, 2009; Souglis, 2015; Ispirlidis, 2008; Coelho, 2013; Ascensao, 2008]. University male soccer players participated in a competitive match, with blood samples taken before and after, and the physiological demands were analyzed [Coelho, 2013]. The study looked at plasma CK levels and found levels significantly ($p < 0.05$) increased from pre to post-match [Coelho, 2013]. Pre and post-match CK concentrations were around $\sim 150\text{U/L}$ and $\sim 220\text{U/L}$, respectively [Coelho, 2013]. The next study had similar pre-match concentrations, but a larger increase post-match [Coelho, 2013; Souglis, 2015]. Souglis assessed CK concentrations in collegiate soccer players before and after a competitive soccer match [Souglis, 2015]. There was a significant increase (pre to post) in mean plasma CK concentrations after the match. Players, before and after the match, had mean plasma CK concentrations around $\sim 160\text{U/L}$ and $\sim 350\text{U/L}$, respectively [Souglis, 2015]. A study by Ispirlidis analyzed CK levels pre and post match for elite male soccer players and compared them to a control, which was made up of players who did not play in the match [Ispirlidis, 2008]. The results showed both groups had a CK concentration around $\sim 110\text{U/L}$ before the match. After the match, the subjects who played had a 154.3%, significant ($p < 0.05$), increase in their pre-match levels whereas the control subjects saw no change from their pre-match concentrations [Ispirlidis, 2008]. The post-match values and increase from pre to post are similar to the next study [Ispirlidis, 2008; Schulpis, 2009]. Schulpis analyzed CK responses for adult (20 y.o) male soccer players before, at halftime, and after a soccer match [Schulpis, 2009].

The CK concentrations significantly ($p < 0.01$) increased at each blood test interval. The mean CK concentrations before, at halftime, and after the soccer game were 86.0, 116.0, and 286.0U/L, respectively [Schulpis, 2009]. The last study examined CK concentrations of professional adult (21 y.o) male soccer players before and after a soccer match [Ascensao, 2008]. The study only provided a graph of the CK, which made it difficult to interpret specific concentrations. However, the mean pre-match CK concentrations were significantly ($p < 0.05$) lower than the concentrations taken 30-minutes after the match [Ascensao, 2008].

Creatine Kinase concentrations were shown to significantly increase after a soccer match when compared to concentrations before the match began [Coelho, 2013; Souglis, 2015; Ispiridis, 2008; Schulpis, 2009; Ascensao, 2008]. One study took a blood sample at halftime, which showed CK concentrations increased more in second half compared to the first half [Schulpis, 2009].

Free Fatty Acids and Glycerol

Free fatty acids (FFA), or non-esterified fatty acids (NEFA), and glycerol are a by-product of lipolysis. They have gained recognition in soccer research because they provide insight in the metabolic response and substrate utilization of players during a match [Clarke, 2008; Harper, 2016a; Krstrup, 2006a; Bendiksen, 2012]. Three of the studies analyzed FFAs or NEFAs and glycerol responses using simulated soccer-specific protocols [Clarke, 2008; Harper, 2016a; Bendiksen, 2012]. Clarke found that subjects had increases of NEFA's and glycerol as the match progressed, with a slightly higher increase during the second half and highest levels at the end of the match protocol [Clarke, 2008]. NEFA levels before, at halftime, and after the protocol were ~ 0.22 mmol/L, ~ 0.52 mmol/L, and ~ 0.84 mmol/L, respectively [Clarke, 2008]. Glycerol levels before, at halftime, and after the protocol were ~ 62 umol/L, ~ 110 umol/L, and

~180 μ mol/L, respectively [Clarke, 2008]. The next study calculated FFA responses to a simulated soccer match (CST) [Bendiksen, 2012]. The study found players, during the first half (45-min) of the CST, had a mean plasma FFA concentration of 0.155-0.20mmol/L [Bendiksen, 2012]. The first half mean FFA concentration was significantly ($p<0.05$) lower than the halftime (0.613 μ mol/L) and 90-minute/end (0.437 μ mol/L) concentrations [Bendiksen, 2012]. The next study took a blood sample every 15-minutes to analyze NEFA and glycerol levels during a simulated soccer match (SMS). Only some of the data points were available, but a graph depicts the trends and fluctuations between NEFA and glycerol throughout the match [Harper, 2016a]. Mean NEFA concentrations were highest at the end of the SMS with a value of 1.0mmol/L. Values were higher during the second half versus the first half and the value at halftime and 75-minute mark (0.8mmol/L) were the next highest. The value just before halftime (45-minute) was around ~0.5mmol/L, which shows the sharp increase during halftime and the second half [Harper, 2016a]. Glycerol values followed a similar trend, except at halftime, to the NEFA values. The glycerol concentration increased during the first half (~80-100 μ mol/L), decreased at halftime (~80 μ mol/L), and increased to even higher levels during the second half (~150-257 μ mol/L), with the highest at the end of the match (257 μ mol/L) [Harper, 2016a]. All three of these soccer studies, which used simulated soccer match protocols, saw relatively similar trends in FFA, NEFA, and glycerol data [Clarke, 2008; Bendiksen, 2012; Harper, 2016a]. The last study looked at plasma glycerol and FFA before, during, and after a soccer match [Krustrup, 2006a]. At rest prior to the match plasma FFA and glycerol were 0.39mmol/L and 81 μ mol/L, respectively [Krustrup, 2006a]. The study took six blood samples for FFA and three for glycerol, with two of the blood samples taken after periods of intense exercise in each half for both. The FFA concentrations during the first half, after the first half, before the second half, during the

second half, and after the game were 0.55, 0.67, 1.07, 0.74, and 1.37mmol/L, respectively [Krustrup, 2006a]. The glycerol concentration taken during the second half (234umol/L) was significantly higher than the one during the first half (185umol/L) [Krustrup, 2006a].

An increase in blood free fatty acid concentrations across the match, with the largest increase during the second half was a common staple in these studies [Clarke, 2008; Bendiksen, 2012; Harper, 2016a; Krustrup, 2006a]. The halftime period also saw an elevation in FFA concentrations most likely because of the sudden stop in exercise. When the second half begins there is an initial lower level of FFA's in the blood [Krustrup, 2006a; Harper, 2016a]. The reason for this could be due to insulin causing its re-synthesis into fat molecules. The positive trend in FFA levels displays an increase in fat oxidation for energy because the body is running out of CHO for fuel. Glycerol concentrations increased throughout the match, with a greater increase during the second half and highest levels at the end of the match [Clarke, 2008; Harper, 2016a; Krustrup, 2006a].

Catecholamines

Catecholamines haven't been specifically studied in the game of soccer, despite their potential role in substrate utilization and blood glucose concentration. In a review, Zouhal assessed the effects of exercise on catecholamines and found that duration and intensity are the main factors to alter catecholamine response to exercise [Zouhal, 2008]. Catecholamines, specifically epinephrine (adrenaline) and norepinephrine (noradrenaline), should increase throughout a soccer match particularly during short and intense periods of activity. Clarke investigated this metabolic response using a 90-minute soccer-specific exercise [Clarke, 2008]. The study was examining the effects of fluid consumption, but the placebo group subjects (male university soccer players) started and ended the exercise with adrenaline levels of ~0.92nmol/L

and 1.78nmol/L, respectively [Clarke, 2008]. A 2009 study, using professional adult male soccer players in Greece, analyzed the catecholamine response before, during, and after a soccer match [Schulpis, 2009]. The study found that the blood levels of adrenaline and noradrenaline significantly increased in player's post-match. Adrenaline levels before the match, during halftime, and after the match were 230pmol/L (0.23nmol/L), 630pmol/L (0.63nmol/L), and 890pmol/L (0.89nmol/L), respectively. Noradrenaline levels before the match, during halftime, and after the match were 1.53nmol/L, 2.7nmol/L, and 3.70nmol/L, respectively [Schulpis, 2009]. A study, using a SMS, found adrenaline levels were highest at the end of the game (14.98nmol/L) compared to other blood samples taken at five times [Harper, 2016a]. The players mean plasma adrenaline levels at the start, before halftime, during halftime, 60-minutes, and after the game were ~2.49nmol/L, ~6.49nmol/L, ~2.99nmol/L, ~6.74nmol/L, and ~14.98nmol/L, respectively [Harper, 2016a]. Nalbandian analyzed the effects of an active versus passive recovery period, in-between exercise bouts, on catecholamine response [Nalbandian, 2017]. The study found that adrenaline levels increased during the active recovery compared to the passive recovery period [Nalbandian, 2017]. The finding highlights that periods of rest blunt the actions of catecholamines.

After reviewing the blood glucose trend literature, it's possible that catecholamine response during periods of rest [Schulpis, 2009; Nalbandian, 2017] influences the lower blood glucose levels after halftime [Harper, 2016b]. The decrease in catecholamines, specifically adrenaline, during periods of rest versus activity (i.e. halftime) could potentially explain the blood glucose drops because of an increased insulin level. The Clarke study showed that an increase in adrenaline equated to a reduction in insulin levels [Clarke, 2008].

Cortisol

The studies that focused on the muscle damage and inflammation response to soccer demands are the main ones that tracked cortisol levels. Sari-Sarraf analyzed the effects of soccer-specific intermittent exercise on cortisol responses and found that the response found during soccer-specific, or laboratory based, protocols didn't highlight the ones in matches [Sari-Sarraf, 2008]. Therefore, the assessment of cortisol levels should be completed through match play for the best evaluation of physical and psychological stress in soccer [Sari-Sarraf, 2008]. The following match studies either took salivary [Thorpe, 2012; Edwards, 2006] or plasma [Souglis, 2015; Coelho, 2013; Ispiridis, 2008] cortisol levels. Thorpe analyzed cortisol levels in adult male semi-professional soccer players before and after a competitive soccer match [Thorpe, 2012]. The cortisol levels, taken via saliva, pre and post match were 10.09nmol/L and 14.88nmol/L, respectively. The post-match values were a ~47% increase, but this was significant ($p=0.01$) because of the large variation seen between levels for subjects. This study only used seven subjects ($n=7$) [Thorpe, 2012]. However, the increase in cortisol levels is still relevant and indicative of physical and psychological stress. A study by Edwards looked at salivary cortisol responses, in male collegiate soccer players, after a soccer match. The study found pre-match and post-match cortisol levels around ~8.55nmol/L and ~20.14nmol/L, respectively [Edwards, 2006]. The match played resulted in a win, which could contribute to the increase level. The study also analyzed the salivary cortisol levels of players who did not play and found a pre-match level (~14.07nmol/L) higher than post-match (~5.79) [Edwards, 2006].

Three studies analyzed plasma, or blood, cortisol levels before and after a competitive soccer match [Souglis, 2015; Coelho, 2013; Ispiridis, 2008]. The Souglis and Coelho studies used male collegiate soccer players as their subjects [Souglis, 2015; Coelho, 2013]. In the Souglis study, the pre and post match plasma cortisol levels were ~325.52nmol/L and

~667.31nmol/L, respectively. The post-match value was a 105% increase from the pre-match value [Souglis, 2015]. Coelho found a similar increase (~69%), pre and post-match plasma cortisol levels of 391.72nmol/L and 565.52nmol/L, respectively [Coelho, 2013]. Ispirlidis took plasma cortisol levels before and after a soccer match played by professional adult male soccer players [Ispirlidis, 2008]. There was an increase of 50.3% from cortisol levels before the match (~275nmol/L) to after (~413nmol/L) [Ispirlidis, 2008]. All three of these studies found significant increases in plasma cortisol levels [Souglis, 2015; Coelho, 2013; Ispirlidis, 2008].

After reviewing the response of cortisol in soccer matches, I found that the studies that took plasma cortisol levels found more significant results between the pre and post-match blood samples [Souglis, 2015; Coelho, 2013; Ispirlidis, 2008]. Many variables contribute to the cortisol response, such as physical and psychological stresses [Thorpe, 2012; Sari-Sarraf, 2008]. It's hard to measure the exact reasoning for an increase in cortisol following a soccer match, but an increase is typical and common during a match.

Summary

A variety of factors influence metabolism during soccer. For instance, the duration and intensity at which a player moves influences the metabolic response. In general, blood metabolites and hormones fluctuate throughout a soccer match, partaking in different trends as the 90-minute match progresses. During intense exercise, epinephrine and cortisol levels in the blood are increased and insulin release is suppressed. The combination of catecholamine increases and insulin decreases, stimulates glucose release from the liver thus elevating blood glucose levels, which provides muscle with an ample supply of carbohydrate for energy production. Blood lactate suppresses the mobilization of fatty acids from the adipose tissue, therefore high levels of blood lactate are typically found in the first half because of less use of

FFAs. However, as exercise progresses and glycogen stores deplete the amount of FFAs increase. During recovery or rest periods, such as halftime, the metabolic responses change within minutes. Catecholamine levels subside and insulin levels rise, which stimulates glucose to move into the liver (and muscle) to be stored as glycogen. These metabolic responses to soccer have the ability to impact performance, specifically blood glucose and insulin because of their responses during the halftime period. This review will look at how nutrition and exercise intervention can influence these metabolic responses.

Second Half Performance

Earlier, the physical demands of soccer were reviewed. Many of the soccer studies that assessed the physical demands discovered a common trend in performance measures. The second half is a period that is associated with a decrease in physical performance measures [Mohr, 2003; Bradley, 2009; Weston, 2011]. A research study, discussed later, concluded that it's difficult to establish a casual relationship between physical performance variables (distance, sprints, speed) and match outcome [Mackenzie, 2013]. However, there is an obvious decline in physical performance measures throughout the second half when compared to the first half [Van Gool, 1987; Bangsbo, 1991; Bangsbo, 1994a; Bangsbo, 1994b; Mohr, 2003; Rampinini, 2007; Randers, 2010; Wehbe, 2014; Torreno, 2016; Bradley, 2009; Bradley, 2013a; Weston, 2011; Lovell, 2009; Russell, 2016; Burgess, 2006]. The reasoning for this decrement can be attributed to a multitude of factors, but an ability to attenuate this decline and control those factors could provide benefits to players and the team. The studies that analyze match performance, specifically differences between the first and second half, employ a variety of mechanisms to measure the physical performance. Later discussed, it's difficult to compare the specific results

from different measurement systems, but the same trend is seen across each study [Randers, 2010].

The literature has reported a decrement in the physical performance of soccer players during the initial phase of the second half of competitive match play. The total distance covered is a common measure to analyze a player's physical performance, which is touched on in the performance measures section. Several studies have compared the distance covered by professional soccer players from various countries [Barros, 2007; Bangsbo, 1991; Mohr, 2003; Rienzi, 2000]. Danish professionals covered a 5% shorter distance in the second half when compared to the first [Bangsbo, 1994]. Belgian university games showed a 9% lower distance travelled in the second half, despite negligible differences in the distance travelled at higher intensities between halves [Van Gool, 1987]. Elite Italian professionals also travelled less distance (3%) in the second half when compared to the first [Mohr, 2003]. Weston analyzed the distance covered by professional players in England, specifically during the initial 15-minute period of the first and second halves. The study found a 6% decrease in total distance covered during the initial period of the second half compared to the first half [Weston, 2011]. **Table 1** summarizes a number of studies, specifically looking at the match half differences in total distance covered.

In addition to total distance covered, the distance covered at high speeds has been shown to be reduced in the first 15-minutes of the second half in comparison with the corresponding period of the first half [Bradley, 2009; Weston, 2011]. Mohr conducted a study to analyze and compare the movements of top-class and moderate level professional soccer players using video recordings and a computerized system, which analyzed each movement across all 129 matches. Both groups covered a greater distance in high-intensity running during the first 5-minutes of the

half than during the first 5-minutes of the second. There was also a higher total distance covered during the first half versus second half [Mohr, 2003]. Another study, analyzed the match demands of professional soccer players in Australia. Sixty-five hours of game film, through videotapes, was assessed and analyzed to compare match-half differences. Despite equal time of both halves of the game, the second-half distances and mean speeds were lower [Burgess, 2006]. A greater proportion of the second half was spent standing or moving at a slower speed [Burgess, 2006]. Bradley analyzed the movement data, using a computerized tracking system, of professional male soccer players in England across two consecutive seasons [Bradley, 2013b]. The study found reductions of 4–7% for total distance covered in the second half for players maintaining ‘moderate’ and ‘high’ levels of activity in the first half. Maintaining ‘high’ levels of activity in the first half resulted in 12% less high-intensity running in the second half. The total distance and high-intensity running were significantly greater in the first versus the second half [Bradley, 2013b].

Research demonstrates that high-intensity running declines from the first to the second half of a match [Di Salvo, 2009; Mohr, 2003]. Several studies used GPS to analyze match performance and found similar decrements [Torreno, 2016; Wehbe, 2014; Russell, 2016]. The first study monitored the activity patterns of elite soccer players in Australia during eight soccer matches [Wehbe, 2014]. The percent time spent in low-intensity activity (standing, walking, and jogging) in the first and second halves were 90.62 and 91.71%, respectively. Percent time spent in high-intensity (running, high-speed running, and sprinting) in the first and second halves were 9.38 and 8.29% respectively. In the second half, percent time spent standing and walking significantly increased, whereas percent time spent jogging, running, and high-speed running significantly decreased compared with the first half. Total distance, average speed, high-intensity

running distance, and very high-intensity running distance significantly decreased from the first half by 7.92, 9.47, 10.10, and 10.99%, respectively, in the second half [Wehbe 2014]. The next study found a substantial decrease in total distance and distance covered in the second half for all players [Torreno, 2016]. The study confirmed a decrement in a player's performance toward the end of a match in all playing positions [Torreno, 2016]. In 2016, Russell found significant decreases in total distance, number of accelerations, and number of decelerations during the second half when compared to the first half [Russell, 2016].

The Mohr study also analyzed specific high-speed movements and work-rate changes between soccer halves [Mohr, 2003]. Given that Mohr found performance declines in the first 5 minutes of the second half in comparison to the first half, the research also found significant declines in accelerations (~9%, $p=0.004$) and decelerations (~9%, $p=0.005$) when analyzing each 45-minute half of play. High-intensity running decreased during the second half of match play [Mohr, 2003]. A similar study conducted at youth level analyzed total distance covered during each half and running speed with the use of GPS [Lovell, 2009]. Thirteen youth team players (16-18 years old) representing an English League One club wore 5Hz GPS units in 10 competitive games. In the second half total distance decreased by 18% compared to the first half [Lovell, 2009]. Similar decrements were recorded for the different speed thresholds such as high intensity running (20%), very high intensity running (20%) and sprinting (24%) [Lovell, 2009]. Another study that analyzed English FA Premier League Players found comparable results with a decline of 4.7% and 12% in total distance and high-intensity running respectively [Bradley 2013a]. These results further emphasize original research findings by Bangsbo [Bangsbo, 1991; Bangsbo, 1994a]. Those research studies indicated that the distances completed at a high to maximal speed are shorter, and the number of discrete sprints fewer, in the second half of a

match compared with the first half [Bangsbo, 1994a; Bangsbo, 1991]. A 2010 study, which analyzed match demands using four different systems, found that total distance covered and high-intensity running declined in the second half compared to the first [Randers, 2010]. Total distance covered and distance covered in high-intensity running in the second half assessed with the multiple-camera system, time-motion analysis, GPS- 1, and GPS-2 were lower ($p \leq 0.001$) than in the first half for all systems ($\sim 7.4\%$, $\sim 10.4\%$, $\sim 7.2\%$, $\sim 10.1\%$ and $\sim 20.0\%$, $\sim 27.2\%$, $\sim 20.2\%$, $\sim 21.9\%$), respectively. Time-motion analysis and GPS-1 detected significantly ($p \leq 0.001$) less distance covered with sprinting during the second half compared with the first ($\sim 27.3\%$ and $\sim 38.6\%$), respectively [Randers, 2010].

The second half is an important period during a soccer match. Two studies analyzed soccer matches to define the moments when the most goals are scored. The first study analyzed two seasons in the top leagues of England, France, Italy, and Spain [Alberti, 2013]. The study found, after analyzing 4,560 matches, that a significantly higher number/percentage of goals (55%) were scored in the second half. The most goals were scored in the last 15-minutes of a game, while the first 15-minutes of the second half had the 2nd or 3rd most depending on the league [Alberti, 2013]. The next study found that the most goals were scored in second half with the 1st, 2nd, and 3rd most likely intervals for goals scored were 75-90min, 30—45min, and 45-60minute, respectively [Armatas, 2009]. Perhaps, there lies an association between high-speed running and crucial moments during a game, such as goals scored. Any intervention that might attenuate some or all of the decrements evident in distance, high-speed running, and work-rate during the second half of matches could have important performance outcomes.

Although it's difficult to correlate, the decline in physical performance during the second half could be an indicator for a variety of outcomes. For instance, two sources highlight an

increased injury rate during the second half [Ekstrand, 2011; NCAA, 2010]. Ekstrand analyzed the occurrence of injuries suffered by European professional soccer players in soccer matches over the course of seven seasons. It was found that the majority of injuries occurred during the second half [Ekstrand, 2011]. The NCAA reviewed the overall injury rate in men's soccer matches across five seasons. They found more injuries occurred in the second half (50.5 percent) versus the first half (34.2 percent) of competitions [NCAA, 2010].

The down regulation of running performance in the second half could be attributed to numerous factors such as fatigue [transient and end game], contextual/tactical factors, and personal choices [Paul, 2015; Alghannam, 2012]. The decrement in the second half is courtesy of several physiological changes [Alghannam, 2012]. Given the importance of the second half and the obvious decrement during the second half, specifically the initial 15-minutes of the second half, there is an opportunity to lessen the decline. The halftime period offers an opportunity to address potential interventions to make a marginal difference [Russell, 2014b]. Although marginal differences describe small changes, they can play an impact in the complexion of a competition. The marginal gains can make a difference in outcomes. A team should address every variable that could influence an outcome or result. The second half is associated with a decline in distance covered, high-speed intensity movements, distance covered at high-speed, accelerations, decelerations, and work-rate [Van Gool, 1987; Bangsbo, 1991; Bangsbo, 1994a; Mohr, 2003; Rampinini, 2007; Randers, 2010; Wehbe, 2014; Torreno, 2016; Bradley, 2009; Bradley, 2013a; Weston, 2011; Lovell, 2009; Russell, 2016]. In addition to these physical performance decrements, goals and injuries increase during the second half [Alberti, 2013; Armatas, 2009; Ekstrand, 2011; NCAA, 2010]. The relationship is difficult to define during a

soccer match, but it can be assumed that a smaller decrement in physical performance can influence outcomes.

Halftime Interventions

Given the decrement during the second half, many studies have focused on ways to attenuate the decline. Soccer is a team sport that has a half time, or intermission, period that intervenes the two 45-minute halves. The half-time period is 15-minutes in duration at the majority of youth levels and all collegiate and professional levels [FIFA, 2016]. The strategies and activities that take place during the 15-minute half-time period are different for each player and team. The team, coach, and player will generally tailor this period to accommodate the needs and desires present [Towlson, 2013]. A study was done to determine the typical half-time practices for professional soccer teams in England. Forty-four teams and coaches were surveyed to better define and record the activities and strategies that take place during the half-time period [Towlson, 2013]. The Towlson study concluded that the make-up of the 15-minute period was allotted as follow: 2-minutes was spent leaving the field to return to the locker room, 3-minutes for “player’s time”/injury treatment, 2-minutes for a coach/team talk, 2-minutes for an individual coach/player interaction, and the last 6-minutes was time for addressing kit/equipment issue and a rewarm-up (3-min). The player’s had the entire 15-minute period to rehydrate and consume any nutrition practices [Towlson, 2013]. This study highlighted that players and teams, playing professionally in England, do not frequently utilize an active rewarm-up in an applied setting with only 58% of coaches reporting a rewarm-up prior to the 2nd half [Towlson, 2013].

A variety of research studies have addressed half-time strategies that could influence and enhance performance during the second half. The majority of studies have looked at heat maintenance strategies or ergogenic aids such as carbohydrates [Mohr, 2004; Edholm, 2014;

Lovell, 2013a; Zois, 2013; Russell, 2015a; Russell, 2015b; Kingsley, 2014; Russell, 2012; Ali, 2009; Ali, 2007; Goedecke, 2013].

Heat Maintenance: Active Rewarm-Up

Soccer players perform a warm-up prior to participation in a game or practice in order to prepare their body for the impending demands. A warm-up prepares players both physical and mentally, reduces the risk of injury, and enhances performance [McArdle, 2007; Woods, 2007; Barengo, 2014; Kistler, 2010]. The idea is that a warm-up increases muscle and body temperature, increases blood flow, actively engages the muscles, and influences metabolic responses [Maughan, 2004; McArdle, 2007; Mohr, 2004; Edholm, 2014; Lovell, 2013a] Team sports often contain an extended period of time when play is halted for an intermission that commonly consists of rest, recovery, and preparation for the subsequent bout of exercise [Russell, 2015a].

Heat maintenance strategies have been used in an effort to assess their effect on muscle temperature and subsequent performance. One study used a passive heat maintenance strategy, a heated jacket, at halftime to assess performance in rugby players. The study wasn't analyzing soccer players, but it concluded that the heated jacket increased muscle temperature during halftime leading to improved peak power output and repeated sprint ability. A more commonly practiced form of heat maintenance is an active rewarm-up [Edholm, 2014; Zois, 2013; Lovell, 2007; Lovell, 2013; Mohr, 2004]. In 2004, Mohr analyzed the muscle temperatures of players during two 90-minute friendly soccer matches. The studies intervention took place at halftime, with one group of players completing an active rewarm-up (7-min, moderate intensity) while the other group (control) performed no activity during the halftime period [Mohr, 2004]. Mohr observed initial elevations in muscle and core temperature during the first half, but during the

passive (control) halftime period the players' muscle and core temperature decreased markedly (2.0 and 1.0 degrees Celsius, respectively). The active rewarm-up group experienced no difference in muscle or body temperatures [compared to baseline]. There was no difference in sprint performance at the end of the game, but the control group experienced a significant drop in sprint performance prior to the second half (~2.4%) [Mohr, 2004]. The control groups' muscle and core temperatures didn't reach baseline levels until 5-minutes into the second half. The study indicates muscle temperature has an impact on sprint performance and can influence the opening stages of the second half [Mohr, 2004]. Edholm performed a similar study to this study and utilized the same rewarm-up (RWU) protocol at halftime. This study consisted of two 90-minute matches separated by 6-days [Edholm, 2014]. The study aimed to examine the acute effects of a halftime rewarm-up on performance and movement patterns in soccer match play. It was a crossover study, so subjects took part in both the rewarm-up and control (passive) groups across the two matches [Edholm, 2014]. The active halftime RWU reduced the decreases in sprint and jump performances seen for the control (CON) group. The CON group had a significant reduction (2.6%) in sprint performance (compared to RWU) prior to the 2nd half. Another finding was that both CON and RWU had less distance covered in the initial 15-minutes of the 2nd half (compared to initial 15-min of 1st half), but the CON group had a greater reduction (9% vs. 4%) [Edholm, 2014]. Lovell completed two studies looking at the effects of an active half-time period. [Lovell, 2007; Lovell, 2013b]. The first study used an uncommon simulated soccer test, which raises some flags when analyzing the results [Lovell, 2007]. There was a 15-minute HT, but the "soccer halves" were only 16.5-minutes long. Lovell looked at the effects of four different halftime strategies on endurance performance and muscle temperature in 17-year-old male soccer players. The rewarm-up consisted of a 7-minute cycle or

7-minute repeated sprint drill and both were performed at an intensity that was 70% of the max heart rate. The study found an active RWU at halftime maintained the distance covered in the second half, but when players rested passively their distance was reduced (~4%) [Lovell, 2007]. The more recent Lovell study used a 90-minute simulated soccer match (SAFT) that had physiological demands indicative of an actual soccer match [Lovell, 2013b]. The 15-minute HT period contained the intervention with three separate groups that were a control (passive for 15-minutes), intermittent agility exercise (IAE: 5-min), and whole body vibration (WBV: intermittent for 5-min). Lovell found that IAE reduced the decreases in muscle temperature and soccer-specific sprint, power, and dynamic strength performance that were seen for the control group. The control experienced a 1.5 degree Celsius decrease in muscle temperature, similar to the Mohr study [Lovell, 2013b; Mohr, 2004]. This study saw the greatest decrease, compared to other HT intervention sprint studies, in sprint performance after a passive HT period (6.2%). The study also found that the control group was the only group who had reduced eccentric hamstring dynamic strength after the HT period [Lovell, 2013b]. Decreased eccentric hamstring strength is associated with hamstring strain injuries, which a 2004 study found was the most common injury in soccer players [Woods, 2004]. Zois also utilized an uncommon soccer exercise protocol for his study that assessed the effects of a halftime rewarm-up [Zois, 2013]. The study had two periods of a 26-minute intermittent activity protocol (IAP) separated by a 15-minute halftime, which contained the rewarm-up interventions. There was a control group (passive) and two rewarm-up groups, where one group completed a 3-minute small-sided game (SSG) and the other a 5-rep maximum (5RM) leg press. [Zois, 2013] These rewarm-ups were unique to this type of study and Zois wanted to highlight specific advantages each may have on performance. The main finding was that the SSG rewarm-up group had a better passing performance post-HT

and post-IAP when compared to the control group (14.7% and 17.7%, respectively) [Zois, 2013]. This finding could suggest that inclusion of a SSG into the rewarm-up can result in improved skill performance during the 2nd half. An earlier Zois study reported that SSG warm-ups can improve acute physical performance in soccer players [Zois, 2011] and a review found similar results in regards to small sided-game activities, indicating they may be an effective re-WU strategy aiding the performance of skilled tasks pertinent to team-sports [Ali, 2011; Zois, 2011].

The benefits of an active rewarm-up at halftime are documented, but it's still not common practice due to worries of fatigue and time [Edholm, 2014]. Lovell completed another study to re-examine the second half work rate of male youth soccer players (~17 y.o), following a passive HT period, using GPS units [Lovell, 2013a]. He found that the passive HT period resulted in transient reductions in performance. There was a large reduction in relative total distance covered, low-speed running, and high-speed running during the opening 5-minute phase (45-50min) of the 2nd half when compared to the means of the first half (0-45 min). There were trivial effect size differences in these same measures during the next 10-minutes (50-60min)[Lovell, 2013b].

The following studies didn't look at a rewarm-up, but rather the initial warm-up prior to the start of a match [Fletcher, 2010; Little, 2006]. It has been demonstrated that a prematch warm-up (WU) containing dynamic stretching (DS) caused an increase of 6.2% in knee extension peak torque and an improvement of 3.9% in vertical jump height [Fletcher, 2010]. The authors also reported that HR and core temperature were higher after DS than after static stretching (SS). These increases in HR and core temperature could result in an increase in the blood flow, increase sensitivity of nerve receptors, and may explain partly the improvement in muscle performance enhancement. Moreover, it has been reported that professional soccer

players increased sprint (2.1%) and agility performance (1.1%) after WU based on DS, compared with general WU without stretching. Warm-ups that include DS as opposed to SS or no stretching are most effective in the improvement of strength and high-speed performances in soccer [Little, 2006]. WU with SS significantly reduced physical performance in soccer players compared to WU without stretching or other types of WU. Muscle strength and vertical jump performance are reduced after a WU containing SS [Zakas, 2006; Fletcher, 2010]. Moreover, WU that contained SS reduced specific performances such as dribbling, speed, and penalty kick performance [Gelen, 2010]. Furthermore, WU containing SS negatively impacted physiological outcomes (HR, core temperature). Fletcher showed that HR and core temperature were significantly higher following WU without SS (jogging or DS) compared with WU with SS [Fletcher, 2010].

In conclusion, the effect of different re-warm-up (RWU) strategies on physical and physiological outcomes in soccer players was investigated in five studies [Lovell, 2013a; Lovell, 2013b; Zois, 2013; Lovell, 2007; Edholm, 2014; Mohr, 2004]. Two studies used 90-minute soccer match and the three others used different intermittent specific activity [Edholm, 2014; Mohr, 2004; Lovell, 2007; Lovell, 2013b; Zois, 2013]. Almost all studies reported that active RWU reduced the negative impact induced by passive half-time practices both on physiological (heart rate; HR, core temperature) or performance outcomes (jump, sprint, distance covered). Overall, Edholm and Lovell found that a passive HT period leads to impaired performance when compared to active re-warm up period [Edholm, 2014; Lovell, 2013a; Lovell, 2013b]. A passive HT period resulted in impaired sprint, jump, dynamic strength, and work-rate after halftime and during the initial phase of the second half [Edholm, 2014; Lovell, 2013a; Lovell, 2013b]. The studies employed a 5-7 minute re-warm up that consisted of SSG, sprints, IAE, strength tests or

cycling [Mohr, 2004; Lovell, 2007; Lovell, 2013a]. An active RWU significantly attenuates the temperature and performance decrement during halftime and second half period in soccer players. Although often considered crucial for tactical reasons, half-time periods can be physiologically considered as a recovery and a preparatory period preceding subsequent competition [Towlson, 2013]. RWU studies are currently scarce in existence, but it seems that traditional passive halftime period during soccer match causes temporary impairment in the players' physical performance capacity. Soccer-specific activity completed at high-intensity with short durations may provide an ergogenic aid for subsequent physical performance. It's also noted that players benefit from DS versus SS, even though this was during the initial WU and not a RWU [Fletcher, 2010; Little, 2006; Zakas, 2006]. Moving forward, it's important to incorporate a RWU that involves some combination of previously established exercise that also incorporate commonly practiced exercises by teams.

CHO supplementation

Glycogen and Performance

Many sports are characterized by high-intensity bouts of exercise interspersed with short bouts of lower intensity exercise or rest. Soccer is one of these intermittent exercise sports. The importance of carbohydrates (CHO) for these types of sports is well known [Cermak, 2013]. The role and effects of carbohydrates during intermittent sports has been studied for years. Some of the first soccer studies highlighted the importance of CHO and glycogen stores on performance.

During the 1970s, researchers were studying the role of carbohydrates in soccer. The first study didn't have an English translation, but several reliable sources reported on the paper (Bangsbo, 1994; Ekblom, 1986; Tumilty, 1993). The study, performed by a Swedish scientist, found that muscle glycogen depletion, during games, could be as high as 84% [Agnevik, 1970].

Muscle biopsy samples were taken from eight players to examine glycogen depletion. There were three main take a ways from this study. First, the muscles of players were nearly emptied of glycogen after a match. Second, the greatest amount of glycogen depletion occurred in the first half of the match [Agnevik, 1970]. This correlated well with the results of another study that found soccer players ran less in the second half than in the first half, presumably because they were running out of fuel [Reilly, 1976]. Third, the initial level of muscle glycogen in the players at the start of the game was very low and similar to that of an untrained person, suggesting these soccer players weren't consuming adequate dietary carbohydrates prior to games [Agnevik, 1970]. These findings are similar to a study by Saltin, who looked at muscle biopsies of soccer players throughout a soccer match and found that muscle glycogen occurred throughout a game [Saltin, 1973]. The depletion had a significant effect on performance. The players who began the game with higher muscle glycogen concentrations completed more high-intensity runs (24% vs. 15%), covered more distance (12km vs. 9.7km), and did less walking (27% vs. 50%) when compared to the players who began the game with low glycogen concentrations (45mmol/kg). [Saltin, 1973].

These studies highlighted the need for CHO during a soccer match, leading to the recommendations of CHO supplementation before and during a soccer match [Thomas, 2016; Burke, 2011; Williams, 2015; Holway, 2011]. CHO consumption prior to exercise provides adequate glycogen stores to help exercise capacity and CHO consumption during supplies those stores while maintaining blood glucose levels [Thomas, 2016; Burke, 2011; Fink, 2015]. The research shows CHO supplementation has positive effects on physical and soccer-specific skill measures [Welsh, 2002; Davis, 2000; Patterson, 2007; Foskett, 2008; Davison, 2008; Ali, 2007;

Ali, 2009; Northcott, 1999; Currell, 2009; Russell, 2012; Zeederberg; 1996; Ostojic, 2002; Russell, 2014a].

CHO supplementation and Physical Performance

Several studies have looked at how CHO supplementation can aid glycogen preservation. Only a few researchers have looked at the effects of CHO supplementation during an actual soccer match [Leatt, 1989; Kirkendall, 1988]. Leatt was one of the first researchers to investigate the effects of carbohydrate ingestion on muscle glycogen depletion during a soccer match. A myriad of factors can influence the physical demands of a soccer game. The study controlled most of the variables that have been shown to influence match demands [Carling, 2008]. The study examined an intra-squad exhibition match. It was found that a 7.0% glucose polymer beverage consumed, before and during halftime of the match, resulted in a 39% reduction in muscle glycogen use when compared to the placebo group [Leatt, 1989]. However, this study only analyzed ten subjects and there was variable timing between the post-match blood and muscle samples. The next study, which examined video data to assess performance of soccer players, looked at the effects of CHO supplementation before and during a match [Kirkendall, 1988]. Players received 400ml (13.5oz) of a 23% glucose-polymer drink or placebo before and at halftime of outdoor matches. The study showed that the carbohydrate supplement increased overall running distance by 20%, with a 40% increase in distance run at speed (cruise and sprint) during the second half. Kirkendall reported that most players in his experiment could perceive a difference in performance between drinks [Kirkendall, 1988]. These are two of the first studies examining an actual match. These studies are often times ridiculed because of the high-variability between matches due to the complex interactions between physical and technical components [Gregson, 2010]. One can reduce the match-to-match variability by controlling as

many variables as possible such as playing formation, weather, field type, competition level, etc. The majority of studies have incorporated simulated soccer match protocols in order to better assess the demands soccer players face.

Commonly, laboratory and field based studies are used to assess effects of carbohydrate supplementation on exercise performance and capacity. However, the majority of studies have incorporated simulated soccer match protocols in order to better assess the demands soccer players endure. A study by Bendiksen looked at players blood metabolites during the Copenhagen Soccer Test (CST), which is one of the commonly used simulated soccer match tests [Bendiksen, 2012]. The CST study found that sprint performance decreased as the match progressed and glycogen concentrations reduced 50% from resting levels [Bendiksen, 2012]. Bendiksen found that muscle glycogen use was highest in the first 15-minutes of the CST, which is similar to actual match player [Mohr, 2003; Mohr, 2010]. In studies where muscle glycogen concentration has been measured, carbohydrate ingestion has also been shown to attenuate muscle glycogen depletion during a soccer match [Winnick, 2005] and following intermittent shuttle running [Nicholas, 1999]. A study analyzed the effects of a CHO rich diet prior to a 90-minute soccer match [Balsom, 1999]. The study found that players, who consumed the high CHO diet (65% vs. 30% of total daily energy intake), had higher pre-match glycogen stores and performed significantly more high-intensity exercise during the match. There were no observed technical differences between the two groups, suggesting the CHO diet didn't influence skill performance [Balsom, 1999].

The Loughborough Intermittent Shuttle Running Test (LIST) is another protocol designed to mimic the demands of team sports, specifically soccer [Nicholas, 2000]. Nicholas found the same reductions in muscle glycogen stores when comparing the players before and

after the LIST. Nicholas used the LIST in a study to examine the effects of a 6.9% CHO beverage on muscle glycogen depletion. Nicholas found that CHO supplementation, compared to a placebo, resulted in 22% reduction in muscle glycogen usage, which highlights more preservation of muscle glycogen [Nicholas, 1999]. An earlier study by Nicholas saw players had a 33% improvement in intermittent exercise capacity during the LIST when the CHO beverage was consumed before and during the test protocol. The supplementation did not improve sprint performance during the LIST [Nicholas, 1995].

Physical performance is a common measure within the game of soccer. The LIST protocol has shown CHO supplementation improves exercise capacity in numerous studies [Welsh, 2002; Davis, 2000; Patterson, 2007; Foskett, 2008; Davison, 2008]. The studies varied in type of subjects, amount of CHO-E % solution, and when the CHO-E was supplemented but each study found the same result of improved performance. Welsh used a modified version of the LIST protocol and had five male and five female subjects [Welsh, 2002]. The subjects consumed a 6% CHO-E beverage before and throughout the LIST, while also receiving an 18% CHO-E beverage at halftime. The supplemented subjects, compared to the placebo subjects, had a 37% longer time to exhaustion and significantly faster sprint performance during the final 15-minutes. However, this modified version of the LIST protocol wasn't tested for validity or reliability. [Welsh, 2002]. The next study gave eight male subjects a 6.0 % CHO-E beverage before and every 15-minutes during the LIST protocol and found a 32% longer time to exhaustion for the supplemented subjects, when compared to the placebo subjects [Davis, 2000]. Patterson used a CHO gel instead of a beverage. The gel was compared to a placebo beverage and not a placebo gel [Patterson, 2007]. The subjects supplemented with the CHO gel had a 45% longer time to exhaustion, than the placebo group, during the LIST [Patterson, 2007]. Foskett used a valid and

reliable modified LIST protocol to test a 6.4% CHO-E beverage [Foskett, 2008]. The players received the beverage before and during the LIST and performed 21% longer. There was a crossover design, so each subject received the placebo and CHO-E beverage during the study [Foskett, 2008]. Davison used a valid and reliable modified LIST protocol to examine the effects of a 6.0% CHO-E beverage, consumed before exercise, on performance [Davison, 2008]. The ten subjects were untrained and only received the beverage 15-minutes prior to the LIST. The supplemented players had an 8% longer time to exhaustion [Davison, 2008]. The LIST protocol doesn't allow for a subject to alter their work rate, therefore the CHO effects on performance are difficult to quantify. The results are contentious and only certain studies highlighted an improved sprint performance during the LIST [Ali, 2007; Winnick, 2005; Welsh, 2002]. Ali supplemented players with a 6.4% CHO-E beverage before and every 15-minutes during an extended LIST and found a significantly faster mean sprint performance during the protocol for supplemented players [Ali, 2007]. The next two researchers found the same significantly faster sprint performances during the final 15-minutes of a modified LIST for supplemented players, but their modified LIST protocol wasn't tested for validity or reliability [Winnick, 2005; Welsh, 2002]. The next study assessed the role effect of CHO supplementation on a players perceived exertion, perceived activation, and blood glucose during a 90-minute simulate soccer match [Backhouse, 2007]. The study found that when players consumed the 6.4% CHO beverage during the trial, they had a lower perceived activation and exertion when compared to the placebo. This suggests a physiological benefit to carbohydrate supplementation for players during a match [Backhouse, 2007]. The nutritional status prior to the studies is a variable that can have major influence on results. Three studies used test subjects who were in a fasted state [Nicholas, 1995; Welsh, 2002; Ali, 2007]. The Foskett study, which saw a 21% increase in exercise capacity for the CHO

supplemented groups, made sure the subjects had well-stocked muscle glycogen stores prior to the LIST [Foskett, 2008]. The carbohydrate loading, which was a high CHO diet for 48 hours before repeating the LIST, increased muscle glycogen levels by about 50%, when compared to their baseline values. After the 90-minute LIST, players continued running till fatigue. The players receiving the CHO-E beverage lasted 27 minutes longer than the placebo players [Foskett, 2008]. One researcher addressed the nutritional status question in a study [Goedecke, 2013]. The study examined the effect of carbohydrate ingestion on performance during a modified LIST. All of the players were in a postprandial state and ingested either a 7.0% CHO-E beverage or a placebo during the LIST protocol [Goedecke, 2013]. The results showed there was no difference in ratings of perceived exertion [RPE], agility, or time to fatigue between the CHO and placebo groups. However, the players with lower body weights had an increased time to fatigue when they ingested CHO, but not placebo. The study highlights that when players consume normal pre-match nutrition, CHO supplementation has little effect on performance [Goedecke, 2013]. The study only provided 28g of CHO per hour including the 15-minute warm-up period. That CHO dose total doesn't fall in the suggested range of 30-60g of CHO/hour for this type of activity [Burke, 2011; Thomas, 2016]. The study highlights that CHO beverage provided wasn't enough to influence performance for larger body mass players. Also, this study didn't advise the players on what to consume. Instead, Goedecke told the subjects to eat as they normally do before the match [Goedecke, 2013]. The next study assessed the effects of carbohydrate supplementation strategies on sprint performance in recreational soccer players during a 90-minute simulated soccer match [Kingsley, 2014]. Kingsley had three trial groups made up of a High CHO (H-CHO) group, CHO group, and placebo group. The H-CHO ingested both a 9.6% CHO-E beverage, with caffeine, and CHO gels prior to the match and during

halftime. The CHO group received a 5.6% CHO-E beverage with placebo gels and the placebo group received a placebo beverage and gels [Kingsley, 2014]. Since the H-CHO beverage included caffeine the results aren't indicative of the effects of CHO. The 5.6% beverage didn't result in a significant improvement in sprint performance, when compared to the placebo group, even though this group had a higher mean sprint speed than the placebo (5.66 vs. 5.58 m/s, respectively) [Kingsley, 2014]. A recent study by Funnell looked at the effects carbohydrate ingestion had on movements during a modified LIST when players were in a fed state [Funnell, 2017]. He found that ingestion of a 12% CHO-E beverage didn't affect self-selected running or sprint performance during a modified LIST [Funnell, 2017]. Harper also examined the influence of a 12% CHO-E beverage on physiological and performance effects during a 90-minute simulated soccer match [Harper, 2017]. The players ingested the beverage before the game and at halftime. The CHO-E beverage improved self-paced exercise performance versus the water and placebo groups. Compared to the water group, mean 15-m sprint times were faster for the CHO-E group [Harper, 2017].

The majority of studies have used the Loughborough Intermittent Shuttle test (LIST), which elicits similar physical demands to a soccer match [Nicholas, 2000; Currell, 2008]. The players in most of these studies ingested a 6%–7% CHO solution prior to exercise, and every 15 min during exercise. In general, these studies have found that CHO ingestion before and during exercise reduces muscle glycogen utilization, improves running time to fatigue, and coordination in the latter stages of the exercise trial [Leatt, 1989; Nicholas, 1999; Nicholas, 1995; Welsh, 2002; Davis, 2000; Ali, 2007; Welsh, 2002]. The effects on sprinting times were less consistent, with only a few studies showing improvements in sprinting performance [Ali, 2007; Welsh, 2002]. The effects of CHO ingestion, on simulated soccer performance, in adolescents have been

studied and the results are similar to those in adults, showing an overall improvement in time to fatigue [Phillips, 2010; Phillip, 2011; Phillips, 2012]. However, two of these studies did not report on the nutritional status of the subjects [Phillips, 2010; Phillips, 2011]. The 2012 Phillips study assessed the difference between a 2%, 6%, and 10% CHO-E beverage on performance during the LIST. The study found that the subjects receiving the 6% CHO-E beverage had a 34% increase in endurance capacity when compared to the 10% CHO-E beverage. However, this study was performed with a low number of subjects (n=7) who were adolescent and in a fasted state [Phillips, 2012].

Overall, the studies that looked at physical performance measures saw slight benefits of CHO supplementation. Many times, the performance is difficult to measure during these exercise protocols and the protocols aren't entirely realistic to a normal soccer match. One of the limitations of many intermittent-type sports activities is the consumption of carbohydrates at regular intervals. In soccer, for example, players are only able to drink at halftime (following 45 min of game time) and/or during pauses in play provided that the player has enough time to obtain and consume a carbohydrate-containing solution on the sidelines. Many studies, which use simulated soccer matches, have the subjects consuming the CHO-E beverage throughout the match, but this isn't realistic in actual soccer match play. Although the US Soccer Federation and FIFA allow teams to complement an additional water break before half time when temperature and humidity are high, generally there are no water breaks or clear opportunities for all players in the game to ingest any fluid until substitution or half-time [FIFA, 2015]. This goes against the American College of Sports Medicine (ACSM) recommendations of ingestion of fluids every 15-minutes during high intensity activity [ACSM, 2007]. Therefore, none of these studies are realistic to the game scenario ingesting fluids every 15 minutes. A study by Clarke, used a

soccer-specific motorized treadmill protocol, which were two 45-minute runs with a 15-minute recovery period in-between, to examine the effects of when a CHO-E beverage is provided [Clarke, 2008]. The subjects received a 6.9% CHO-E beverage before the test and during recovery for the first trial (trial 1) and a 6.9% CHO-E beverage at 15-minute intervals for the next trial (trial 2). There were no differences between the trials, but players did report more gut fullness during trial 2 [Clarke, 2008]. Gastric emptying of CHO-E beverages has been demonstrated to be slower during brief, intermittent, high-intensity exercise compared with rest or steady-state moderate exercise conditions [Leiper, 2001]. Since the timing of CHO ingestion had little effect on performance, the half-time period for ingestion would be the most plausible to highlight the effects. **Table 2** summarizes ten of the above studies looking at the effects of CHO on physical performance in soccer.

CHO supplementation and Skill Performance

Skill performance is a crucial component in the game of soccer; therefore many studies have examined the effects of CHO supplementation on soccer skill performance [Ali, 2007; Ali, 2009; Northcott, 1999; Currell, 2009; Russell, 2012a; Zeederberg, 1996; Ostojic, 2002; Russell, 2014a]. The first study looked at how a 6.4% CHO-E beverage influenced soccer skill performance in sixteen male ex-professional and collegiate team players [Ali, 2007]. Ali used the LIST and developed his own valid and reliable test to assess passing and shooting performance. It was a cross over study design and the study found that subjects, who consumed the CHO beverage, had an increased shooting performance after the LIST compared with the placebo subjects. There was no difference in passing, post LIST, with the CHO beverage [Ali, 2007]. In 2009, the researcher designed another experiment to reexamine the effects of CHO supplementation on a players passing performance [Ali, 2009]. The study looked at how a 6.4%

CHO-E beverage influenced soccer skill performance in seventeen male ex-professional and collegiate team players. The players, when consuming the CHO-E beverage, had an improved passing performance in the last 15-minute period of the 90-minute LIST [Ali, 2009]. The passing test trials were performed in a 12-hour fasted state. The CHO-E trial subjects had a 3% reduction, before and after, in passing skill performance, while the placebo trial subjects had a 14% reduction. The provision of CHO during exercise tended to show a better ability to maintain the soccer skill performance [Ali, 2009]. There two studies utilized the LIST, but in 2008 a researcher found that the LIST wasn't a valid measure for soccer skill performance (Currell, 2008). A study by Northcott, found that players had improved skill proficiency when supplemented with an 8.0% CHO beverage, but the passing and shooting skill tests weren't tested for validity or reliability [Northcott, 1999]. Currell found that a 7.5% CHO beverage improved dribbling and shooting performances of recreational male soccer players during a 90-minute simulated soccer match [Currell, 2009]. The study measured skills using a time dribbling test and a shooting target. The players, when they consumed the CHO beverage, had increased dribbling and shooting performance in each trial when compared to placebo [Currell, 2009]. A 2012 study found CHO supplementation improved shooting speed and performance by 10% compared with the placebo [Russell, 2012a]. The study had a cross over design and used a 90-minute simulated soccer match. The players received a 6.0% sucrose-electrolyte beverage before and during the match. CHO supplementation had no effect on the players passing or dribbling performance [Russell, 2012a]. The next study used a 75-minute simulated soccer match with an integrated shooting performance test [Abbey, 2009]. The study found no improvements in shooting performance when players where supplemented with a 6.0% CHO-E or 6.0% honey-E beverage, before and during the test, when compared to a placebo [Abbey, 2009].

Two studies examined CHO supplementation effects on soccer skill performance during and after a 90-minute soccer match [Zeederberg, 1996; Ostojic, 2002]. Zeederberg found no significant effect of CHO ingestion on soccer skill performance during a 90-minute match [Zeederberg, 1996]. However, Ostojic found that a 7.0% CHO beverage consumed before and during match play improved dribbling performance by 5% after the match [Ostojic, 2002]. A review by Russell found that six out of eight studies, which analyzed the effects of CHO on performance, saw an improvement in at least one performance aspect [Russell 2014b]. All of these studies provided 30-60g/hour of CHO via a 6-8% CHO-E beverage solution [Russell, 2014b]. Lastly, Harper found that a 12% CHO-E beverage improved dribbling and speed dribbling during a simulated soccer match [Harper, 2017]. The benefits of CHO supplementation during a soccer match, for soccer-specific skill improvement, are less conclusive than its benefits for physical performance. **Table 3** summarizes six of the above studies looking at the effects of CHO on soccer-specific skill performance.

Motor skills and cognitive performance also play a crucial role on the performance of players and these performances decrease during the second half. CHO supplementation has been shown to decrease these decrements during a match [Phillips, 2011; Bandelow, 2010]. One of the studies that saw an improvement in cognitive and motor skill function found that the speed improvement was due to elevated blood glucose (BG) concentrations [Bandelow, 2010]. The study highlights the importance of euglycemia during a soccer match.

Interventions and Metabolic Response

Some research studies have seen blood glucose reductions at halftime when no activity is performed and when CHO supplementation is integrated [Russell, 2011; Kingsley, 2014; Russell, 2012a; Russell, 2014a; Harper, 2017]. In Russell's first study, he aimed to compare the

soccer demands of a simulated soccer match (SMS) and an actual match in order to validate the exercise protocol [Russell, 2011]. The study used youth soccer players, took blood samples, and provided a carbohydrate-free beverage throughout the matches for both trial groups. It was found that the simulated soccer match corresponded with the demands of an actual soccer match. An interesting finding was, compared to initial values, a reduction of 19% and 17% in blood glucose concentrations was seen just before the second half for both the simulated soccer match and soccer match, respectively. [Russell, 2011] The greatest reduction was seen during the measurements taken during the 45-60 minute period (~4.0mmol) [Russell, 2011]. Russell didn't provide a CHO beverage, so this was an exercise-induced drop in BG. The reduction prior and during the initial portion of the second half is similar to an earlier study [Krustrup, 2006a]. Krustrup analyzed blood metabolites of semi-professional soccer players during three matches. The players received the blood samples before and after periods of play. Krustrup found that the players experienced the lowest mean blood glucose level (4.1mM) before the second half [Krustrup, 2006a]. Both studies controlled the feedings of the players' prior to the trial so the BG responses were realistic in nature (not fasted). These two studies highlighted the potential effects of halftime on BG levels [Krustrup, 2006a; Russell, 2011].

The next studies used these findings to assess the effects of CHO supplementation. A 2012 study analyzed the effects of CHO supplementation on soccer-specific skill performance in male (18 y.o) players during a SMS [Russell, 2012a]. Blood samples were taken every 15-minutes throughout the SMS, similar to his previous study. There were two SMS and subjects took part in both the placebo and CHO groups (double-blind). The CHO supplement that was a 6.0% sucrose-electrolyte beverage, which is different than the usual glucose-fructose beverage, was consumed before and during the entire SMS [Russell, 2012]. A transient decrease in blood

glucose concentrations was seen 15-minutes (60-min) into the second half for CHO group. The BG levels were around 4mmol, which is a similar to finding to his 2011 study that didn't supplement a CHO beverage, which is a 30% decrease from the BG levels taken just ~20 minutes prior (45-min) [Russell, 2011; Russell 2012]. Two years later, two more studies reviewed the effects of CHO supplementation on blood metabolites during a SMS and soccer match [Kingsley, 2014; Russell, 2014a]. Kingsley took adult male recreational soccer players and conducted three separate trials, with three separate trial groups, using a prior established simulated soccer match protocol [Kingsley, 2014; Russell, 2011]. The study design had a crossover and double blind format for the supplementation. The three trial groups were a 9.6% CHO-E (w/ caffeine) beverage with CHO gels, 5.6% CHO-E beverage with placebo gels, and a non-CHO beverage with placebo gels and the groups consumed a CHO gram total of 142g/hr, 54g/hr, and 5g/hr, respectively [Kingsley, 2014]. All of the groups experienced a drop in blood glucose concentrations at halftime. The 9.6% and 5.6% groups, in comparison to the placebo group, had higher BG levels throughout exercise (~23% and ~7.7%, respectively). However, at the 60-minute mark (15-minute into second half), BG levels fell rapidly for all three groups. Out of all subjects, 71% experienced BG concentrations below 4.0mmol and 57% had concentrations less than 3.80mmol [Kingsley, 2014]. This finding suggests that CHO supplementation during the SMS couldn't alleviate the transient drop in BG post halftime (~60-min). The 2014 study by Russell specifically analyzed the role CHO supplementation, before and during, has on blood glucose during a soccer match [Russell, 2014a]. The subjects were male youth (~15 y.o) players for a professional soccer academy team. Two 90-minute matches were played, a week apart, with two trial groups that were a control and CHO group [Russell, 2014a]. The study design had a crossover and double blind format. Blood samples were taken every 15-minutes of the match

using a “fill-in” player format. The CHO supplement was a 6.0% sucrose-electrolyte beverage and equal amounts (14mL/kg/hr) were consumed each time the player left the field for a blood sample. The CHO group, compared to their baseline, had 30% higher BG concentrations at end of the first half [45-min]. Both groups had reductions in BG at halftime (~30% from 30-45min) and both groups experienced their lowest BG level during the first 15-minutes of the second half [Russell, 2014a]. A final study, analyzed the effects of a 12% (60g) CHO-E beverage during a simulated soccer match [Harper, 2017]. Even though the CHO supplementation elevated BG throughout the match, there was still a 27% drop in BG at the 60-minute mark (15-min post HT) [Harper, 2017]. The earlier study by Krstrup took less frequent blood samples than the later studies by Russell and Kingsley [Krstrup, 2006a; Russell, 2012a; Russell, 2014a; Kingsley, 2014; Harper, 2017]. The majority of studies took blood samples at rest and every 15-minutes through the simulated soccer match, but the methodology involved to test blood during a soccer match required the substitution of players in and out to avoid a stoppage in play [Russell, 2014a; Kingsley, 2014; Harper, 2017]. These studies depict the BG values of focus are before the game, throughout HT, and 15-minutes into the second half. When the interventions take place during the halftime phase, it’s important to monitor the BG values around this time. Values taken at these times will provide a realistic representation of BG values via an obtainable methodology.

CHO supplementation resulted in elevated BG levels for players, but supplementation still resulted in a transient BG drop at half and during the initial phase of the second half. [Russell, 2014a] All of these studies found similar blood glucose responses to CHO supplementation. The studies supplied subjects with a CHO beverage (~5.6-12.0%) [Kingsley, 2014; Russell, 2012a; Russell, 2014a; Harper, 2017] and saw no differences in the transient reduction of BG levels at halftime and early in the second half [Krstrup, 2006a; Russell, 2011].

None of the studies had the subjects in a fasted state, but the fed state wasn't in line with nutrition guidelines for soccer athletes. Kingsley and Russell fed study subjects 2-hours prior to their respective soccer matches, but the CHO content of the meal was far below the general recommendation for a pre-competition meal [Kingsley, 2014; Russell, 2012a, Russell, 2014a]. The Kingsley study fed subjects, with a mean weight of 79kg, about 62g of CHO. The Russell studies fed subjects, with a mean weight of 65kg, about 54g of CHO. The CHO consumption totals are less than half of what the players should have consumed prior to the match (158g and 130g CHO, respectively) [Kingsley, 2014; Russell, 2014a; Russell, 2012a]. Harper fed subjects a meal (10% of energy needs) 2-hours prior to the match [Harper, 2017]. Every study employed a passive, no activity, halftime period for players. The exercise protocol was 90-minutes with a 15-minute halftime period, but only one study analyzed actual soccer matches [Russell, 2014a]. First off, the same research group performed all of these studies creating a hesitation when analyzing their data. A sucrose based CHO beverage was used instead of the typical glucose blend seen in sports drinks, but sucrose has a similar oxidation rate to glucose [Jeukendrup, 2000]. The findings of these studies suggest that the CHO supplementation doesn't eliminate the BG reduction that occurs at halftime and during the initial phase of the second half. Lastly, the feeding protocol varied between studies and lacked the recommendation for CHO. The goal of my study will be to have players in similar fed states as a typical match and each player will receive the same volume of CHO throughout the soccer match. **Table 4** highlights six of these soccer studies that saw blood glucose reductions during a match or simulated match

Summary

A number of studies have identified a decline in player work rate within the initial phase of the second half in comparison with the corresponding phase in the first half [Lovell, 2013a;

Mohr, 2003; Weston, 2011]. The decrement in performance could be inevitable due to fatigue, but studies have analyzed the halftime period and its potential in attenuating the decrease in performance [Mohr, 2004; Edholm, 2014; Lovell, 2007; Lovell, 2013b; Zois, 2013].

Compounding this issue is the fact that at the elite level, in particular, there is limited time during the half-time break for re-warm-up activities to be undertaken with practitioners, suggesting that only a 3-minute window is available [Towlson, 2013]. Zois completed the only study that investigated a 3-minute re-warm-up strategy, which was a SSG or 5RM leg press [Zois, 2013]. A longer re-warm-up strategy, such as the completion of a 5-minute repeat-sprint drill, also enhanced repeat sprint and CMJ performance in comparison with no re-warm-up [Lovell, 2013b], while a 7 min repeat-sprint drill or cycle exercise prompted an increase in the distance covered within the second half [Lovell, 2007]. Improvement in second-half performance was also correlated with better core temperature maintenance resulting from completion of either of the two active re-warm-up strategies [Lovell, 2007]. Finally, a 7-minute halftime re-warm-up strategy improved and maintained repeat-sprint performance in comparison to the control (passive/no activity) [Mohr, 2004; Edholm, 2014]. The decline in core and muscle temperature was reduced during a 15-min half-time break with this re-warm-up strategy [Mohr, 2004]. It appears that completion of an active re-warm-up during the half-time break can enhance subsequent performance, although only a small timeframe has been identified (~3 min) for a re-warm-up to be completed. More research that highlights its benefits will ultimately promote more time to be allotted for a RWU. A review by McGowan, which analyzed warm-up strategies for sports, found that a completion of a 3–7 minute halftime re-warm-up strategy involving activities such as SSG, repeat-sprint drills or continuous running can also enhance second half performance by minimizing the decline in muscle temperature during the half-time break [McGowan, 2015].

Carbohydrates are a staple in the game of soccer and are regularly consumed during a game to attenuate decreases in performance, improve or maintain soccer skill performance, and lessen decreases in muscle glycogen concentration by maintaining available exogenous glucose or endogenous stores [Ali, 2009; Goedecke, 2013; Guerra, 2004; O'Reilly, 2013; Ostojic, 2002; Russell, 2014a; Northcott, 1999; Currell, 2009; Nicholas, 2000]. CHO supplementation has evident advantages, but studies show it's unable to reduce the exercise-induced drops in blood glucose at halftime or during the initial phases of the second half [Russell, 2014a; Russell, 2012; Kingsley, 2014].

A new, metabolic benefit of an active halftime rewarm-up may be possible after reviewing the biological effects carbohydrate supplementation during soccer matches. The studies supplying a CHO beverage didn't incorporate an active rewarm-up during halftime [Russell, 2014a; Russell, 2012; Kingsley, 2014]. The active halftime RWU studies didn't focus on whether it affected blood glucose or other metabolic responses during the second half [Zois, 2013; Lovell, 2013a; Lovell, 2007; Mohr, 2004; Edholm, 2014]. Instead, these studies incorporated performance measure protocols or time-motion analysis to quantify the second half performance effects of the RWU [Edholm, 2014; Zois, 2013; Lovell, 2013a, Lovell, 2007; Edholm, 2014]. No studies have used GPS data to analyze performance differences between an active and passive HT rewarm-up. Thus, research that use GPS devices to investigate the effect of an active halftime rewarm-up on second half performance is warranted. There haven't been any studies that combine both the ingestion of CHO during a match and an active HT intervention. It's possible that the exercise-induced drop in BG during a passive halftime can be eliminated by an active rewarm-up during the halftime period. Gradually, over the course of halftime there will be physiological changes such as reductions in core temperature, reductions in muscle temperature, and changes in the

physiological response to exercise and recovery [Kingsley, 2014; Russell, 2014a; Russell, 2012a; Russell, 2011; Krstrup, 2006a; Mohr, 2004]. The metabolic mechanisms in sport are still studied to this day, but when exercise ceases there is an increase in insulin, which causes glucose uptake by the previous active muscles and reduced glucose output by the liver [Bangsbo, 1994; Bangsbo, 2007]. A period of rest can create ramifications to your body's responses. The body is resting and doesn't know a subsequent bout of exercise is going to commence. The body is responding to this period of rest as if it were a period of complete recovery [Bangsbo, 2007]. If exercise is commenced when plasma insulin concentrations are high, for example following a pre-exercise CHO load, the metabolic response to exercise is characterized by a rapid decline in blood glucose during the first 10–20 min of exercise [Costill, 1977; Marmy-Conus, 1996; Sparks, 1998]. The decrease in plasma glucose concentration is the result of the additional effects of the high insulin concentration and increased glucose uptake by the exercising muscle. The halftime period, in a passive state and with CHO supplementation, could lead to a large insulin response, decreased BG levels, and potentially decreased second half performance, specifically during the initial stages (15-minutes). Since CHO supplementation effects have been positive, restricting CHO during the halftime phase of a match wouldn't be realistic or beneficial on subsequent performance. Lastly, since Clarke [Clarke, 2008] pointed out no difference between supplementation every 15-minutes and supplementation at halftime, the realistic application of CHO supplementation at halftime will be the best practice.

Carbohydrate Recommendations for Soccer Players

Nutrition is very important for soccer players to provide adequate energy to meet the challenges of high-intensity, intermittent exercise. A variety of fuel sources are utilized during a

soccer match, but carbohydrates are of vital importance because muscle glycogen is the predominant substrate for energy production during a match.

Carbohydrates are the main fuel source during the game of soccer. Soccer is a game with various intensities and the body's aerobic and anaerobic energy pathways can use carbohydrates. Carbohydrates provide a key fuel for the brain, central nervous system, and muscles [Burke, 2011; Fink, 2015]. Studies have shown that performance in intermittent high-intensity exercise, such as soccer matches, can be enhanced by strategies that maintain glycogen stores and blood glucose to the demands of the match [Hawley, 1997; Krstrup, 2006a]. Depletion of the body's carbohydrate availability is associated with fatigue in the form of decrements in skill and reduced work rates [Rampinini, 2009; Baker, 2015; Bangsbo, 2007; Anderson, 2016]. Therefore, soccer players should adopt specific nutrition strategies to maximize glycogen stores in order to aid performance during a soccer match. There are a variety of recommendations in regards to daily nutrition, nutrition on match day, before a match, during a match, and after a match. Briefly, a soccer player should be consuming 5-10g/kg of CHO per day, depending on the needs and goals of the individual athlete [Burke, 2011; Beck, 2015; Thomas, 2016]. The focus will be on match day nutrition, specifically pre-competition meals and nutrition during the match.

Match day

On the day of a match, it's important to promote high carbohydrate availability to promote optimal performance in competition. Given the relevance of muscle CHO for performance, every nutritional feeding strategy can influence performance [Burke, 2011]. The general consensus and recommendations for an acute feeding strategy prior to the match is consume the meal and/or snack 1-4 hours before the event [Burke, 2011]. The recommendation is for the individual to consume 1-4 grams of CHO per kg of body weight. The 1-4g/kg (0.45 –

1.82g/lb.) corresponds to the hour in which you eating, for example 3 hours before the event players should consume 3g/kg of CHO [Thomas, 2016]. The goal is replenish glycogen stores that may be depleted due to a fast. The position stand of the Academy of Nutrition and Dietetics suggests a meal and/or snack that emphasizes low glycemic index CHO and minimizes fiber, protein, and fat [Thomas, 2016; Burke, 2011; Fink, 2015]. This type of meal will minimize gastrointestinal problems and promote gastric emptying [Rehrer, 1992] A study showed that a high-CHO meal prior 2-3 hours prior to competition helps restore liver glycogen and that a meal closer to competition can delay absorption and digestion. The study saw only an 11% increase in muscle glycogen content before exercise, in fasted endurance runners, after a high-CHO meal (2.5g/kg CHO) was consumed 2 hours before [Chryssanthopoulos, 2004]. The results suggest a meal 3-4 hours prior is more ideal for optimal absorption and digestion of CHO. Therefore, the last meal should ideally take place 3-4hours before the match and include easy-to-digest foods. Research studies, looking at the effects of different glycemic index (high: HGI or low: LGI) pre-competition meals on metabolic and performance measures have found similar data. A study looked at the effects of a LGI and HGI meal 2 hours before high-intensity exercise in soccer athletes. No performance differences were found, but the LGI group had decreased BG during the late phases of exercise and reduced insulin levels at the beginning of exercise. [Bennett, 2012]. The general consensus is that glycemic index of pre-competition meals had no effect on performance or metabolic responses when the meals contained similar CHO and caloric contents. [Hulton, 2013; Bennett, 2012; Little, 2010]. Overall, the meals 4 hours before a match can contain more CHO, with smaller meals with less CHO consumed when less time is available prior to the match (1-2 hours prior).

Half-time and during a match

In addition to high endogenous pre-event muscle glycogen stores, it is widely accepted and promoted that exogenous CHO feeding during sport improves physical, cognitive, and technical elements of performance [Stellingwerf, 2014]. The benefits of exogenous CHO ingestion during endurance exercise are well established and the recommendation for CHO intake during “stop and start” sports, such as soccer, or exercise durations of 1-2.5 hours is 30-60g of CHO per hour [Thomas, 2016; Burke, 2011; Holway, 2011]. Studies highlight a decrease in performance during the second half, but CHO has been shown to improve said performance and will be discussed in following sections [Baker, 2015]. The carbohydrate intake provides a source of fuel for the muscles to supplement endogenous stores. The recommended 60g per hour is an upper limit because it appears that the rate of gastric emptying and intestinal absorption is a limiting factor to exogenous carbohydrate utilization. A study analyzed the absorption and appearance rate of glucose in the bloodstream using different doses of carbohydrates. It was found that the optimal range for absorption was 0.96-1.04g per minute. [Jeukendrup, 1999]. Research has shown that glucose, sucrose, glucose polymers/maltodextrins, and starches are all absorbed and oxidized at high rates and therefore appropriate fuels during exercise. Fructose is absorbed half as fast and requires a different transport mechanism, making it less desirable in soccer. However, in combination with various sugars, it can enhance CHO absorption and oxidation during endurance exercise [Trommelen, 2017; Jeukendrup, 2010]. The oxidation rate by muscle is the same as the intestinal absorption rate, which is approximately 1.0-1.1 grams of glucose per minute [Jeukendrup, 2000; Fink, 2015; Trommelen, 2017]. The exogenous oxidation rate is important during exercise because you want quick uptake by the active muscles. Increased intestinal absorption, through different CHO’s using different transporters, can result in greater

absorption and uptake [Jentjens, 2004; Trommelen, 2017] The carbohydrate recommendation during exercise is largely dependent on each individual [Baker, 2014]. Different individuals can consume more grams of CHO per hour without gastrointestinal distress and some individuals can only tolerate so many grams before discomfort. [Burke, 2011; Fink, 2015; Baker, 2014]. Sports beverages are a common source for CHO consumption during exercise and it's recommended that athletes chose a sports beverage containing 6-8% carbohydrate [Fink, 2015]. A 6-8% carbohydrate beverage means that the drink will contain 6-8g of CHO per 100mL. Many sports drinks, such as Gatorade and PowerAde, use a combination of carbohydrates. My study will use Gatorade, which is made up of sucrose, glucose, and fructose. Gatorade contains 38g of CHO per 591 mL, which equates to a 6.4% CHO beverage. A systematic review by Russell found that when players ingested 30-60g of CHO per hour, via a 6-8% CHO beverage solution, during a soccer match or simulated soccer match performance increased in the majority of studies with no decrement in performance due to supplementation [Russell, 2014b].

Conclusion

Nutrition plays an important role in soccer and the recommendations provided for pre-match and during match are based upon the soccer literature. Several studies have completed soccer studies with controlled feedings or pre-match fasts that don't equate to the needs of the players [Kingsley, 2014; Russell, 2012a; Russell, 2014a; Nicholas, 1995; Ali, 2007; Ali, 2009; Phillips, 2012]. When an actual soccer match takes place, players will generally utilize the recommendations and practices set forth by science, which highlights the importance to include regularly practiced strategies in an effort to control the nutrition related variables that influence performance. It's important to control variables, and relate them to common practices, in an effort to highlight the effects of the study. Soccer players need to consume a high (1-4g/kg) CHO

meal 1-4hours prior the match, with the ideal meal to take place 3-4 hours before the match [Thomas, 2016]. During a soccer match, it's recommended that players consume 30-60g CHO every hour via a 6-8% CHO beverage solution [Thomas, 2016].

Quantifying Performance

The objective of soccer is to score more goals than your opponent in an effort to win the game. A team, or players, performance and ability to score a goal hinges on a plethora of factors. The soccer research over the years has attempted to quantify performance and highlight the key indicators or measurements that influence performance during a soccer match [Osgnach, 2009; Bradley, 2013b; Sarmiento, 2014; Ali, 2011]. Performance in soccer depends upon a variety of individual skills and their interaction and integration among different players within the team. Technical and tactical skills are considered to be predominant factors. For example, pass completion, frequency of forward and total passes, balls received and average touches per possession are higher among successful teams compared to less successful teams [Bradley, 2013b; Dellal, 2011; Rampinini, 2007]. However, individual physical and physiological capabilities [both aerobic and anaerobic] must also reach a certain level for players to be successful [Bradley, 2013b; Haugen, 2013; Haugen, 2014; Krustup, 2006a; Rebelo, 2013; Tonnessen, 2013]. Earlier studies employ specific-soccer tests or performance tests in a laboratory, or exercise protocol, setting to quantify performance [Stolen, 2005; Aziz, 2007; Buchheit, 2012; Ekblom, 1986; Drust, 2000]. These test include linear sprinting, agility, repeated sprint ability, VO₂max, Yo-Yo intermittent tests, etc. [Bangsbo, 1994b; Bangsbo, 2008; Haugen, 2014; Haugen, 2013; Krustup, 2006b; Sporis, 2010; Sporis, 2009; Stolen, 2005; Tonnessen, 2013]. However, a marked trend has arisen the last decade, as semi-automatic computerized player-tracking technologies and global/local positioning systems with integrated accelerometers

have been for match-analysis [Castellano, 2014; Cummins, 2013]. The match analysis of a soccer player has generally been divided into three components: technical, tactical, and physical [Sarmiento, 2014]. In general, studies focus on one of these three components to assess how it changed or influenced by common soccer match variables. The technical components primarily consist of the quality of skills executed during a match. The tactical component refers to the overall strategy and style of play executed to defeat the opposition and studies have drawn comparisons between the effectiveness of different tactical approaches [Bush, 2015; Di Salvo, 2007; Tierney, 2016]. The physical performance is the most common and incorporates all of the discrete movements and efforts made by a player during a match [Carling, 2008; Bradley, 2013b; Baker, 2015; Abderrahman, 2013; Bradley, 2010; Carling, 2012; Edholm, 2014; Paul, 2015; Zois, 2013; Weston, 2011; Rampinini, 2007]. Soccer performance is multifaceted, complex, and largely unpredictable due to the vast variety between matches. In many research studies, acknowledgement of the contextual variables that could impact performance are ignored or unrecorded [Mackenzie, 2014]. I will review skill and physical performance, the variables that influence them, and key performance indicators that could potentially influence a match.

Technical Performance

The assessment of technical and soccer-specific skills, such as passing, dribbling, shooting, tackling, and heading, have been studied because of their fundamental feature in soccer matches [Zeederberg, 1996; Rampinini, 2007; McGregor, 1999; Fletcher, 2010; Russell, 2011; Ali, 2007; Ali, 2009]. Previously mentioned, these studies use simulated soccer matches and laboratory settings, which control contextual variables, to highlight and analyze skill performance [Northcott, 1999; Zeederberg, 1996; Fletcher, 2010; Ali, 2011]. There are a variety of skill tests employed to measure technical performance in a simulated match setting [Russell,

2011; Russell, 2012; Ali, 2007; Ali, 2009; Ostojic, 2002]. However, this assessment trend is disappearing due to improved mechanisms for match-analysis. Therefore, another way to analyze technical performance is through notational analysis with the use of defined skill performances [Rampinini, 2009; Bradley, 2013; Dellal, 2011; Harper, 2014; Lago-Penas, 2012; Bradley, 2011; Carling, 2011]. These studies use computerized data analysis systems to assess the video-recordings of the match. The systems have pre-assigned definitions, with various interpretations, for technical performances, such as successful passes, length of passes, dribbles, and possession [Mackenzie, 2014; Ali, 2011]

Since there are so many potential technical measures, the performance results in soccer studies are not uniform [Russell, 2013; Rampinini, 2009; Harper, 2014]. Both systems for measuring technical performance have limitations. The skill tests are not representative of the actual skill-related performance because they lack the contextual variables that typically dictate skill during soccer matches [Ali, 2011; Aquino, 2017]. Notational analysis is subjective to the reviewer and the skill performance definition used [Ali, 2011; Mackenzie, 2014]. The literature varies on findings so I won't be focused on specific skill performance, even though Rampinini observed a significant decline between the first and second half for several technical measures (involvements with the ball, short passes and successful short passes) in Italian Serie A players [Rampinini, 2009]. Similar findings have been reported in a group of young soccer players, and the decline in technical performance had a significant relationship with physical fitness level [Rampinini, 2008]. Despite these studies showing decrements in skill are associated with reduced physical performance [Rampinini, 2009; Rampinini, 2008], another study states otherwise. A study, using a computerized tracking system, measured skill and physical performance to see how they related [Carling, 2011]. The study found that a decline in physical performance didn't

impact skill performance, but a reduction in high-speed distance resulted in a lower frequency of some skill performance variables [Carling, 2011]. The literature varies on findings due to the large number of skills that can be measured. I won't be focused on specific skill performance during the second half, but rather physical performance in relation to work-rate.

Physical Performance

Soccer is a sport where the complexity of the activities does not allow a single measure to represent physical performance. Previously pointed out, performance is also dependent on psychological, technical, and tactical factors. The measure of physical performance analyzes generic movements involved in a soccer match, such as walks, jogs, runs, and sprints then categorizes them into volume, intensity, and work-rate.

Physical performance of soccer players has been evaluated in a variety of manner such as laboratory and field tests [Stolen, 2005; Svensson, 2005]. Tests such as vertical jump, maximal strength, repeated sprint ability, and exercise until fatigue have been used to tests the effects of various factors on physical performance [Oliver, 2008; Oliver, 2007; Mohr, 2010; Zois, 2013; Rampinini, 2007; Lovell, 2013a; Ispirlidis, 2008; Edholm, 2014; Harper, 2016b; Goedecke, 2013; Nedelec, 2013]. However, these types of tests cannot be used to predict performance in match play conclusively because of the complex nature of performance [Svensson, 2005]. Several researchers develop soccer-specific exercise protocols to mimic the demands of a soccer match [Nicholas, 2000; Ali, 2014; Bendiksen, 2012; Russell, 2011], but lack some of the variables that influence physical performance during an actual match. Match-analysis is one of the most-common methods to analyze performance fluctuations. Current analysis technologies include semi-automatic camera systems or wearable tracking systems [Buchheit, 2014]. Several studies have used match-analysis to highlight the physical demands and performance during a

soccer match [Bradley, 2013; Castellano, 2011; Carling, 2010; Carling, 2011; Dellal, 2011; Gregson, 2010; Di Salvo, 2009; Torreno, 2016; Di Salvo, 2010; Andrzejewski, 2012; Mallo, 2015; Wehbe, 2014]. The studies quantified physical performance based upon the movements measured and how they fluctuated during a match, specifically the decrease throughout the second half. However, some studies analyzed performance, both physical and technical, in relation to the factors that could impact it during a soccer match [Castellano, 2011; Mohr, 2012; Lago-Penas, 2012; Dellal, 2011; Bradley, 2013b; Brocherie, 2015; Rampinini, 2007]. These studies highlight some of the contextual variables that could impact performance; therefore limiting these can better underline true performance measures.

Variables that influence performance

Performance is a complex variable that is influenced by a variety of factors during a soccer match. Performance, both physical and technical, is subjective to a myriad of contextual variables. Simulated soccer matches and soccer-specific exercise protocols are used by studies to control variables, but at the same time they lack the same stimuli an actual soccer match employs. This has led to the analysis studies focused on the impact these variables have on performance in actual match play. The decrements in physical performance have been previously mentioned in this review, but a reminder is that some these influential variables include playing position, match-location, weather, formation, playing surface, and talent of opposition [Mohr, 2012; Castellano, 2011; Nedelec, 2013; Bradley, 2011; Bush, 2015; Carling, 2011; Lago-Penas, 2011; Di Salvo, 2007; Tierney, 2016; Rampinini, 2007]. Mohr found matches played in the heat decreased the amount of high intensity running and distance [Mohr, 2012]. Castellano found the talent level of the opposition influenced work-rate and distance during a soccer match [Castellano, 2011]. Di Salvo pointed out that a player's position significantly changes the

physical demands [Di Salvo, 2007]. Tierney highlighted the impact of a team's formation on physical demands [Tierney, 2016]. In a study comparing playing surfaces, it was found that the surface influenced physical performance [Nedelec, 2013]. Rampinini found that the level (talent, skills, rank) of opposition greatly influenced the work-rate of players [Rampinini, 2007]. In addition to physical measures, technical performance is also influenced by variables such as formation, position, level of opposition, and match location. One study, which assessed the impact of playing position on technical performance, found that total passes, tackles, possession, interceptions, and pass success rate greatly varied amongst player positions for professional players in England [Bush, 2015].

Bradley analyzed twenty professional soccer matches and found that the tactical formation used influenced the amount of successful practices [Bradley, 2011]. Also, Carling analyzed forty-five soccer matches across three seasons and found that the opponent's tactical formation influenced the number of passes and touches on the balls [Carling, 2011]. Lago-Penas analyzed professional matches in Spain and found that the home team significantly more goals, shots on goal, dribbles, successful passes, passes made, and ball possession [Lago-Penas, 2011]. It's difficult to comprehensively measure and control for all extraneous influences, therefore it's important to control them when a study isn't focused on highlighting the performance effects of said variable. Future studies can analyze match performance by controlling the variables that effect important performance measures.

Measures of performance and methods

Mentioned earlier, match-analysis refers to the objective recording and analysis of discrete events during a competition. There are a variety of employed mechanisms to analyze a soccer match. Current analysis technologies include semi-automatic camera systems or wearable

tracking systems. The majority of research studies use the camera systems, such as ProZone or Amisco Pro, to track match demands [Di Salvo, 2010; Di Salvo, 2009; Bradley, 2013b; Lago-Penas, 2009; Rampinini, 2007; Dellal, 2011; Carling, 2012; Andrzejewski, 2013; Castellano, 2014]. Wearable tracking systems such as the Global positioning systems [GPS] and accelerometers have become increasingly popular due to their ability to quantify movements [Dellaserra, 2014; Vickery, 2014; Scott, 2016; Wehbe, 2014; Tierney, 2016]. Before 2015, professional teams and players weren't allowed to wear the GPS units in competitive matches [FIFA, 2015]. The integration of GPS units into match-analysis allows for more physical performance events to be measured, such as accelerations, decelerations, bodyload, metabolic load and power.

Researchers focus on the loads placed on soccer players during match play because it allows for specific training and recovery programs to be developed, which in turn may lead to a decrease in injuries and improvement in performance. The load experienced during match play can be categorized into either external or internal loads [Impellizzeri, 2005]. The external load is a measure of the work done, such as distance covered, speed, accelerations, etc. and internal load is the physiological response to the work performed, such as heart rate, energy expenditure, etc. [Impellizzeri, 2005]. When researchers attempt to quantify performance during a soccer match, they use external load measures. Generally, time-motion analyses, employing video and global positioning systems (GPS) are used to determine external loads during match-play, and heart rate (HR) telemetry to determine internal loads [Eniseler, 2005; Varley, 2013; Wehbe, 2014; Bradley, 2013b; Edholm, 2014; Suarez-Arrones, 2015] In order to obtain an accurate match load profile, researchers should use methods that allow for the simultaneous analyses of both internal and external match loads of players [Alexandre, 2012]. The distance a player covers during a match

is a common indicator measured because it may be used to represent a player's load [Reilly, 2007]. However, distance provides little information about intensity. High-intensity activity has been associated with the final outcome of a soccer match [Bradley, 2009; Di Salvo, 2010; Di Salvo, 2009; Mohr, 2003; Stolen, 2005; Faude, 2012].

One of these studies attempted to define the actions that correlate to goals scored, since that is the ultimate objective of soccer. Faude analyzed videos of 360 goals in the first German national league and observed that anaerobic actions preceded the majority of goals scored, both for the scoring and assisting player [Faude, 2012]. The study also found that straight sprinting is the most frequent action in goal situations, 45% of all goals, and concluded that both power and speed abilities are important within decisive situations in professional football [Faude, 2012].

Another study analyzed when goals were scored across two seasons in the top leagues of England, France, Italy, and Spain [Alberti, 2013]. The study found, after analyzing 4,560 matches, that a significantly higher number/percentage of goals (55%) were scored in the second half. The most goals were scored in the last 15-minutes of a game, while the first 15-minutes of the second half had the 2nd or 3rd most depending on the league [Alberti, 2013]. When looking at goals scored and shots, Hughes found that there were differences between successful and unsuccessful teams in converting possession to shots on goal, with the successful teams having the better ratios [Hughes, 2005]. Lago-Ballesteros indicated that top teams had more shots and shots on goal than the middle and bottom teams [Lago-Ballesteros, 2010]. In this line, another study found that top teams (Professional Greek Soccer League) made more shots and had a better ratio between goals scored and shots made than bottom teams [Armatas, 2009]. Also, the most goals were scored in second half with the 1st, 2nd, and 3rd most likely intervals for goals scored were 75-90min, 30—45min, and 45-60minute, respectively [Armatas, 2009].

The number and frequency of efforts, as well as the distance covered, are general indicators of player movement that much of the match analysis studies have focused to quantify player movement performance. There is a lot of evidence that has demonstrated reductions in the physical performance of players at the beginning of the second half of competitive match. Previously mentioned, researchers found that the total distance covered in the first 15-minutes of the second half and the distance covered at high speed are reduced when compared with the first 15-minutes of the first half [Bangsbo, 1991; Mohr, 2003; Bradley, 2009; Weston, 2011; Bradley, 2013b]. Most studies that analyzed the impacts of halftime interventions on performance use soccer match simulation or designed physical tests to measure performance [Zois, 2013; Lovell, 2013a; Lovell, 2007; Mohr, 2003; Mohr, 2004]. Only one study has used match-analysis in an actual soccer match to study an interventions impact on performance in the second half and this study only looked at the first 15-minute periods [Edholm, 2014]. The study used video cameras to capture movement profiles and looked at total distance covered, workload, and distance covered with high intensity runs or sprints [Edholm, 2014].

Although various match-analysis methods enable researchers to measure the external match loads of players, literature suggests that GPS analysis is more accurate than manual video tracking and less expensive than semi-automated video tracking [Barros, 2007; Di Salvo, 2006; Buchheit, 2014; Dellassera, 2014; Cummins, 2013]. One of the limitations of video analysis is the difficulty to determinate the exact point that a player crosses movement speed categories, which can be a concern in regards to inter- and intra-rater reliability of such systems [Harley, 2010]. Additionally, GPS analysis can be used to integrate both motion analysis and HR analysis. GPS technology provides quantitative data on the position, displacement, velocity, decelerations and accelerations of players on the field [Dwyer, 2012]. A study investigated the

physical and physiological profile of professional soccer players in official games using GPS and HR devices [Suarez-Arrones, 2015]. It was found players with less overall running throughout the game were the worst in performance efficiency, highlighting a potential relationship between overall running performance and performance efficiency [Suarez-Arrones, 2015]. Research has shown significant declines in accelerations (~9) and decelerations (~9%) when analyzing each 45-minute half of play. Through the computerized time-motion analysis, of 18 professional soccer players during a competitive season, it was concluded that high-intensity running decreased during the second half of match play [Mohr, 2003]. There have been a couple of studies that used GPS units to analyze accelerations and decelerations during a soccer match, but some of them analyzed the impact of formation and position on these measures [Varley, 2013; Tierney, 2016]. Two studies looked at the acceleration and decelerations throughout a match to draw comparisons between trends [Akenhead, 2013; Russell, 2016]. The first study found significant attenuations in the second half (versus first half) for total accelerations, decelerations, low-moderate accelerations, and low-moderate-high decelerations [Akenhead, 2013]. The next study found a reduction, in the second half compared to the first half, in distance covered, total number of accelerations, total number of decelerations [Russell, 2016]. Accelerations and decelerations can give insight into the work-rate of players and provide another measure of performance.

A final measure of physical performance is metabolic load, the load players experience during a soccer match. The first researcher to highlight this new approach to soccer player performance was Osgnach [Osgnach, 2009]. The study helped devise a system to analyze the energy cost of accelerations and decelerations and also categorized metabolic power, which takes speed and distance to determine estimated energy expenditure [Osgnach, 2009]. Metabolic

power has been referred to as a “shortcut” to define the amount of energy required, per unit of time, to perform a specific movement [Di Prampero, 2015]. In other words, metabolic power is a measure of the amount of ATP, per unit of time, necessary to perform the specific task [Di Prampero, 2015; Buchheit, 2015]. In a traditional sense, metabolic power is an estimate of energy expenditure and is typically measured using a “gold-standard” protocol such as indirect calorimetry. The variables such as metabolic load (J/kg) and high metabolic load distance (m), which analyzes the speed and changes in direction, give further insight into the work-rate of players [Rampinini, 2015; Osgnach, 2009; Buchheit, 2015].

Ultimately, the training load (TL) can be quantified in a variety of ways due to vast number of variables that can be analyzed. A study sought out to define the current practice of professional teams who used the GPS units to monitor training load [Akenhead, 2016]. Eighty-two high-level football clubs from Europe, the United States, and Australia were invited to answer questions relating to how TL is quantified and their perceptions of the effectiveness of monitoring. The study received forty-one responses from teams that used GPS and heart-rate monitors during all training sessions. The top-5-ranking TL variables were acceleration (various thresholds), total distance, distance covered above 5.5 m/s, estimated metabolic power, and heart-rate exertion [Akenhead, 2016]. All of these variables provide great insight into the performance of the player, even though they only highlight the physical and physiological measures of performance. Physical performance is important given that studies in England [Di Salvo, 2009] and Italy [Rampinini, 2009] have reported an association between physical output and final league ranking. More specifically, match activity such as high-speed running in relation to league position at the end of the playing season [Carling, 2013]. Chmura compared the data from the 2014 World Cup. The study compared the data for Germany, the champion, to all other

teams and found that Germany had a significantly higher percent distance covered at a high-intensity (10.04%) than the other teams. They also had a higher total distance covered per game than the other teams (10.39km vs. 10.05km) [Chmura, 2017]. Further solidifying the literature that physical performance can influence the success of team [Di Salvo, 2009; Rampinini, 2009; Carling, 2013; Chmura, 2017].

Performance Implications

There are a variety of factors that can potentially implicate performance. The main factor is fatigue and much of the research focuses on the reasons and effects of fatigue on performance [Reilly, 2008; Russell, 2011; Rampinini, 2009; Mohr, 2010; Mohr, 2005; Algahannam, 2012; Rampinini, 2011; Boksem, 2008; Bangsbo, 2007]. There are a variety of proposed variables that can contribute to fatigue. The ones I focused on are improper nutrition strategies prior to a match and the effects of hypoglycemia. Carbohydrate oxidation is the primary mode of energy production during a soccer match. The active muscles have two sources of carbohydrates in blood glucose and muscle glycogen. Mentioned in previous sections, when muscle glycogen stores deplete and there isn't adequate fuel than performance dwindles because of fatigue and exhaustion [Bangsbo, 2006; Nicholas, 1999; Reilly, 1997; Foskett, 2008; Mohr, 2005].

Therefore, entering a game in a fasted state, or without adequate glycogen stores, can increase the likelihood of fatigue and decreased performance [Saltin, 1973; Nicholas, 1999; Nicholas, 2000; Balsom, 1999; Leatt, 1989; Kirkendall, 1988]. Hypoglycemia, either induced by exercise or inadequate compensation by the body, can result in performance detriments and fatigue due to the importance of blood glucose during exercise [Brun, 2001] Glucose is the only source of fuel for the brain so hypoglycemia impacts cognitive function, speed, and motor skills [Cox, 1993;

Stevens, 1989]. The effects of hypoglycemia haven't been studied in soccer, but the blood glucose effects on the brain and fatigue highlight the potential for negative effects.

There are a variety of methods to analyze the performance of a soccer player. The new method is to quantify the physical performance using internal and external load measures that depict the distance, intensity, and work-rate of a player during a match. The development of the GPS, with accelerometers, and HR monitors has made it easier to quantify player performance and make comparisons.

Global Positioning Systems

In recent years, the global positioning system (GPS) has received a ton of attention and been utilized by researchers in the soccer setting to analyze performance measures [Balbero-Alvarez, 2010; Castagna, 2009; Jennings, 2010; Portas, 2010; Johnston, 2012; Wehbe, 2014; Russell, 2016; Page, 2015; Tierney, 2016; Johnston, 2014; Akenhead, 2013]. The first GPS devices used for sport operated at 1-Hertz (Hz). The Hz. defines the amount of samples the device can provide in one second, where the number of Hz. equals the number of samples taken in one second, i.e. a 1-Hz GPS device provides one sample per second. The current market and literature use GPS devices that operate at 1-Hz, 5-Hz, 10-Hz, and 15-Hz. There are several different brands and companies, such as Catapult and GPSports, which manufacture the GPS unit hardware and software. The majority of research soccer research uses one of these two systems to analyze players, matches, and training sessions. There has been a significant improvement in both the validity and reliability of GPS devices through the years due to an increase in sampling rate, updated hardware/software, and integration of advanced technologies such as triaxial accelerometers, heart rate indicators, magnetometers, and gyroscopes. The triaxial accelerometer produces data by recording the total amount of accelerations in three perpendicular axes (x, y,

and z), which are: medial-lateral, anterior-posterior, and vertical. By measuring the frequency and magnitude of these movements, the accelerometer is able to calculate the total forces the athlete is exposed too [Chambers, 2015]. At first, global positioning systems were limited to measures of distance, speed, and velocity metrics, but current research studies can monitor bodyload, metabolic power, work-rate, and energy cost with the integrated technologies (IT). [Akenhead, 2013; Russell, 2016; Tierney, 2016; Page, 2015; Casachimana, 2012].

1-Hz GPS Devices

The majority of soccer literature, during the initial phase of GPS integration, made use of other match-analysis systems such as video-based time motion analysis and semi-automatic camera systems. In 2010, a research study was performed that compared the application of four different match-analysis systems [Randers, 2010]. The four systems were a video recording (time-motion), multiple-camera (Amisco), and two different GPS devices, one was a 1-Hz device (SPI Elite; GPSports) and the other a 5-Hz. (MinimaxX; Catapult). Each system tracked the players' activity patterns, with a focus on distance and distance covered at various speeds [Randers, 2010]. The study found that all four systems found similar total distances covered, but varying distances were measured within each speed category [Randers, 2010]. The 1-Hz GPS device, because of its lower sampling rate, detected a lower distance during sprints compared to the three other systems. The researcher suggests to use caution when comparing data from differing match-analysis systems due to the variability in the distances covered at different speeds. However, since all systems were able to highlight the same movements trends, such as performance decrements, they can likely be used in studies that address fatigue and lapses in movement [Randers, 2010].

In 2008, a study that used a 1-Hz GPS device validated the speed and distance of three subjects performing linear and circular movements [Townshend, 2008]. The mean error for distance measures was 1.08m and speed error was 0.1m/s for 90.8% of values. A subject's speed during the curved movements was slightly underestimated compared to a criterion, indicating a potential limitation for the 1-Hz device [Townshend, 2008]. Two years later, another researcher assessed the validity and reliability of a 1-Hz GPS device (SPI Elite; GPSports) to track peak speed and submaximal peak speed during a repeated sprint ability test (RSAT) [Barbero-Alvarez, 2010]. It was a 30m sprint performed seven times by each subject, with the speeds tracked by lasers (criterion) and the GPS devices. The study found a coefficient variation (CV), measure of validity, of 1.7% and 1.2% for submaximal peak speed and peak speed, respectively [Barbero-Alvarez 2010]. The findings indicate a 1-Hz device is a valid measure for peak and submaximal peak speed during RSAT of 30m [Balbero-Alvarez, 2010].

Since a prior validity was in place, Castagna used a 1-Hz device (SPI Elite; GPSports) to quantify movements in a soccer match and study the effects of a fatigue test post-match [Castagna, 2009]. The study found that the 1-Hz device wasn't able to accurately measure high-speed movements such as sprints, because a lack of correlation between sprints performed and fatigue test scores. The study didn't test the validity of the GPS device, but their findings give insight into the limitations of its use. If the sprints players performed during the match were of a short distance, then it's likely Balbero-Alvarez [Balbero-Alvarez, 2010]. Also, the Townshend study didn't analyze movements in various directions, similar to match play, or at speeds as fast and constant as the defined sprint (>18km/hr) in this study [Townshend, 2008; Castagna, 2009]. It's evident that the 1-Hz GPS loses accuracy as the speed increases, due to its insufficient sampling rate of one sample per second [Townshend, 2008; Balbero-Alvarez, 2010; Castagna,

2009]. A final validity and reliability study for 1-Hz GPS devices to measure movement demands of team-sports came to the same conclusion [Coutts, 2010]. The study used three different 1-Hz GPS devices (SPI-10, SPI Elite, and WiSPI; GPSports) from the same manufacturer. The GPS validity for distance and speed was assessed using a tape measure and timing gates, respectively. The exercise protocol mimicked the demands of team-sports with sections for various intensity running speeds that could be analyzed by the GPS. The study found a distance CV of -4.1%, -2.0%, and 0.7% for the SPI-10, SPI Elite, and WiSPI, respectively, indicating each device provided accurate and reliable information on total distance traveled. However, the researcher advises for the devices to not be used interchangeably due to their variations. Peak speeds were accurately measured, but none of the 1-Hz devices accurately measured the non-linear high-intensity activities (>20km/hr) [Coutts, 2010].

1 Hz. vs. 5 Hz

The next wave of studies tested the validity and reliability of both 1-Hz and 5-Hz GPS devices in an effort to draw comparisons [Jennings, 2010; Portas, 2010]. The first study, similar to previous validity studies, tested the device capabilities using team-sport specific running patterns that involved acceleration, deceleration, and change of direction over short distances [Jennings, 2010]. The same company, Catapult, manufactured both GPS units, 1-Hz (MinimaxX) and 5-Hz (Team 2.5) [Jennings, 2010]. The study found that both GPS devices used in this study have an acceptable level of validity and reliability for recording movement patterns at lower speeds and with higher sampling rates during the longer efforts [Jennings, 2010]. For example, the CV for the 5-Hz device dropped from 39.5% to 9.2% for sprint distances of 10m and 40m, respectively. Neither device had great accuracy for the change of directions measures, but the 5-Hz had less error in change of direction and during high-intensity movements due to its higher

sample rate. Reliability and validity of both GPS devices to estimate longer distances is acceptable, but brief, high-intensity movements and changes of direction highlight limitations in match-analysis [Jennings, 2010]. Portas also compared the validity and reliability of the same two GPS units, 1-Hz and 5-Hz, but included a linear, multi-directional, and soccer-specific movement course for activity pattern analysis [Portas, 2010]. Both sample frequencies (1-Hz, 5-Hz), in a measure of validity, demonstrated comparable standard error estimates (SEE) values during the linear motion walk and run movements (2.6 to 2.7% for 1-Hz and 2.9 to 3.1% for 5-Hz). For multidirectional run and walk movements, the 5-Hz device had an SEE range (2.2-4.4%) that was much more accurate than the 1-Hz device (1.8-6.8%). The higher sampling rate enabled a more accurate measure of multidirectional movements [Portas 2010]. Both units had small and similar ranges for SEE during the soccer-specific movements. Similar to the Jennings study, the findings highlighted that both the 1-Hz and 5-Hz devices can accurately measure distance and speed linearly, but both lack accuracy when it comes to changes of direction in small areas [Portas, 2010; Jennings, 2010]. The 5-Hz is a more valid and reliable device when multi-directional movements take place, suggesting the higher sample rate equates to better and more consistent accuracy.

The 1-Hz GPS insufficiencies and slow sample rate became evident and studies became solely focused on the validity and reliability of the 5-Hz GPS. A 2012 study analyzed the validity and reliability of a 5-Hz unit (MinimaxX; Catapult) as a measure of team sport demand [Johnston, 2012]. This study utilized the same team-sport exercise protocol used in the Coutts study [Coutts, 2010; Johnston, 2012]. The test subjects were equipped with two GPS devices to test inter-unit reliability of the devices. The study also utilized the same criterion devices for validity as the Coutts study, which were the tape measure (distance) and timing gates (speed).

The GPS units had similar results to the criterion in peak speed and total distance. 5-Hz GPS units gave a reliable measure of the time spent and the number of efforts performed at the same speed zones, although for all movement demands, as the speed of the exercise increased, the level of GPS error also increased [Johnston, 2012]. The data findings further demonstrated an inability of the 5-Hz GPS to accurately measure movement demands performed at very high intensities and sprints, which is similar to the findings in the Jennings study [Jennings, 2010; Johnston, 2012]. The reliability levels (%typical error measurement: %TEM) for the 5-Hz GPS units suggests that they only be used to measure the distance, time spent, and number of efforts performed at different speed zones, more specifically low speeds. The %TEM was highest for sprinting distance, sprinting efforts, and time spent in a sprint [Johnston, 2012]. One researcher used a 5-Hz GPS device (SPI Elite; GPSports), different from the previous study validation studies, to analyze movements during a soccer match [Wehbe, 2014]. The study reported the device was validated by two earlier research studies, one on cricket and one on rugby, but I didn't dive into those studies because they didn't pertain to soccer. It was stated that the CV was less than 4% for distances covered during speeds 0-18km/hr and ranged 2-13% for distances covered during speeds >18km/hr. The Jennings study found that the 5-Hz GPS was capable of measuring movement demands performed at velocities less than or equal to 20 km/hr, but more caution is to be exercised when analyzing movement demands collected at velocities greater than 20km/hr [Jennings, 2012]. However, the purpose of Wehbe's study wasn't to validate the 5-Hz unit, but to define movements during a match, especially accelerations, and highlight the effect of situational factors on these movements [Wehbe, 2014]. The study found match data that aligned with previous findings that used different match-analysis systems such as the semi-automatic camera-based system [Wehbe, 2014]. Although the study didn't focus on validity and

reliability, it highlighted a decrement in second half performance, which has been a novel finding in previous soccer literature [Bradley, 2010; Bradley, 2009; Mohr, 2003]. The literature for the use of 5-Hz GPS devices isn't conclusive, consistently accurate, or similar amongst the studies. However, its higher sampling rate shined the light on the potential of GPS in match-analysis.

5-Hz vs. 10-Hz

There are two main studies that analyzed the validity of both a 5-Hz and 10-Hz GPS device and compared the results [Varley, 2011; Rampinini, 2015]. In 2011, the 10-Hz GPS unit became commercially available which led to a researcher performing a study to test its validity and reliability. The study aimed to determine the validity and reliability of both a 5-Hz and 10-Hz device on measures of instantaneous velocity during acceleration, deceleration, and constant velocity phases of straight-line runs [Varley, 2011]. The two Catapult brand devices were the MinimaxX V2.0 and V4.0, which correlated to the 5-Hz and 10-Hz units, respectively. Subjects had to run in a straight line and were equipped with two 5-Hz or two 10-Hz devices, to limit inter unit reliability, to measure acceleration, deceleration, and constant velocity. The velocity results were compared to a laser (50-Hz) for validity. The study saw the 10-Hz device was two-three times more accurate and six times more reliable than the 5-Hz device [Varley, 2011]. CV range for 10-Hz and 5-Hz was 3.1-11.3% and 3.6-33.3%, respectively, for accelerations, decelerations, and constant velocities at the differing speed measures (1-8m/s). The CV for 10-Hz data was less than 5% for all velocity measures, besides decelerations (11.3%). This data displays the significant advantage in validity and inter unit reliability the 10-Hz has on the 5-Hz device when measuring instantaneous velocity [Varley, 2011].

The next study sought the accuracy of 5-Hz and 10-Hz GPS devices to measure high-intensity running in field-based teams sports, such as soccer [Rampinini, 2015]. The reason for

this study is obvious, given the importance of high-intensity movements in matches. The study used an exercise protocol that highlighted the typical movements demands during a team-sport game. Subjects wore both the 5-Hz (SPI-Pro; GPSports) and 10-Hz (MinimaxX; v4.0 Catapult) GPS devices, which were used to monitor total distance, high-speed running distance, very high-speed running distance, energy cost, and metabolic power during exercise bouts [Rampinini, 2015]. As mentioned in the performance section, the Osgnach study made way for the metabolic power and energy cost equations to be used by match-analysis systems and GPS devices [Osgnach, 2009]. The results found that the 10-Hz GPS was more accurate than the 5-Hz GPS for the majority of measures, but both systems showed greater error for the highest categories of speed and power. The typical error, or coefficient variant (%CV) for the 5-Hz and 10-Hz devices during very high-speed running was 23.2% and -7.3%, respectively, while the %CV for very high metabolic power was 11.6% and -7.1%, respectively [Rampinini, 2015]. The higher sample rate, 10 samples per second, equated to a more accurate measure and decreased error. These findings are similar to ones from the Varley study [Varley, 2011, Rampinini, 2015]. Rampinini stressed the importance of not utilizing data, from different systems, interchangeably.

The findings of this study highlight limitations of the 5-Hz device used in the Wehbe study [Varley, 2011; Wehbe, 2014]. A study in 2014 systematically assessed the effect of rapid directional change on the distance measurement validity of a previously untested GPS device. The GPS device (SPI Pro X; GPSports) was 5-Hz, but it had an interpolation algorithm that output the device data at a 15-Hz frequency [Rawstorn, 2014]. The study didn't specify the specifics of the algorithm, which made it difficult to assess its effect on the validity. A commonly used soccer match simulation test (LIST), performed on a shuttle or curvilinear track, was used to replicate rapid directional change. Both linear and curvilinear distance, measured by

the GPS, was significantly different than the criterion (trundle wheel) distance. However, the measurement bias (mean error) was good for walking, jogging, running, and sprinting during both the shuttle LIST (-2.16%) and curvilinear LIST (2.99%) [Rawstorn, 2014]. The study highlighted the 5-Hz (15-Hz) device had reduced validity, but good reliability when tracking distance during a rapid directional change protocol test.

10-Hz

The validity and reliability findings of the Varley study started the use of 10-Hz devices for movement analysis in actual soccer matches and simulated soccer matches [Casamichana, 2012; Akenhead, 2013; Russell, 2016; Page, 2015; Tierney, 2016]. The 10-Hz GPS, regardless of brand, come integrated with technologies such as accelerometers, heart rate transmitters, and magnetometers or gyroscopes that broaden the metrics these devices can expose. Integrated technologies (IT) highlight new measures that can expand the possibilities for researchers, coaches, teams, and players [Dellassera, 2014]. The remainder of these studies will employ IT's that increase the benefits of a GPS device in match-analysis.

A 2012 study took advantage of the 10-Hz (MinimaxX; Catapult) GPS and its IT capabilities to analyze the physical demands of a soccer match, specifically bodyload and high-intensity efforts [Casamichana, 2012]. Casamichana aimed to compare the soccer match (FM) to small-sided games (SSG) in order to improve training regimens, but this data doesn't validate the GPS. The study utilized the recently validated device to measure distance covered per minute, maximum speed, percentage of time spent in different speed zones, and player workload using the integrated accelerometer [Casamichana, 2012]. The findings gave insight for individuals increased in tapering a practice to the needs of a team or player, but no indicator for validity or reliability was given [Casamichana, 2012]. The results from the FM were similar to soccer

studies that tracked the demands of a soccer match [Bangsbo, 1994; Stolen, 2005]. In 2013, a study used the 10-Hz GPS device (MinimaxX; Catapult) to describe the distances covered by various accelerations and decelerations during a soccer match [Akenhead, 2013]. The device is the same one Varley validated and Casamichana used in their respective studies [Varley, 2011; Casamichana, 2012]. Akenhead broke the 90-minute match up into 15-minute segments to determine analyze the movements that took place. Since this was a descriptive study, the findings portray the events that took place and not the validity or reliability of the GPS units. However, the movement trends found were in line with previous findings within soccer literature [Akenhead, 2013; Mohr, 2010; Bradley, 2009]. Although validity and reliability aren't measured or specified, this study highlights the capability of the 10-Hz device to accurately analyze soccer match demands [Akenhead, 2013]. Three years later, another descriptive study sought to profile the physical demands of a soccer match, with a specific focus on the number of acceleration and decelerations efforts during a match [Russell, 2016]. Subjects wore the same 10-Hz GPS device (Viper pod; STATSports) each match to improve inter unit reliability. The study found similar results to the Akenhead study in regards to a decrease in physical movements during the second half of the match [Akenhead, 2013; Russell, 2016]. The GPS device was able to successful describe the movements fluctuations during a match and provide baseline data for future researchers [Russell, 2016]. Second half performance is the focus of my thesis and the data found in this study provides a potential benchmark for data comparison.

The 10-Hz GPS unit (MinimaxX; Catapult), with an integrated 100-Hz triaxial accelerometer, was also used to quantify the playerload (bodyload) during a simulated soccer match [Page, 2015]. The results showed a valid quantification of playerload by the triaxial accelerometer and GPS when compared to prior playerload studies, which further supports the

accuracy of this performance metric by the 10-Hz GPS and IT [Page, 2015]. Another study used a 10-Hz GPS (STATSports) device to describe the physical demands during a 90-minute soccer match, with a focus on variations between playing formations [Tierney, 2016]. The GPS device used in this study came equipped with a 100-Hz gyroscope, 100-Hz triaxial accelerometer, and 10-Hz magnetometer [Tierney, 2016]. Gyroscopes measure angular velocity and magnetometers are magnetic compasses that measure absolute orientation and can detect the exact direction of travel. Many GPS units lack their IT's that make the accelerometer a better measurement tool for acceleration and impact, especially when changes in direction occur [Dellaserra, 2014]. Tierney used the device to measure total distance, high metabolic load distance, high speed running, accelerations, and decelerations. Each metric had a definition for its measurement and the findings in the Akenhead study helped with the definitions [Akenhead, 2013; Tierney, 2016]. This is the first study I've seen that used high metabolic load distance as a performance metric, which gives insight into its ability to define work-rate and load during a match [Tierney, 2016].

10-Hz vs. 15-Hz

The research has made it clear that the 10-Hz unit is superior to 5-Hz unit because of its increased sampling rate, but also due to an updated system (hardware/software) by the manufacturers. There is very limited data pertaining to 15-Hz devices. None of the discussed studies so far have included a defined 15-Hz GPS device in the study. Rawstorn had validated a device that used an algorithm to sample at 15 samples per second, which showed good reliability, but still limitations were in question [Rawstorn, 2014]. Therefore, a study aimed to determine the reliability and accuracy of three different sample rate GPS devices, a 5-Hz and 10-Hz (MinimaxX; Catapult), and 15-Hz (SPI; GPSports). The three devices measured distance, mean speed, and peak speed during straight running, multi-directional movements, and

unstructured movements typical of court and field-based sports [Vickery, 2014]. Validity measures were set by a 100-Hz high-resolution camera system (VICON). A unique aspect of this particular study, and potential limitation, was that each subject wore a total of six (5-Hz x 2; 10-Hz x 2; 15-Hz x 2), devices at one time during the study [Vickery, 2014]. During both the unstructured court and field-based movements, there were no significant differences in distance, speed, or peak speed for any of the devices and VICON. The results of this study found that each GPS device possess an acceptable level of accuracy and reliability when measuring moderate to longer distances while running at slow to moderate speeds [Vickery, 2014]. The 15-Hz device showed no significant differences in distance validity to the VICON during multidirectional and short high-intensity linear based running. Despite the 15-Hz device having the highest sampling rate, its benefits weren't evident compared to the 5-Hs and 10-Hz devices [Vickery 2014].

The same year, Buchheit performed a study to examine the possible differences between GPS devices of the same brand during commonly reported running based measures [Buchheit, 2014]. Fifty GPS devices (15-Hz) were used, each from the same manufacturer (GPSports) but varying models and software chips. The 15-Hz devices were attached to a sled that a player was harnessed to and measures of total distance, distanced traveled above 14.4km/hr and 25.1km/hr, peak acceleration, peak speed, and number of accelerations and decelerations were measured by the devices [Buchheit, 2014]. The study reported on distance and velocity reliability, but no information was provided on validity during this study. The study found that the 15-Hz GPS units had good to moderate inter unit reliability when reporting total distance, low-speed running, and high-speed running (CV: 3%, 2%, and 6%, respectively). However, very poor inter unit reliability when measuring peak acceleration, accelerations, and decelerations (CV: 10%, 31-43%, and 42-56%, respectively) [Buchheit, 2014]. These findings don't equate too much

given that no validation measures were given. The paper was very brief and didn't provide much in terms of data. The poor inter unit reliability will be taken with a grain of salt and controlled by using the same unit for players during the study.

The final study assessed the validity and inter-unit reliability of 10-Hz (MinimaxX; Catapult) and 15-Hz (SPI-ProX; GPSports) GPS devices for quantifying athlete movement demands [Johnston, 2014]. The study employed the same team sport simulation circuit used by Coutts, Jennings, and Johnston in prior years. [Coutts, 2010; Jennings, 2010; Johnston, 2012]. Both units measured total distance, peak speed, distance covered at different speed intervals, time spent running at different speeds, and number of high-speed / very high-speed runs performed through the study. As in the past studies, a tape measure and timing gates were used as criterion validity measures for distance and velocity, respectively [Johnston, 2014]. The study found no significant difference between the criterion distance and total distance reported by both GPS units during the team sport circuit. When looking at the inter unit reliability for distance, the %TEM was 1.9%, 2.0%, 7.6%, and 12.1% for total distance, low speed running distance, high speed running, and very high speed running distance, respectively. This finding suggests a reduced inter unit reliability as the speed increases [Johnston, 2014]. The velocity validity for the 10-Hz didn't differ from the criterion ($r=0.76$) while the 15-Hz device had a significant difference ($p=0.009$) and a correlation coefficient ($r=0.64$) less than the 10-Hz device [Johnston, 2014]. The enhanced sampling rate of the 15-Hz potentially has no additional benefit, compared to 10-Hz, when tracking peak speeds. The %TEM for inter unit peak speed reliability was also higher for the 15-Hz (8.1%) versus the 10-Hz device (1.6%). Both the 10-Hz and 15-Hz devices still struggle to reliably measure movements performed at speeds greater than 20km/hr [Johnston, 2014].

Conclusion

All GPS devices, regardless of sampling rate, can accurately quantify distance during team sport simulations and therefore can be justifiably be used during team sport matches, such as soccer. In early research, GPS units were moderately reliable for measuring player locomotion, but struggled during high-speeds, and during short and fast changes in direction [Jennings, 2010; Portas, 2010]. In terms of velocity and speed measures, the GPS device accuracy increased with a higher sampling rate, but decreased with the increase in speed [Cummins, 2013; Dellaserra, 2014]. The studies that focused on the 10-Hz GPS units highlighted its evident superiority in measures in comparison to the smaller sampling rate units. Most soccer match and soccer match simulation studies use various models of the 10-Hz device to analyze the physical and physiological demands. In recent years, additional micro-sensors (accelerometers, gyroscopes, magnetometers, and heart rate monitors) have also been included inside the conventional GPS units worn by athletes. These little units, or integrated technologies (IT), are now multifaceted devices that possess additional technology other than just GPS. The units with the integrated technologies possess an ability to further quantify movements and demands of soccer [Page, 2015; Russell, 2016; Akenhead, 2013; Casamichana, 2012]. The 15-Hz units covered in these studies (GPSports) are not necessarily derived from 15 GPS data points per second but from interpolated data. This is a 10 Hz GPS sampling rate supplemented with accelerometer data in an attempt to improve the reliability of the tracking data [Johnston, 2014; Vickery, 2014; Buchheit, 2014; Rawstorn, 2014]. The common metrics, or measures, for a GPS in studies is total distance, number and distance of high-speed runs and sprints, number of accelerations and decelerations, player/bodyload, and heart rate exertion. However, the IT opened the door for secondary metrics such as metabolic power, fatigue index, energy cost,

power, and high-metabolic power distance. The metrics can insight into performance measures, which is why I will focus on the ones related to my study. The general consensus among researchers was to not compare data findings to different systems or sample rate GPS units because the data, for the most part, is not interchangeable [Coutts, 2010; Rampinini, 2015; Jennings, 2010; Johnston, 2014]. The research is limited for the 15-Hz GPS units, but a 15-Hz unit is a valid distance measure [Johnston, 2014]. The use of the same GPS device, within a study and its subjects, will provide comparable data to analyze the effects of an intervention.

Conclusion

After a review of all of the literature that pertains to my study, the ideology of my thesis comes to light. There is going to be a slight variation in the physical demands of soccer due to a multitude of influential variables and methods of assessment. The general consensus is that a player will cover anywhere from 9 – 14 kilometers throughout a 90-minute match, with a slightly variation dependent on position. The midfield players will likely cover more distance than the forwards and defenders. The mean match heart rate for players will range between 157-176 beats/min. Since all of my subjects will be male, and of a certain age, their heart rates will likely be consistent with what the literature found. Since formations, positions, and talent-level influences physical performance measures, my study will employ two teams of equal equivalency that will play the same formation and position during the trials, which eliminates any potential discrepancy in measures. Accelerations and decelerations performed throughout a game have been more recently studied, suggesting their crucial role in physical match performance and outcomes. Even though the majority of movements in a match are executed in a low to moderate intensity state, the scattered high-intensity movements are an important performance measure. Energy expenditure is a number greatly influenced by work rate and the

specific individual, which provide further insight into quantifying performance. The varying data suggests that there is a fluctuation when different analyzing systems are used such as the video-based, camera-based, and wearable technology based systems. Due to the different strategies used by different research teams, it becomes difficult to extrapolate data and findings. However, the study I will perform will be focused how a specific intervention changes the physical measures within a team and individual. The physical data found, via the GPS units, will be compared between the trial subjects, teams, and similar study groups that used the same analysis system.

Soccer, from a physiological and metabolic view, is an activity that demands a lot from its players. Players perform numerous different types of exercise intensities during the game. In accordance, both the aerobic and anaerobic energy systems contribute to the physiological demands of the game. The total duration of active play in football is typically 90 minutes, indicating that the primary energy source during the game is supplied via aerobic glycolysis, with an average maximal oxygen uptake (VO_{2max}) of around 70 – 80% during the match. The mean and peak heart rates of players were estimated to be around 85 and 98, respectively. There are a variety of metabolic trends and responses to a soccer match due to the complexity of substrate utilization, energy production, and homeostasis. A common trend is the suppression of insulin during intense exercise, with a rise in catecholamines, cortisol, and FFA's. Several studies have seen a drop in blood glucose during at halftime and initial phases of the second half, with the reasoning likely induced and associated with exercise.

Second half performance has shown to decrease compared to the first half, more specifically the first 15-minutes of the second half. The total distance covered, distance covered at high intensity speeds, accelerations, decelerations, work-rate, etc. have all been reduced during

the second half. There are a myriad of factors that can influence these performance measures, but the halftime period offers an area of research and focus for attenuating second half performance decrements.

Several studies have employed strategies to analyze their effects on physical or skill measures. Almost all studies reported that active RWU reduced the negative impact induced by passive half-time practices both on physiological (heart rate; HR, core temperature) or performance outcomes (jump, sprint, distance covered). Overall, a passive HT period leads to impaired performance when compared to active re-warm up. Active RWU significantly attenuates the temperature and performance decrement during halftime and second half period in soccer players. Although often considered crucial for tactical reasons, half-time periods can be physiologically considered as a recovery and a preparatory period preceding subsequent competition. Although RWU studies are currently scarce, it seems that traditional passive halftime period during soccer match causes temporary impairment in the players' physical performance capacity. Studies have used 5-7 minute RWU that include various activities and movements. Soccer-specific activities, dynamic stretching, and moderate-high intensity movements have shown benefits on performance when compared to no activity and static stretches. A 5-7 minute RWU seems long in professional soccer settings, but in order to highlight its potential and effects I believe an 8-minute RWU, with SSG, DS, and high-intensity movements, is needed.

Carbohydrates are a staple in the game of soccer and are regularly consumed during a game to attenuate decreases in performance, improve or maintain soccer skill performance, and lessen decreases in muscle glycogen concentration by maintaining available exogenous glucose or endogenous stores. CHO supplementation has evident advantages in soccer-specific skill

performance and physical performance, but studies show it's unable to reduce the exercise-induced drops in blood glucose at halftime or during the initial phases of the second half.

A new, metabolic benefit of an active halftime rewarm-up may be possible after reviewing the biological effects carbohydrate supplementation during soccer matches. The studies supplying a CHO beverage didn't incorporate an active rewarm-up during halftime. The active halftime rewarm-up studies didn't focus on whether it affected blood glucose or other metabolic responses during the second half. No studies have used GPS data to analyze performance differences between an active and passive HT rewarm-up. Thus, research that use GPS units to investigate the effect of an active halftime rewarm-up on second half performance is warranted. There haven't been any studies that combine both the ingestion of CHO during a match and an active HT intervention. It's possible that the exercise-induced drop in BG during a passive halftime can be eliminated by an active rewarm-up during the halftime period. Gradually, over the course of halftime there will be physiological changes such as reductions in core temperature, reductions in muscle temperature, and changes in the physiological response to exercise and recovery. When exercise ceases there is an increase in insulin, which causes glucose uptake by the previous active muscles and reduced glucose output by the liver. A period of rest can create ramifications to the body's responses. The body is resting and unaware of a subsequent bout of exercise is going to commence. The body is responding to this period of rest as if it were a period of complete recovery. If exercise is commenced when plasma insulin concentrations are high, for example following a pre-exercise CHO load, the metabolic response to exercise is characterized by a rapid decline in blood glucose during the first 10–20 min of exercise. The decrease in plasma glucose concentration is the result of the additional effects of the high insulin concentration and increased glucose uptake by the exercising muscle. The

halftime period, in a passive state and with CHO supplementation, could lead to a large insulin response, decreased BG levels, and potentially decreased second half performance, specifically during the initial stages (15-minutes). Since CHO supplementation effects have been positive, restricting CHO during the halftime phase of a match wouldn't be realistic or beneficial on subsequent performance. Studies have analyzed blood samples frequently through a soccer match or simulated soccer match to gain more insight of the trend. It's important to include multiple blood samples throughout the match, without impacting the flow, timing, and consistency of it.

The CHO recommendations for soccer are in place to ensure adequate glycogen stores prior to and during a match. The ideal pre-competition meal should take place 3-4 hours before the match and provide about 3-4g/kg of CHO. Several studies used fasted subjects or provided subjects with meals that were inadequate in CHO content. Nutrition plays an important role in the physiological response to soccer, thus creating a limitation in the majority of studies. The studies wanted to highlight the effects of their variables, but my study aims to study the effects in a normal/usual soccer match setting. Therefore, all players will be advised and educated on what to eat prior to the match to ensure all subjects are in similar fed states prior to both matches.

One of the limitations of simulated soccer matches is the consumption of carbohydrates at regular intervals, because this isn't achievable during an actual soccer match. Simulated soccer matches also lack self-pacing portions and common variables that influence match play such as competition, formation, and position. Therefore, an actual soccer match can provide applicable insight into the effects of CHO supplementation and an active RWU. Match play studies are often times ridiculed because of the high-variability between matches due to the complex interactions between physical and technical components. However, controlling as many variables

as possible such as playing formation, weather, field type, competition level, etc. can help reduce match-to-match variability. Teams will be split up evenly and play the same formations, with players in the same position during both trials. The same field will be used during both trials with an effort to play on days with similar weather.

There are a variety of methods to analyze the performance of a soccer player. The measure of technical performance has limitations. Soccer-specific skill tests are not representative of actual skill-related performance because they lack contextual variables typically involved in soccer matches and notational analysis is subjective to the reviewer and the skill performance definition used, therefore skill performance is difficult to quantify during a soccer match. A new method is to quantify physical performance using internal and external load measures that depict the distance, intensity, and work-rate of a player during a match. The development of the GPS, with accelerometers, and HR monitors has made it easier to quantify player performance and make comparisons. The performance measures of total distance, average speed, speed exertion, high metabolic power distance, energy expenditure, accelerations, and decelerations will provide a complete representation of physical performance. The additional measure of shots on goal and goals scored is an objective measure that can further define performance, although it's subjective in nature.

Wearable tracking systems such as the Global positioning systems (GPS) and accelerometers have become increasingly popular due to their ability to quantify movements. The integration of GPS units into match-analysis allows for more physical performance events to be measured and quantified, such as accelerations, decelerations, bodyload, metabolic load and power. Although various match-analysis methods enable researchers to measure the external match loads of players, literature suggests that GPS analysis is more accurate than manual video

tracking and less expensive than semi-automated video tracking. Additionally, GPS analysis can be used to integrate both motion analysis and HR analysis. GPS technology provides quantitative data on the position, displacement, velocity, decelerations and accelerations of players on the field. The validity and reliability of GPS units are still tested to this day. However, comparing GPS units within themselves and assigning the same GPS unit to players alleviates any disagreement and reduces inter-unit reliability.

Overall, Halftime is typically a recovery period that causes the bodies response to change because of the sudden stop in game play. When exercise stops, metabolic responses change within minutes of stopping exercise. Catecholamine levels subside and insulin levels rise, which stimulates glucose to move into the liver (and muscle) to be stored as glycogen. When a carbohydrate sports drink is taken in and glucose enters the blood, the insulin response may be greater. This in turn, could lead to greater glucose uptake by the liver and reduced blood glucose or a “transient hypoglycemia” during the halftime period. A carbohydrate drink did not necessarily cause hypoglycemia, but it did not prevent the drop in glucose during recovery.

Instead of having players enter “recovery mode” during halftime, they simply transition to and from a period of light activity. A key benefit of this approach to halftime might be suppression of insulin and maintenance of epinephrine. Combined, this could help the player maintain blood glucose levels, especially when a carbohydrate beverage is implemented. The low blood glucose state found in literature might be prevented by an active re-warm up. There are no research studies that combine a re-warm up and CHO supplementation during halftime. Blood glucose levels decline during the halftime recovery period and during the initial phases of the second half, which could impact performance. A halftime re-warm up does benefit performance, particularly at the start of the second period without negatively affecting the later

stages of the match. It is possible that this effect is due, in part to maintaining blood glucose and avoiding the negative effects of hypoglycemia. Literature considered, an active rewarm-up during the halftime portion should keep blood glucose levels elevated and attenuate physical performance at the start of the second half. The CHO beverage, since it's common practice in soccer and has supported benefits, should supply the active RWU subjects with a benefit that passive subjects won't experience. The passive subjects will receive the CHO, but the passive exercise state may cause reduced BG concentrations during the second half due to metabolic changes (i.e. increases in insulin) at halftime.

Table 1. Distance

Study	Subjects	Method	Distance (vs. First Half)	Significant?
Barros, 2007	Adult Male; Professionals, Brazil	Automatic Tracking System	8% Reduction	Yes
Bangsbo, 1991	Adult Male; Professionals, Denmark	Video Camera	5% Reduction	Yes
Mohr, 2003	Adult Male; Professionals, Italy	Video Cameras	3% Reduction	Yes
Rienzi, 2000	Adult Male; Professionals, South America & England	Video Camera	4% Reduction	Yes
Bradley, 2009	Adult Male; Professionals, England	Semi-automatic Video tracking	3% Reduction	Yes
Wehbe, 2014	Adult Male; Professionals, Australia	GPS	8% Reduction	Yes
Russell, 2016	Adult Male; Professionals, England	GPS	7% Reduction	Yes

Table 2. CHO & Physical Performance

Study	Exercise Protocol	Subjects	Supplement and When	Result	Limits
Leatt, 1989	Soccer Match	Highly trained players (n=10)	7% glucose polymer (0.5L) before and HT	~39% reduction in muscle glycogen use	Low-subject numbers, no performance measures, single-blind
Winnick, 2005	Modified LIST	Active (n=20; 10 F)	6% CHO-E solution before and during (every 15-min)	Significantly faster sprint times during final 15-min	No validity or reliability testing for modified LIST; Not possible to consume CHO every 15-min in actual match
Nicholas, 1999	90-min LIST	Trained players (n=6)	6.9% CHO-E solution before and during (every 15-min)	22% reduction in muscle glycogen use	Didn't state blinding procedures; Not possible to consume CHO every 15-min in actual match
Welsh, 2002	Modified LIST; run to exhaustion after	Trained players (n=10)	18% and 6% CHO-E solution before and during (every 15-min)	37% longer time to exhaustion and Significantly faster sprint times during final 15-min	No validity or reliability testing for modified LIST; Players were in a fasted state; Normal to run to exhaustion after a match?
Foskett, 2008	Modified LIST (90-min); run to exhaustion after	Active males (n=6)	6.4% CHO-E solution before and during (every 15-min)	21% longer time to exhaustion	Low subject numbers; Not possible to consume CHO every 15-min in actual match

Study	Exercise Protocol	Subjects	Supplement and When	Result	Limits
Goedecke, 2013	LIST; run to fatigue after	Male Soccer Players (n=22)	7% CHO-E beverage before and during LIST (29g/hr)	Players with lower body weights had increased time to fatigue (low dose – didn't impact heavier subjects)	~only provided 29g/hr (outside suggested range); didn't control feeding (eat as usual); Not possible to consume CHO every 15-min
Kingsley, 2014	90-min Soccer match simulation (SMS)	Recreational soccer players; male (n=14)	9.6% CHO (w/ caffeine*) and CHO gels (total: 142g/hr), 5.6% CHO-E solution w/ CHO gels (54g/hr) before and during (every 15-min)	Improved sprint performance for 9.6% group; 9.6% negatively effected hydration status ,caused gut discomfort	Caffeine included in the 9.6% CHO beverage; Not possible to consume CHO every 15-min in actual match
Funnell, 2017	90-min Modified LIST	Male soccer players (n=16)	12% CHO-E solution (500mL) before and at HT; subjects were in a fed state	No improvement in self-selected running performance or sprint speed; Abdominal discomfort	Used a LIST protocol, different variables to an actual match
Harper, 2017	90-min SMS	University male soccer players (n=15)	12% CHO-E solution (500mL) before and at HT (250mL each)	Increased self-paced exercise performance and improved sprinting speed (2.7%)	~Standard night meals (48-hours prior); meal (10% daily kcal needs) 3 hours before SMS
Ali, 2007	Extended LIST (90-min) after glycogen depleting exercise (80-min cycle at 70% VO2max)	Trained players (n=16)	6.4% CHO-E solution before and during (every 15-min)	Significantly faster mean sprint time during LIST	Didn't state blinding procedures

Table 3. CHO & Skill Performance

Study	Exercise Protocol	Subjects	Supplement and When	Result	Limits
Ostojic, 2002	90-minute soccer match and timed 18.0m dribble test immediately after match	Professional male soccer players in Yugoslavia (n=22)	7% CHO-E beverage before and during the match (every 15-minutes)	Improved dribble test performance by 5%	~Only 800kcal 4 hours prior to the match (realistically needed 310g (77.5kg) or 1,240kcal prior to match)
Currell, 2009	90-min match simulation; timed dribbling test, shooting target, and max jump and heading test	Recreational soccer players; male (n=11)	7.5% CHO beverage	Improved dribbling and shooting performances	No control of speed and no distance measure during protocols
Abbey, 2009	75-min match simulation; shooting test (target 7m away)	Collegiate male soccer players (n=10)	6.0% CHO-E beverage and 6.0% honey-E beverage	No effect on exercise or shooting	Training and diet wasn't controlled
Harper, 2017	90-min SMS w/ dribbling performance	University male soccer players (n=15)	12% CHO-E solution (500mL) before and at HT (250mL each)	Improved dribbling speed, but not success or precision	SMS use
Ali, 2007	Extended LIST (90-min) after glycogen depleting exercise; LIST passing and shooting test	Ex- Collegiate and professional players (n=16)	6.4% CHO-E solution before and during (every 15-min)	Improved shooting performance	Didn't state blinding procedures; Subjects in glycogen depleted state; LIST doesn't have a HT
Russell, 2012	90-min SMS with shooting, passing, dribbling analyzed	Academy soccer players (~18y.o) (n=15)	6.0% sucrose-E beverage before and during (every 15-min)	Improved shooting speed and performance (10%), no effect on passing or dribbling	Consumed beverage every 15-minutes: not realistic; only ~54g/CHO roughly 2 hours before SMS (62% of needs)

Table 4. Blood Glucose & Soccer

Study	Subjects	Exercise Protocol	HT - Intervention	CHO?	Fed state?	Time of lowest BG (lowest) and # of samples	Potential Reasoning / Assumptions
Russell, 2011	Youth, male players in England (n=10)	90-min simulated match & 90-min match	15-min Passive	No	Fed	45-60minute interval (~4.0mmol/L) and 7 samples	First study to take 7 blood samples during a match
Krustrup, 2006	Adult, male pro players in Denmark (n=31)	90-min soccer match; 3 matches	Unknown; Not specified	No	Fed	Prior to second half (~4.1mmol/L) and 6 samples.	High BG b/c of catecholamines and lowered insulin
Russell, 2012	Adult (18), male academy players in England (n=15)	90-min simulate match (SMS), 2 trials; cross-over	15-min passive	Yes; 6.0% CHO-E beverage before and every 15-min	Fed; low CHO intake before match though (~54g)	60-min (~4.1mmol/L) and 9 samples	CHO didn't attenuate BG drop... the inactivity at HT could create problems
Kingsley, 2014	Adult, male, rec players (n=14)	90-min SMS; 3 trials, cross-over double-blind	15-min passive	Yes; 9.6% and 5.6% with CHO gel before and during	Fed; low CHO intake before match ~62g	60-min (71% <4.00mmol/L & 57% <3.80mmol/L) and 7 samples	Increased insulin during HT and reduced liver glucose output
Russell, 2014	Youth, male, academy players (n=10)	90-min soccer match, 2 matches cross-over/double-blind	15-min passive	Yes; 6.0% CHO-E, before and during every 15-min	Fed; low CHO intake before match though (~54g)	45-60min interval (~3.9-4.1mmol/L) and 8 samples	Increase glucose uptake by muscles, lowered catecholamine, reduced liver glycogenolysis
Harper, 2017	University, male players (n=15)	90-min SMS	15-min passive	Yes; 12.0% CHO-E before and every 15-min	Fed; meals 48hr. prior to preSMS	PLA: 60-min CHO: first half, but ~38% decrease from HT to 60-min	CHO beverages are implemented to maintain BG, but a new strategy needs to work w/ CHO

Chapter 3:

Effects of an active halftime rewarm-up, with carbohydrate supplementation, on players' blood glucose and second half performance during a collegiate soccer match

Methods

Participants:

Twenty male collegiate soccer players with a mean age of 20.53 (range:18-24; SD:±1.50) years represented the subjects for this study. The subjects had an average height of 178.41cm (±8.51cm), roughly 70.2 inches or 5'8.5", and a mean body mass of 72.66 (±4.46kg.) kg. All of the subjects were recruited from the Virginia Tech Men's Club Soccer (VTMCS) team and the participating subjects were all members of the VTMCS team. Player's were selected on the basis of interest, playing position, screening data, and availability to participate in the study. Only field players (defenders, midfielders, forwards) were included as subjects. Subjects were excluded if they were unable to play in both of the soccer matches due to an injury or schedule conflict. Subjects were also excluded if they had a history of cardiac or thyroid problems, diabetes, or were taking any medications that could influence their participation (asthma medication, decongestants). All players were informed of the design, experimental procedures, and potential discomforts associated with the study before consent to participate. The players did not receive any compensation or incentive for their time or participation. The Virginia Tech Institutional Review Board approved all study procedures prior to the on-set of subject recruitment.

Design:

Subjects were recruited through an information session held at a VTMCS practice. Prior to the practice, the VTMCS president and vice-president were contacted to discuss the study, logistics, gauge interest, and ensure optimal attendance the subsequent practice. An information session and screening visit were held prior to the studies main procedures.

The subjects participated in a total of two 90-minute soccer matches that took place 24-hours apart. A 90-minute soccer match the main exercise protocol and the 90-minute period was split

into two 45-minute halves interceded by a 15-minute halftime period. The games were played by a total of twenty-two players, eleven players versus eleven players (11 v. 11). Two of the twenty-two players were goalkeepers and the same goalkeepers played both matches with their respective team, but they excluded as study subjects since their running distance is minimal (performance measure) compared to field players. The twenty subjects were only field players (defenders, midfielders, and forwards), and were split into two teams of ten players each. The selection of the two teams was made in close collaboration with the VTMCS president and vice-president to ensure that the teams were of equivalent status (skill, work-ethic, position).

The halftime period contained the intervention of the study, which was an active rewarm-up (RWU). The study had a crossover design so all twenty subjects, split into two teams of ten players, participated in both the intervention (RWU) and control (CON). The two 90-minute soccer matches took place on successive days (24 hrs. apart) because of weather issues and player availability. The RWU was an 8-minute moderate-intensity bout of soccer-specific exercises and the CON was a corresponding period of passive activity, such as sitting and static stretches.

The active RWU consisted of small-sided keep away, small-sided possession (SSP), small-sided games (SSG), and a 20-yard dynamic stretching/movement segment (DS). During the halftime period both teams, all twenty subjects, were provided with a carbohydrate-electrolyte (CHO-E) beverage that was consumed completely before the second half. Subjects had five separate fingersticks, to obtain blood glucose values, throughout the entire 90-minute match. Four subjects, two from each team, had venipuncture blood draws to obtain serum glucose and serum insulin measurements. The venipuncture was done three separate times for each one of the four participating subjects. The objective of the study was to assess the effects of the active

halftime rewarm-up, with CHO-E beverage consumption, on blood glucose, insulin, and second half performance in collegiate soccer players. The study controlled and limited the influence of variables through procedures, protocol, education, restrictions, and controls.

Procedures:

Recruitment & Information Session

The schedule and flow of procedures is depicted in figure 2. A meeting with the president and vice president of VTMCS was set-up to begin recruitment. During this meeting, study design was discussed to gauge interest and compliance. A result of this meeting was support and interest in the study. An information session took place prior to a VTMCS team practice that included twenty-eight players on the team. The president and vice president ensured full attendance at the practice to create a large potential subject pool. The information session was used to introduce the study, gauge further interest, educate players on the study procedures, answer questions, and retrieve contact information. A phone number and email was received from twenty-eight players, all who expressed interest in participation. A hardcopy of the screening visit questionnaire (appendix) was brought to the information session for the players who wanted to fill it out.

Screening Visit

Players signed up for a screening visit, which took place roughly 5-7 days prior to the first match, via a googledoc sent out to each subject who was interested in participating in the study. The screening visit lasted approximately 30-minutes and took place in Wallace Hall room 233. The visit included the hardcopy completion of both the screening and health history questionnaires (dix). The screening questionnaire assessed availability, medications, injury history, contact information, self-reported height and weight, and whether the subject takes any supplements. The health history questionnaire assessed the individual's medical history and

examined medications to determine eligibility for the study. The questionnaires were reviewed to validate subject eligibility for the study and once subjects were approved, screening visit procedures continued. Next, the consent form, which reviewed the study protocol, purpose, and logistics, was read and appraised by the subjects.

The subjects were informed of each aspect of the study; specifically, the fingerstick and blood draw procedures. The potential study participant was given a copy of the consent form to take home with them to review if they aren't ready to sign. Despite this option, all subjects felt informed, aware, and gave assent with a signature at the initial screening visit. After the consent form was signed, each subject was assigned an identification (ID) number (80-99). An electronic documentation system was used to keep track of each subject.

Baseline measures of height and weight were obtained with the use of a wall-mounted stadiometer (Seca Model 216, Seca; Chino, CA) and a digital scale (Scale-Tronix 5002, Welch Allyn; Skaneateles Falls, NY), respectively. The evaluation of BMI was calculated with the subjects' height and weight measurements. The height was recorded in inches (in.) and centimeters (cm.) while weight was recorded in both pounds (lbs.) and kilograms (kg.) Height and weight were measured three times for each subject and the average of the three measurements was taken. Attached in the appendix is the body weight and height document used to record each measurement taken (appendix). The clothes worn and any additional notes were recorded on the measurement sheet. The subjects who were blood draw participants were determined by consent and desire to participate in the venipuncture. Each subject was asked if they had an interest in this portion of the study. The first four subjects who expressed interest and a desire to be a blood draw participant were included. Subjects were no longer asked about blood draw participation once four subjects consented.

Subjects were required to record food and beverage consumption, using a food intake record, on the day of the match testing sessions (wake-up to start of match), in order to determine caloric and carbohydrate intake on match day. Subjects were instructed on how to appropriately fill out a food log, with an emphasis on accuracy and specificity. A hardcopy of the food intake record, found in appendix, was provided and subjects were informed to return it at the soccer. An electronic copy of the food log was also provided to each study subject the night before the match day. Additionally, hard copies of the food log were brought to the soccer match for an individual to complete. An email and text message reminder was sent out on the day of the match and each day until the food log was received. The food log was completed on both match days and only included the foods consumed on the day of the match (morning until the match).

Lastly, each subject was educated on the studies recommendations and restrictions. Attached in the appendix is the Test Day Recommendations and Restrictions document. The study included several restrictions prior to the match. No alcohol consumed 48 hours prior to the match, no caffeine consumed 24 hours prior to the match, no strenuous or exertive exercise performed 48 hours prior to the match, and no food or beverages (besides water) consumed once there was 60 minutes or less until the start of the match. Each subject received an education and recommendation on what to consume on match day. The general recommendations were to consume a high carbohydrate (CHO) meal 3-4 hours before the match begins. The recommendation was consistent with current evidence-based research in the field of sports nutrition [Thomas, 2016]. The recommendation was to consume 3-4g of carbohydrate (CHO) for every kg. of body weight 3-4 hours prior to the match. Each subject's bodyweight was included on the Active Recovery Test Day Instructions. The general pre-game meal CHO recommendations based upon bodyweight in kg was computed and recorded for each subject at

the screening visit. The active recovery test day instruction sheet had blank spaces for CHO recommendations to be recorded. The sheet described an “ideal meal” and what to avoid. Some example game day meals and snacks, with CHO content, were depicted based upon what Virginia Tech campus dining halls offered and commonly consumed foods. The meal recommendations weren’t mandatory, but the reasoning and benefits of its compliance were discussed. Every subject was advised to eat similar items/meals prior to both matches. The completed sheet was sent home with each subject following its discussion.

In summary, the subject completed a screening questionnaire, health history questionnaire, signed the consent form, received education on food logs, and received education on the studies restrictions and recommendations.

Resources & Logistics:

Equipment

All twenty-study subjects were fitted and assigned a triaxial Global Positioning System (GPS) device and heart rate (HR) strap/monitor. The GPS devices and HR monitors non-invasively recorded physical and physiological measures. The GPS devices were GPSports HPU SPI units and HR monitors were Polar heart rate monitors. Respectively, these two units measured player movements such as running distance, speed, accelerations, decelerations, energy expenditure, body load, and heart rate. The GPSports units contained a 15- Hz GPS receiver and a 100Hz, 16g accelerometer. The units recorded positional data at 5-Hz, which was then supplemented by accelerometer data to record interpolated position at 15-Hz. The triaxial accelerometer orientation is determined by a 50 Hz magnetometer, which is used to orient the axes of the accelerometer. Each GPS unit measures 74mm x 42mm x 16mm and weighs 56g. The units communicate with a Polar T31 coded heart rate monitor (15-Hz determination of heart

rate), which takes 15 HR samples per second. The subjects wore the GPS units and HR monitor straps during both soccer matches. The units were secured on the back, between the scapulae, using a custom designed vest similar to a women's sports bra. The HR monitors were secured to the vests and situated on the front of the thorax, just below the sternum. The GPS unit signals were transmitted in real time to a receiver, which was located adjacent to the playing field, using two-way wireless encryption and manufacturers software (GPSport RealTime). Following each 90-minute match, data stored on the units was downloaded onto a computer and stored on a secured hard-drive.

Experimental Beverage

The carbohydrate-electrolyte (CHO-E) beverage was a 20 oz. (591 ml.) bottle of Gatorade, flavored lemon-lime or orange. The lemon-lime Gatorade was provided for match 1 and the orange Gatorade for match 2, but the two flavors didn't differ in contents. The Gatorade provided 36g of carbohydrates (CHO), which equated to a 6.09% CHO-E solution beverage. The subjects were required to consume the CHO-E beverage in its entirety during the halftime period. Water was provided in form of a prepackaged 16.9oz. bottle (Kroger brand). Subjects were able to drink the water bottle during halftime, if they desired, once the CHO-E beverage was completely consumed. The 6.09% CHO-E beverage was in line with the recommendations for CHO intake during a soccer match [Baker, 2014; Thomas, 2016; Burke, 2011; Russell, 2014a].

Days leading up to the first match

Once the screening visits were complete for all twenty subjects, they were divided into two teams of ten subjects. The VTMCS president and vice president, who were study subjects, were consulted for the equivalent split of the twenty subjects into two teams. The president and vice president were aware of the four blood draw participants to ensure that there were two on

each team. The teams were equally split and documented. The players' name, ID #, position, and whether the team was the control (CON) or intervention group (RWU) was documented (attached in appendix). The team information document was sent out the night before the match to ensure players were aware of their respective team. Each team was assigned a jersey color, white or maroon, for the matches. Equipment for the match (balls, cones) were provided by the VTMCS team.

Location, Time, and Weather

The two matches took place during the spring semester, which was the VTMCS off-season. The first match took place on a Monday and second match on Tuesday, which was 24-hours after the original match. The games were suppose to take place during the week on Tuesday or Thursday, because these were typical practice days, and have a week in-between each match. However, inclement weather and field availability resulted in the rescheduling of games. The games took place during the night at approximately 7pm.

The field location was selected with the help of the Intramural Sports Coordinator for the Department of Recreational Sports and the VT Club Sports Coordinator. The matches took place at the Lower South Recreation Area (SRA) fields. The SRA field used was turf with dimensions that were in line with the FIFA regulations [FIFA, 2015]. The same SRA turf field was used for both of the matches. Subjects arrived at the field 30-minutes prior to the start (~7pm) of the game. An early arrival ensured enough time for equipment distribution (GPS and HR), pre-match warm-up, and re-familiarization of study protocol.

The mean temperature at the start of the matches was 62° F ($\pm 1.41^\circ$). The skies were clear and neither match experienced any inclement weather or rain. Inclement weather resulted in

an original match date to be rescheduled, but the subsequent two matches had similar weather, temperatures, and field conditions.

Match & Protocol

Match

The research team arrived at the field an hour before the match to set up. The subjects played in a standard 90-minute match (45-minute halves) with a 15-minute halftime. A typical soccer game incorporates referees and player substitutions, but the study excluded substitutions and referees. Player's refereed the match, which is common practice in a soccer scrimmage. Additional time, typically added in the result of a tie or extended stoppage in play, wasn't added to the match. The match ended after the 90-minute period regardless of the score because a match winner was not an aim of this study. The total time for the trial was about three hours (6:30 arrival – 9:30 departure).

Arrival: Equipment Distribution

The subjects checked in upon arrival at the field and their hands were marked, using a sharpie, with their respective ID #. The GPSport HPU SPI units and Polar heart rate monitors were assigned to the players prior to the match. A handout, with the players' ID numbers, was used to track which GPS unit number the player was assigned (appendix). The GPS devices were secured on the back, between the scapulae, using an appropriately fitted vest and subjects wore the same unit for both matches. The HR monitors were distributed arbitrarily because they were adjustable and weren't numbered. The research team ensured each GPS device was charged and worked properly before and during the match. Subjects wore the devices and HR straps for the entire soccer match.

Medical Procedures

A fingerstick blood sample was taken five times for all twenty subjects throughout the trial period. A trained medical team operated the fingerstick blood samples. Tables were set up for each team and tables were clearly labeled with the appropriate team. The subject approached the same table for each of the five BG checks. Each table had two trained and qualified research team members conducting the BG fingersticks. The players knew their ID # and their hands were labeled with their respective number. This process made it easier to identify and document each subject. The fingerstick blood glucose (BG) data was recorded on a data sheet and each had their own data sheet marked with their ID#. A member of the medical team recorded the BG reading onto the data sheet, while the other member performed the fingerstick. The test subjects were not told the results of these measurements. Appropriate equipment and methods were used for the fingerstick procedures. There was a separate glucometer (OneTouch: UltraMini), used to determine BG, for each subject. The glucometers were treated with a control solution, according to the manufacturers instruction, prior to the first match. A total of twenty glucometers were used, each one labeled with a number 80-99 that represented the ID # for the corresponding subject. An alcohol swap was used prior to each stick. A single-use lancet was used to prevent multi-uses of said lancet. The blood sample was collected from the fingertip every time, but not the same fingertip. Gauge pads and Band-Aids were provided to subjects after the stick to minimize bleeding. The appropriate disposal of lancets, alcohol swaps, test-strips, gauge-pads, and Band-Aids was practiced.

A team of trained medical technicians/professionals operated the venipuncture blood draws. Two separate blood draw stations were set up for the four test subjects. The two subjects, on the same team, visited the same table and medical professional for all three of the blood draws. Aseptic conditions were followed during all the procedures, with universal precautions

taken during in collection and handling of all blood samples. A small needle will be inserted into the subject's arm to draw blood, approximately 1 tablespoon each time for a total of 3 tablespoons. A member of the research team appropriately transported, using a vehicle, the blood samples back to the lab immediately following each blood draw. The transfer of blood samples took place after each of the three blood draws. After the game, there were twelve (3 vials per subject: 4 subjects) vials of blood to be analyzed. The entire study had twenty-four vials of blood to be analyzed for serum blood glucose and serum insulin measurements.

Before Game & First Half

Subjects warmed up twenty minutes prior to the start of the match. The warm-up was unregulated, but the club team president and vice president ensured common practices were utilized. Subjects received their first fingerstick blood sample five minutes before the start of the game. The four subjects participating in the venipuncture received the first of three blood draws during this time. Both teams played the match in the same formation. The VTMCS president decided the playing formation based on usual playing style, formation, and players participating in the study. The subjects played in the same position for the entire duration of the match across both games. The same playing formations and playing position helped limit the study variability seen by previous researchers [Tierney, 2016; Bush, 2015]. The teams started the game at the same end of field for both games and kick-off was approximately 7pm for both matches.

Once all GPS devices and HR straps were distributed, player's warmed up and the first BG test and blood draws were completed. The first half of the game lasted 45-minutes with no stoppages in playtime for no injuries occurred. The time was tracked with a sports watch, stopwatch, and time clock. Shots on goals and goals scored throughout the first half were manually tracked and recorded. Every goal scored received a time-stamp. The research team

prepared the second BG test and blood draw as the first half came to a close. After the 45-minute half ends, the players exited the field and completed the second BG check.

Halftime

A 15-minute halftime period (HT) began immediately after the first 45-minute period. The HT period consisted of the intervention (RWU), control (CON), CHO-E supplementation, and blood measures. The half-time period was a 15-minute segment that was split into three separate phases. The three phases were the initial phase, intervention phase, and closing phase.

The initial phase was 3.5 minutes in duration and consisted of the second fingerstick (BG check) and CHO-E beverage consumption. It was also a time for teams to discuss game tactics and use the restroom. The CHO-E beverage was handed out and initial consumption was after the second fingerstick.

The intervention phase was 8 minutes in duration and included the RWU protocol (listed below). During the intervention phase, the CON group relaxed, remained seated, or static stretched (SS). Whereas the RWU, intervention phase, consisted of four different activities/exercises. The four exercises were four versus one (4 v. 1) keep away, five versus five (5 v. 5) small-sided possession (SSP), five versus five (5 v. 5) small-sided game (SSG), and dynamic stretches/movements (DS). All of the RWU exercise/activities are depicted in figure 1. Keep away was played in a 5 x 5-yard box and four players kept the ball away from a lone defender. Once the defender stole or intercepted the pass he switched places on the outside with the player who turned the ball over. Keep away lasted for a total of 2-minutes. The 5 v. 5 SSP game was played inside a 20 x 20-yard box measured out by cones. The object of the game was to keep possession of the ball amongst the team through passing and dribbling. SSP lasted a total of 2.5 minutes. The 5 v. 5 SSG used the same team as SSP. The SSG was played on the same

box outlined by the cones set down for SSP. However, colored pinnies marked two 1-yard goals on opposite sides of the box. The objective was to score a goal by dribbling, under control, through the goal. Once a team scored on one goal they attacked the opposite goal. SSG lasted a total of 2-minutes. Those three RWU exercises lasted a total of 6.5 minutes. A pause in the RWU intervention took place. RWU and CON subjects got their third BG check. The two RWU and two CON venipuncture participants completed the second blood draw during this time period as well, five minutes prior to start of the second half. The DS segment of the RWU took place during the last 1.5 minutes of the HT period and concluded the intervention phase. The DS protocol included commonly practiced dynamic stretches, jogging movements, and sprinting movements that were performed in a linear 20-yard space. The DS included activities such as high knees, butt kicks, jogging hip abductors, jogging hip adductors, walking lunges, walking quad stretch, 75% sprint, 5-yard back pedal to a sprint, and a full sprint with a jog back. Each DS exercise was completed linearly 20 yards in distance and then re-done linearly 20 yards returning back to the starting position. The starting position, for the DS exercises, was on the touchline of the field with the endpoint measured 20 yards linearly from the touchline.

The closing phase was 3.5 minutes in duration. The closing phase represented the end portion of the 15-minute halftime period took place during the minutes before the start of the second half. During this phase both the CON and RWU groups finished their respective CHO-E beverages and, as previously mentioned, completed the third BG check. The RWU groups closing phase began before the CON group, because the DS portion of the intervention phase was 1.5 minutes before the second half. The CON subjects did not jog, sprint, or perform DS prior to the second half and only walked or performed SS. SS were allowed to help loosen muscles, whilst preventing injury.

Additional water was distributed and consumed once the CHO-E beverage was finished, but the amount consumed wasn't monitored. The additional water was provided in the form of 16.9 oz. packaged water bottles. CHO-E beverage consumption was monitored for completion through observation, but the weight of the bottles was not recorded. The entire HT period, time, and duration was monitored and controlled via a sports watch and stopwatch.

Half-Time Summarized:

The half-time period was 15-minutes in duration. The two teams, CON and RWU, completed their second BG check. The BG check was during the first 3-minutes of the halftime period (0:00-3:00 min. mark). The two teams received the 6% CHO-E solution beverage after their second BG check. Subjects consumed the entire beverage over the next 12-minutes. The intervention phase began and the CON group completed their phase in a passive, inactive state in which they sat, rested, and relaxed. The RWU began the active rewarm-up intervention during this phase. RWU players randomly split into two groups of five and completed keep away, SSP, and SSG in marked grids (4:00-10:30 min. mark). These players finished their CHO-E beverages, tended to their own needs, and completed the third BG check over the next 3-minutes (10:30-13:30 min. mark). The CON group had the third BG check beginning at the 11:30 min. mark. Once the BG check was complete, they remained inactive or performed static stretches (SS). The four-venipuncture subjects began the second blood draw at the 10-10:30 min. mark. Once the blood draws were complete the subjects rejoined their respective teams. The RWU group began the last portion (1.5-minutes), which was the DS, of the active rewarm-up intervention at the 13:30-15 min. mark. At the end of the 15-minute HT, both groups completed the second and second BG checks and consumed their entire 6.0% CHO-E solution beverage. The blood draw participants completed the second blood draw. The RWU group completed an 8-

minute active rewarm-up intervention and the CON group remained inactive and seated during the corresponding 8-minutes. The half-time minute timeline is described in figure 3 and minute breakdown for CON and RWU in figure 4.

Second Half & Post Game

The second half began immediately following the HT period. The start time was approximately 8pm for both matches. Shots on goals and goals scored were recorded throughout the second half, specifically focused on the shots and goals scored in the first 15-minutes of the second half. Gameplay was halted 15-minutes into the second half (60-min. mark) for the fourth BG check. Play was stopped during a dead ball situation and the game was resumed at the exact spot play was halted. The players went to their respective table of medical staff located on the sidelines and the fourth BG check took place in a 5-minutes window. Players did not drink any additional fluids during this time period. Once the BG check was complete, players returned to the spot they left moments earlier and time/play resumed. The players continued to play for the last 30-minutes. The research team prepared for the final fingerstick and blood draws.

The game ended in the 90th minute and extra time was not played.

Subjects left the field after the 90-minute match and completed the fifth and final fingerstick. The four-venipuncture subjects completed the third and final blood draw at this time. The research team recollected the GPS units and HR monitors from each player.

Data Measures and Analysis:

Performance Measures: GPS/Accelerometer/HR

Player movements (running distance, speeds, etc.) and heart rates were measured non-invasively using a GPSports HPU SPI unit and Polar heart rate monitor. These devices allow for the daily collection of over 100 variables describing the training load exerted on a specific

individual. The devices utilize an external heart rate strap, worn below the xiphoid process, GPS, accelerometer, and magnetometer. The devices are described in detail under the equipment section. The data provided by the GPS device and HR monitors were used to analyze and quantify performance.

Following each 90-minute match, data stored on the units was downloaded onto a computer and stored on a secured hard-drive. The GPS device, 15 Hz. GPSports SPI HPU, can track a variety a performance measures, but the study focused on specific ones. A total of nine performance measures were taken to quantify performance. The nine measures analyzed physical and physiological data that focused on distance, speed, and metabolic load. The measures included distance covered (m), average speed (km/hr), high metabolic power distance (m), energy cost, max heart rate (bpm), average heart rate (bpm), HR exertion, accelerations (#), and decelerations (#).

Distance was the total distance (TD) covered during the match in meters (m) and determined from the GPS recordings. Average speed was the average speed defined by kilometers covered per hour (km/hr). High metabolic power (HMP) distance was the distance covered above 20 watts per kilogram (20W/kg). Energy cost, or metabolic load, relative to body weight (kJ/kg) was defined as the energy cost to complete an activity. The energy expenditure (EE) was calculated based on a formula developed, and refined by two researchers, that uses slope, mass, terrain, and accelerations to determine the relative energy cost during a soccer match [Osgnach, 2010; Di Prampero, 2015]. Average HR was the mean number of heartbeat per minute experienced by the subjects. HR exertion, developed by a researcher, was time spent in each HR zone (six zones: 0-115bpm; 115-130bpm; 130-160bpm; 160-170bpm; 170-180bpm; >180bpm) multiplied by a (configurable) weighting factor [Alexiou, 2008]. It was determined

using a proprietary algorithm based on the training impulse (TRIMP) method of a researcher [Banister, 1991]. The resultant values were summed to provide the HR exertion for the specific time-interval [Alexiou, 2008]. HR exertion (HRE), defined by arbitrary units, was the time spent above defined HR thresholds. Accelerations and decelerations were defined as the total number of movements greater than 1.0m/s^2 . The summation of all the accelerations and decelerations performed in the three different zones (1-2; 2-3; 3-4 m/s^2) equaled the total number of movements, respectively.

Performance Measures: Shots & Goals

The shots on goal and goals scored were recorded throughout both matches as another method to quantify performance, although these measures are less concrete and more subjective. A single researcher recorded the data manually onto a notepad and transferred the data onto excel for analysis.

Blood Data

The medical procedures for the fingerstick blood samples and venipuncture blood draws are extensively described in the above *Medical Procedures* section.

Each subject had five-fingerstick blood samples, via a OneTouch: UltraMini glucometer, completed for plasma blood glucose (BG) values. The fingerstick, or BG check, blood samples were collected on all participants at five separate time points. Glucometer BG data was grouped into the five time-intervals ($T_1 - T_5$) it was taken. The first fingerstick was five minutes before the start of the game (T_1). The second fingerstick was at the end of the first-half, which was roughly 45-50 minutes after the first fingerstick (T_2). The third fingerstick was at the end of halftime, minutes before the second 45-minute half began (T_3). The fourth fingerstick was 15-minutes into the second half of the game, which was the 60-minute mark of the game (T_4). The

fifth and final fingerstick was immediately following the end of the game, which was the end of the 90-minute match (T₅).

The venipuncture blood draw was used to obtain serum blood glucose and serum insulin values. It took place at three separate time points on four subjects. Like plasma BG levels, the serum blood draw (BD) data was grouped by the time it was completed (BD₁ – BD₃). In addition, venipuncture subjects also had the five-fingerstick blood samples taken. The first venipuncture blood draw was prior to the first half, the second just before the start of the second half, and third at the end of the game. The minute mark, for the entire study, of each blood draw was the 0-minute mark, 55-minute mark, and 110-minute mark. The first draw was 5-10 minutes before the start of the 90-minute match (BD₁). The second blood draw was 5-minutes before the start of the second half, which was 10-minutes into the halftime period (BD₂). The last blood draw was immediately after the 90-minute match, which was the 105-110-minute mark in real-time (BD₃).

Glucometer data was recorded on data sheets and venipuncture blood draw samples were stored in a laboratory freezer (-80° C) immediately following their completion to await analysis.

Food Intake Data

Food logs tracked what foods each subject consumed (serving size, time, brand) throughout both match days. A log was completed for both match days (n=2) and turned in upon completion.

Statistical Analysis:

GPS/Accelerometer/HR

The GPS data and physical demands were analyzed off-line using the manufacturer's proprietary software (GPSports, TeamAMS). Each match was analyzed as a whole with 15-

minute time-intervals. Each subject's data (heart rate, accelerometer, and GPS) was split into 15-minute time-interval (TI) segments throughout the 90-minute match and halftime period. A total of seven time-intervals were created, with six of them during the match and one at halftime. The time-intervals were labeled as TI and include the respective number related to its placement during the match. The time-interval for HT was (TI-HT), 0-15 minutes (TI-1), 15-30 minutes (TI-2), 30-45 minutes (TI-3), 45-60 minutes (TI-4), 60-75 minutes (TI-5), and 75-90 minutes (TI-6). Differences in each variable between match time-intervals were identified by a statistical test.

The TeamAMS software ran two way repeated measures analysis of variance (ANOVA) for each separate variable, adjusted for repeated measures. The source of variation was the condition (RWU or CON), time-interval (TI=7), and condition x time-interval. When a statistically significant ($P < 0.05$) difference or interaction existed between conditions, time-interval, or condition x time-interval a pairwise multiple comparison procedure was complete via a Tukey Test. Each variable was compared within itself to determine what was significantly different. Each time-interval within each condition was analyzed and compared with the respective time-interval of the conflicting condition. The comparisons tested for significant differences ($P < 0.05$) between the two conditions within each time-interval.

All of the data was grouped into three separate tables for easier interpretation and evaluation. The three separate tables group each group three of the performance measures. Each table included the mean and STDev of each measure (condition) within each time-interval. The significant differences were marked by bold and an asterisk. A clustered column graph, with significant difference between conditions (RWU & CON) labeled, was used to depict the table data for some of the performance measures.

Match vs. Match Analysis

The two matches took place 24-hours apart, with a short period for recovery, and the data from both matches was analyzed for any significant differences between days. A two way repeated measures ANOVA, adjusted for repeated measures, was used to analyze each data variable and the potential effect of match day. The ANOVA tested for variation, significant difference in days and significant interaction between day x time-interval.

Shots & Goals Analysis

The data collected from the matches was analyzed using chi-square statistic to find out the significance differences between the two conditions. In all cases a significant level of $P < 0.05$ was used for the level of confidence. Data was further grouped into first and second halves for comparison of conditions.

Blood Data Analysis

The blood draw samples were analyzed five days after the second match was complete. A total of 24 serum blood samples (4 subjects: 3 time points per subject x 2 match days), which were stored in the laboratory freezer, were analyzed for BG and insulin concentrations. Insulin was measured using an Immulite 1000 immunoassay analyzer (Seimens Healthineers). Glucose was measured using an Amplex Red Glucose/Glucose oxidase kit (Invitrogen) according to the manufacture's instructions. Plasma blood glucose measures were provided immediately on match days and recorded onto data sheets for analysis.

The blood data was grouped into time points based on when the blood sample or blood draw took place. The glucometer (plasma BG) fingerstick blood samples were separated into five time points (T_1 - T_5). The blood draw (serum BG and serum insulin) sample data was grouped into three time points (BD_1 - BD_3). Two way repeated measures ANOVA tests, adjusted for repeated

measures, were used to analyze glucometer and blood draw data. The ANOVA tested for variation in condition (CON vs. RWU), time, and condition x time. When a statistically significant ($P < 0.05$) difference or interaction existed between the tested sources, pairwise multiple comparison procedures were complete via a Tukey Test.

Data tables and graphs were used to further highlight and emphasize trends. The data for BG (plasma and serum) and insulin was graphed and labeled with any significant differences. A comparison graph was made that looked out how the mean glucometer BG compared to the mean serum BG and how they both compared (blood draw BG; $n=4$) to the mean glucometer BG for all subjects ($n=19$).

Food Intake Analysis

Food log data was analyzed using nutrient analysis software (Nutritionist Pro), USDA SuperTracker, Virginia Tech campus dining nutrition information, and various company sites for further validation on nutrition content (Chick-fil-A, Tropical Smoothie, Wendy's, etc.). The data was categorized into the amount of carbohydrates (CHO) consumed on match day (g/d), total calories consumed on match day (kcal/d), and percentage (%) of total calories from CHO consumed on match day. In addition to these three measures, data was analyzed for the pre-match, or pre-competition, meal or snack. Data was analyzed and categorized for the amount of CHO (g) consumed during the pre-match meal, how many hours before the match the meal or snack was consumed, and relative amount of CHO consumed per bodyweight (g/kg) during the pre-match meal or snack. The data was analyzed separately for each match.

The mean and standard deviation (STDev) were taken for each measure during the two matches and a mean and STDev for the two matches combined. It was important to determine if a significant difference in food intake existed between Match 1 and Match 2. A One way

repeated measures ANOVA test used to determine if the dependent variables (kcal/d, g/kg, etc.) had a significant difference ($P < 0.05$) between conditions (Match 1 & Match 2).

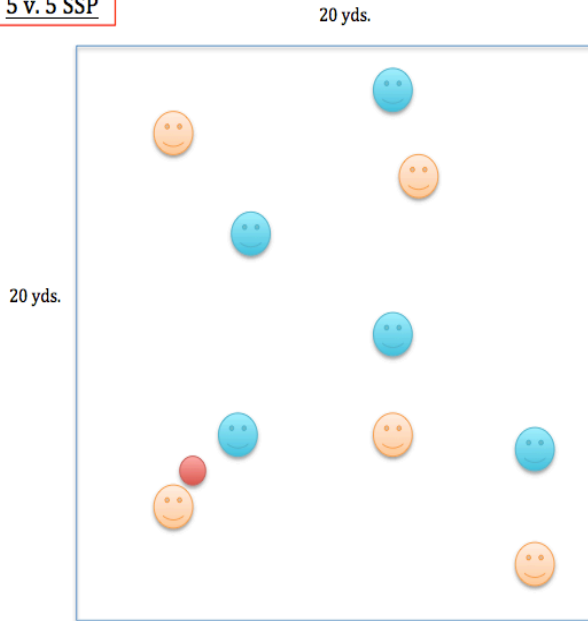
Contingencies and Alternatives:

No subjects experienced an injury or medical procedures implications during either match. However, two subjects had to be replaced due to a rescheduled match-date caused by weather. During the first scheduled match, a thunderstorm and lightening caused the match to be cancelled. The two subjects added prior to the first match, to replace the dropouts, were members of the VTMCS team and completed the same protocols necessary for inclusion in the study. The teams were adjusted accordingly and the matches continued as planned.

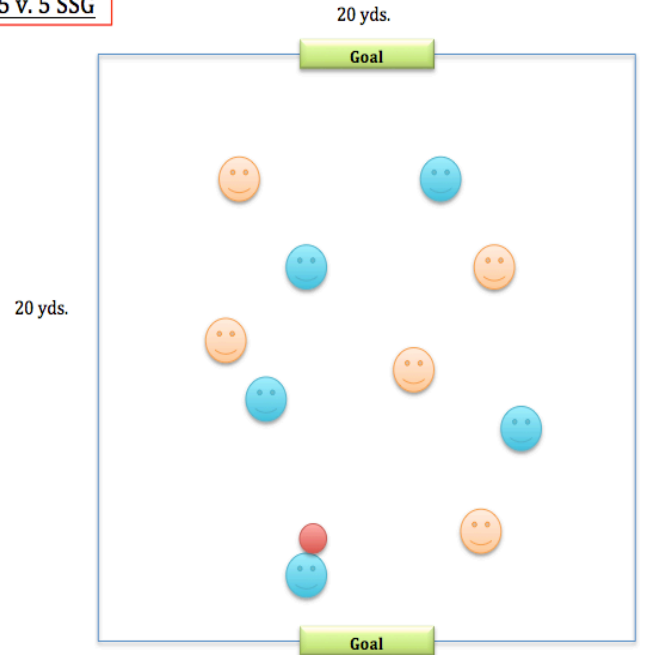
One subject played in the first match, but was unable to play in the second due to a conflict. The data for this subject was excluded from the study and analysis, which resulted in a data set for a total of nineteen subjects. A prior subject took the place of the dropout subject during the second match, but this subject didn't partake in the blood samples and GPS data wasn't analyzed. The fill-in subject played the same position as the dropout and was of equivalent talent according to the VTMCS president and vice-president.

Figure 1.

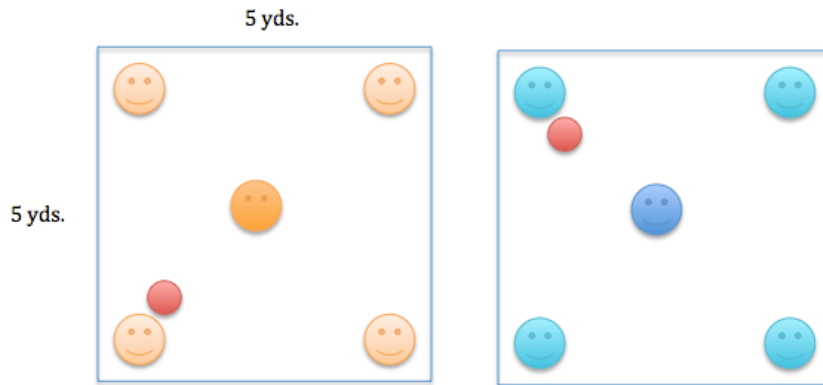
5 v. 5 SSP



5 v. 5 SSG



4 v. 1 Keep-away [x 2]



Dynamic Movements

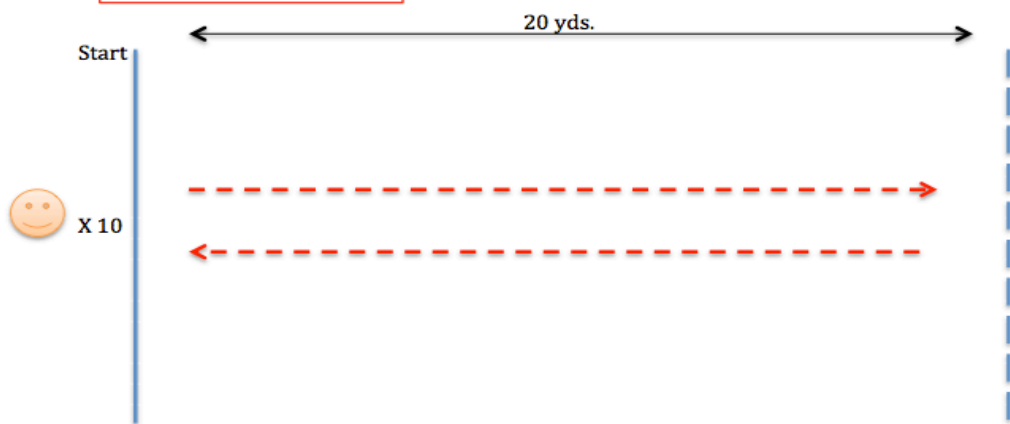


Figure 2.

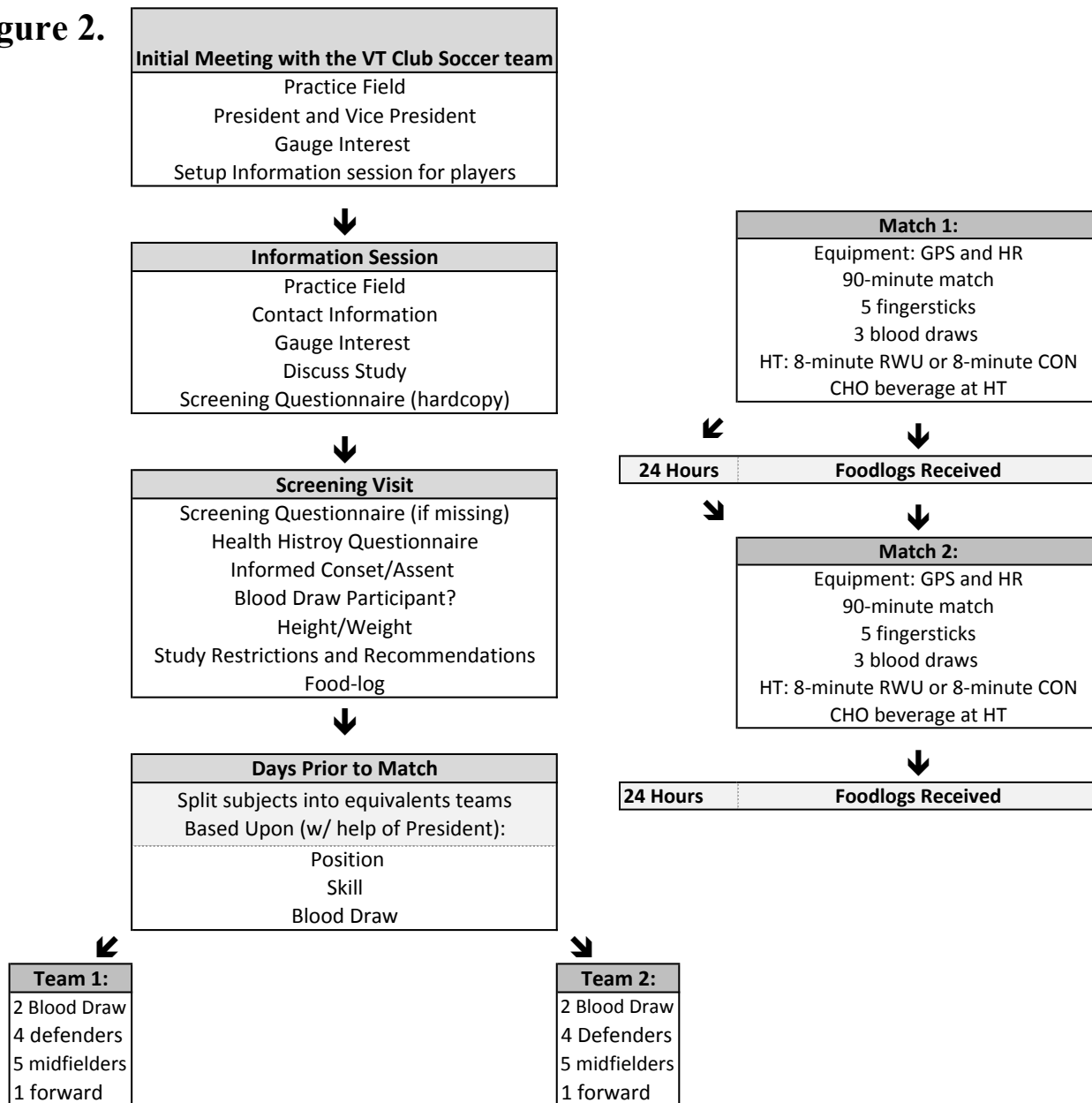


Figure 3.

* Equipment Distribution * Warmup Unregulated				* CHO-E beverage consumption * Active RWU OR CONI			* Match halted 15-minutes in		
↑				↑			↑		
Warm Up	→	1st Half	→	Half-Time	→	2nd Half	↑	2nd Half	
20 minutes	BG Check #1	45 minutes	BG Check #2	15 minutes	BG Check #3	15 minutes	BG Check #4	30 minutes	BG Check #5
	BD #1				BD #2		2.5-5 minutes		BD #3

Figure 4.

Half-Time Protocol Timeline
RWU Group

Time Mark:
0 – 3rd minute → **2nd BG check** AND **CHO-E beverage** consumption following BG check (roughly one half)
*** Research team** setting up the half-time intervention with cones. A 5x5 yard box for the **4 v. 1 keep away**.

3rd – 4th minute → Familiarize the intervention group subjects with the active RWU protocol and procedures. Split the ten players into two groups of five for the first activity.

4th – 6th minute → **4 v. 1 keep away** (x 2 groups)
*** Research team** observing and setting up a 20x20 yard box
(2 minutes)
*** The two groups of five players** will remain in that same group for the next group of RWU up procedures. One team of five players will wear colored pennies, while the other team of five will remain penniless.

6 – 8.5 minute → **5 v. 5 small-sided possession (SSP)**
(2.5 minutes)
*** Research team** set up one goal, with two colored pennies separated by 1-yard, on opposite sides of the 20x20 yard box

8.5 – 10.5 minute → **5 v. 5 small-sided game to goal (SSG)**
(2 minutes)

10.5 – 13th minute → Subjects will finish their CHO-E beverage, tend to their own personal needs, and complete their **3rd BG check**.

10.5 minute → The venipuncture subjects (2) will complete their **2nd blood draw** at this point. The two subjects will rejoin the other **RWU** subjects for the **DS** segment.

13.5 – 15th minute → **Dynamic movements/stretchers (DS)** (20 yards) up and back. Intervention subjects will be spread across the touchline. The **DS** will consist of jogging high knees, jogging butt kicks, jogging hip abductors, jogging hip adductors, walking lunges, walking quad stretch, 75% sprint, 5-yard back peddle to a sprint, full sprint with a jog back.
(1.5 minutes)
*** Make sure the CHO-E beverage is completely finished** for all ten subjects prior to start of 2nd half.

Total time of 8-minutes for the active RWU intervention

Control Group (CG):

Time Mark:
0 – 3.5 minute → **2nd BG check** AND **CHO-E beverage** consumption following their **2nd BG check**.

3.5 – 11.5 minute → Sit, rest, and relax; Static stretches if subject desires. Continue consumption of CHO-E beverage and will aim for complete consumption during this time period.
*** 10th minute mark** → The two-venipuncture subjects will get their **2nd blood draw completed**

11.5 – 15th minute → Complete **3rd BG check**. **CON** subjects will remain inactive/passive during this time, with only the option of **static stretching (SS)**.
*** Make sure the CHO-E beverage is completely finished** for all ten subjects.

Results

The environmental conditions were similar during both match days (weather log report for Blacksburg). The subjects had a mean (\pm STDev) age, height (cm.), weight (kg.), and BMI of 20.52(\pm 1.50), 177.18cm(\pm 6.14), 72.66kg(\pm 4.46), and 23.17(\pm 1.19), respectively (Table 1). There were no significant differences between the two teams for age, height, weight, or BMI. Team 1 had a mean age, height (cm.), weight (kg.), and BMI of 20.44, 177.09cm, 73.59kg, and 23.44, respectively. Team 2 had a mean age, height (cm.), weight (kg.), and BMI of 20.6, 177.26cm, 71.82kg, and 22.92, respectively. All of the subjects GPS/Accelerometer and HR data for each match (Match 1 & Match 2) were split into seven 15-minute time-intervals (TI). Six of the time-intervals represent the 90-minute match period (TI-1 through TI-6) and the seventh TI (TI-HT) represents the 15-minute HT period. The six TI during the 90-min match were broken up as follows 0-15min (TI-1), 15-30min (TI-2), 30-45min (TI-3), 45-60min (TI-4), 60-75min (TI-5), and 75-90min (TI-6). The HT TI took place in-between TI-3 and TI-4, as a typical halftime period intercedes two consecutive 45-minute periods of play.

GPS/Accelerometer/HR Data

Total Distance (m):

The mean total distance (m) covered during both 90-minute matches for the CON and RWU groups were 9,775.4m and 9,903.5m, respectively. RWU and CON had a mean total distance of 1520.39m and 1430.66m, respectively, across all seven time-intervals. The effect of RWU or CON (condition) depends on the time-interval (TI) and there was a statistically significant interaction ($P < 0.001$) between condition and time-interval. There were significant differences in total distance (TD) covered during TI-HT and TI-4. Compared to the CON group, the RWU group covered significantly ($p < 0.001$) more distance during halftime (TI-HT) and the

first 15-minutes of the second half (TI-4). There was a 208.98% increase in distance covered during TI-HT with the distance covered for RWU and CON at $739.1 \pm 42.9\text{m}$ and $239.2 \pm 33.4\text{m}$, respectively. During TI-4, RWU and CON covered a mean total distance of $1708.9 \pm 45.1\text{m}$ and $1576.6 \pm 45.5\text{m}$, respectively. RWU had an 8.4% higher ($P= 0.003$) total distance during TI-4. There were no other significant differences in TD covered when analyzing the condition (RWU vs. CON) and time-interval. During TI-4, mean TD was second and fifth highest when comparing the six match TI's for RWU and CON, respectively. TI-1 and TI-5, for both groups, had the highest and lowest mean TD, respectively. Both groups had similar TI-1 distances, but RWU did not have a significant difference ($P=0.084$) between TI-1 and TI-4 whereas CON did ($P<0.05$). Regardless of condition, mean distance during TI-4 was $1,642.76\text{m}$, which was ranked third in total distance covered of the six match time-intervals. The data points for both conditions (RWU & CON) at each TI can be seen in Table. 2. Table 2 also highlights the condition x time-interval significant differences.

Average Speed (km/hr):

The mean average speed (km/hr) during both 90-minute matches for the CON and RWU groups was 6.517 and 6.603km/hr , respectively. CON and RWU had a mean average speed of 5.668 and 5.912km/hr , respectively, across all seven time-intervals (includes TI-HT). The effect of condition depends on the TI and there was a statistically significant interaction ($P=<0.001$) between condition and time-interval. There was a significant difference in average speed during TI-HT and TI-4. Compared to the CON group, the RWU group was significantly ($P<0.001$) faster during halftime (TI-HT) and the first 15-minutes of the second half (TI-4). There was a 7.8% increase in average speed during TI-4 for RWU (6.836km/hr) compared to CON (6.306km/hr). At halftime (TI-HT) the CON and RWU had average speeds of 0.5732 and

1.771km/hr, respectively, which represents a 208% increase for the RWU group. There were no significant differences for average speed when comparing conditions during any of the other time-intervals. Both groups had their highest average speed during TI-1 (CON: 7.355; RWU: 7.322). Despite both groups having similar TI-1 average speeds, RWU did not have a significant difference ($p=0.965$) between TI-1 and TI-4 whereas CON did ($p<0.05$). During TI-4, average speed was second and fifth highest when comparing the six match TI's for RWU and CON, respectively. TI-5, for both groups, had the lowest average speeds (CON: 5.729; RWU: 5.769). The data points for both conditions (RWU & CON) at each TI can be seen in Table. 2.

High Metabolic Power (HMP) Distance:

The mean high metabolic power (HMP) distance (m) during both 90-minute matches for the CON and RWU groups was 2,216.48 and 2,384.98m, respectively. CON and RWU had a mean HMP distance of 317.94 and 354.397m, respectively, across all seven time-intervals (includes TI-HT). Regardless of condition, a mean total HMP distance of 2,300.74m was covered and TI-1, TI-4, and TI-5 had the highest, third highest, and lowest mean HMP distance covered, respectively. The effect of condition depends on the TI and there was a statistically significant interaction ($P=0.017$) between condition and time-interval. RWU had a significantly higher ($p<0.05$) HMP distance, compared to CON, during TI-2, TI-HT, and TI-4. There was a 14.5% higher HMP distance covered by the RWU group during TI-2, 15-30minutes. TI-2 HMP distance was 408.5 ± 29.4 m and 356.9 ± 25.8 m for RWU and CON, respectively. A similar increase was seen during TI-4 (13.6%) when RWU was compared to CON (409.4 ± 24.5 m and 360.5 ± 23.0 m, respectively). The mean HMP distance for RWU and CON during halftime was 95.8 ± 12.3 m and 9.07 ± 3.99 m, respectively. The RWU did not have significant differences between TI-1, TI-2, and TI-4, whereas the CON had a significant difference between TI-1 and

TI-2 ($p < 0.001$), TI-1 and TI-4 ($p < 0.001$). Both groups, regardless of condition, had significantly lower HMP distances during TI-5 ($p < 0.001$) when compared to all match time-intervals (TI-1, TI-2, TI-3, TI-4, TI-6). The data points for both conditions (RWU & CON) at each TI can be seen in Table 2.

Average HR (bpm)

The average heart rate (bpm) during both 90-minute matches for the CON and RWU groups was 158.53 and 161.6bpm, respectively. The average HR throughout, regardless of condition, was 160.07bpm. The mean maximum HR, using mean age and the 220-age formula, was 199.47bpm. The match was played at roughly ~80.2% of HR max, which signifies a moderate-intensity level match. CON and RWU had a mean average HR of 151.9 and 157.2bpm, respectively, across all seven time-intervals (includes TI-HT). The effect of condition depends on the time TI and there was a statistically significant interaction ($P = 0.038$) between condition and time-interval. There was only one TI (TI-HT) with a significant difference ($p < 0.05$) between RWU and CON. RWU had a 16.1% higher avg. HR value than CON during halftime. RWU and CON had a mean average HR of 130.63 ± 2.82 and 112.1 ± 2.18 bpm, respectively. Regardless of the condition, both highest and lowest mean average HR during the match was during TI-2 (164.17bpm) and TI-4 (156.1bpm), respectively. There were no significant differences in mean average HR between match time-intervals for CON and only one for RWU (TI-1 vs. TI-4). The data points for both conditions (RWU & CON) at each TI can be seen in Table 3. Table 3 also highlights the condition x time-interval significant differences.

HR Exertion

The mean HR exertion (au) throughout the match, regardless of condition, was 66.08AU. The mean HR exertion during both 90-minute matches for the CON and RWU groups was 64.45

and 67.71au, respectively. There was no significant difference between conditions ($P=0.107$), but there was a significant difference between time-intervals ($P<0.001$). The effect of condition depends on the TI and there was a statistically significant interaction ($P=0.05$) between condition and time-interval. RWU had a significantly different ($P<0.05$) HR exertion during TI-2 and TI-HT. The RWU at halftime had no apparent effect on HR exertion during the second half, but the HT protocol did cause a higher HR exertion at TI-HT for RWU compared CON (47.70 ± 4.27 au and 29.56 ± 1.47 au, respectively). The 15-30min interval of the first half had a significantly higher ($P<0.05$) HR exertion for the RWU (80.58 ± 4.43 AU) compared to CON (69.24 ± 6.26), which was a 16.4% higher value. The CON HR exertion, compared to RWU, was higher during TI-4 at values of 63.64 ± 4.99 and 58.97 ± 5.43 au, respectively. However, this difference wasn't significantly ($P=0.43$) different. The data points for both conditions (RWU & CON) at each TI can be seen in Table. 2. Table 2 also highlights the condition x time-interval significant differences

Speed Exertion

The mean speed exertion (au) throughout the match, regardless of condition, was 129.49au. The mean speed exertion during both 90-minute matches for the CON and RWU groups was 126.84 and 132.14au, respectively. There was no significant difference between conditions ($P=0.107$), but there was a significant difference between time-intervals ($P<0.001$). The effect of condition depends on the TI and there was a statistically significant interaction ($P=0.047$) between condition and time-interval. RWU had a significantly different ($P<0.05$) speed exertion during TI-2, TI-HT, and TI-4. The 15-30min interval of the first half had a significantly higher ($P<0.05$) speed exertion for RWU (155.3 ± 13.2 au) compared to CON (137.6 ± 10.8 au), which was a 12.9% higher value. The active RWU at halftime had an apparent

and significant effect on speed exertion during the initial portion of the second half, compared to CON (153.3 ± 10.4 au and 136.44 ± 9.45 au, respectively). This was a ~12.4% higher speed exertion for RWU compared to CON. The CON speed exertion, compared to RWU, was higher during TI-1 and TI-5. However, these differences weren't significantly ($P > 0.05$) different. Both groups had similar speed exertions during TI-1, but RWU did not have a significant difference ($P = 0.093$) between TI-1 and TI-4 whereas CON did ($P < 0.05$). The data points for both conditions (RWU & CON) at each TI can be seen in Table 3.

Accelerations

The mean number of accelerations (number $> 1.0 \text{ m/s}^2$) during both 90-minute matches for the CON and RWU groups was 187.16 and 196.7, respectively, which was significantly different. The average # of accelerations (Acc.) throughout the match, regardless of condition, was 192. CON and RWU had a mean # of Acc. of 26.94 and 30.8, respectively, across all seven time-intervals (includes TI-HT). The effect of condition depends on the TI and there was a statistically significant interaction ($P = < 0.001$) between condition and time-interval. There were significant differences in the # of Acc. during TI-HT and TI-4. Compared to the CON group, the RWU group performed significantly ($p < 0.001$) more Acc. during halftime (TI-HT) and the first 15-minutes of the second half (TI-4). There was a 92.5% decrease in the # of Acc. performed during TI-HT with the # of Acc. for RWU and CON at 18.95 ± 2.18 and 1.42 ± 0.84 , respectively. During TI-4, RWU and CON performed a mean total # of Acc. of 37.32 ± 2.68 and 30.79 ± 1.89 , respectively. RWU had a 21% higher ($P = 0.002$) # of Acc. during TI-4. There were no other significant differences in number of accelerations performed when analyzing the condition (RWU vs. CON) and time-interval. TI-1 and TI-5, for both groups, had the highest and lowest mean # of Acc., respectively. During TI-4, mean # of Acc. was second and fourth highest when

comparing the six match TI for RWU and CON, respectively. The RWU TI-4 phase was significantly different (higher) than all other time-intervals except for TI-1. Whereas CON had a significantly different (lower) # of Acc. between TI-1 and TI-4. The HT RWU had a significant effect ($P < 0.05$) on number of accelerations during the initial portion of the second half (TI-4). The data points for both conditions (RWU & CON) at each TI can be seen in Table 4. Table 4 also highlights the condition x time-interval significant differences.

Decelerations

The mean number of decelerations (number $> 1.0\text{m/s}^2$) during both 90-minute matches for the CON and RWU groups was 112.57 and 116.27, respectively. The average # of decelerations (Dec.) throughout the match, regardless of condition, was 114.42. CON and RWU had a mean # of Dec. of 16.16 and 18.039, respectively, across all seven time-intervals (includes TI-HT). The effect of conditions depends on the TI and there was a statistically significant interaction ($P = < 0.001$) between condition and time-interval. There were significant differences in the # of Dec. during TI-HT and TI-4. Compared to the CON group, the RWU group performed significantly ($p < 0.001$) more Dec. during halftime (TI-HT) and the first 15-minutes of the second half (TI-4). There was a 94.74% decrease in the # of Dec. performed during TI-HT with the # of Dec. for RWU and CON at 10.00 ± 1.23 and 0.53 ± 0.37 , respectively. During TI-4, RWU and CON performed a mean total # of Dec. of 22.11 ± 1.7 and 18.84 ± 1.59 , respectively. RWU had a 17% higher ($P = 0.036$) # of Dec. during TI-4. There were no other significant differences in number of decelerations performed when analyzing the condition (RWU vs. CON) and time-interval. TI-1 and TI-5, for both groups, had the highest and lowest mean # of Dec., respectively. During TI-4, mean # of Dec. was second and fourth highest when comparing the six match TI for RWU and CON, respectively. The RWU TI-4 phase was not significantly different

than TI-1 for either group. The HT RWU had a significant effect ($P<0.05$) on number of decelerations during the initial portion of the second half (TI-4). The data points for both conditions (RWU & CON) at each TI can be seen in Table 4.

Energy Cost (kJ/kg)

The mean amount of energy (kJ/kg) expended during both 90-minute matches for the CON and RWU groups were 49.72 and 50.97kJ/kg, respectively. The values of 49.72 and 50.97kJ/kg translate to 11.88kcal/kg and 12.18kcal/kg, respectively. Regardless of condition, the mean energy cost during the match was 50.35kJ/kg (12.03kcal/kg) and using the mean subject weight (72.66kg) the kcal/game value is ~874. RWU and CON had a mean energy cost of 7.28 and 7.85kJ/kg, respectively, across all seven time-intervals. The effect of condition depends on the TI and there was a statistically significant interaction ($P<0.001$) between condition and time-interval. There were significant differences in energy cost during TI-HT and TI-4. Compared to the CON group, the RWU group expended significantly ($p<0.001$) more energy during halftime (TI-HT) and the first 15-minutes of the second half (TI-4). There was a 225% increase in expended energy during TI-HT with the energy cost for RWU and CON at 3.942 ± 0.24 kJ/kg and 1.211 ± 0.17 kJ/kg, respectively. During TI-4, RWU and CON expended a mean energy amount of 8.763 ± 0.24 kJ/kg and 8.063 ± 0.23 kJ/kg, respectively. RWU had an 8.7% higher ($P= 0.003$) energy cost during TI-4. There were no other significant differences in energy cost when analyzing the condition (RWU vs. CON) and time-interval. During TI-4, mean energy expenditure was second and fifth highest when comparing the six match TI's for RWU and CON, respectively. TI-1 and TI-5, for both groups, had the highest (RWU: 9.42; CON: 9.47) and lowest (RWU: 7.59; CON: 7.08) mean energy cost, respectively. Both groups had similar TI-1 energy expenditure, but RWU did not have a significant difference ($P=0.07$) between TI-1 and

TI-4 whereas CON did ($P < 0.001$). The data points for both conditions (RWU & CON) at each TI can be seen in Table 4.

***Table 5** highlights the significant differences for all measures between conditions based on time-intervals

Match 1 vs. Match 2:

The date of the match, and two matches taking place 24-hours apart, had no significant effect on any of the measured variables according to a two way ANOVA. There were no statistically significant differences ($P = 0.081-0.697$) between Match 1 and Match 2 for any variable and no statistically significant interaction between match day and time-interval ($P = 0.061-0.434$) for any variable.

Blood Data:

Plasma Blood Glucose (BG) via glucometers

The mean BG concentration throughout the entire match, including the half-time period, for CON and RWU was 118.9 ± 16.51 mg/dL and 114.19 ± 13.04 mg/dL, respectively. There was no statistically significant difference ($P = 0.334$) in BG concentrations between RWU and CON (conditions), but there was a significant difference ($P < 0.001$) when comparing the time of the fingerstick blood sample ($T_1 - T_5$). The lowest mean BG concentration was at 15-minutes into the second half (T_4) and before the match (T_1) for CON and RWU, respectively. There was a statistically significant interaction between condition and time ($P = 0.033$). CON had a significantly higher BG than RWU before the match (T_1) and before the second half (T_3). At T_1 and T_3 the mean plasma BG values were 111.9 ± 29.22 mg/dL and 145 ± 39.22 mg/dL for CON and 96.42 ± 15.56 mg/dL and 129.16 ± 27.14 mg/dL for RWU. Mean BG values increased significantly ($P < 0.001$) from T_1 to T_3 for both CON (29.59%) and RWU (33.95%). Even though CON,

compared to RWU, had a significantly higher mean BG at T₃, the value decreased significantly (P<0.001) at T₄ to a value lower than RWU. CON mean BG value, from T₃ to T₄, decreased 28.6% (103.57±26.56mg/dL) and RWU (P=0.027) only decreased 14% (110.95±24.19mg/dL) but the condition and time interaction wasn't statistically significant (P=0.315). The post-match mean BG (T₅) was nearly identical (P=0.96) for CON and RWU at 109.37±16.90mg/dL and 109.74±10.57mg/dL, respectively. A visual representation of the mean BG trend throughout the match can be seen in Figure 5a.

Serum BG and Serum Insulin via Blood Draw

The mean serum BG concentration across the three blood draws (BD₁-BD₃) for CON and RWU was 115.75±40.36mg/dL and 97.83±20.11mg/dL, respectively. There was no statistically significant difference between conditions (CON vs. RWU), but the time of the BD (BD₁ vs. BD₂ vs. BD₃) resulted in a significant difference (P=0.012) between BG concentrations. Regardless of condition, there were significant differences (P<0.05) between pre-match blood draw (BD₁) and prior to second half blood draw (BD₂) and also between BD₂ and post-match blood draw (BD₃). There was a significant increase (P=0.014) from BD₁ to BD₂ and decrease (P=0.028) BD₂ to BD₃. There were no significant interactions between condition and time (P=0.087) likely due to the small sample size (N=4). Mean serum BG at BD₂ for CON and RWU was 161.8±36.94mg/dL and 105.25±17.52mg/dL, respectively. At BD₃, the mean serum BG value from B₂ decreased 42.72% for CON. The decrease in mean serum BG for RWU, from BD₂ to BD₃, was only 10.26%. Although there isn't a statistically significant interaction between condition and time, there appears to be a tendency for the CON subjects to have a greater reduction in second half BG values compared to the RWU subjects. CON and RWU values at

BD₃ were 86.25±21.42mg/dL and 94.5±13.5mg/dL, respectively. A visual representation of the mean serum BG trend throughout the match can be seen in Figure 5b.

The mean serum insulin concentration across the three blood draws (BD₁-BD₃) for CON and RWU was 15.64±18.91uIU/mL and 8.202±5.67uIU/mL, respectively. There were no statistically significant differences between conditions (P=0.379) or time (BD₁ vs. BD₂ vs. BD₃) (P=0.118) and no significant interaction (P=0.218) between condition and time. The mean serum insulin concentration at BD₁ for CON and RWU was 11.3±5.59uIU/mL and 10.9±6.44uIU/mL, respectively. Despite no interaction between condition and time, the CON had a 74% higher mean serum insulin value (30.01±28.86uIU/mL) than the RWU (7.81±6.81uIU/mL) at BD₂ (HT). CON had a 166% increase in insulin from BD₁ to BD₂, but RWU had a 28.4% decrease during the same time-interval. Although there was an obvious difference in insulin means at halftime, both CON and RWU had very similar insulin concentration at BD₃ (5.62±3.58uIU/mL and 5.93±3.64uIU/mL, respectively). A visual representation of the mean serum insulin concentration trend throughout the match can be seen in Figure 5c.

Food Intake:

CHO (g/d) intake, % of total calories, and total calories (kcal/d)

Match 1 and Match 2 had a total mean for CHO consumed per match day (g/d) of 228.68±65.38g/d and 237.53±70.56g/d, respectively. The total mean for both match days combined was 233.11±77.13g/d. There was no statistically significant difference (P=0.568) between Match 1 and Match 2 (conditions).

Match 1 and Match 2 had a mean % of calories/d from CHO of 55.1±0.151% and 55.4±0.1%, respectively, each day. The total mean for both match days combined was

55.21±0.16%. There was no statistically significant difference (P=0.929) between the CHO % of calories/day on Match 1 and Match 2 (conditions).

Match 1 and Match 2 had a mean total calories consumed per match day (kcal/d) of 1,704.84±404.13kcal/d and 1,659±641.15kcal/d, respectively. The total mean for both match days combined was 1,682±721.07kcal/d. There was no statistically significant difference (P=0.757) between conditions. The subjects consumed similar grams of CHO, total calories, and % calories from CHO on both match days. Table 6 shows the collective (Match 1 & Match 2) mean for all subject food intake data.

Pre-match meal: CHO (g), Hours prior to match, and Relative CHO intake (g/kg)

Match 1 and Match 2 had a mean total of CHO consumed (g) during the pre-match meal of 114±48.38g and 115.91±41.34g, respectively. The total mean for both match days combined was 115.03±41.73g. There was no statistically significant difference (P=0.775) between conditions.

Match 1 and Match 2 had a mean of 3.13±0.62hrs and 3.11±0.66hrs, respectively, for the amount of hours (hrs.) before the match that the pre-competition meal was consumed. The mean for both match days combined was 3.12±0.94hrs. There was no statistically significant difference (P=0.667) between conditions. The pre-match meal recommendation, in terms of hours prior to the match, was 3-4 hours.

The mean relative, to bodyweight, CHO intake (g/kg) at the pre-match meal during Match 1 and Match 2 was 1.59±0.72g/kg and 1.613±0.614g/kg, respectively. The subjects specific BW (kg.) was used to determine each individual's relative CHO consumption during the pre-match meal. The mean consumption for both match days combined was 1.60±0.614g/kg. There was no statistically significant difference (P=0.784) between conditions. The subjects

consumed similar pre-match meals relative to the amount CHO (g), hours prior to the match, and relative CHO consumed (g/kg) on both match days. However, the recommendation was to consume x amount of CHO (g) per kg for x amount of hours prior to the match (i.e. 3-4g/kg for 3-4hrs prior). Using the means for hours prior (3.12hrs.) and relative CHO (1.60g/kg), subjects only consumed 51.344% of the recommendation. Table 6 shows the collective (Match 1 & Match 2) mean for all subject food intake data.

Shots on Goal and Goals

First vs. Second Half Shots on Goal (CON vs. RWU)

The mean number of shots on goal during the first half, across both matches, for CON and RWU was 11 ± 4.24 and 8 ± 1.4 , respectively. The mean for shots on goal in the second half for CON and RWU was 7 ± 4.24 and 12 ± 2.83 , respectively. When comparing the first half versus the second half, CON had a 36.4% decrease and RWU had a 50.0% increase in shots on goal. The chi-square statistic was 3.3778 with a p-value of .0661. The difference in shots on goal between halves for conditions (CON vs. RWU) was not significant at $P < 0.05$. However, there was a tendency for more the RWU to have more shots in the second half, specifically in the first 15-minutes (TI-4) of the second half. Shots on goal, during the first 15-minutes of the first half (TI-1), were not recorded or monitored. During TI-4, CON and RWU had a mean number of shots on goal of 3 ± 2.82 and 5 ± 2.82 , respectively. There was not a big enough sample size ($N=2$) for a significant difference to be identified, but there was a trend of more shots on goals during the second half for the RWU compared to CON.

First vs. Second Half Goals (CON vs. RWU)

The mean number of goals, scored regardless of condition, was 10.5 a match. CON and RWU scored a mean number of 5.5 ± 3.54 and 4.5 ± 3.54 goals per match. The mean number of

goals during the first half, across both matches, for CON and RWU was 4 ± 4.24 and 1.5 ± 2.12 , respectively. During the second half, CON and RWU mean for goals was 2 ± 1.41 and 3 ± 1.41 , respectively. When comparing the first half versus the second half, CON had a 50.0% decrease and RWU had a 100% increase in goals. The chi-square statistic was 2.291 with a p-value of 0.131. The difference in goals scored between halves for conditions (CON vs. RWU) was not significant at $P < 0.05$. Goals were time stamped and so a comparison between goals during TI-1 and TI-4 was made. Across both matches, CON and RWU scored a total of 3 goals and 1 goal, respectively, during TI-1. During TI-4, CON scored a total of 0 goals and RWU scored 4. A tendency could be evident for more goals scored after a RWU, but a multitude of factors influence goal scoring.

Summary of Results

The subjects covered a mean total distance of 9.7-9.9km between the two soccer matches at an average speed of 6.5-6.6km/hr, both dependent on condition. Subjects had a mean average HR of 158-161bpm with the RWU group having a slightly higher mean. Compared to the CON, RWU covered 8.4% more distance and had a 7.8% higher speed during the first 15-minutes of the second half (TI-4). Nine of the nine (100%) measured data variables were significantly higher during the half-time period (TI-HT) for RWU, compared to CON. This result was expected given RWU was active and CON was passive during this time period. Seven of the nine (77.8%) performance variables were significantly ($P < 0.05$) higher during TI-4 when RWU was compared to CON. TI-4 was the first match period directly after the HT interventions, which provides the best representation of its effect on subsequent performance. Speed-exertion, accelerations, decelerations, and HMP distance were all significantly higher for RWU during TI-4, which likely attributed to the 8.7% increase in energy expenditure. Neither of the

physiological measures of HR (avg. HR or HRE) had significant differences during the second half, specifically the first portion (TI-4).

The mean plasma blood glucose concentrations between the two soccer matches were 114-119mg/dL (6.3-6.6mmol/L), contingent on condition. The values were significantly higher for CON, compared to RWU, before the match (T_1) and before the second half (T_3). There were no other significant interactions between the conditions and time, but there were significant differences dependent on time. T_3 to T_4 plasma BG significantly decreased 28.6% for CON and only 14% for RWU. CON experienced their lowest mean BG concentration at T_4 . Serum BG significantly differed based on the timing of the blood draw, with the HT period (BD_2) having the highest BG concentrations for CON and RWU. Serum insulin had no statistically significant differences between time and condition, with no interaction between the two variables. Both conditions started the match (BD_1) with similar levels and ended the match (BD_3) with similar levels that were lower than BD_1 . However, compared to RWU, CON had a 74% higher mean insulin value at BD_2 that was a 166% increase from BD_1 .

The average food intake, across both match days, was $1,682 \pm 721$ calories with 55.21% stemming from CHO consumption (~ 233 g). On average, a prematch meal was consumed 3.12 ± 0.94 hours before the match with a mean relative CHO consumption of 1.6 ± 0.6 g/kg. There were no significant differences for food intake between match 1 and match 2.

Discussion

This study had multiple purposes and tons of data to analyze in an effort to highlight the importance of various half-time strategies and determine the best method to maximize second half performance. The first purpose was to determine the effects of an active rewarm-up,

compared to a passive period, at halftime on various measures of performance during the first 15-minutes of the second half using GPSports SPI HPU units. This aimed to identify the effects of the active versus passive half-time period, with carbohydrate beverage supplementation, on blood measures such as plasma blood glucose, serum blood glucose, and serum insulin concentrations. The purpose was to analyze if these blood measures were influenced by the half-time period protocols and if they had an impact on performance. This study had tons of data that mimicked previous findings, created new questions, and provided conclusive as well as speculative results that can be implemented to optimize soccer match performance.

GPS/Accelerometer/HR findings

The players in this study covered a mean distance of 9,775-9,904m (9.7-9.9km) with significantly ($P<0.05$) more distance covered in the first half (~410m), compared to the second half. The total distance covered is in line with previous research studies that analyzed soccer match movement patterns, using GPS devices, of elite soccer players [Tierney, 2016; Wehbe, 2014; Bush, 2015; Russell, 2016]. The significantly greater distance covered in the first half (7.9%) is common in previous soccer studies that compared halves [Wehbe, 2014; Barros, 2007; Russell, 2016]. The matches were played at an average speed of 6.5-6.6km/hr, which translates to low-intensity movements. A soccer match is characterized by the majority of time spent in a low-intensity speed zone [Casamichana, 2012; Mohr, 2003), with an average speed of ~6.4-6.7km/hr during a competitive soccer match [Burgess, 2006; Wehbe, 2014]. The mean average HR during the two soccer matches, regardless of the condition, was 160.07bpm. Several studies have seen average heart rates of 157-176bpm during competitive soccer matches, fluctuating due to a variety of factors such as age, ethnicity, and level of play [Alexandre, 2012; Krstrup, 2006; Souglis, 2015; Ali, 1991; Mohr, 2003; Russell, 2014a]. If the mean average HR was to be given

as a percent of maximum HR, using the 220-age formula and subject mean age, the match was played at about ~80% of maximum HR.

Energy expenditure was indirectly calculated using measures of speed, acceleration, and metabolic power. Relative to body weight, RWU and CON subjects expended a mean total of 50.973kJ/kg and 49.721kJ/kg, respectively, each match. The average bodyweight of the subjects was 72.66kg, which means subjects expended roughly 3,612.73 – 3,703.7kJ per match. This value in kilocalories (kcal) is about 863 – 885kcal per match. Energy expenditure is highly variable, but several previous studies are concluded similar energy cost numbers [Garcia, 2005; Coelho, 2010; Osgnach, 2010].

The current study was an intrasquad scrimmage based friendly match. The literature is full of match analysis for competitive matches at all levels and despite this study being a friendly the subjects data was comparable to these studies. A friendly match can be seen as a limitation because the players may not put forth maximum effort during the match, but the findings suggest that there was no definitive difference and no observable difference during play.

The halftime period was a key component to this study given its possession of the rewarm-up protocol. An 8-minute moderate intensity bout of exercise, with four separate soccer related activities, was implemented. The current study had significant differences for every measured physical and psychological variable during TI-HT for RWU compared to CON. These results were expected given the active nature of subjects versus completely passive subjects. The HR of subjects was of a particular interest and focus given the desired intensity of the rewarm-up protocol. Several studies have implemented active halftime exercise protocols, but this is the first to use an 8-minute duration [Edholm, 2014; Mohr, 2004; Russell, 2015b; Zois, 2013; Lovell, 2013a]. Two studies incorporated a 7-minute moderate-intensity warm-up at HT that was

completed at ~70% HRmax (~135 bpm) and found improved muscle/body temperature as well as sprint and jump performance [Mohr, 2004; Edholm, 2014]. The current study found that RWU subjects had a mean average HR of 130bpm during TI-HT, which was 16.1% higher than CON subjects. A HR of 130bpm is roughly, using mean age and 220-age, 65.2% of estimated HRmax. The active rewarm-up during HT was completed at a moderate-intensity, which was the goal and in line with previous studies that found benefits.

The first main finding of the current study was that an active half-time rewarm-up (RWU), compared to a passive period with controlled static stretches, had significantly superior physical performance measures during the start of the second half.

The first period of the second half (TI-4) was the main focus area for performance differences between CON and RWU because this was the first part of the match after their respective interventions. When analyzing the first 15-minutes of the second half (TI-4) several trends and significant differences were seen. The total distance covered during TI-4 was significantly lower than TI-1 for CON, but not for RWU. A significant lower total distance covered was seen in previous studies (Weston, 2011; Bradley, 2013; Lovell, 2013a), but this study attenuated the difference with an active HT period. One study saw an 8.0% decrement in distance covered (TI-1 vs. TI-4), which was similar to the CON group in this study (~14%) [Weston, 2011]. Immediately following HT, RWU subjects were able to cover a distance similar to TI-1 ($P=0.97$) and significantly greater than their CON counterpart ($P=0.03$).

A flagship study, regarding an active versus passive HT period and its effect on second half performance, found no differences in distance covered or high-intensity distance covered between groups (RWU & CON) using video film analysis [Edholm, 2014]. However, the current study found significant differences between the RWU and CON in regards to distance covered

and high-intensity movements during TI-4. Edholm also found that both the RWU and CON groups had significant decreases in these two measures when the initial portion of the second half was compared to the same portion of the first half [Edholm, 2014]. Once again, the current study found that during TI-4 the RWU group did not statistically differ from TI-1 in total distance covered and high-intensity measures while the CON group did.

TI-4 was a period of markedly higher outputs of physical measures, such as volume, intensity, speed, and distance. Speed exertion was designed as a marker to quantify running volume and intensity. A higher speed exertion level translates into more high-intensity movements. A study found that significantly more high-intensity running distance was covered in the first 15-minutes of first half compared to the first 15-minutes of the second half [Bradley, 2009]. A similar study saw the same decline, comparing the same time intervals, in high-intensity running distance (Russell, 2016). Although speed exertion isn't specifically a measure of distance covered, it falls into the same category of running volume and intensity. This study found that the RWU prevented a significant difference between TI-1 and TI-4, while CON had a significant difference between these two time-intervals. High metabolic power (HMP) distance was developed as an indirect method of measuring workload and work-rate relative to bodyweight ($> 20\text{W/kg}$). The higher the HMP distance covered equates to more work and energy expended. CON and RWU Subjects covered a total mean HMP distance of 2,216.48m and 2,384.98m, respectively. These values exceed the values found in a different study, but that study employed different GPS devices, different data analysis software, and a different definition for the measure [Tierney, 2016]. However, a study by Osgnach found that power ($>20\text{W}$) distance ($\sim 2,836\text{m}$) made up $\sim 25.9\%$ of total distance covered [Osgnach, 2010]. If mean HMP distance is divided by mean total distance, this study finds a similar percentage value (22.7-24.8%). Similar

to speed exertion, this study saw a significant increase in HMP distance for RWU during TI-4 when compared to CON. A side of TI-4, HMP distance and speed exertion were significantly higher for RWU, compared to CON, during TI-2. However, this difference doesn't attribute to any other measures such as distance, HR, energy cost, or even shots and goals. Energy cost was significantly higher (8.4%) for RWU subjects during TI-4 compared to CON and no studies have previously quantified the energy cost in specific time-intervals. Energy cost provides further insight into how much work was performed by RWU, compared to CON, during TI-4. RWU had an 8.4% higher energy expenditure (kJ/kg) that was not significantly different from TI-1, whereas CON's TI-4 expenditure was different.

Accelerations and decelerations performed throughout a match provide additional insight into the work-rate and intensity of players. This study defined the number accelerations as quickening movements that were greater than 1.0m/s^2 and decelerations as slowing movements greater than 1.0m/s^2 . The distance covered through accelerations or decelerations, although measured in some soccer studies, wasn't chosen for analysis. Instead this study focused on the discrete numbers of such movements and found RWU subjects performed significantly more accelerations and decelerations than CON subjects throughout the match. Accelerations and decelerations go hand and hand, but in this study the number of accelerations exceeded the number of decelerations, which was also seen in previous soccer match studies [Akenhead, 2013; Wehbe, 2014; Russell, 2016]. The number of Acc. performed by RWU during TI-4 was significantly higher than all other time-intervals, except for TI-1. Whereas CON had a significantly lower # of Acc. between TI-1 and TI-4. A 2016 study, which also split the 90-minute into 15-minute intervals, found that the number of accelerations during "TI-1" were significantly different than every time-interval except "TI-4" [Russell, 2016]. The current study

aligns with this study in regards to RWU, but the CON did differ from TI-1. The HT RWU had a significant effect ($P < 0.05$) on number of accelerations during the initial portion of the second half (TI-4). The same 2016 study found that the number of decelerations during “TI-1” were significantly different (greater) than all other time-intervals [Russell, 2016]. However, the current study found that neither condition had significant differences in the # of Dec during TI-4 or TI-2 when compared to TI-1. The current study is one of the only studies to group the movements into 15-minute segments for analysis, because many studies strictly compare halves instead of intervals [Wehbe, 2014; Randers, 2010; Akenhead, 2013; Varley, 2013b]. The sustained number of Acc. and Dec. at the start of the second half contribute to the trend of increased high-intensity movements during TI-4 for RWU, which was not a trend seen in a previous active rewarm-up study [Edholm, 2014].

Edholm observed a significantly higher mean HR for the RWU, compared to CON, during the first three minutes of the second half. The current study didn't find a significant difference during TI-4, but the measures were a mean of a 15-minute segment and weren't as specific in time as the Edholm study [Edholm, 2014]. In regards to HR, CON had a 4.3% higher mean HR during TI-4 ($P = 0.183$). Despite the RWU, compared to CON, having a significantly higher average speed, speed exertion, HMP distance, accelerations, decelerations, and total distance covered during TI-4, subjects didn't have a higher average HR or HR exertion. This finding disagrees with the HR responses found during the Edholm study, perhaps because that study implemented physical performance tests for both the CON and RWU before and after HT [Edholm, 2014].

The study found no significant differences in the physical, or physiological, data between the two matches despite them taking place 24-hours apart. The findings agree with a recent study

that saw no differences between running performance measures [Varley, 2017]. Although there was a collective agreement in the current study, specific individuals could have been affected by the recovery period, which creates a potential limitation.

The shots on goal and goals scored had limited data to draw from. Only two matches were analyzed, which creates a restriction on finding the effects of variables and significant differences. However, the limited data appeared to show a tendency for RWU to have more shots on goal and goals during the second half, specifically during the first 15-minutes. The data is hard to quantify due to a myriad of factors that influence these variables, but moving forward there are definitely no implications on shots or goals due to a RWU at HT.

Blood Measures

An additional key finding was the absence of transient hypoglycemia post-HT, but trends still existed that could potentially influence performance. There was limited conclusive evidence of the RWU improving blood glucose or insulin responses during the matches. RWU and CON experienced the same trends of elevated BG levels at halftime and reductions in the second half. Previous studies, that analyzed soccer matches, found the lowest mean BG values were either prior to the second half or during the first 15-minutes of the second half [Krustrup, 2006; Russell, 2011; Russell, 2014a]. CON had their lowest mean BG concentration (103.57mg/dL) at the 60-minute mark (T₄), which agrees with the previous studies. However, those studies found a mean BG value of ~3.9-4.1mmol/L (70.27-73.87mg/dL), which is roughly a 43% increase for the CON in the current study. Several studies implemented a passive HT recovery and CHO-E beverage, similar to this study [Russell, 2014a, Kingsley, 2014, Russell 2012]. This study didn't have any plasma BG values that were hypoglycemic, which is roughly a BG concentration below 3.6-3.9mmol/L (64.86-70.27mg/dL). Kingsley had 10 subjects experience BG values below

4.0mmol/L at the 60-min mark, but this study used a simulated soccer match and supplemented CHO before and during the match [Kingsley, 2014]. All of the studies that saw BG concentrations around 74mg/dL had supplied their subjects with a CHO-E beverage during the match [Russell, 2014a; Russell, 2012; Kingsley, 2014]. Although the current study didn't see these low BG concentrations, there was a significant reduction in mean BG from T₃ and T₄ for CON (28.6%). This 28.6% reduction is equivalent to reductions seen by subjects with a passive HT and CHO supplementation (~30-38%) [Harper, 2017; Russell, 2012]. The RWU only had a 14% reduction and their T₄ mean BG was 110.95mg/dL (6.16mmol/L). The effects of a sudden and significant drop in blood glucose are unknown in sport. CON dropped a mean value of 42mg/dL in 15-minutes, which could cause potential effects on performance.

Serum BG, although only taken three times, for CON saw the same trend of an elevated HT BG and a significant drop during the second half with the lowest mean BG value post-match. There was a 46.6% drop in BG for CON from BD₂ to BD₃, which is 75.55mg/dL in 45-minutes. Once again, this significant decrease is unknown and only seen to this extent in the CON subjects, why?

Serum insulin was lowest at the end of the match, as expected, but during HT (BD₂) CON had a 74% higher insulin concentration than RWU. RWU insulin levels at BD₂ were lower than BD₁, but higher for CON. A simulated soccer match study saw insulin levels increase during a passive halftime, but the levels weren't above pre-match levels [Harper, 2016]. Previous studies have highlighted the sudden increase in insulin once exercise stops or a recovery period begins [Nalbandian, 2017; Wahren, 1973]. These levels subside due to the fall in catecholamine's and maintenance of blood glucose. The intake of a CHO beverage is going to further increase the response of insulin, which is probably why CON had such high serum insulin concentrations.

Since RWU remained active, their insulin levels remained low despite CHO beverage consumption likely due to sustained catecholamine levels. There was not a significant difference between conditions, but there was a tendency for insulin to be much higher during HT for CON and reduced for RWU. Perhaps the low subject numbers and prevented a significant difference between conditions, but the potential implications of insulin response are evident. CON, although insulin levels weren't taken during the second half, likely had significantly higher concentrations on insulin. There higher concentrations likely attributed the significant drops in BG that were seen at TI-4 and post-match for serum BG.

CHO Beverage & Food Intake

The benefits of exogenous carbohydrate supplementation are well studied in soccer, with benefits and no clear reason for it to not be utilized. The 6.09% CHO-E beverage supplied at halftime

The objective was to have players eat normally, without a controlled diet, but provide research-based recommendations for pre-match meal consumption to ensure the match was “normal”. A soccer match isn't “normal” if players are in a glycogen depleted, or fasted, state. It was important to ensure players had similar match day intakes, in order to decrease variability. Despite extremely consistent food intake patterns, players were well below current nutrition recommendations for soccer players. The recommendations are 6-10g/kg of CHO per day and 1-4g/kg of CHO before a match directly related to the number of hours before [Thomas, 2016]. However, subjects only consumed a mean of 3.23g/kg of CHO per match day and 1.6g/kg of CHO during the pre-match meal, but the pre-match meal was taking place 3.12 hours before the match. Subjects consumed 53.8% of the daily relative CHO intake and 51% of the prematch relative CHO intake. However, the matches took place during the week and schedules could have

conflicted with players' true match day practices. The below recommendation intake didn't appear to influence BG concentrations similar to previous studies where subjects weren't given the recommended amount of CHO prior to the game [Russell, 2012; Kingsley, 2014; Russell, 2014]. Subjects consumed as they normally did, which allows for this studies intervention to be directly implemented, without a controlled diet needed for performance effects.

Implications / Application

Performance measures were significantly increased during the first 15-minutes of the second half when an active rewarm-up was completed at halftime. CON subjects, when they had a completely passive HT period, had reductions in performance and an activity period (TI-4) that didn't compare well with the rest of the match. CON had higher insulin concentrations during halftime and significant reductions in BG during the start of the second half. RWU didn't experience the elevated insulin levels or the drastic drop in BG concentrations 15-minutes into the second half or post-match. It's likely that the lower insulin levels, because of the active halftime period mixed with the CHO-E beverage, helped attenuate the extent of the significant drop in BG. The insulin levels likely attributed the radical drop in BG between T₃ and T₄, which could be a contributing factor to the significant decreases in physical performance measures during this period (TI-4) for CON subjects. The passive HT period likely diminished catecholamine's and mixed with the CHO beverage likely amplified the insulin response. The effects of a sudden and significant drop in blood glucose are unknown in sport, but it could be a variable that contributes to the reduction in performance. RWU had benefits on performance, less significant drop in BG, and lower insulin values at half-time.

Soccer is a sport where marginal differences can have a major impact, especially as the level of play increases. It was necessary to address these potential variables that can influence

and impact performance in order to implement the strategies to maximize future performance. The HT period is critical to subsequent match performance. 8-minutes for a RWU pushes the envelope for professional teams, but tailored and adjusted approaches to the HT period could integrate the necessary RWU practices. Towlson surveyed professional teams/coaches in England in regard to their HT practices and Russell designed a depiction of their response [Towlson, 2013; Russell, 2015]. Figure 6 is my representation of what a potential HT period could look like for players and coaches at the collegiate, amateur level. The 8-minute moderate-intensity warm-up can be integrated into any HT regime with the proper adjustment and used to attenuate physical performance decrements during the second half. It's unknown whether the CHO is an auxiliary piece to the better performance, but CHO supplementation didn't create concern when players remained active. Moving forward, it should be examined whether the active rewarm-up with or without a CHO supplement holds precedence. A study could compare the separate effects of CHO and HT activity on physical performance and blood measures with the use of four study groups each with a different HT protocol (Passive, Active, Passive + CHO, Active + CHO). It's not realistic to consume beverages during a soccer match, but perhaps additional CHO intake before the match could further emphasize a blood metabolite response that's been seen in other works. Lastly, if a passive HT period is implemented, than one should monitor when and how much CHO is supplemented to players due to the potential rebound hypoglycemia enhanced by CHO and recovery.

Limitations

This study had some limitations, with the first being that the study used actual soccer matches as the exercise protocol. Researchers typically use simulated soccer match protocols in order to better control the effects of an intervention or ergogenic aid. However, these types of

studies lack the variables commonly experienced during an actual soccer match. This study couldn't control weather or the level of effort put forth by players, these variables were monitored and didn't appear to influence the study. The results of this study can be directly transferred into a real match situation. This was a friendly intrasquad scrimmage match, which can vary in the determination of competitive match. Another limitation was all subjects played both matches in their entirety and no substitutions were allowed. It's common for players to play the full 90-minutes, but it's also common for substitutions to be made specifically in collegiate soccer. The match was also stopped 15-minutes into the second half for a blood sample. Although this halt was during a stoppage in play and only lasted about 5-minutes, it still could influence play (like a time-out in basketball). Another limitation was this study only monitored the food intake of subjects on the day of the match and not 48 or even 72 hours prior. The food intake was related to their mean BW taken 5-7days before the first match, perhaps drastic weight fluctuations could have influenced nutrient intake analysis. Neither nutrition nor hydration status was measured before the match and malnourished/dehydrated subjects could have experienced performance decrements. The two matches had to be rescheduled 24-hours apart, which created an unplanned potential limitation for recovery nutrition and physical measures during the second half. Recovery nutrition wasn't provided to the subjects, but the physical measures didn't differ between matches on a team level. Lastly, the CHO-E beverage provided in this study was observed for completion and wasn't weighed. The same volume of the CHO-E beverage was provided to each subject and it wasn't adjusted for bodyweight. The entire 591mL (20oz.) bottle was consumed during the HT period, which has been shown as acceptable for players [Clarke, 2008]. The CHO provided in this study (36g/hr) is on the bottom end of the CHO recommendation during soccer, so perhaps this intake amount was too low to trigger a BG

response. The subjects were not allowed to consume any CHO or sport-drinks an hour before the match, but perhaps CHO intake was needed before the match. It'd be interesting to compare how a higher percentage of CHO beverage impacts BG and insulin response with an active and passive HT intervention.

Conclusion

In conclusion, the active rewarm-up at halftime, compared to a passive period, mixed with CHO supplementation significantly improved physical performance at the start of the second half during a collegiate soccer match. The RWU had significantly higher measures for total distance, average speed, speed exertion, accelerations, HMP distance, decelerations, and energy expenditure during the first 15-minutes of the second half when compared to the completely passive group of subjects. There was a tendency of more shots on goals and goal scored during the second half for the RWU groups. No subjects, regardless of condition, experienced blood glucose concentrations that bordered hypoglycemia, but the CON group did have a significant drop in BG after half-time and the lowest mean BG at 15-minutes into the second half. Insulin levels were highest, and higher than prematch levels, during HT for CON, but were lower for RWU. The 8-minute moderate intensity rewarm-up at halftime shows obvious benefits when compared to a passive period with static stretches. The suspected significant interaction between conditions and time did not exist for BG and insulin. However, a drastic and significant drop in BG after HT, courtesy of potentially elevated levels of insulin and metabolic responses, could elicit implications on soccer performance. A passive HT period is not advised or optimal, given its role in temporary physical performance deficits in the second half of soccer matches. The results from this study provide a strong rationale for collegiate soccer players and

teams to incorporate the 8-minute moderate-intensity into the halftime regime in an effort to optimize second half performance. The inclusion of a CHO-E beverage is supportive, but many questions remain on the metabolic responses to its ingestion with passive recovery, specifically how much and how often are ideal.

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Table 1.

					Team 1:				
Subject #	Age (y.o)	Ht. (cm)	Wt. (kg)	BMI	Subject #	Age (y.o)	Ht. (cm)	Wt. (kg)	BMI
80	19	179.48	75.43	23.57	81	20	169.1	63.267	22.1
81	20	169.1	63.267	22.1	82	21	183.3	77.167	23
82	21	183.3	77.167	23	85	20	175.2	70.73	23
83	22	169	68.8	24.1	86	21	175.6	76.6	24.8
84	20	187.9	76.2	21.6	87	18	176.9	73.2	23.4
85	20	175.2	70.73	23	90	20	184.1	72.9	21.5
86	21	175.6	76.6	24.8	91				
87	18	176.9	73.2	23.4	95	19	176.2	75.5	24.3
88	22	173.6	70.26	23.3	97	23	172.4	70.1	23.6
89	20	178.5	71.3	22.4	98	22	181	82.9	25.3
90	20	184.1	72.9	21.5	Mean	20.4444444	177.088889	73.596	23.4444444
91					STD.DEV	1.50923086	4.94278374	5.47415672	1.22587837
92	20	186.5	77.2	22.2					
93	20	167.9	66.6	23.6					
94	19	182.9	70.8	21.2	Team 2:				
					Subject #	Age (y.o)	Ht. (cm)	Wt. (kg)	BMI
95	19	176.2	75.5	24.3	80	19	179.48	75.43	23.57
96	20	168.6	70.8	24.9	83	22	169	68.8	24.1
97	23	172.4	70.1	23.6	84	20	187.9	76.2	21.6
98	22	181	82.9	25.3	88	22	173.6	70.26	23.3
99	24	178.2	70.8	22.3	89	20	178.5	71.3	22.4
Mean	20.5263158	177.177895	72.6607368	23.1668421	92	20	186.5	77.2	22.2
STD.DEV	1.50437957	6.13532176	4.45996816	1.19154453	93	20	167.9	66.6	23.6
					94	19	182.9	70.8	21.2
					96	20	168.6	70.8	24.9
					99	24	178.2	70.8	22.3
					Mean	20.6	177.258	71.819	22.917
					STD.DEV	1.57762128	7.31797452	3.3887869	1.16504697

Subject raw data with means with \pm STDev. Solid dark red block = dropout subject, subjects also categorized into respective teams.

Table 2.

Time-Interval	DISTANCE (m)		AVERAGE SPEED (km/hr)		HMP Distance (m)	
	CON	RWU	CON	RWU	CON	RWU
TI-1	1838.8 ± 45.2	1830.5 ± 35.2	7.355 ± 0.181	7.322 ± 0.141	468.0 ± 28.6	460.6 ± 25.1
TI-2	1639.3 ± 48.1	1669.1 ± 53.5	6.557 ± 0.192	6.677 ± 0.214	356.9 ± 25.8	408.5 ± 29.4*
TI-3	1669.9 ± 51.0	1600.0 ± 62.1	6.681 ± 0.204	6.40 ± 0.249	389.2 ± 27.1	387.9 ± 30.4
TI-HT	239.2 ± 33.4	739.1 ± 42.9 *	0.5732 ± 0.08	1.771 ± 0.10*	9.07 ± 3.99	95.8 ± 12.3*
TI-4	1576.6 ± 45.5	1708.9 ± 45.1*	6.306 ± 0.182	6.836 ± 0.18*	360.5 ± 23.0	409.4 ± 24.5*
TI-5	1432.5 ± 37.1	1442.1 ± 47.6	5.729 ± 0.151	5.769 ± 0.191	276.7 ± 18.9	319.9 ± 21.4
TI-6	1618.3 ± 43.1	1652.9 ± 54.4	6.473 ± 0.176	6.612 ± 0.217	365.1 ± 24.6	398.8 ± 30.0

Values are means ± SD. * **Significantly different** (P<0.05) from CON. Time-Interval (TI): 15-minute segments in the match TI-1 (0-15), TI-2 (15-30), TI-3 (30-45), TI-HT (15-Halftime), TI-4 (45-60), TI-5 (60-75), TI-6 (75-90)

Table 3.

Time-Interval	AVERAGE HR (beats/min)		HR EXERTION (AU)		SPEED EXERTION (AU)	
	CON	RWU	CON	RWU	CON	RWU
TI-1	158.94 ± 5.67	164.68 ± 2.83	68.36 ± 7.13	74.62 ± 5.40	186.1 ± 11.9	180.06 ± 9.34
TI-2	160.47 ± 4.77	167.86 ± 2.22	69.24 ± 6.26	80.58 ± 4.43*	137.6 ± 10.8	155.3 ± 13.2*
TI-3	158.06 ± 5.58	162.46 ± 3.12	66.00 ± 5.38	69.84 ± 4.96	155.3 ± 12.2	150.6 ± 12.3
TI-HT	112.10 ± 2.18	130.63 ± 2.82*	29.56 ± 1.47	47.70 ± 4.27*	4.57 ± 2.82	23.39 ± 3.53*
TI-4	159.51 ± 2.60	152.64 ± 6.00	63.64 ± 4.99	58.97 ± 5.43	136.44 ± 9.45	153.3 ± 10.4*
TI-5	160.18 ± 2.84	162.14 ± 2.34	55.89 ± 4.30	58.29 ± 3.28	121.53 ± 9.29	110.6 ± 10.2
TI-6	154.01 ± 8.93	159.84 ± 2.59	63.55 ± 6.23	63.96 ± 4.56	146.3 ± 10.6	151.7 ± 13.1

Values are means ± SD. * **Significantly different** (P<0.05) from CON. Time-Interval (TI): 15-minute segments in the match TI-1 (0-15), TI-2 (15-30), TI-3 (30-45), TI-HT (15-Halftime), TI-4 (45-60), TI-5 (60-75), TI-6 (75-90)

Table 4.

Time-Interval	ACCELERATIONS (#)		DECELERATIONS (#)		ENERGY (kJ/kg)	
	CON	RWU	CON	RWU	CON	RWU
TI-1	37.05 ± 2.07	37.79 ± 1.92	23.00 ± 1.92	23.05 ± 1.76	9.468 ± 0.243	9.421 ± 0.194
TI-2	34.16 ± 1.99	35.05 ± 1.32	20.37 ± 1.41	20.421 ± 0.890	8.400 ± 0.251	8.595 ± 0.270
TI-3	31.79 ± 2.17	29.16 ± 2.06	18.95 ± 1.35	16.88 ± 1.35	8.516 ± 0.273	8.168 ± 0.317
TI-HT	1.421 ± 0.835	18.95 ± 2.18*	0.526 ± 0.37	10.00 ± 1.23*	1.211 ± 0.171	3.942 ± 0.240*
TI-4	30.79 ± 1.89	37.32 ± 2.68*	18.84 ± 1.59	22.11 ± 1.70*	8.063 ± 0.234	8.763 ± 0.242*
TI-5	25.21 ± 1.76	25.97 ± 1.76	14.83 ± 1.22	15.96 ± 1.28	7.082 ± 0.216	7.587 ± 0.239
TI-6	28.16 ± 1.95	31.37 ± 1.76	16.58 ± 1.47	18.05 ± 1.62	8.189 ± 0.229	8.442 ± 0.289

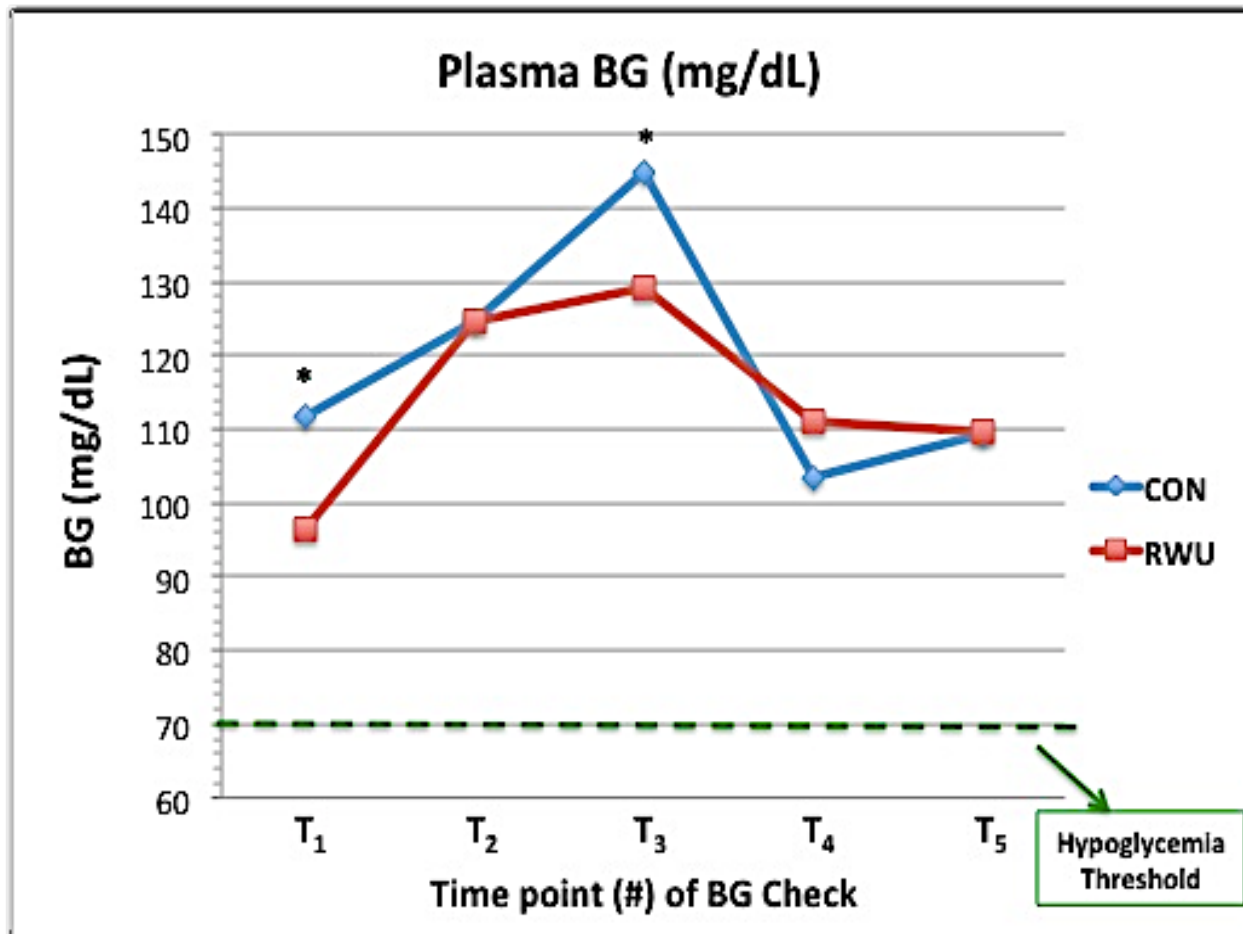
Values are means ± SD. * **Significantly different** (P<0.05) from CON. Time-Interval (TI): 15-minute segments in the match TI-1 (0-15), TI-2 (15-30), TI-3 (30-45), TI-HT (15-Halftime), TI-4 (45-60), TI-5 (60-75), TI-6 (75-90)

Table 5.

	TI-1	TI-2	TI-3	TI-HT	TI-4	TI-5	TI-6
Distance (m)				RWU ↑	RWU ↑		
Avg. Spd (km/hr)				RWU ↑	RWU ↑		
HMP Dist.(m)		RWU ↑		RWU ↑	RWU ↑		
Avg. HR (bpm)				RWU ↑			
HRE (au)		RWU ↑		RWU ↑			
Speed Exertion (au)		RWU ↑		RWU ↑	RWU ↑		
Acc. (#)				RWU ↑	RWU ↑		
Dec. (#)				RWU ↑	RWU ↑		
EE (kJ/kg)				RWU ↑	RWU ↑		

Comparison of means. Colored box = **Significantly different** (P<0.05) from CON, arrow indicates increase or decrease; Time-Interval (TI): 15-minute segments in the match TI-1 (0-15), TI-2 (15-30), TI-3 (30-45), TI-HT (15-Halftime), TI-4 (45-60), TI-5 (60-75), TI-6 (75-90). Y-axis: performance variables via GPS/Accelerometer/HR

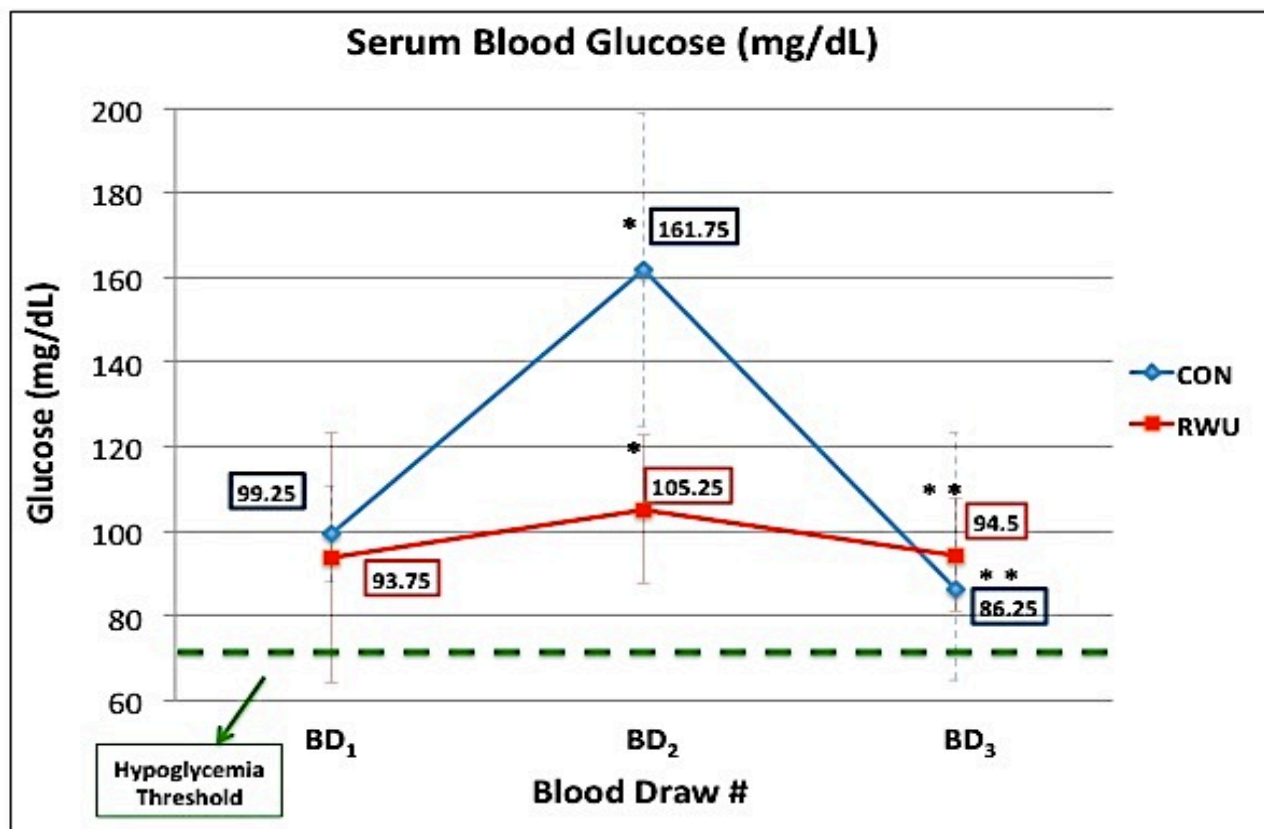
Figure 5a.



Values are means. CON: blue, RWU: red. Plasma BG(mg/dL)

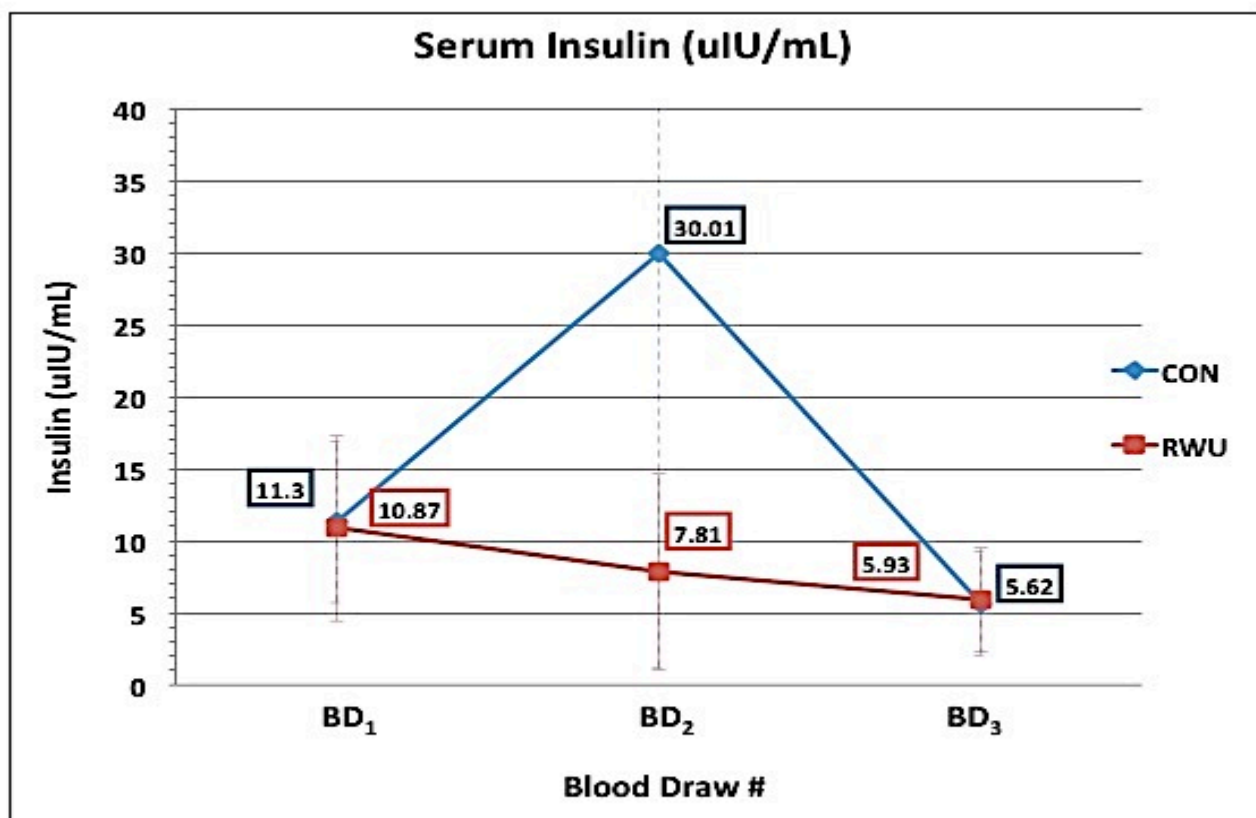
* **Significantly different** ($P < 0.05$) from RWU. Number on y-axis, Timing of fingerstick blood sample (T): T₁ before the match, T₂ after the first half, T₃ before the second half, T₄ 15-min into the second half, T₅ immediately after the match

Figure 5b.



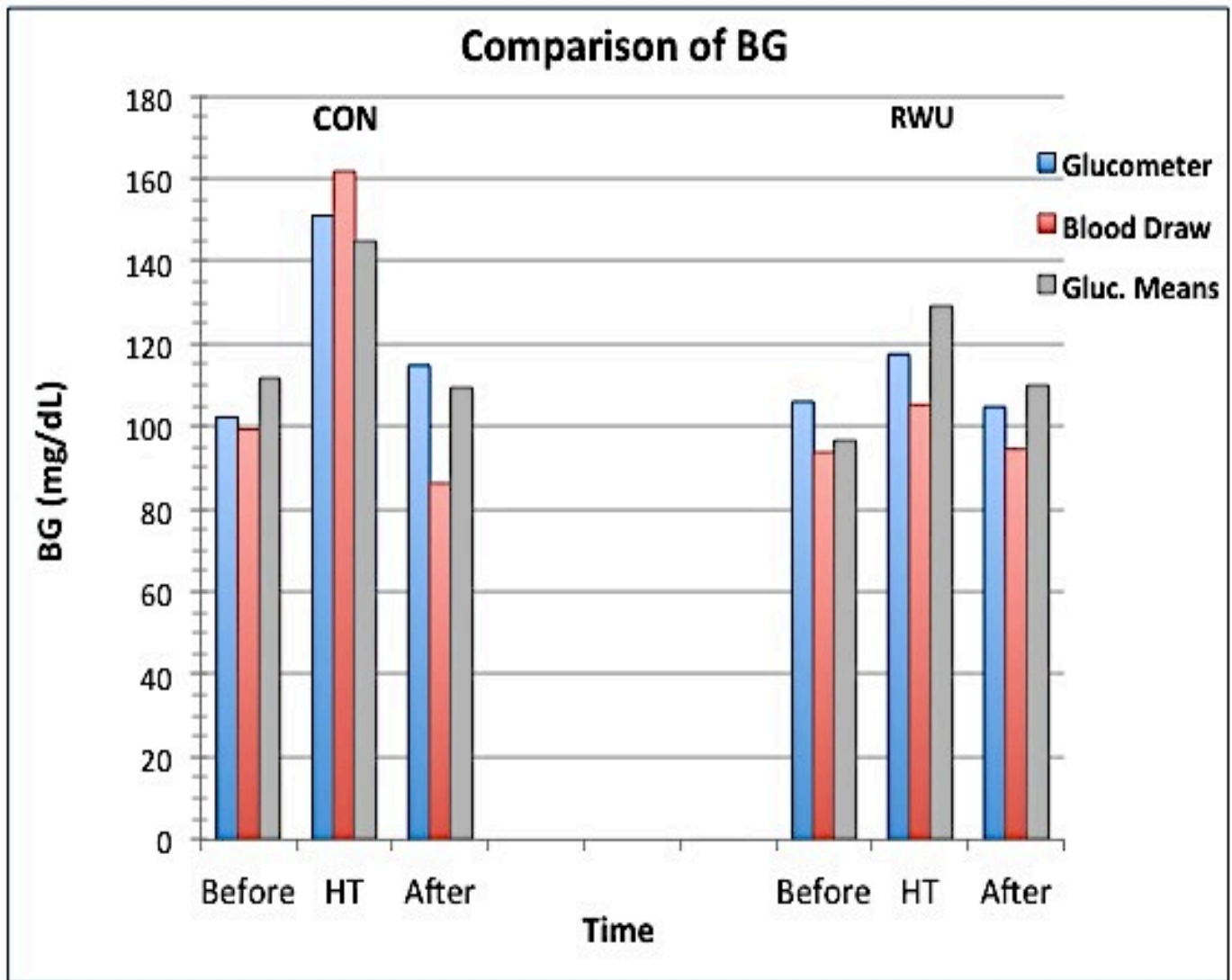
Values are means \pm STDev bars . CON: blue, RWU: red. Serum BG(mg/dL)
* **Significantly different** ($P < 0.05$) from BD₁ ; ** **Significantly different** ($P < 0.05$) from BD₂.
Number on y-axis, Timing of Blood Draw (BD): **BD₁** 5-min before the match, **BD₂** 5-min before the second half, **BD₃** Immediately after the match

Figure 5c.



Values are means \pm STDev bars . CON: blue, RWU: red. Serum insulin (uIU/mL)
* **Significantly different** ($P < 0.05$) from CON. Number on y-axis, Timing of Blood Draw (BD): **BD₁** 5-min before the match, **BD₂** 5-min before the second half, **BD₃** Immediately after the match

Figure 5d.



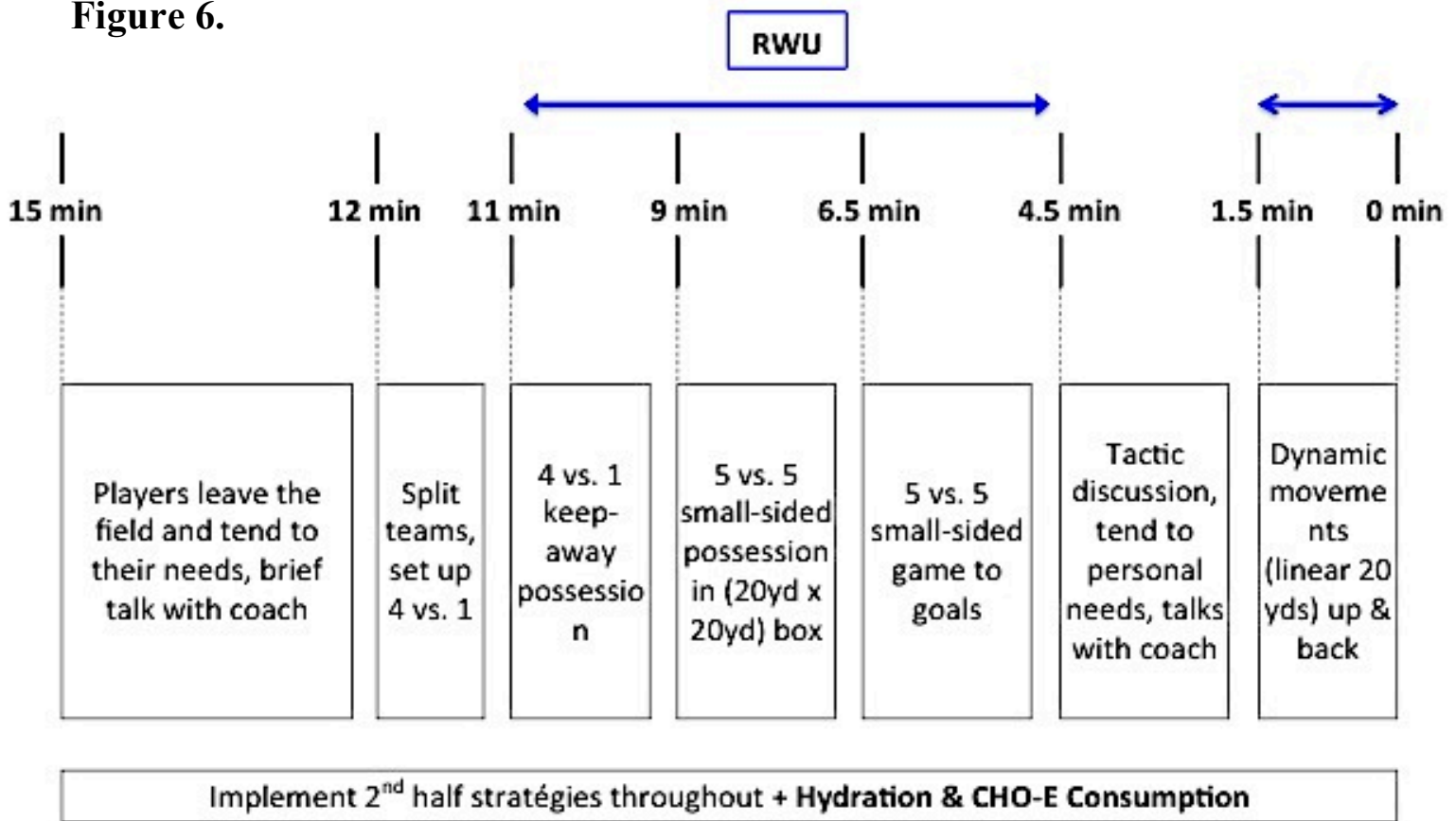
Values are means. Blood draw subjects (4): Glucometer (plasma BG): blue, Serum BG: red, Nonblood draw (19) Glucometer (plasma BG): Grey. BG(mg/dL)
Y-axis, Timing of BG sample: **Before** the match, **Halftime**, **After** the match

Table 6.

	CHO (g/d)	% of calories from CHO	Total Calories	Pre-match Meal			BW (kg.)	g/kg CHO (day)
				CHO (g)	Hours Prior to Match	g/kg Consumed		
Total Mean	233.11	55.21%	1,682	115.03	3.12	1.60	72.66	3.23
Total STDEV ±	77.13	15.6%	721.07	41.73	0.94	0.59	18.11	0.98

Values are means with ± STDev. Both matches combined, food intake data.

Figure 6.



Appendix:
Supplemental Documents

Screening Questionnaire

Active Recovery Study Screening (This is administered online through Qualtrics)

Welcome to the online screening survey for the Active Recovery study being conducted in the Department of Human Nutrition, Foods, and Exercise! Please fill out the following questions to help us determine your eligibility to participate in the study. We appreciate your interest in our research study!

This information will be kept confidential. If it is determined that you are not eligible to participate in this research study, these data will be discarded.

*Note: If the question is multiple choice, please click on the box to highlight your desired answer.

For contact purposes, please enter the following information:

First and Last Name

Email Address

Preferred Phone Number

Preferred Mode of Contact (click on one of the boxes below)

- Email (1)
- Phone (2)

Home Address (City, State minimum)

The following questions are related to your personal and health information.

Gender

- Male (1)
- Female (2)

Age

Height - Feet

Height - Inches

Weight - Pounds

Are you on the VT Club soccer team?

- Yes (1)
- No (2)

What is your position?

Can you participate in 2 soccer matches as part of the VT Club soccer team?

- Yes (1)
- No (2)

Are you taking any prescribed medications, over-the-counter medications and/or supplements or vitamins?

- Yes (1)
- No (2)

List your current medications and/or supplements or vitamins. Please include how long you have been on your current dose.

Have you been diagnosed with cardiac or thyroid problems (Example, Hypothyroidism)?

- Yes (1)
- No (2)

Have you been diagnosed with diabetes?

- Yes (1)
- No (2)

Have you had an injury in the three months?

- Yes (1)
- No (2)

Please tell us about this injury?

Is there anything else you would like to tell us about your medical history?

- Yes (1)
- No (2)

Please tell us about your medical history.

Thank you! **You will be contacted by study staff once your survey entry is reviewed.**

Body weight & height
document

Body Weight Sheet

Participant ID#: _____ Visit: _____

Date: _____

Clothes worn: _____

Body Weight:

Trial	Lbs.	Kg.
Trial 1:		
Trial 2:		
Trial 3:		
Average:		

Height:

Trial	Inches	Cm.
Trial 1:		
Trial 2:		
Trial 3:		
Average:		

Notes:

Food Intake Record

Subject ID Number _____

Date _____

Match Day (circle): 1 2

Food Intake Record

Time of Day	Place	Food Description (Please specify, if known: brand names, cooking method, type of product, and include labels when possible)	Portion Size: How many?	Condiments?	Beverage

Test Day Recommendations & Restrictions

Active Recovery Pre-Match Food Recommendation

Goals:

- Consume a high carbohydrate meal 3-4 hours before the match study sessions.
EAT SIMILAR MEALS BEFORE BOTH MATCHES!
- No food consumption once there is 60 minutes or less until the start of the match
- No alcohol 48 hours before the study
- No caffeine 24 hours before the study
- No exercise 48 hours before the study

Participants should consume:

4g/kg of carbohydrates 4 hours before the match or
3g/kg of carbohydrates 3 hours before the match

Key: **1 kg = 2.2 lb**

Weight: _____ lbs / 2.2 = _____ kg

Weight: _____ kg X 3g = _____ g of carbohydrates 3 hours before the game

Weight: _____ kg X 4g = _____ g of carbohydrates 4 hours before the game

Ideal meal:

- HIGH in quality carbohydrates (Pasta, Rice, Potatoes, Rolls)
- MODERATE in Lean Protein (fish, chicken, lean beef) *Don't go overboard on the protein
 - Consists of some vegetables (salad, broccoli, green beans)
 - LOW in fiber
- LOW in fat (**AVOID:** fried foods, heavy sauces/creams, high fat desserts, food with a lot of butter)

AVOID: Sports drinks [Study contains], spicy foods, carbonated beverages, foods high in sugar (Cakes, pies, cookies, sugary cereals), foods high in protein and low in carbohydrate.

FLUID (To avoid dehydration)
→ **16 - 24oz. of water 2-3 hours before match**
→ **Urine should be clear to pale yellow in color**

EXAMPLE GAMEDAY ITEMS/MEALS

3-4 hours before competition

175 lbs. = 80 kg. = [240 – 320] g CHO

Include water at each meal

- Westend:** Entrée Spaghetti : 57g
Meat Sauce: 20g
Breakstick: 42g
Fruit Bowl: 32g
Small Peach (12 oz.) smoothie: 55g
Minute Maid: Apple juice or Tropical Blend (52g or 35g)
- Turner:** Wheat roll: 29g
Garlic Mashed Potatoes: 28g
Grilled chicken or Salmon: <2g
Grilled veggies: <2g
Roasted Sweet Potatoes: 27g
Brueggers Bagel Sandwiches (turkey, chicken): (60g – 70g)
Minute Maid: Apple juice or Tropical Blend (52g or 35g)
Brueggers Fruit Smoothie: 100g +
8 Piece California Roll: 74g
- Owens:** Pasta w/ meat sauce: 63g
Breadstick: 14g
Whipped Potatoes: 25g
Chicken Quesadila: 63g
Black beans: 17g
Cilantro Rice: 25g
Minute Maid: Apple juice or Tropical Blend (52g or 35g)
Fruit Smoothies: 60 – 80g
- Home meal:** 2 cups of pasta: 90g
Large Wheat roll: 15g
Side of salad
Piece of fruit (banana, orange, apple): 30g
Fruit Juice (12 oz.): 45g

Examples of Carbohydrates and their grams: Read food labels prior to consumption

1 cup of pasta: 45g	½ cup of corn: 15g
1 cup of rice: 45g	½ cup of black beans: 15g
½ a bagel: 30g	1 small apple: 15g
1 small tortilla: 15g	1 small banana: 20g
1 slice of bread: 15g	1 medium orange: 15g
1 biscuit: 15g	1 cup of berries: 15g
½ cup of oatmeal: 15g	½ cup of fruit juice: 15g
½ large baked potato: 30g	1 cup of milk or 2/3 cup of yogurt: 12g
3 sandwich crackers: 15g	

Snacks: 20-30g of carbohydrates

- 6 Peanut Butter Crackers
- 1 Large piece of Fruit (apple, banana, orange)
- ½ cup of Applesauce
- PB & J sandwich
- ½ cup of Trail Mix
- 1 cup of Pretzels
- 1 Granola Bar
- ½ Bagel

Consent Form

Informed Consent for Participants of Investigative Projects

Department of Human Nutrition, Foods and Exercise

Virginia Tech

TITLE: Active Recovery

INVESTIGATORS: Mathew W. Hulver, Ph.D.
Jay Williams, Ph.D.
Madlyn Frisard, Ph.D.
Patrick O'Brien
Jennie Zabinsky, MAEd, RD
Janet Rinehart

MEDICAL DIRECTOR: Judy Gustafson, MD

PURPOSE: The halftime of a soccer match is important for a number of reasons. This break is a time to recover after the first half and to prepare for the second half of the match, and a time to get recovery foods and fluids to be ready for the second half of the game. Sometimes this includes drinking a carbohydrate drink like Gatorade while resting or can include drinking Gatorade while doing some light physical activity like jogging, etc, which is known as active recovery. It is not known whether active recovery while drinking a recovery drink during half-time is better than resting on performance (running distance) in the second half of the match. The purpose of this study is to determine whether active recovery with carbohydrate intake is better for performance in the second half of the match than drinking a carbohydrate beverage alone.

METHODS:

You are being asked to be involved in a study to determine whether active recovery while drinking a carbohydrate beverage during halftime improves performance in the second half of the game.

If you agree to be involved in the study, you will participate in two soccer matches, one week apart. During the halftime of the soccer matches, you will be randomized to consuming a carbohydrate drink while either resting or participating in an active recovery period. The half-time period will be split into 3 phases. The initial phase is 3.5 minutes, the intervention phase is 8 minutes, and the closing phase is 3.5 minutes. During the intervention phase, you will either participate in active recovery or rest. The 8-minute active recovery period will include small-sided game, small-sided possession, and intermittent agility exercise. The small-sided game (SSG) is a 5 player vs. 5 player game towards goals marked by cones. This game is played inside of a small box; 20 yards by 10 yards. The game will include limitations such as number of touches allowed and number of passes needed before a goal. Small-sided possession (SSP) is a 4 player versus 1 player keep away game played inside a small box; 5 yard by 5-yard square. Intermittent agility exercise (IAE) includes dynamic stretching, jogging, and sprinting in a linear 20-yard line. The 8-minute resting period will include resting and static stretching.

During the initial phase, you and your team will drink a carbohydrate drink, discuss tactics, go to the bathroom, and get a finger stick to measure blood glucose, and blood draw to measure glucose and insulin. During the closing phase, you will get a finger stick and blood draw.

You will also get finger sticks right before the start of the game, at the end of the first half, 15-minutes into the second half of the match, and at the end of the game. You will also get a blood draw at before the start and at the end of the game.

If you agree to be involved in this study you will first have to fill out an online screening questionnaire. The additional tests are described below under each testing session. You may be able to be a subject if you are between 18 and 30 years of age and you are a member of the Virginia Tech Club Soccer Team. You will not be eligible to participate in this study you are unable to play in a soccer match or are the goal keeper of the soccer team, have a history of cardiac or thyroid problems (Ex. hypothyroidism), diabetes, or are taking any medications that could influence your participation in the study (Ex. medicine for asthma or decongestants).

Testing Sessions:

To be included in the study, you will complete all components of the baseline testing session once, and the soccer match testing session twice, one week apart.

Baseline Session One: Approximate time required is 30 minutes

This study session will take place at the Integrative Physiology Laboratory at War Memorial Hall.

- **Overnight Fast:** You will be asked to avoid eating for 12 hours prior to this visit so that the test results will not be influenced by the food you eat or by the normal digestion process.
- **Health History:** You will be asked to complete an online health history questionnaire prior to the visit. This questionnaire is used to screen for health problems or reasons you should not participate in this study. The study staff will go over your medical history during the study visit.
- **Weight and Height:** Your height and weight will also be measured at this time. Your body weight will be measured on a standard digital scale. Your height will be measured with a standard stadiometer (ruler on the wall). Your waist, hip, and neck circumference will be measured using a measuring tape.
- **Instructions for Testing Visit:** You will be provided instructions for the test visit. This information about your food intake, etc., prior to the testing session. Also, please refrain from alcohol and exercise 48 hours before the match and caffeine 24 hours before the match.

Soccer Match Testing Visit: Approximate time required is 3 hours

This study session will take place at the VT men's club soccer field.

You are being asked to participate in a soccer match testing visit consisting of a standard 90-minute soccer match. There will be two soccer match testing visits.

- **Match preparation instructions:** Please follow the dietary recommendations you have been provided. Also, please refrain from alcohol and exercise 48 hours before the match and caffeine 24 hours before the match.
- **Food Records:** To get an idea of your dietary habits the day of the match, you will be asked to record all of the food you eat for the day of the match (6am-10pm).
- **Fingerstick blood sample:** You will have your blood glucose measured from a finger stick blood sample at the following time points, 1) before the start of the game (within 15 minutes), 2) at the end of the first half, 3) at the end of the half time, 4) fifteen minutes into the second half of the game, and 5) immediately following the game.
- **Blood Draw:** A small needle will be inserted in your arm to draw blood (approximately 1 tablespoon each time – total about 3 tablespoons). We will measure glucose and insulin. You

Page 2 of 5

will have a blood draw, 1) before the start of the game (within 15 minutes), 2) at the end of the half time, and 3) immediately following the game.

- **Global Position System to track movement:** Your movements (running distances, speeds, etc.) and heart rate will be recorded non-invasively using a GPSports HPU SPI unit and Polar heart rate monitor, respectively. The unit will be secured on your back, between the shoulder blades, using a custom designed vest (similar to a sports bra). Heart rate monitors are also secured to the vests and situated on the front of the thorax, just below the sternum.

SUMMARY OF SUBJECT RESPONSIBILITIES

- Provide an accurate history of any health problems or medications you use before the study begins.
- Inform the investigators of any discomfort or unusual feelings before, during or after any of the study sessions.
- Be on time and attend the scheduled experiments.
- Follow all participant instructions for each session.

RISKS OF PARTICIPATION

- **Catheter and Blood Draw:** Some pain or discomfort may be experienced when the catheter is inserted in the vein, but this should persist for only a short time. During the blood draws, you may have pain and/or bruising at the place on your arm where the blood is taken. In about 1 in 10 or 10% of the cases, a small amount of bleeding under the skin will cause bruising. The risk of a blood clot forming in the vein is about 1 in 200, while the risk of infection or significant blood loss is 1 in 1000. There is a small risk of the vein becoming inflamed and/or painful in the hours or days after the catheter is removed. If you feel faint during or after a blood draw, you should notify the study doctor or study staff immediately and lie down right away to avoid falling down. Having staff experienced in catheter placement and blood draws will minimize these risks.
- **HIV/ Hepatitis B/ Hepatitis C:** In the event a researcher or other staff person is inadvertently exposed to your blood, your blood will be tested for the presence of HIV, the Hepatitis B Virus, and the Hepatitis C Virus. There will not be any cost to you for this test. The research team will follow proper procedures for testing and reporting as outlined by Virginia State Law, which includes sending the sample to a certified laboratory. Please note that, should your blood require testing, you will be informed of your test results and provided with the opportunity to receive appropriate and timely counseling. In addition, positive test results will be sent to the local health department.
- There are no risks with wearing the global positioning system or the heart rate monitor. There may be some discomfort from the added weight of the vest, however this should be minimal.
- There may be some risks associated with participating in a soccer game as there is always a risk of injury associated with playing any kind of sport. Collisions with other players can cause bruises and even concussions. All the running involved in a soccer game can lead to muscle pulls and sprains, and overuse injuries.
- It is not possible to identify all potential risks in an experiential study. However, the study doctors and study staff will take all possible safeguards to minimize any known and potential

risks to your well-being. We believe the overall risks of participation are minimal. All of the procedures are well established and used routinely in the study investigators laboratory.

- Side effects are possible in any research study despite high standards of care, and could occur through no fault of your own or the study doctors or study staff.
- The decision to participate or not will not have any effect on their participation as part of the VT Men's club soccer team.

BENEFITS OF PARTICIPATION

There are no direct benefits of participating in this study. However, your participation will provide you with the following information at the end of the study. Information on your body fat percentage.

- Information on your body weight and height
- Information on your body mass index

COMPENSATION

You will not be monetarily compensated for participating in this study.

CONFIDENTIALITY

Because this study is being conducted during a team practice, individuals present at the practice (athletic trainers, spectators, etc.) may be aware that you are participating in a research study. However, the data from this study will be kept strictly confidential. No data will be released to anyone but those working on the project without your written permission. Data will be identified by subject numbers, without anything to identify you by name. In the event that any of your information indicate that you are at increased risk for any disease, Dr. Gustafson or investigators may want to share this information with your doctor but he will request your approval first.

FREEDOM TO WITHDRAW

You are free to withdraw from the study at any time for any reason. Simply inform the experimenters of your intention to cease participation. In addition, circumstances could arise which would lead to your exclusion from the study. For example, lack of compliance to instructions, failure to attend testing sessions, and illness could be reasons for the researchers to stop your participation in the study.

INJURY DURING PARTICIPATION IN THIS STUDY

Neither the researchers nor the University have money set aside to pay for medical treatment that would be necessary if injured as a result of your participation in this study. Any expenses that you incur including emergencies and long-term expenses would be your own responsibility. You should consider this limitation before you consider participating in this study.

APPROVAL OF RESEARCH

This research has been approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Tech. You will receive a copy of this form to take with you.

SUBJECT PERMISSION

I have read the informed consent and have had all my questions satisfactorily answered. I hereby give my voluntary consent to be a participant in this research study. I agree to abide by the rules of the project. I understand that I may withdraw from the study at any time.

If you have questions, you may contact:

- Principal Investigator: Matthew Hulver, Associate Professor, Department of Human Nutrition, Foods, and Exercise. (540) 231-7354; After hours: (540) 809-0584
- Personnel: Madlyn Frisard, Research Assistant Professor, Department of Human Nutrition, Foods, and Exercise. (540) 231-9994; After hours: (540) 818-9907

Should you have any questions or concerns about the study's conduct or your rights as a research subject, or need to report a research-related injury or event, you may contact the VT IRB Chair, Dr. David M. Moore at moored@vt.edu or (540) 231-4991.

Name of Subject (please print) _____

Signature of Subject _____ Date _____

Signature of Witness _____ Date _____

Match 1: Team document

Match Day 1: Monday May 1st, 2017

Team 1: Intervention "Rewarm - Up"		WhiteTeam	Subject #
1.		CB	82
2.		RB	97
3.		hardt: RB/LB	85
4.		CM	86
5.		on: LB	81
6.		CM	98
7.		co: M	95
8.		: M	91
9.			90
10.		d: M	87

Team 2: Control **Maroon Team**

1.		CB	92
2.		re : RM	80
3.		s : D or M	99
4.			93
5.		n: D or M	94
6.		D	89
7.		Anywhere	84
8.		M	83
9.		d: M	96
10.		F	88

BLOOD DRAW PLAYERS

GPS unit form

NAME	GPS Unit #	Wt.
T [REDACTED] re	04	166 lbs.
[REDACTED]	03	140 lbs.
[REDACTED]	11	170 lbs.
[REDACTED]	01	175 lbs.
[REDACTED]	20	168 lbs.
[REDACTED]	15	170 lbs.
[REDACTED]	07	169 lbs.
[REDACTED]	17	161 lbs.
[REDACTED]	05	155 lbs.
[REDACTED]	19	157 lbs.
[REDACTED]	12	161 lbs.
[REDACTED]	06	137 lbs.
[REDACTED]	14	170 lbs.
[REDACTED]	16	147 lbs.
[REDACTED]	10	156 lbs.
[REDACTED]	09	152 lbs.
[REDACTED]	13	156 lbs.
[REDACTED]	18	166 lbs.
[REDACTED]	02	183 lbs.
[REDACTED]	08	156 lbs.

Blood Data
documents

Active Recovery
Fingerstick Blood Glucose

Subject: _____

Date: _____

Study Visit: _____

Measurement Timepoint	Confirmed Taken	Measurement
1 (Before game)		
2 (End of first half)		
3 (End of half time)		
4 (15 minutes in second half)		
5 (End of game)		

Study Visit: _____

Measurement Timepoint	Confirmed Taken	Measurement
1 (Before game)		
2 (End of first half)		
3 (End of half time)		
4 (15 minutes in second half)		
5 (End of game)		

Blood collection for glucose and insulin

Subject: _____

Date: _____

Study Visit: _____

Red top collection tube (serum separator tube): _____

Measurement Timepoint	Confirmed Taken	Measurement
1 (Before game)		
3 (End of half time)		
5 (End of game)		

Date: _____

Study Visit: _____

Measurement Timepoint	Confirmed Taken	Measurement
1 (Before game)		
3 (End of half time)		
5 (End of game)		