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**THE UTILISATION OF A NEW
SOCCER MATCH SIMULATION THAT
INCORPORATES TECHNICAL
ACTIONS**

MARK RUSSELL

Submitted to the University of Wales in
fulfilment of the requirements for the Degree of
Doctor of Philosophy

2011

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ABSTRACT

This research used video analysis techniques and a new exercise simulation (Soccer Match Simulation) to examine the influence of fatigue and carbohydrate supplementation on the speed, precision and success of passing, shooting and dribbling skills performed throughout soccer-specific exercise.

Study one examined the test-retest reliability and construct validity of new soccer skills tests in twenty soccer players (10 professional and 10 recreational). Small non-significant biases existed between trials in the speed, precision and success of passing, shooting and dribbling skills performed on different days. Moderate to moderately-strong relative reliability and construct validity was confirmed in at least one outcome measure for all skills.

Study two demonstrated that the physiological demands of the Soccer Match Simulation, which incorporated the newly developed skills tests, were representative of actual match-play in ten professional soccer players.

The third study examined the effects of fatigue on soccer skills performed throughout the Soccer Match Simulation in fifteen professional players. Soccer-specific exercise caused decrements in at least one outcome measure of passing and shooting performance.

In a randomised, double-blind, and cross-over fashion, fifteen professional players ingested 6% carbohydrate-electrolyte or fluid-electrolyte solutions before and during the Soccer Match Simulation. Although carbohydrates attenuated the reduction in shot speed that occurred in the placebo trial, blood glucose concentrations were reduced at the onset of exercise during the second half.

The final study examined the metabolic responses to carbohydrates ingested before and during actual soccer match-play. Ten professional players participated in 90 min of soccer match-play on two separate occasions after ingesting a 6% carbohydrate-electrolyte or fluid-electrolyte beverages in a randomised, double-blind, and cross-over design. Carbohydrate consumption caused a sharp decline in blood glucose concentrations when re-starting exercise after a half-time break.

In summary, this research has provided further information concerning the skilled and metabolic responses to soccer match-play.

Some of the findings presented in this thesis have been published in peer-reviewed journals as follows:

Russell, M., Benton, D. and Kingsley, M. (2010). The reliability and construct validity of soccer skills tests that measure passing, shooting, and dribbling. *Journal of Sports Sciences*, **28**, 1399-1408.

Russell, M., Benton, D. and Kingsley, M. (In press). The effects of fatigue on soccer skills performed during a soccer match simulation. *International Journal of Sports Physiology and Performance*.

Russell, M. and Kingsley, M. (In press). Influence of exercise on skill proficiency in soccer: A review. *Sports Medicine*.

Russell, M., Rees, G., Benton, D. and Kingsley, M. (In press). An exercise protocol that replicates soccer match-play. *International Journal of Sports Medicine*.

DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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SUMMARY

This research aimed to develop a new exercise protocol (named the Soccer Match Simulation; SMS) that included the performance of technical actions (i.e., skills) throughout soccer-specific exercise. Further information concerning the effects of exercise and carbohydrate provision on the physiological and technical responses elicited during simulated soccer match-play has been identified from research that has incorporated the SMS.

Study 1 examined the reliability and construct validity of new soccer skills tests, which can be completed throughout the SMS. Twenty soccer players (10 Professional and 10 Recreational) repeated a trial incorporating passing, shooting and dribbling skills on different days. Passing and shooting skills required players to kick a moving ball, delivered at a constant speed, towards one of four randomly determined targets. Dribbling required players to negotiate seven cones over a 20-m course. Each trial consisted of 28 passes, 8 shots and 10 dribbles. Ball speed, precision and success were determined for all tests using video analysis. Systematic bias was small (<9% in all measures) and no significant differences existed between trials in any outcome measure. Ball speed (passing, shooting, dribbling; CV: 6.5%, 6.9%, 2.4%; RLOA: 0.958 \times/\div 1.091, 0.990 \times/\div 1.107, 0.993 \times/\div 1.039), precision (passing, shooting, dribbling; CV: 10.0%, 23.5%, 4.6%; RLOA: 0.956 \times/\div 1.147, 1.030 \times/\div 1.356, 1.000 \times/\div 1.068) and success (passing, shooting, dribbling; CV: 11.7%, 14.4%, 2.2%; RLOA: 1.017 \times/\div 1.191, 0.913 \times/\div 1.265, 0.996 \times/\div 1.035) were reproducible. Professional players

performed better than Recreational players in at least one measurement outcome for all skills. These findings demonstrate that the described protocols are reliable and able to differentiate between playing standards.

As study one demonstrated the test-retest reliability and construct validity of the skilled component of the SMS, the second study aimed to compare the demands of the SMS to the demands of actual match-play. Ten professional soccer players participated in actual (match) and simulated (SMS) match-play whilst ingesting a fluid-electrolyte beverage at a rate of $14 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$ body mass (BM). Blood samples were obtained every 15 min during exercise, and 10 min into half-time. No significant differences existed for mean heart rate (HR) between trials (SMS, match: $158 \pm 4 \text{ beats}\cdot\text{min}^{-1}$, $160 \pm 3 \text{ beats}\cdot\text{min}^{-1}$; $P=0.587$), peak HR (SMS, match: $197 \pm 3 \text{ beats}\cdot\text{min}^{-1}$, $197 \pm 4 \text{ beats}\cdot\text{min}^{-1}$; $P=0.935$) and mean blood glucose concentrations (SMS, match: $4.5 \pm 0.1 \text{ mmol}\cdot\text{L}^{-1}$, $4.6 \pm 0.2 \text{ mmol}\cdot\text{L}^{-1}$; $P=0.170$). Inter-trial coefficient of variance values (with Bland and Altman limits of agreement) for mean HR, peak HR, and mean blood glucose concentrations were 2.6% ($-19.4 - 15.4 \text{ beats}\cdot\text{min}^{-1}$), 1.6% ($-14.3 - 14.7 \text{ beats}\cdot\text{min}^{-1}$), and 5.0% ($-0.9 - 0.7 \text{ mmol}\cdot\text{L}^{-1}$) respectively. Although the pattern of blood lactate response was similar between trials, blood lactate concentrations were higher at 15 min in SMS when compared to match. Notably, blood glucose concentrations were depressed by $17 \pm 4\%$ and $19 \pm 5\%$ at 15 min after half-time during match-play and SMS, respectively. Time spent completing low intensity, moderate intensity and high intensity activities were similar between trials. These findings demonstrate that the SMS replicates the physiological demands of match-play while including technical actions.

After demonstrating the test-retest reliability of the new skills tests which can be included throughout the SMS (study one), and the validity of the SMS protocol (study two), the third study aimed to (i) determine the test-retest reliability of the physiological responses to the SMS and (ii) use the SMS to examine the effects of exercise on soccer skills performed throughout simulated match-play. Performance, metabolic and physiological responses to the SMS were shown to demonstrate test-retest repeatability as preliminary testing in 10 players identified that systematic bias did not exist between two SMS trials in mean ($P=0.089$) and peak ($P=0.708$) HR, blood lactate concentrations ($P=0.834$), sprint velocities ($P=0.865$) and mass losses ($P=0.845$). Therefore, fifteen professional soccer players completed one further trial of the SMS and video analysis was used to determine the precision, success rate and average ball speed for all skills performed. Blood samples were obtained before exercise (pre-exercise), every 15-min during the simulation (15, 30, 45, 60, 75 and 90-min), and 10 min into the half-time break (half-time). Exercise influenced shooting precision (timing effect: $P=0.035$) and pass speed (timing effect: $P=0.011$). Specifically, shots taken post-exercise were $26 \pm 4\%$ less accurate than those taken before exercise and passes in the last 15 min were $8 \pm 4\%$ slower than those in the first 15 min. Dribbling performance was unaffected by exercise and blood lactate concentrations were elevated above pre-exercise values from the first 15-min of exercise (time of sample effect: $P<0.001$). These findings demonstrate that soccer-specific exercise influenced the quality of skill performances, such as passing and shooting. Therefore, further research is warranted to develop interventions that can maintain skilled performance throughout the full duration of a soccer match, especially during the second half.

The fourth study aimed to evaluate the influence of carbohydrate supplementation on the quality of skills performed throughout the SMS. After preliminary testing and familiarisation, 15 soccer players completed the SMS on two separate occasions. In a randomised, double-blind, and cross-over design, participants received a 6% carbohydrate-electrolyte solution (CHO) or a fluid-electrolyte solution (PL). Video analysis was used to determine precision, success rate, ball speed, and an overall index of speed-precision-success (SPS) for all skills. Blood samples were obtained at rest, immediately before exercise, every 15 min during exercise (first half: 15, 30, 45 min; second half: 60, 75, 90 min), and 10 min into the half time break (half-time). Supplementation influenced shooting performance during exercise (time x treatment interaction: $P=0.017$), where CHO attenuated the decline in shot speed and SPS index from initial values that occurred during exercise in the PL trial. Supplementation did not affect performance in passing or dribbling. Blood glucose responses to exercise were influenced by supplementation (time x treatment interaction effect: $P=0.002$), where concentrations were higher at 45 min and during half-time in CHO compared with PL. However, blood glucose concentrations reduced by $30 \pm 1\%$ between half-time and 60 min in CHO, demonstrating an exercise-induced rebound glycaemic response. These findings demonstrate that a carbohydrate-electrolyte solution can attenuate decrements in shooting performance that occur during simulated soccer match-play. However, the rebound glycaemic response suggests that further research is warranted to develop optimal supplementation regimes to enhance skill during high intensity intermittent sports, such as soccer.

Given the interesting findings concerning the glycaemic response to carbohydrate supplementation observed in study four, the final study aimed to investigate the metabolic response to carbohydrates ingested prior to, and during actual soccer match-play. Following preliminary testing, 10 professional soccer players participated in 90 min of soccer match-play on two separate occasions. In a randomised, double-blind, and cross-over design, players received a 6% carbohydrate-electrolyte solution (CHO) or a fluid-electrolyte solution (PL). Blood samples were obtained at rest, every 15 min during the match (first half: 0-15, 15-30, 30-45 min; second half: 45-60, 60-75, 75-90 min), and 10 min into the half-time break (half-time). Supplementation influenced the blood glucose response to exercise (time x treatment interaction effect: $P=0.048$), where glucose concentrations were higher at 30-45 min in CHO compared with PL. However, at 45-60 min blood glucose concentrations fell by $40 \pm 4\%$ when compared to pre half-time values in CHO, demonstrating an exercise-induced rebound glycaemic response. Blood lactate concentrations were elevated above rest in the first 15 min of exercise (time of sample effect: $P<0.001$) and remained elevated throughout exercise; however, supplementation did not influence the pattern of response (time x treatment interaction effect: $P=0.487$). Ingesting a 6% carbohydrate-electrolyte beverage during soccer match-play caused a sharp decline in blood glucose concentrations when re-starting exercise after a half-time break. The findings from this study suggest that further research is warranted to develop optimal supplementation regimes that maintain elevated blood glucose concentrations throughout the duration of the match.

Collectively, the results from these studies provide evidence that:

1. a new battery of soccer skills tests can reliably assess the speed, precision and success of technical actions performed by male soccer players and also discriminate between players of different standards.
2. the SMS protocol (that incorporates the new battery of soccer skills tests) replicates the metabolic, physical, and technical demands of soccer match-play.
3. exercise influences the quality of technical actions in motor skills performed throughout the full duration of the SMS.
4. carbohydrate-electrolyte ingestion prior to, and during, soccer-specific exercise can attenuate the loss in technical proficiency observed in the second half of the SMS in soccer players ingesting a fluid-electrolyte placebo beverage.
5. an exercise-induced rebound glycaemic response that occurred in the initial stages of the second half of simulated match-play while players ingested a carbohydrate-electrolyte beverage also occurred in actual match-play; however, the possible performance effects resulting from, and mechanisms responsible for causing, such a glycaemic response remain to be fully elucidated.

TABLE OF ABBREVIATIONS

Abbreviation	Meaning
ANOVA	Analysis of variance
BM	Body mass
Ca ²⁺	Calcium ion
CBM	Criterion-based measure
CHO	Carbohydrate
CV	Coefficient of variance
GDH-NAD	Glucose dehydrogenase
GLUT-4	Glucose transporter type 4
H ⁺	Hydrogen ion
H ₂ O ₂	Hydrogen peroxide
Hb	Haemoglobin
Hct	Haematocrit
HR	Heart rate
ICC	Intraclass correlation coefficient
K ⁺	Potassium ion
LIST	Loughborough intermittent shuttle test
LOA	Limits of agreement
LOD	Lactate oxidase
LSPT	Loughborough soccer passing test

TABLE OF ABBREVIATIONS (cont.)

Abbreviation	Meaning
LSST	Loughborough soccer shooting test
MD	Minimum differences needed to be considered real
MSFT	Multistage fitness test
Na ⁺	Sodium ion
NAD ⁺	Nicotinamide adenine dinucleotide cofactor
NADH	Reduced form of NAD ⁺
PCO ₂	Partial pressure of carbon dioxide
pH	Measure of hydrogen ion concentration
PL	Placebo
PO ₂	Partial pressure of oxygen
RLOA	Ratio limits of agreement
RPE	Rate of perceived exertion
SEM	Standard error of measurement
SMS	Soccer match simulation
T1	Trial 1
T2	Trial 2
$\dot{V}O_{2\max}$	Maximum oxygen uptake
95% CI	95% Confidence intervals
1,10-PQ	1,10-phenanthroline quinone

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CHAPTER ONE

REVIEW OF LITERATURE

1.0 REVIEW OF LITERATURE

Performance during soccer match-play is influenced by a range of factors that include technical, tactical, mental, physical and physiological factors (Stolen *et al.*, 2005). The quality of the technical response (i.e., skilled performance) is dependent on cognitive, perceptual and motor skills, which interact in a rapidly changing environment (Bate, 1996). Skilled performers receive information (e.g., movement of ball and targets), rapidly analyse this information and execute appropriate responses with maximum certainty and minimum outlay of time and energy (Bate, 1996). In comparison with the physiological responses to intermittent exercise, technical responses (e.g., the performance of skills, such as passing, shooting and dribbling) to the physical demands of team sports are not well understood. This is somewhat surprising considering that the proficiency of skilled performance is almost exclusively responsible for determining the outcome of competitive fixtures in sports such as soccer, rugby (league and union), field hockey and basketball. A possible reason for the scarcity of literature regarding the influence of exercise on sports skills is the lack of exercise simulations that truly replicate, in a controlled and repeatable manner, the movement and technical demands of team sports.

The aim of this chapter was to summarise current research that evaluates the technical response to exercise, using soccer as the main area of interest. Computerised literature searches were performed in PubMed, Google Scholar and SportDiscus databases between November 2008 and November 2010. Keywords such as: “soccer,” “football,” “skill,” “technical,” “passing,” “shooting,” “dribbling” and “juggling” were used, and articles evaluating the technical responses of rugby

were excluded. All abstracts were scanned and relevant articles were retrieved for review. In addition, the reference lists of both the original and review articles retrieved were also reviewed for relevant literature. The chapter will: (i) describe the total amount of soccer skills performed during match-play, (ii) discuss the methods currently employed to simulate and evaluate the demands of match-play, with a particular focus on the measurement of soccer skills (iii) discuss the influence of exercise on skills, and (iv) examine the factors that affect the technical response to exercise.

1.1 TECHNICAL DEMANDS OF SOCCER

Soccer is a primarily aerobic sport; evident through consistent observations that players cover in excess of 10 km in a match (Reilly and Thomas, 1976; Withers *et al.*, 1982; Bangsbo *et al.*, 1991; Di Salvo *et al.*, 2007; Bradley *et al.*, 2009). However, success during soccer match-play is associated with high-intensity activity (Mohr *et al.*, 2003) and the quality of skilled actions, such as passing and shooting (Hughes and Franks, 2005; Redwood-Brown, 2008). Considering that a disproportionate number of goals are scored in the last 15 min of a match (Reilly, 2003), the ability of a team to maintain technical proficiency while engaged in prolonged high intensity intermittent exercise is a primary determinant of success in competitive fixtures.

Although the primary focus of notational analysis has been the quantification and classification of physical activities, this methodology has also revealed vital information about the total count of sports-specific motor skills performed in soccer

(Carling *et al.*, 2008; Carling, 2010). Throughout the full duration of a soccer match, each player completes between 50 and 110 technical involvements (Burgess *et al.*, 2006; Bloomfield *et al.*, 2007; Carling, 2010); however, fullbacks have been reported to have a higher total count of technical involvements than all other positions (Carling, 2010). In order to score a goal a successful team must take on average 10 shots and make between 16-30 attacks (Luhtanen, 1990), whereas analysis of individual actions has revealed that dribbles and short passes are the most frequently performed skills during match-play (Luhtanen, 1994; Bloomfield *et al.*, 2007).

Despite the number of skilled actions that occur throughout match-play being a consequence of aerobic fitness, positional role, and the team's league position (Rampinini *et al.*, 2009a; Carling, 2010), relatively little information is available to evaluate the possible time-course of decay in the total amount and/or success of technical performances executed during a match. Although half to half variations in the total count of skilled performances have previously been reported (Rampinini *et al.*, 2009a), no study has aimed to determine whether technical proficiency varies over smaller match intervals (e.g., every 15 min) in the full range of playing positions. This is somewhat surprising considering that it has been reported that lapses in concentration could partially explain the disproportionate number of goals that are scored in the latter stages of match-play relative to all other times during a game (Reilly, 2003).

Based on the technical demands of soccer, and the importance of skilled actions in defining success, it is warranted that soccer players allocate a large proportion of

their training time to improving skilled actions. Unlike other predictors of soccer success, such as a maximal aerobic capacity in excess of $60 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (Shephard, 1999), coaches do not regularly monitor the efficacy of training on technical performances using means other than empirical observations despite the amount of training time that technical practice occupies. Nevertheless, the growing interest in soccer skill amongst researchers has led to the development of various methods to evaluate the quality of skilled performances; however, soccer teams are yet to regularly incorporate the use of such protocols within their testing batteries.

1.2 METHODS CURRENTLY EMPLOYED IN THE EVALUATION OF SOCCER SKILL PERFORMANCE

The use of global measures of soccer skill performance (such as match results) have strong ecological validity, which is defined as the degree to which congruence exists between the environment that the subject in an investigation experiences and the intended properties of the environment that the investigator assumes (Bronfenbrenner, 1977), but incorporate too much variability to consistently identify changes associated with interventional research. For example, using the number of goals scored and/or conceded, Zeederberg *et al.* (1996) concluded that carbohydrate supplementation did not improve technical performance during soccer match-play. In addition to challenging the utilisation of this global outcome measure, similarities in plasma glucose concentrations between the carbohydrate and placebo trials suggest that the supplementation regime used was not optimal and may also have contributed to the lack of treatment effects observed in skilled performances.

To minimise external factors that influence the repeatability of match-play (e.g., opponents activity profiles and success experienced throughout the season; Rampinini *et al.*, 2007; Rampinini *et al.*, 2009a), a number of tests have been devised that isolate the performance of soccer skills (see Table 1.1; Zelenka *et al.*, 1967; Reilly and Holmes, 1983; McGregor *et al.*, 1999; Northcott *et al.*, 1999; Cox *et al.*, 2002; Finnoff *et al.*, 2002; Ali *et al.*, 2007a; Mirkov *et al.*, 2008; Rostgaard *et al.*, 2008; Currell *et al.*, 2009; Figueiredo *et al.*, 2010; Kelly *et al.*, 2010). These protocols can be categorised into tests that assess ball control and tests that measure ball accuracy.

Table 1.1: Summary of soccer skill tests that isolate specific technical actions

Reference	Skill	Measure of	Assessment method	Measurement outcome(s)
Zelenka <i>et al.</i> (1967)	Shooting Dribbling	Accuracy Ball control	Criterion-based measure Timing	Points scored Time
Reilly and Holmes (1983)	Ball juggling Dribbling Wall volley Shooting	Ball control Ball control Ball control Accuracy	Total amount of successful touches Timing Total amount of successful touches Criterion-based measure	Number of touches Time Number of continuous touches Points scored
McGregor <i>et al.</i> (1999)	Dribbling	Ball control	Timing	Time
Northcott <i>et al.</i> (1999)	Passing Shooting	Accuracy Accuracy	Criterion-based measure Criterion-based measure	Points scored Points scored
Cox <i>et al.</i> (2002)	Shooting	Accuracy	Criterion-based measure	Points scored
Finnoff <i>et al.</i> (2002)	Passing	Accuracy	Manual distance measurement	Distance
Ali <i>et al.</i> (2007a)	Passing Shooting	Accuracy and ball control Speed, accuracy and ball control	Criterion-based measure and timing Radar speed gun, criterion-based measure, and timing	Time Speed and points scored
Mirkov <i>et al.</i> (2008)	Throw-in Kicking Dribbling	Maximal upper body power Maximal lower body power Ball control	Manual distance measurement Manual distance measurement Timing	Maximal distance Maximal distance Time
Rostgaard <i>et al.</i> (2008)	Passing	Accuracy	Criterion-based measure	Points scored
Currell <i>et al.</i> (2009)	Dribbling Kicking Heading	Ball control Accuracy Maximal height	Timing Criterion-based measure Height measurement	Time Points scored Maximal height
Figueiredo <i>et al.</i> (2010)	Ball juggling Dribbling Passing Shooting	Ball control Ball control Accuracy and ball control Accuracy	Total amount of successful touches Timing Criterion-based measure Criterion-based measure	Number of continuous touches Time Points scored Points scored
Kelly <i>et al.</i> (2010)	Shooting	Accuracy	Criterion-based measure	Points scored
Williams <i>et al.</i> (2010)	Shooting	Accuracy	Criterion-based measure	Points scored

1.2.1 Tests that measure ball control

The ability of a player to control the ball during soccer a match, either when receiving a pass from a team mate or while running into an opponent's territory, is an important skill; consequently, a number of authors have designed tests that aim to assess this facet of soccer skill performance (Zelenka *et al.*, 1967; Reilly and Holmes, 1983; McGregor *et al.*, 1999; Ali *et al.*, 2007a; Mirkov *et al.*, 2008; Currell *et al.*, 2009; Figueiredo *et al.*, 2010). A method that has been used to assess ball control is ball juggling, whereby the total amount of consecutive and successful (i.e., preventing the ball from touching the ground) ball touches are counted, and higher values are deemed to represent a greater level of skill. Figueiredo *et al.* (2010) reported that performance on a reliable ball juggling task (coefficient of reliability: 0.77) was influenced by the sexual maturity of Portuguese junior soccer players as 13-14 year olds outperformed their 11-12 year old counterparts (69.5 touches vs. 25.2 touches). However, although ball juggling is commonly observed on the training ground, empirical observations of competitive match-play seldom reveal ball juggling to be a frequently occurring skill. Therefore, as a marker of technical proficiency, the ecological validity of ball juggling is questionable in comparison to more match-specific actions such as dribbling.

A 20-m timed sprint-dribble devised by McGregor *et al.* (1999) has been used to identify that when players abstained from fluid intake during a soccer-specific exercise protocol, a 5% reduction in dribbling performance relative to a fluid-provision trial occurred. Although subsequent studies have incorporated this test of soccer skill (e.g., Ostojic and Mazic, 2002), the main performance variable in timed

dribbling tasks is speed, with no concern for the “quality” of the skill. Although some people would argue that a shorter time to complete such tests represents a more skilled action, this is not necessarily the case. For example, a skilled dribbler is able to keep the ball close to the desired position while travelling at high speed and a lack of ball control will increase the likelihood of losing possession of the ball. Consequently, the ability to quantify the actual ball position in relation to desired position (precision) and the ability to complete the desired task without mistakes (success rate) are additional measurement outcomes that provide further information about the proficiency of this technical action; however, to date no single dribbling test exists that provides such information.

1.2.2 Tests that measure ball accuracy

The precision of skilled performances influence the winning and losing of possession during match-play; therefore, it is not surprising that the majority of soccer skill tests incorporate a measure of accuracy (Table 1.1). However, most skill tests in soccer research are those that produce accuracy outcomes from criterion-based measurements, whereby discrete (i.e., outcomes can only take certain values) as opposed to continuous (i.e., outcomes can take any value) data are produced. Consequently, conclusions drawn from the use of such tests are heavily influenced by the values assigned in the scoring criteria and may not necessarily reflect the difficulty of the tasks performed.

For example, the Loughborough Soccer Shooting Test (LSST) allocated the greatest number of points to shots placed in the corners of a goal as this limits the chance of

the goalkeeper saving the shot (Ali *et al.*, 2007a). However, participation in a similar shooting task devised by Currell *et al.* (2009) assigned the lowest number of points when shots were placed towards the corners. Consequently, conclusions derived from tests that rely on criterion-based outcomes are heavily dependent on the scoring criteria used and limit the like-for-like comparison of data between different tests that aim to assess the same variables of skilled performance.

The Loughborough Soccer Passing Test (LSPT) devised by Ali *et al.* (2007a) requires that participants aim passes towards coloured targets while negotiating a coned area. Performance is determined by the time to complete the task plus any additional penalty points accumulated. Although the LSPT has been extensively used to examine the influence of a number of interventions on soccer passing performance in both male (Ali *et al.*, 2007b; Ali and Williams, 2009; Foskett *et al.*, 2009) and female players (Ali *et al.*, 2010), the outcome measure lacks ecological validity as the outcome of the test, which is designed to measure kicking accuracy, is expressed in time (s) rather than distance.

In comparison to outcomes derived from criterion-based soccer skill tests, relatively few authors have published data concerning the accuracy of skills involving kicking. Finnoff *et al.* (2002) reported a median deviation of approximately 90 cm over a 6.1 m distance when ball impacts were measured manually, whereas Young *et al.* (2010) implemented video analysis procedures to yield deviations of 0.8-0.9 m when Australian football players kicked a ball towards a target that was 16 m away.

The omission of match-specific cognitive processes (such as decision making and visual searching) when a ball is kicked towards a target in a pre-planned manner,

and differences in the motor skills between football codes, limit the application of these studies to soccer research. However, these studies do provide evidence that alternative methods exist to the criterion-based outcome measures that have previously dominated soccer skill research.

1.2.3 Additional issues concerning the use of isolated skills tests

While attempting to standardise the testing protocol, some researchers have designed skill tests that require the kicking of a stationary ball (Northcott *et al.*, 1999). At the time of their development these tests provided novel findings that supported the use of selected ergogenic aids when aiming to maintain skilled performances; however, such tests focus on technique rather than skill because the use of a stationary ball fails to include cognitive aspects involved in match-play (e.g., decision making and visual searching processes; Bate, 1996; Ali *et al.*, 2007a). The array of different technical movements involved in match-play further complicates the issue of testing soccer skills in isolation; consequently, consideration should be given to various factors that influence performance in isolated skill tests (see Table 1.2). In addition, a range of environmental factors (e.g., location, wind and playing surface) should also be considered.

Table 1.2: Factors to consider when designing isolated skill tests

Skill	Testing considerations
Clearance	Standardisation of ball delivery Player movement at the start and throughout the test Outside interference when clearing the ball Position of ball clearance
Corner	Type of corner (e.g., cross, short) Speed, accuracy and success of outcome
Cross	Standardisation of ball delivery Player movement at the start and throughout the test Outside interference when crossing Speed, accuracy and success of outcome
Dribble	Standardisation of ball delivery Player movement at the start and throughout the test Path covered (e.g., distance, direction, turns) Cessation of test (skill performed on completion; e.g., pass) Speed, accuracy and success of outcome
Free kick	Type of free kick (e.g., pass, shot, cross, position) Outside interference when taking the kick (e.g., defensive wall) Speed, accuracy and success of outcome
Header	Standardisation of ball delivery Player movement at the start and throughout the test Outside interference when heading Type of header (e.g., towards opponents goal or team mate) Speed, accuracy and success of outcome
Pass	Standardisation of ball delivery Player movement at the start and throughout the test Type of pass (e.g., foot, chest, head, long, short) Outside interference when passing Speed, accuracy and success of outcome
Penalty	Speed, accuracy and success of outcome
Shot	Standardisation of ball delivery Player movement at the start and throughout the test Outside interference when shooting Type of shot (e.g., long or short range, power or placement) Speed, accuracy and success of outcome
Tackle	Standardisation of ball delivery Player movement at the start and throughout the test
Throw-in	Ball trajectory on release Type of throw (e.g., long, short, position of target)

Since the quality of a skill is dependent on the interaction of the speed and accuracy of execution (Fitts and Posner, 1967), and given that success is a valuable outcome, information concerning these subcomponents of skilled sports performances could provide independent measurement outcomes that are of relevance to players, coaches, and sports scientists. Criterion-based tests determine accuracy in terms of total points scored and rarely determine speed; therefore, future research in this field should employ analysis methods that provide outcome measures that possess high ecological validity and quantify skilled performances in terms of continuous data (as opposed to discrete data) when examining the technical performances of soccer players.

1.3 SIMULATING SOCCER-SPECIFIC EXERCISE

As a sport with worldwide participation and being the most popular of the football codes (Reilly and Gilbourne, 2003), the commercial value of findings from soccer research are potentially high; consequently, a number of exercise protocols that aim to replicate the demands of competition have been developed (e.g., Nevill *et al.*, 1993; Drust *et al.*, 2000; Nicholas *et al.*, 2000; Thatcher and Batterham, 2004; Kingsley *et al.*, 2005; Williams *et al.*, 2010). The primary reason for developing an exercise simulation is to control the movement requirements and thereby standardise the physiological demands. In doing so, the variation in responses that usually exists between matches is limited and the effects of exercise become repeatable. The most obvious benefit of simulation protocols is that they minimise external variation and allow for more prominent effects to be identified in sometimes subtle

physiological changes that result from supplementation protocols, strength and conditioning regimes, and/or other performance altering interventions.

Studies aiming to assess the validity of exercise protocols, which were designed to replicate the demands of soccer match-play, have generally tended to compare simulation data to the results of notational analysis studies collected during match-play in a different subject pool. According to Drust, Atkinson and Reilly (2007), if an exercise simulation is to be validated against the demands of match-play, then a single group of participants would be required to undergo both experimental conditions (i.e., match-play and the simulation) and their responses subject to statistical analysis. However, few researchers have adopted this approach when assessing the validity of an exercise simulation. Thatcher and Batterham (2004) demonstrated the comparability of physiological responses between individuals participating in actual match-play and a non-motorised treadmill protocol. However, the lack of lateral and backwards movements performed in unidirectional treadmill protocols, limits the ecological validity of this protocol. Thus, there is a need to assess the validity of an exercise simulation that better replicates the demands of actual match-play in a single population of participants.

The Loughborough Intermittent Shuttle Test (LIST) is a commonly employed intermittent exercise simulation that has been used to examine the effects of various ergogenic aids on exercise performance (Nicholas *et al.*, 1995; Morris *et al.*, 2003; Erith *et al.*, 2006). The LIST consists of 75 min of intermittent activity that is followed by a shuttle run to exhaustion. This free-running exercise simulation that replicated the movement demands of soccer was a valuable progression from

unidirectional treadmill-based protocols that had been used previously (e.g., Nevill *et al.*, 1993). However, the omission of a half-time period and the lack of game specific skills, some of which have been previously found to have an energy consuming consequence (e.g., dribbling; Reilly and Ball, 1984), reduces the ecological validity of the LIST and may also compromise the integrity of the physiological strain imposed by this protocol when compared to actual match-play.

The inclusion of soccer skills throughout exercise protocols designed to replicate the demands of a soccer match was rare in early research. Although this might be somewhat surprising considering the influence that soccer skills have in defining success, players with a lower skill level might lack the ability to simultaneously perform skills throughout the duration of an exercise simulation; thereby compromising the overall exercise intensity required. In a research field where the recruitment of large numbers of homogenous participants is already acknowledged as a major challenge (Drust *et al.*, 2007), it is not surprising that the technical responses of soccer players have received relatively little attention; nevertheless, more recent studies have attempted to include soccer skills into exercise simulations.

Soccer skill tests have been completed before and after exercise. In a study evaluating the effects of dehydration on soccer skill, McGregor *et al.* (1999) required participants to perform a timed dribbling task before and after 90 min of soccer-specific exercise. Similarly, Ali *et al.* (2007b) investigated the ergogenic potential of carbohydrate-electrolyte provision relative to a non-electrolyte placebo beverage on passing and shooting skills performed before and after a modified LIST protocol. Consequently, some authors have investigated the effects of exercise and

various ergogenic aids on the quality of skilled performances in soccer (McGregor *et al.*, 1999; Ali *et al.*, 2007b). However, only assessing soccer skills pre and post-exercise does not provide data concerning the possible time-course of decay in technical proficiency throughout the duration of a match while players are simultaneously engaging in high intensity intermittent exercise. Furthermore, information concerning the skilled response when assessed at the end of 90 min of exercise is only applicable to players who are about to enter a period of extra time.

More recent work has sought to rectify this problem by incorporating the performance of isolated soccer skills throughout exercise protocols (e.g., Rampinini *et al.*, 2008; Ali and Williams, 2009; Currell *et al.*, 2009; Foskett *et al.*, 2009; Williams *et al.*, 2010). For example, Ali and Williams (2009) required fasted and previously glycogen-depleted players to perform a criterion-based passing test (LSPT) every 15 min throughout a 90 min modified LIST protocol, whereas Currell *et al.* (2009) assessed kicking accuracy by means of a criterion-based shooting task on six occasions throughout a 90 min exercise simulation. These protocols suggest that soccer skills decline during the second half of exercise; however, criterion-based outcomes limited the ecological validity of these findings. Difficulties in interpreting the results from these tests, particularly the magnitude of the effect and the element of the skill that is influenced by fatigue, means that there is a need to utilise soccer-specific exercise simulations that include regular assessment of soccer skills throughout the duration of a match. Furthermore, the skill tests should incorporate game-specific cognitive processes and provide outcome measures that quantify the speed, precision and success rate of skilled performances.

1.4 THE EFFECTS OF EXERCISE ON SOCCER SKILLS

The reduction in the physical performances throughout match-play has been the focus of a number of research articles (Reilly and Thomas, 1979; Bangsbo *et al.*, 1991; Rienzi *et al.*, 2000; Mohr *et al.*, 2003; Mohr *et al.*, 2004; Carling *et al.*, 2008; Carling, 2010). Challenges to homeostasis, such as core temperature changes (Mohr *et al.*, 2004) and the accumulated effects of match-related fatigue (Mohr *et al.*, 2003; Krustup *et al.*, 2006), are generally thought to explain these performance decrements. However, considerably fewer articles have investigated the effects of exercise on the technical performances involved in team sports, such as soccer. As mentioned previously (see Section 1.1), a disproportionate number of goals are scored in the last 15 min of a match (Reilly, 2003); therefore, it is plausible that a link exists between match-related fatigue and the technical proficiency of soccer players (Ostojic and Mazic, 2002).

Rampinini *et al.* (2009) reported that the number of involvements with the ball, short passes, and successful short passes decreased from the first to the second halves in Italian Serie A matches. When these data were expressed as a function of the fatigue experienced during a game, using the decrement in high intensity running throughout the match as an indicator of fatigue, the differences between halves were no longer evident. This finding suggests that fatigue reduces the quality of skills executed during match-play (Rampinini *et al.*, 2009a). Similarly, game related events, such as kicking, heading and tackling have been observed to decrease by 11% in the second half when compared to the first half during Australian league matches (Burgess *et al.*, 2006). These findings support the existence of an

association between fatigue and soccer skill proficiency during match-play. Further attempts to elucidate the effects of exercise on soccer skills have used isolated skill tests, primarily incorporating tests of dribbling, passing and shooting.

1.4.1 Effect of soccer-specific exercise on dribbling performances

Dribbling is considered a valuable skill in soccer as players have the potential to advance deeper into an opponent's territory whilst still maintaining possession of the ball. Despite the importance of this skill, the effect of exercise on dribbling performance has received relatively little attention (Abt *et al.*, 1998; McGregor *et al.*, 1999; Ostojic and Mazic, 2002). Using a 20-m timed sprint-dribbling test, McGregor *et al.* (1999) observed reductions in performance as a consequence of 90 min of soccer-specific exercise performed under conditions of fluid abstinence. However, when the same sprint-dribbling task was performed in a more ecologically valid scenario, where players consumed a fluid-electrolyte solution during exercise, skilled performance was maintained. Consequently, dribbling speed is maintained throughout soccer-specific exercise scenarios that replicate the hydro-nutritional practices advocated by soccer teams; however, no data exists to evaluate the influence of fatigue on other aspects that affect the quality of dribbling (e.g., precision and success) during match-play or simulations of soccer.

1.4.2 Effect of soccer-specific exercise on passing performances

It has been reported that the top five teams in the Italian Serie A league complete more short passes (< 37 m) than their less successful counterparts (Rampinini *et al.*,

2009a) and longer passing sequences are associated with an increased number of goals per possession in successful teams (Hughes and Franks, 2005). Additionally, an early study that assessed passing proficiency in international competitions found that 57% of goals were scored after a period of play that includes short passing (Olsen, 1988) and the accuracy of passing has previously been found to discriminate between teams that score and concede goals (Redwood-Brown, 2008). Therefore, the maintenance of passing proficiency throughout the duration of a match probably contributes to the scoring of goals. However, studies examining the effects of exercise on isolated soccer passing performances have produced conflicting findings.

McMorris *et al.* (1994) investigated passing performance at rest and following cycling exercise at moderate (70%) and high (100%) percentages of maximal power output. Results indicated that moderate intensity exercise yielded improvements in passing performances which exceeded that of all other intensities. In contrast, passing performance has been observed to decrease following a bout of high intensity lower body resistance training (Lyons *et al.*, 2006b). Variations in the intensity of exercise, mode of exercise and the interaction between exercise and cognitive processes (i.e., inverted U theory; Easterbrook, 1959) are likely to explain the lack of agreement between authors. Consequently, the practical application of these findings are somewhat limited due to the likely differences that exist between the effects of fatigue induced by isolated bouts of high intensity exercise compared to exercise which is similar to that encountered during match-play.

With this in mind, other authors have used exercise protocols that simulate soccer match-play to evaluate the influence of fatigue on passing performances (e.g., Ali *et al.*, 2007b; Rampinini *et al.*, 2008; Ali *et al.*, 2010); however, equivocal findings exist with some researchers supporting the observation that fatigue influences the quality of passing performances (Rampinini *et al.*, 2008), whereas others disagree (Ali *et al.*, 2007b; Ali *et al.*, 2010). Rampinini *et al.* (2008) showed that the amount and success of short passes were reduced during the second half when compared to the first half of match-play. Conversely, in a study examining the effects of fluid balance on the physical and technical performances of female soccer players, Ali *et al.* (2010) identified that participation in 90 min of a modified LIST protocol did not influence overall performance measures in the LSPT (Ali *et al.*, 2007a), despite a 2.2% reduction in body mass (BM) in a fluid-abstinence trial. The use of analysis methods with greater application to on-field performances, in conjunction with the use of exercise simulations that better replicate the patterns of soccer activity, could improve our understanding of the technical response to exercise in respect to soccer passes performed throughout the duration of a match.

1.4.3 Effect of soccer-specific exercise on shooting performances

Shooting is arguably the most valuable skill in soccer as it directly contributes to the outcome of match-play. Empirical observations and research demonstrates that shooting is also the skill that exhibits the most variability, where coefficient of variance (CV) values have been found to exceed 20% in isolated shooting tasks that utilise a moving ball (Ali *et al.*, 2007a; Ali *et al.*, 2010). At first glance, this degree of variation appears to be relatively high in comparison to generally accepted

standards; however, from an applied perspective, it is not uncommon for even the most prolific of goal scorers to exhibit considerable variation in goal scoring success between matches. Due to the dynamic nature of shooting, tests that incorporate decision making and visual searching processes may incorporate more variation than tests that focus on technique alone (Ali *et al.*, 2007a); however, the use of such tests are warranted by the greater level of ecological validity that they offer in relation to tests that incorporate a stationary ball.

It has consistently been observed that shooting performances are reduced under conditions that are associated with physical fatigue. After 6 min of stepping exercise, reduced co-ordination between the upper and lower leg was proposed to cause a reduction in shot speed (Lees and Davies, 1988). This finding has since been confirmed using a more sports-specific exercise protocol (Kellis *et al.*, 2006). However, in soccer shooting, the ball must be aimed towards areas within the goal that will allow for an increased chance of scoring (Ali *et al.*, 2007a). Therefore, visual search and decision making processes are vital contributors to success in soccer shooting; unfortunately, such factors have not always been accounted for in previous research (e.g., Lees and Davies, 1988; Kellis *et al.*, 2006).

The assessment of shot speed before and after 90 min of soccer-specific exercise led to initial reports that shooting performance was maintained following exercise (Ali *et al.*, 2007b). However, the exclusion of shots that were slower than an arbitrary value resulted in significant reductions in shooting performance being observed. Unfortunately, no justification was provided for determining the threshold at which these shots were excluded and the number of shots remaining in the subsequent

analyses was not reported. Consequently, employing analysis methods that produce continuous rather than discrete data has the potential to extend earlier findings.

Therefore, the literature demonstrates that under physiological conditions that threaten homeostasis, a *speed-accuracy trade-off* (Fitts and Posner, 1967) exists in skills that contribute to success in soccer. From an applied perspective, this seems sensible as a player who lacks precision when shooting has no chance of scoring, whereas a shot which has the required precision but lacks pace may still be successful. Similar responses have been observed in other high intensity intermittent sports, such as tennis, where players alter specific subcomponents associated with skill execution in the favour of maintaining either accuracy or speed (Hornery *et al.*, 2007). It is reassuring that performances in a sport that is also dominated by fitness, unorthodox locomotive patterns and technical proficiency, exhibits similar skilled responses under conditions of homeostatic disturbance that results from fatiguing exercise.

In summary, given the lack of research that documents absolute measures of technical proficiency it is difficult to evaluate the skilled response to exercise. Nevertheless, it appears that the exercise-induced effects of fatigue may vary according to the soccer skill being performed; with shooting appearing to be the most susceptible, and dribbling the least, to modification by exercise. Given the importance of skills performed during exercise and the evidence that exists concerning the decline in skilled sporting actions due to match-related fatigue, it is important that coaches account for factors that can affect the proficiency of technical performances throughout exercise.

1.5 FACTORS AFFECTING SKILLS EXECUTED DURING EXERCISE

1.5.1 Aerobic fitness

It has previously been suggested that a maximal aerobic capacity ($\dot{V}O_{2\max}$) in excess of $60 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ is one of many physiological attributes that predicts success in elite soccer (Shephard, 1999; Reilly, 2003). In addition to separating teams in terms of physical performances, aerobic fitness influences technical performances during soccer match-play, specifically during the latter stages. The decline in passing proficiency after a bout of high intensity running has been correlated to aerobic fitness levels (Rampinini *et al.*, 2008). Although the physiological mechanisms of soccer fatigue remain unclear and are likely to be multifaceted in origin, this study suggests that there is a potential role for sport-specific fitness training to reduce the decline in the quality of skilled performances that occurs during periods of the game where homeostasis is disturbed. This claim is further substantiated by the observation that a period of aerobic interval training increased the involvement with the ball during match-play (Helgerud *et al.*, 2001) and attenuated the decline in passing performance following a period of high intensity running (Impellizzeri *et al.*, 2008). Moreover, it has been reported that the aerobic fitness of soccer players fluctuate throughout a season (Caldwell and Peters, 2009). Given the link that exists between aerobic fitness and the decline in skilled performances that result from fatigue, the efficacy of a mid-season aerobic training plan to counteract the decline in aerobic fitness presents itself as a research opportunity for investigating the concomitant effects that such a program would have on skilled performances executed in times of homeostatic disturbance.

1.5.2 Hydration status

During exercise, metabolic heat produced via contracting musculature causes elevations in core temperature. This leads to increased sweat production and modified blood flow to the periphery for heat dissipation (Convertino *et al.*, 1996). Even moderate hypohydration (1-2% BM loss) can impair exercise (Schoffstall *et al.*, 2001; Dougherty *et al.*, 2006; Baker *et al.*, 2007) and cognitive (Gopinathan *et al.*, 1988; Dougherty *et al.*, 2006; Baker *et al.*, 2007) performances; both of which are crucial to high intensity intermittent sports (Hornery *et al.*, 2007). Similar magnitudes of hypohydration have been observed in soccer players who were free to voluntarily consume fluids during training and competition (Convertino *et al.*, 1996); therefore, efforts to maintain euhydration are vital when aiming to optimise soccer performance as thirst alone is not a good enough indicator of fluid loss (Burke and Hawley, 1997).

Despite the potential for dehydration in soccer, few studies have examined the effects of modified hydration status on the technical aspects of the game; this is surprising considering that it is common practice for teams to seek more thermally challenging climates (i.e., increased daytime temperatures) to complete part of their pre-season preparations in which technical work will account for a large proportion of their training time. Nevertheless, the effect of fluid restriction on a timed dribbling task completed before and after intermittent running has previously been investigated (e.g., McGregor *et al.*, 1999). The increased cardiovascular strain associated with dehydration resulted in the elevation of a number of physiological measures that are associated with thermal stress in the no-fluid trial (i.e., serum

osmolality, serum cortisol concentrations, and heart rate). Moreover, a 5% deterioration in dribbling performance occurred when players abstained from fluid intake.

Additionally, shooting performances have been observed to reduce in fasted and previously glycogen-depleted players who exercised for 90 min whilst consuming a non-electrolyte placebo beverage (Ali *et al.*, 2007b). Although the practical applications from these studies are difficult to interpret due to the limited ecological validity of the methods used to assess skill and the fluid-intake regimens employed, the link between hypohydration and impaired soccer performance is strengthened by the fact that attributes key to success in the game such as strength, power and anaerobic endurance are also compromised by hypohydration (Bigard *et al.*, 2001; Schoffstall *et al.*, 2001; Watson *et al.*, 2005). However, a study by Ali *et al.* (2010) has failed to substantiate these findings in respect to passing performances (assessed by the LSPT) in female soccer players.

Baker and colleagues (2007) examined the effects of hypohydration on basketball shooting drills. The authors concluded that gradual hypohydration impaired skilled performance, with the critical threshold at which a statistically significant decline in skills was achieved, being 2% BM loss. Despite this study not being specific to soccer, both sports include intermittent bouts of high intensity activity repeated over a prolonged period of time while simultaneously executing sports-specific skills. It is therefore reasonable to assume that the effects of hypohydration observed by previous researchers in other multi-sprint sports (e.g., basketball; Dougherty *et al.*, 2006; Baker *et al.*, 2007) could impact on skilled performances in soccer.

Consequently, players should aim to limit water loss to within 2% BM and adhere to published guidelines regarding hydration strategies during exercise (Convertino *et al.*, 1996).

1.5.3 Blood glucose concentrations

Reduced blood glucose concentrations are considered to be a mechanism responsible for the deterioration of both cognitive (Holmes *et al.*, 1984; Stevens *et al.*, 1989; Widom and Simonson, 1990; Fanelli *et al.*, 1993; Fanelli *et al.*, 1994a; Fanelli *et al.*, 1994b; Veneman *et al.*, 1994; Maran *et al.*, 1995; Maran *et al.*, 2000; Benton, 2002; Benton and Nabb, 2003) and physical (Nicholas *et al.*, 1999; Davis *et al.*, 2000; Welsh *et al.*, 2002; Winnick *et al.*, 2005; Ali *et al.*, 2007b) performances. Given that team sports such as soccer require the execution of sports-specific skills while performing high intensity intermittent exercise, and that the brain is primarily dependent on blood glucose for maintenance of cerebral function (Duelli and Kuschinsky, 2001), reductions in blood glucose concentrations during exercise probably influence performances in soccer; particularly in respect to the skills executed during match-play.

A substantial body of evidence from the non-exercise setting demonstrates that markers of cognitive function, including: reaction time, arithmetical ability, verbal fluency, hand-eye co-ordination, and visual scanning are consistently impaired when blood glucose concentrations fall between 2.0 and 3.0 mmol·L⁻¹ (Widom and Simonson, 1990; Fanelli *et al.*, 1993; Fanelli *et al.*, 1994a; Fanelli *et al.*, 1994b; Veneman *et al.*, 1994; Maran *et al.*, 1995; Evans *et al.*, 2000; Maran *et al.*, 2000).

Furthermore, complex cognitive tasks are more sensitive to reductions in blood glucose concentrations than simple tasks (Warren and Frier, 2005). Although match-play has been observed to reduce blood glucose concentrations (Ekblom, 1986) the mean values of soccer players have not been reported to fall below $3.0 \text{ mmol}\cdot\text{L}^{-1}$. Nevertheless, serum glucose concentrations appear to be an important determinant of cognitive function before, at half-time and after soccer match-play performed in the heat (Bandelow *et al.*, 2010), where higher glucose concentrations were associated with faster visual discrimination, faster fine motor speed and faster psycho-motor speed. Soccer requires the simultaneous execution of cognitive, perceptual, and motor skills in a rapidly changing environment (Bate, 1996). Therefore, transient reductions in blood glucose concentrations could influence cognitive function and the performance of soccer-specific skills during a match, which could influence the outcome of the game.

Although studies that induce hypoglycaemia have provided information concerning the influence of blood glucose concentrations on cognitive performance, the stepped hyperinsulinaemic glucose clamp technique enabled researchers to determine the threshold at which blood glucose concentrations impair cognitive function. In non-diabetic adults, almost immediate reductions in cognitive performance occur when blood glucose concentrations fall below $3.4 \text{ mmol}\cdot\text{L}^{-1}$ (Holmes *et al.*, 1984; Stevens *et al.*, 1989; Widom and Simonson, 1990; Fanelli *et al.*, 1993; Fanelli *et al.*, 1994a; Fanelli *et al.*, 1994b; Veneman *et al.*, 1994; Maran *et al.*, 1995; Evans *et al.*, 2000; Maran *et al.*, 2000); concentrations which, although below average, have been reported to occur during soccer match-play (e.g., Ekblom, 1986).

As cognitive processes are crucial to the skilled actions involved in competitive team sports (Hornery *et al.*, 2007), and the role that blood glucose plays in maintenance of cerebral functioning (Duelli and Kuschinsky, 2001), it is plausible that carbohydrate supplementation regimes could maintain selected soccer skills in the latter stages of a soccer match (Reilly, 2003; Burgess *et al.*, 2006; Rampinini *et al.*, 2009a). However, the influence of additional carbohydrates (either with or without simultaneous electrolyte provision) on the skilled performances involved in high intensity intermittent sports has resulted in equivocal findings, where some studies support carbohydrate supplementation (Vergauwen *et al.*, 1998; Northcott *et al.*, 1999; Ostojic and Mazic, 2002; Welsh *et al.*, 2002; Winnick *et al.*, 2005; Bottoms *et al.*, 2006; Dougherty *et al.*, 2006; Ali *et al.*, 2007b; Currell *et al.*, 2009) whereas others do not (Zeederberg *et al.*, 1996; Ferrauti *et al.*, 1997). Table 1.3 summarises the studies that examine the effects of carbohydrate supplementation on technical aspects involved in the game of soccer.

Contradictory findings currently exist concerning the effects of carbohydrate usage in attenuating a decline in certain aspects of technical performance. It is likely that early methods of skill evaluation such as the use of global measures of skilled performance (e.g., the number of goals scored or conceded during match-play) were too variable to consistently detect the subtle changes involved in supplementation research and this may account for the inconsistent findings (e.g., Muckle, 1973; Zeederberg *et al.*, 1996). Similarly, studies with self-perceived exercise intensities (e.g., Northcott *et al.*, 1999), and/or criterion-based outcome measures have also failed to agree on the effects of carbohydrate provision on various skills performed

before, after and during exercise (e.g., Northcott *et al.*, 1999; Ali *et al.*, 2007b; Ali and Williams, 2009; Currell *et al.*, 2009).

Table 1.3: The influence of acute carbohydrate supplementation on skilled performances of soccer players

Reference	Subjects	Supplementation particulars	Timing (and dose) of supplementation	Exercise protocol	Measurement of skill	Effect on skilled performance
Muckle (1973)	n/a	350–450 Kcal glucose syrup	30 min prior (n/a)	90 min match	Total amount of ball contacts, goals scored or conceded, ball involvements per player	CHO ↑ goals scored, CHO ↑ defensive performances in last 30 min
Zeeđerberg <i>et al.</i> (1996)	11 M	6.9% glucose polymer-electrolyte solution or PL	15 min prior (5 ml·kg ⁻¹ BM), half-time (5 ml·kg ⁻¹ BM)	90 min match	Subjective evaluation of controlling, passing, dribbling, heading, tackling, and shooting	No effects of CHO
Northcott <i>et al.</i> (1999)	10 M	8% glucose-polymer or water PL	15 min prior (8 ml·kg ⁻¹ BM), half-time (8 ml·kg ⁻¹ BM)	90 min match simulation	CBM of various lengths of passing (10, 20 and 30 m) and shooting (15 m)	CHO ↑ skill proficiency in last 15 min compared to PL
Ostojic and Mazic (2002)	22 M	7% CHO-electrolyte solution or plain water PL	Immediately prior (5 ml·kg ⁻¹ BM), every 15 min during exercise (2 ml·kg ⁻¹ BM)	90 min match	Timed dribbling test (see McGregor <i>et al.</i> , 1999)	CHO ↑ dribbling performance compared to PL
Ali <i>et al.</i> (2007b)	16 M	6.4% CHO-electrolyte beverage (Lucozade Sport™) or a non-electrolyte PL	Immediately prior (5 ml·kg ⁻¹ BM), every 15 min during exercise (2 ml·kg ⁻¹ BM)	90 min match simulation	CBM of passing and shooting	CHO ↑ shooting performance compared to PL, post-exercise. No effect of exercise or CHO on passing
Ali and Williams (2009)	17 M	6.4% CHO-electrolyte beverage (Lucozade Sport™) or a non-electrolyte PL	Immediately prior (8 ml·kg ⁻¹ BM), every 15 min during exercise (3 ml·kg ⁻¹ BM)	90 min match simulation	CBM of passing	No effects of CHO
Currell <i>et al.</i> (2009)	11 M	7.5% maltodextrin solution or PL	30 min prior (6 ml·kg ⁻¹ BM), half-time (4 ml·kg ⁻¹ BM), every 12 min during exercise (1 ml·kg ⁻¹ BM)	90 min match simulation	Timed dribbling test, CBM of shooting, and a max jump height heading task	CHO ↑ dribbling and shooting performances in each trial

M = Males, CHO = Carbohydrate, PL = Placebo, CBM = Criterion-based measure, ↑ = Indicates significant improvement ($P \leq 0.05$)

Ali & Williams (2009) suggested that exogenous carbohydrate must be supplied at a minimum rate of $50 \text{ g}\cdot\text{h}^{-1}$ in order to improve motor skill performance. This statement was based on the findings of previous authors (e.g., Northcott *et al.*, 1999; Welsh *et al.*, 2002). Interestingly, supplementing fasted and previously glycogen-depleted participants with $52 \text{ g}\cdot\text{h}^{-1}$ of carbohydrates yielded no benefit to LSPT performance when assessed before, after and during exercise (Ali and Williams, 2009). This finding supports previous work from the same laboratory where passing was assessed before and after exercise and carbohydrates were supplied at a rate of $30 \text{ g}\cdot\text{h}^{-1}$ (Ali *et al.*, 2007b). However, $30 \text{ g}\cdot\text{h}^{-1}$ of carbohydrate was beneficial to shooting performances post-exercise when compared to a non-electrolyte placebo trial. Although these results should be interpreted carefully due to methodological limitations regarding the skilled performance outcome measures (detailed in section 1.2) and the hydro-nutritional status of the players pre-exercise (i.e., fasted and previously glycogen-depleted), the results suggest that the effects of carbohydrate provision can differ according to the type of skill being performed. Therefore, determining the critical blood glucose concentration at which skilled performance is challenged presents itself as a future research opportunity.

It appears that the dose of carbohydrate is important when seeking to improve soccer skill performance. However, the optimal dose of carbohydrate has not been elucidated when seeking to maintain soccer skill proficiency in the latter stages of a match. Given that a dose response relationship exists between carbohydrate provision and cognitive function in the non-exercise setting (Messier *et al.*, 1998), it remains to be determined whether higher doses of carbohydrates ingested during exercise will further increase the performance of skills. If so, caffeine, which has

previously been reported to enhance the absorption (Van Nieuwenhoven *et al.*, 2000) and oxidation (Yeo *et al.*, 2005) of co-ingested carbohydrates, might be of interest to team sports players; especially, given the influence that this ergogenic aid has on the central nervous system. However, adding 3.7 mg·kg⁻¹ BM of caffeine to a 6% carbohydrate-electrolyte solution did not improve performance in the LSPT (Gant *et al.*, 2010).

The consumption of a high-glycaemic index carbohydrate in the hour before exercise can lower blood glucose concentrations 15-30 min after starting exercise (Jentjens *et al.*, 2003; Jentjens and Jeukendrup, 2003). Although the effects of exercise-induced hypoglycaemia have been reported to reduce performance (Foster *et al.*, 1979), more recent research suggests that physical performance is not adversely influenced (Jentjens *et al.*, 2003; Jentjens and Jeukendrup, 2003). Studies involving non-exercising participants have demonstrated that almost immediate reductions in cognitive performance occur when blood glucose concentrations fall below 3.4 mmol·L⁻¹ (Holmes *et al.*, 1984; Stevens *et al.*, 1989; Widom and Simonson, 1990; Fanelli *et al.*, 1993; Fanelli *et al.*, 1994a; Fanelli *et al.*, 1994b; Veneman *et al.*, 1994; Maran *et al.*, 1995; Evans *et al.*, 2000; Maran *et al.*, 2000; Kelly *et al.*, 2010); a finding which has been found to influence the skilled performances of type 1 diabetics (Kelly *et al.*, 2010). Moreover, the restoration of euglycaemia after a hypoglycaemic episode does not lead to an immediate recovery of cognitive function. Delays of up to 90 min have been reported before cognitive function is restored to pre-hypoglycaemic levels (Tallroth *et al.*, 1990; Evans *et al.*, 2000); therefore, it is plausible that even transient reductions in blood glucose concentrations might adversely affect the performance of skills due to a deterioration

in decision making. Nevertheless, the influence of reduced blood glucose concentrations on skill performance during high-intensity intermittent exercise remains to be evaluated.

1.6 RESEARCH AIMS

The purpose of this chapter was: (i) to provide current information concerning the total amount of skills performed during a soccer game, (ii) to review the methods currently employed in the simulation and evaluation of responses to soccer match-play, with a particular focus on the measurement of soccer skills, (iii) to discuss the current understanding of exercise on skills, and finally, (iv) to examine the factors that may influence the technical response to exercise. This approach was taken in order to inform researchers and coaches about issues pertinent to soccer skill investigations and also to provide a platform for future research in the field. Nevertheless, it should be noted that the issues raised in this chapter are not exclusive to soccer; application of the findings to other high intensity intermittent sports is encouraged.

The unpredictable and erratic nature of soccer has limited the use of actual matches as an exercise protocol when examining the effects of interventions on performance; consequently, a number of soccer-specific exercise simulations have been developed to elicit repeatable responses to exercise. Despite the frequent application of simulation protocols in scientific research, the ecological validity of these protocols is questionable. This problem is further complicated by the array of skilled movements involved in soccer and problems associated with performing such movements under controlled laboratory conditions. Thus, the majority of research in this field has incorporated methods of skill assessment where the ball is aimed towards a target, with the performance judged and scored according to set criteria (Northcott *et al.*, 1999; Ali *et al.*, 2007a; Ali *et al.*, 2007b; Impellizzeri *et al.*, 2008;

Rampinini *et al.*, 2008; Currell *et al.*, 2009; Ali *et al.*, 2010). Although the use of skill tests that provide criterion-based outcome measures has overcome some of the problems associated with assessing skills throughout match-play, the results are difficult to interpret as the outcomes are heavily influenced by the values assigned in the scoring systems employed.

Factors that contribute to the decline in physical performances in soccer (e.g., aerobic fitness, dehydration and hypoglycaemia) might also moderate skill proficiency during match-play, particularly in the latter stages. Early research, in combination with findings from other high intensity intermittent sports, supports further investigation into interventions such as aerobic training, fluid-provision and carbohydrate-electrolyte supplementation to attenuate the decline in technical performance that is associated with fatigue. However, because the mechanism(s) responsible for the deterioration in skill performance remain unclear, more research is required to develop appropriate strategies to maintain skill proficiency throughout soccer match-play.

In light of all of the above, the series of studies in this thesis were designed to investigate the following:

- (1) Due to the lack of tests that provide data of a continuous nature (as opposed to discrete data) concerning the evaluation of technical performances involved in soccer, the purpose of the first study was twofold; (i) to examine the test-retest reliability of a new battery of soccer skills tests that provides data concerning the speed, precision, and success of soccer skills which incorporate visual search and decision making processes, and (ii) to determine whether such tests could differentiate between players of differing ability (construct validity).
- (2) Given the lack of validity studies that have directly assessed the demands of an exercise simulation to actual match-play in a single subject population, the aim of the second study was to compare the physiological, movement and skilled demands of a protocol (named the soccer match simulation; SMS) that incorporated the skills tests used in study one, to the demands of actual match-play.
- (3) When examining the influence of exercise on soccer skills, previous authors have either assessed technical performance before and after exercise and/or relied on criterion-based outcome measures. As evidence from notational analysis studies tends to suggest that fatigue may contribute to impaired technical performances during match-play, the aim of the third study was to use the analysis procedures proven to be reliable in study one, in combination with the exercise simulation validated in study two, to determine whether soccer-specific exercise would influence the quality of

shooting, passing and dribbling skills assessed throughout the full duration of a match simulation.

- (4) The administration of carbohydrate and/or carbohydrate-electrolyte solutions has been demonstrated to improve cognitive function and attenuate the reduction of some sports related skills following prolonged exercise. However, due to methodological limitations in the timing of assessment (i.e., before and after exercise) and/or the type of skills tests undertaken (i.e., criterion-based tests producing discrete data), the influence of exogenous carbohydrate on the performance of soccer skills during soccer-specific exercise is not clear. Therefore, the aim of the fourth study was to consider whether ingestion of a carbohydrate-electrolyte beverage would influence the quality of the performance of soccer skills when assessed before, during and after the SMS.
- (5) Compromised glucose availability has the potential to negatively influence motor skills and cognitive function; both of which are vital for optimum performance in intermittent sports, such as soccer. Findings from the fourth study suggested that a transient lowering of blood glucose concentrations occurred in the initial stages of the second half of exercise while players routinely ingested a carbohydrate-electrolyte beverage in a manner that is recommended to intermittent team sports players. As the existence of this phenomenon during soccer match-play had previously been unreported, the aim of the final study of this thesis was to investigate the metabolic responses to carbohydrate ingestion prior to, and during, actual soccer match-play.

CHAPTER TWO

GENERAL METHODS

2.0 GENERAL METHODS

This chapter describes the general methods and procedures that were used throughout the main studies (chapters 3 to 7) contained within this thesis. Specific methods and procedures that are not presented within this section are described in the methods sections within the relevant chapters.

2.1 PARTICIPANTS AND STUDY APPROVAL

All of the studies (chapters 3 to 7) involved human volunteers. Male soccer players from a University reserve team (Recreational) participated in chapter 3, whereas male players from a Championship team competing in the second tier of professional soccer within Britain (Professional) participated in all studies (chapters 3 to 7). The inclusion and exclusion criteria for each study are presented in the relevant chapters.

Prior to undertaking each study, approval was sought and gained from an ethical committee of Swansea University (Appendix A). All participants received verbal and written information that explained the purpose and requirements of the study that they volunteered to undertake. Before taking part in any investigation, all participants provided written informed consent (Appendix B) and completed health questionnaires (Appendix C). In addition, the participants were made aware of their right to withdraw from the study at any stage without explanation.

2.2 STUDY DESIGN

Familiarisation trials were included in all studies in order to reduce the effects of trial order. The details of these trials are included in the methods section within each chapter (chapters 3 to 7). Studies four and five employed a double-blind placebo controlled crossover design.

2.3 SUPPLEMENTATION

Studies 4 and 5 describe placebo controlled oral carbohydrate supplementation studies. The specific composition of the carbohydrate and placebo supplements are detailed in chapters 6 and 7 and all beverages were provided in generic containers to ensure that the solutions were delivered to participants in a double-blind manner.

2.4 DIETARY ANALYSIS

All participants were requested to weigh and record their dietary intake on two consecutive days before each main trial. Energy intake and dietary composition were determined for each participant using a commercially available computerised programme (CompEat version 5.8.0; Nutrition Systems, UK). These results were used to ensure that any changes between trials were not the result of modifications in dietary intake beforehand.

2.5 ANTHROPOMETRY

In all studies (chapters 3 through 7), the participant's mass and height were measured in accordance with the International Standards for Anthropometric Assessment published by the International Society for the Advancement of Kinanthropometry (Kinanthropometry, 2001). Near-nude body mass (BM) was determined using digital scales (model 770; Seca Ltd, Birmingham, UK; sensitive to nearest 0.1 kg) while the players were dressed in minimal clothing (i.e., wearing only playing shorts). Free standing height was determined using a portable stadiometer (Portable Stadiometer; Holtain Ltd, Wales, UK) to the nearest 0.001 m. The participants maintained an upright posture with the head positioned in the Frankfort plane, by standing with their feet together and heels touching the base of the stadiometer while the head board was lowered to the vertex of the head.

2.6 STUDY CONTROLS

Prior to involvement in any testing or familiarisation session, the players were asked to refrain from undertaking strenuous activities before each main trial. The time period for this request during each study is described within the methods section of each study (chapters 3 to 7). This control was included in order to reduce the influence of additional activities on test performance. All of the participants gave their verbal assurance that they had complied with these instructions.

2.7 EXERCISE SIMULATION: SOCCER MATCH SIMULATION (SMS)

Studies 2, 3, and 4 (chapters 4, 5, and 6) incorporate the soccer match simulation (SMS), which is an exercise protocol similar to that devised by Nicholas *et al.* (2000), but has subsequently been adapted to include additional components (i.e., backwards movements, lateral movements, more jogging and a half-time period) that further replicate the demands of soccer match-play (Kingsley *et al.*, 2005) and the performance of soccer passing, shooting and dribbling skills. Players were paired according to estimated aerobic capacity and completed two 47-min halves of intermittent activity that were separated by a 15-min recovery period (half-time). Movements were dictated by audio signals from CDs that were specifically made for all player pairings and each participant alternated between sprinting and dribbling during each cycle.

More specifically, exercise was made up of 4.5-min blocks that consisted of 3 repeated cycles of three 20-m walks, one walk to the side, an alternating 15-m sprint or a 18-m dribble test (see section 2.8), a 4-s passive recovery period, five 20-m jogs at a speed corresponding to 40% maximal aerobic capacity ($\dot{V}O_{2\max}$), one 20-m backwards jog at 40% $\dot{V}O_{2\max}$ and two 20-m strides at 85% $\dot{V}O_{2\max}$ (see Figure 2.1). A 1-min passing test (see section 2.8) and a 1-min recovery period were completed after all blocks of exercise. Seven blocks of intermittent exercise and skill testing were completed during each half of exercise. The participants covered a total distance of 10.1 km and completed 56 passes, 16 shots, and 21 dribbles during the protocol.

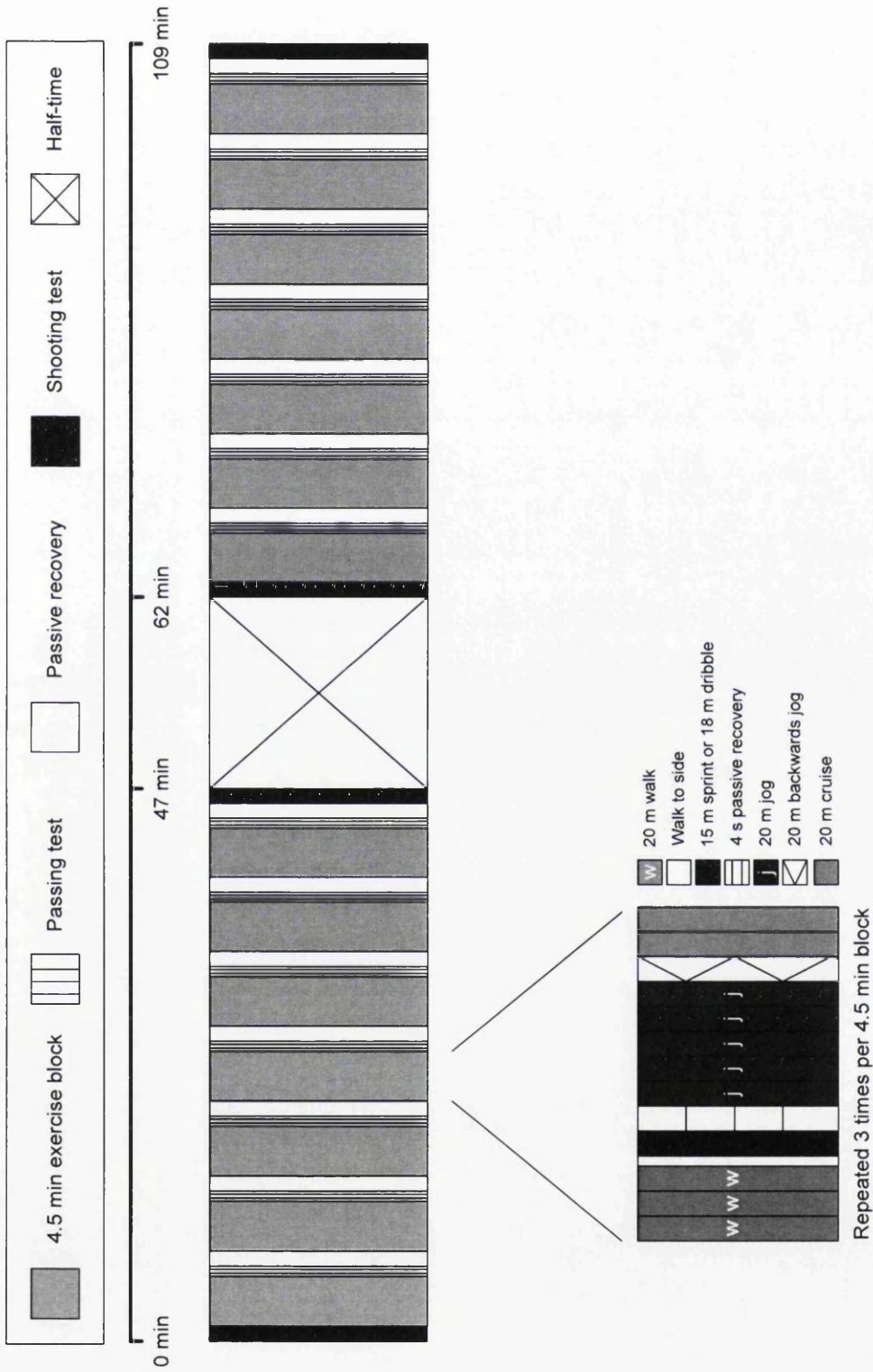


Figure 2.1: Schematic of the soccer match simulation (SMS)

2.8 SKILL TESTING PROCEDURES

Figure 2.2 presents a schematic of the passing, shooting and dribbling skill tests used in studies 1 through 4 in this thesis. The tests were performed on a synthetic running track in an indoor training facility that was maintained at an air temperature between 16 and 18°C. Balls (Total 90 Aerow: size 5; Nike Inc, USA) were released at a constant speed of $2.3 \text{ m}\cdot\text{s}^{-1}$ by means of a commercially available ramp (measuring 0.68 m high and 1.43 m long; Mark 3 bowling ramp: Pete's Pro Shop, UK) towards a 1.5 x 1.5-m square (action zone), where participants were instructed to kick the ball. The participants kicked towards one of four randomly determined targets (identified by a custom lighting system). Consequently, the players were required to carry out visual searching and decision making during each attempt. Motion sensors on the ball release mechanism ensured that a delay of 0.64 s existed between target identification and the ball reaching the centre of the action zone. Pilot work during the tests development found this to be the most appropriate time delay.

Passes and shots were performed in bouts of four attempts, whereas dribbles were performed singularly. At least 30 s of recovery separated each individual kick, and shots were performed before and after each half of exercise that incorporated seven bouts of passing that were separated by 5.5 min. Participants commenced the passing and shooting skill tests from a standing start before jogging into the action zone when the ball was released. The 2.0 x 1.0-m passing targets were placed at distances of 4.2 m (short pass) and 7.9 m (long pass) away from the centre of the action zone. Each target had a 0.50 x 0.25-m target box which was centred at ground level and was marked with calibration lines. The shooting target was a standard 11-

aside adult soccer goal measuring 7.33 x 2.44 m with transparent netting stretched across it. Four target lights were positioned 1.0 m horizontally inside each post and 0.5 m vertically inside the upper and lower edges of the goal. Targets were placed in the corners of the goal as this has been identified as optimal ball placement to beat a goalkeeper when shooting (Ali *et al.*, 2007b).

The participants were instructed to aim passes at the centre of the target box on the illuminated target. When shooting, participants were instructed to kick the ball as accurately as possible at the illuminated target within the goal. During the passing and shooting tests the ball was alternately delivered from the right and left side of the action zone. To enhance ecological validity, no prior touches were allowed to control the ball (Olsen, 1988) and participants kicked the ball with their foot of choice.

The layout of the dribbling test was similar to that employed by McGregor *et al.* (1999) with start and finish lines placed 20-m apart (Figure 2.2). Cones 2 through 7 were placed 3-m away from the preceding cone, and cones 1 and 7 were 1-m away from each end of the course. Participants were required to dribble the ball as fast and as accurately as possible. Participants dribbled towards a video camera that was placed directly in line with the cones.

2.9 ANALYSIS OF SKILLS TESTING

Video footage of each skill performed during studies 1, 3 and 4 were captured on to digital tapes (DVM60-PR3; Sony Ltd, UK) using 50 Hz video cameras (DCR-HC96E; Sony Ltd, UK) which were positioned as shown in Figure 2.2. Specific variables of speed, precision, and success were calculated for all skills via manual digitisation of the footage by one analyst. Coefficients of variance (CV) for values derived by these methods were less than 2% in all cases (see Appendix D).

2.9.1 Determination of ball speed

Average ball speeds were calculated for all skills using the distance-time relationship, where the time component was calculated using biomechanical analysis software (Quintic Coaching 4.01 version 14; Quintic Consultancy Ltd, UK). In the case of passing and shooting, distances covered were assumed to originate from the centre of the action zone and were calculated via Pythagoras' Law in conjunction with precision data from the respective targets. Figure 2.3 illustrates the various distances (and transformations) involved when calculating the distance covered in shooting. For dribbling, average ball speed was calculated using the known values of the length of the dribble course with the time difference between initial ball contact and completion of the required distance.

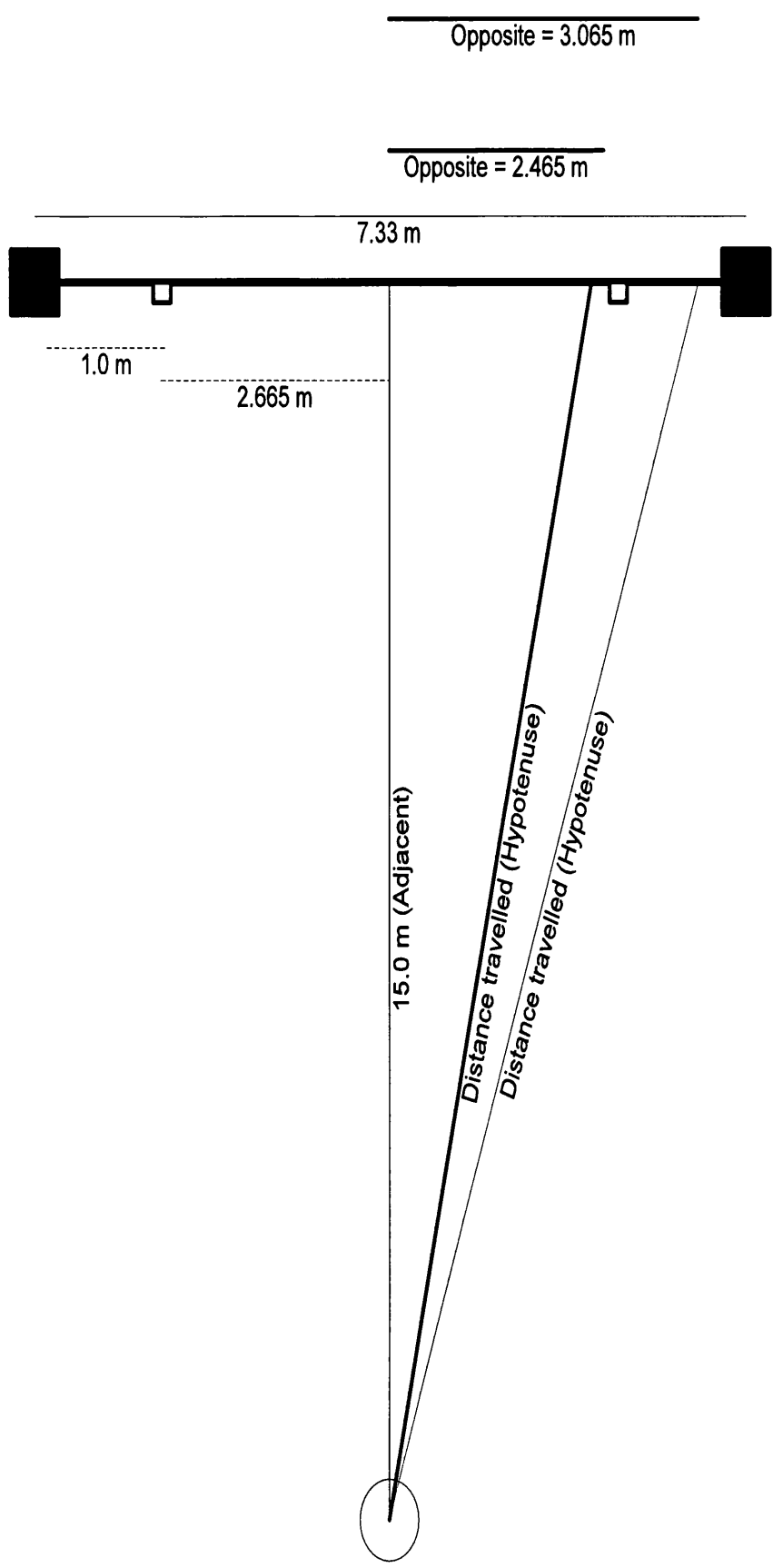


Figure 2.3: Illustrative example of how precision data are used in conjunction with Pythagoras' Law to derive values for the distance travelled by the ball

2.9.2 Determination of ball precision

Precision was determined at the frame corresponding to ball impact on the target (passing and shooting; Figure 2.4), and at the frame where horizontal deviation from the cones was maximal (dribbling; Figure 2.4) by digitisation of video footage (Vicon Motus version 9.2; Vicon Motion Systems, USA). For each image, the two most lateral points of the ball, which according to their manufacturer remains completely spherical when kicked, were digitised (see Figure 2.4) and the midpoint was calculated. For all skills, precision represents the distance of the centre of the ball from the centre of the target. Image deformations were corrected for by modified direct linear transformation using known positions of calibration markers to calculate calibration constants. The regression equations derived for these images were strong ($r^2 > 0.98$).

2.9.3 Determination of success rate

Success in passing and shooting was defined as those skills that were executed within the confines of the action zone and the ball impacted the correct target box or within the goal, respectively. Passing and shooting success represents the percentage of passes or shots that met these criteria. During dribbling, if a cone was touched by the ball or was not completed in the required direction, the cone was considered to be unsuccessfully negotiated. Success in dribbling represents the percentage of cones successfully completed.

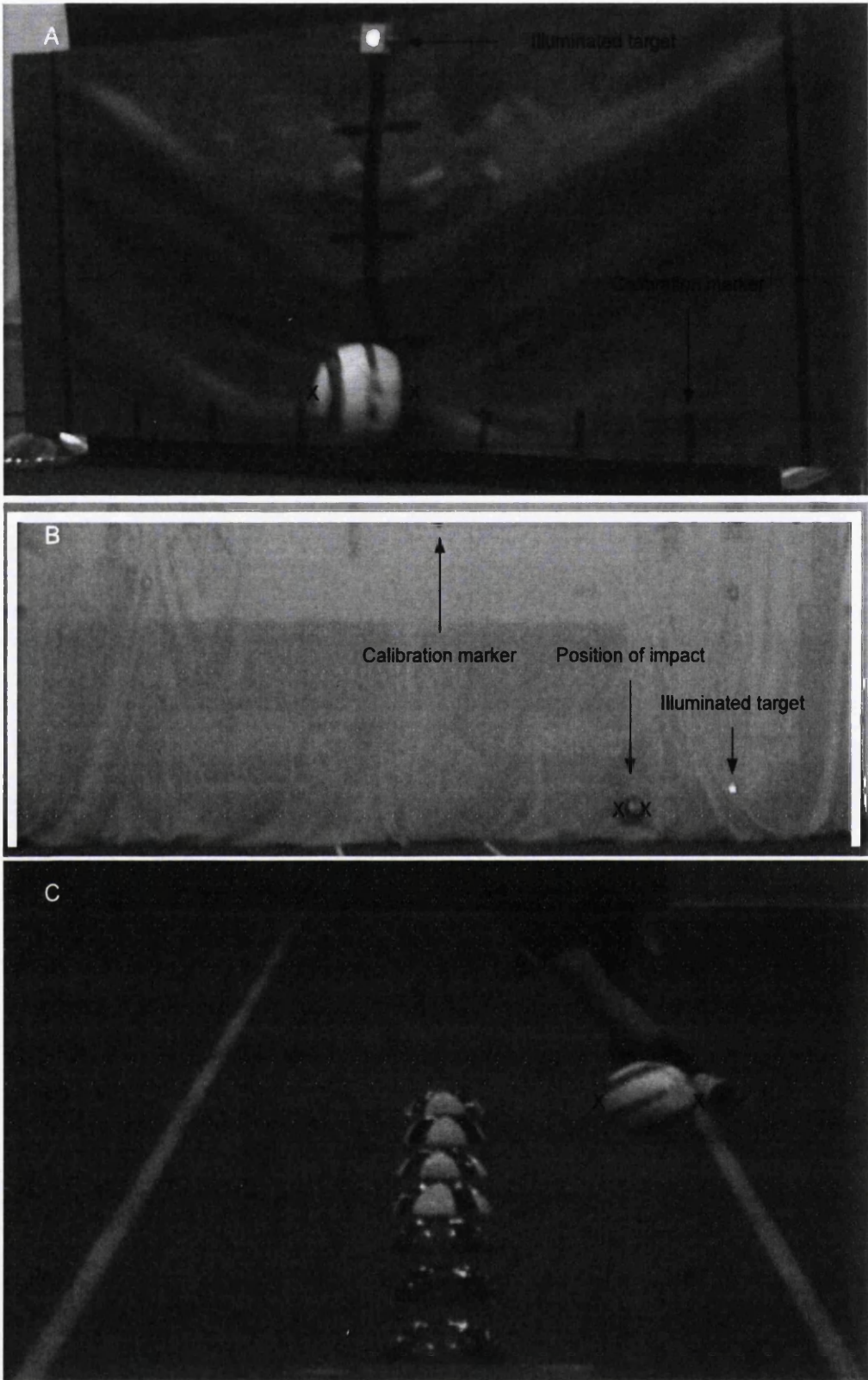


Figure 2.4: Positions of the ball when digitised during passing (A), shooting (B), and dribbling (C) for the determination of precision data. X represents positions of digitisation

2.9.4 Criteria for inclusion of skilled data

To contextualise the outcomes of speed, precision, and success to the skills performed, the criteria for the exclusion of data differed with each skill. For example, a shot that is not on target can never be successful in terms of scoring a goal, whereas a pass that lacks accuracy may still be considered successful if the recipient is able to modify posture and/or field position (within limits) to accommodate for the lack of precision. Consequently, for shooting, speed and precision data represents only attempts that were deemed successful whereas for passing, speed and precision data comprises of attempts that were executed from within the confines of the action zone and where the ball impacted on the 2-m wide target. For dribbling, the ability to keep the ball close to a preferred position while travelling at high speed is desirable as failure to do so provides a defending player with an opportunity to dispossess an opponent; consequently, if a dribble was deemed to contain a cone that was unsuccessfully negotiated, this dribble was excluded from all other analyses. Due to inter-individual variation in the manner in which players commenced and finished their dribbles, all included dribbling analyses represent data collected between the first and last cones (i.e., analysed over an 18 m distance); however, participants were unaware of this and thus were instructed that they were assessed over the full 20 m distance.

2.10 ACTUAL SOCCER MATCH-PLAY

Studies 2 and 5 (chapters 4 and 7) required that soccer matches were played. Each match was 90 min in duration, consisting of two 45-min halves that were separated by a 15-min passive recovery period (half-time). All matches were played in accordance with FA regulations. Specifically, games took place on a floodlit grass pitch measuring 95 x 68 m, used official balls (Total 90 Aerow: size 5; Nike Inc, USA), and were officiated by an FA qualified referee.

The outfield players of the test team ($n=10$) were subject to periodic blood sampling and left the pitch on six occasions during match-play (i.e., once every 15 min). To ensure minimal disruption to the match, players were removed individually and in an order that remained consistent between time-points and between matches (applicable only to study 5). Matches were divided into six 15-min periods (first half: 0-15, 15-30, 30-45 min; second half: 45-60, 60-75, 75-90 min). Two minutes into each of these periods, the first player left the pitch for blood sampling (i.e., after 2, 17, 32, 47, 62 and 77 min of match-play). When the first player returned to the match, the next player left the pitch; this sequence continued until the 10 players had been sampled within each 15-min period. Consecutive blood samples were separated by 1.5 ± 0.1 min.

In order to maintain the standard number of players on the pitch at all times, one utility player (deemed by coaching staff as able to fulfil all positional demands) was used as a substitute. The substitute changed positions as different players left the

pitch for blood sampling. This player was not subject to any analyses and did not play for the first two minutes of every 15-min period of the match.

2.11 BLOOD ANALYSES

Throughout studies 2 to 5 (chapters 4 to 7) blood was sampled using fingertip puncture procedures. Specific procedures of blood analyses used in each study are described in the methods sections contained within chapters 4 to 7. The following section provides a description of the principle and precision of each analysis technique used during the relevant chapters of this thesis.

2.11.1 Determination of blood lactate and glucose concentrations using hand-held analysers

Studies 2 and 5 required that outdoor testing be performed. Consequently, portable and hand-held analysers were used for the determination of blood lactate and glucose concentrations throughout the main trials.

2.11.1.1 Lactate

Approximately 5 μL of whole blood was removed for the determination of blood lactate concentration using a portable automated electrochemical analyser (Lactate-Pro; Arkray, Japan). The measurement is based on the principle that once drawn up into the test strip, lactate in the blood sample reacts with Lactate Oxidase (LOD). A simultaneous conversion of potassium ferricyanide (oxidised form) to potassium

ferrocyanide (reduced form) is proportional to the lactate concentration of the analysed sample (Reaction 2.1). Potassium ferrocyanide is then oxidised to potassium ferricyanide (Reaction 2.2) producing an electrical current that is proportional to the substrate, as follows:



The precision of measurement for blood lactate concentrations had a CV of 5.8% (see Appendix E) and when compared to a laboratory based analyser (YSI 2300D stat plus; YSI Incorporated, USA) values differed by no more than 3.4% (see Appendix E). The device has previously been found to be reliable in simulated outdoor and altitude conditions and has also been validated against an enzymatic photofluorometry reference method (Medbo *et al.*, 2000).

2.11.1.2 Glucose

Approximately 5 μL of whole blood was required for the determination of blood glucose concentration using a portable automated electrochemical analyser (Medisense Optium Xceed Glucose monitor; Abbott Laboratories, USA). Blood glucose concentrations are derived on the basis that glucose is oxidised by the enzyme (Glucose Dehydrogenase, GDH-NAD) catalysed reaction with Nicotinamide Adenine Dinucleotide (NAD^+) cofactor. The reduced form of NAD^+ (NADH) is re-oxidised by reaction with 1,10-phenanthroline quinone (1,10-PQ). The reduced mediator is re-oxidised via electron transfer at the electrode surface with the current being translated into a reading after the application of production

batch-specific calibration information. The interassay CV values for blood glucose concentrations were 3.3% (see Appendix E) and when compared to a laboratory based analyser (YSI 2300D stat plus; YSI Incorporated, USA) values differed by no more than 0.9% (see Appendix E).

2.11.2 Determination of blood lactate and glucose concentrations, pH values, and pCO₂ and pO₂ using the GEM Premier 3000 analyser

The main trials in study 4 were conducted indoors; consequently, a laboratory based analyser was chosen for analysis of blood samples. At each time-point 170 µL of whole blood was analysed immediately (GEM Premier 3000 blood gas analyser, Instrumentation Laboratory, UK). The central component to the analyser is a sensor card which provides a low volume, gas tight chamber in which the blood sample is presented to the sensors. Specific sensors that are capable of analysing pH, pCO₂, pO₂, Na⁺, K⁺, Ca⁺⁺, haematocrit (Hct), Glucose and Lactate, in addition to a reference electrode, are key parts of the chamber, with chemically sensitive membranes permanently attached to the chamber body. When the cartridge is installed, the chamber is maintained at 37 ± 0.3°C in a thermal block, and provides the electrical interface to the sensors. The interassay CV for these assays ranged from 0.2% to 5.0% for blood pH and blood lactate concentration, respectively (see Appendix E)

2.11.2.1 pH sensor

The pH sensor is based on the principle of ion-selective electrodes. That is, an electrical potential can be established across a membrane that is selectively permeable to a specific ion. The pH sensor is a polyvinyl chloride based ion-selective electrode, consisting of an internal Ag/AgCl reference electrode and an internal salt layer. Their potentials are measured against the card reference electrode.

2.11.2.2 Glucose and lactate sensors

The glucose and lactate sensors consist of a platinum electrode poised at a positive potential with respect to the card reference electrode. Glucose or lactate determination is accomplished by enzymatic reaction of glucose or lactate oxidase and the detection of hydrogen peroxide (H_2O_2). The current flow between the platinum and the common (ground) electrodes is proportional to the glucose or lactate concentration.

2.11.2.3 pCO₂ and pO₂ sensors

The pCO₂ sensor is reliant on a pH selective polymer as a gas permeable outer membrane which internally encloses an Ag/AgCl reference electrode and a bicarbonate buffer. The pCO₂ in the sample comes to equilibrium with the internal solution, causing a change in the internal pH. The generated potential versus the pH sensor is correlated with the logarithm of pCO₂ content in the sample.

The oxygen sensor is an amperometric electrode consisting of a small platinum electrode poised at a negative potential with respect to the card reference electrode. The current flow between the platinum and the counter (ground) electrodes is proportional to the oxygen partial pressure.

2.11.3 Calculation of plasma volume changes

Calculated changes in plasma volume (%) were derived from measured haemoglobin (Hb) and Hct data, as described in Dill and Costill (1974).

2.11.3.1 Haemoglobin (Hb)

Concentrations of Hb were determined (in duplicate) from whole blood using an automated 2-wavelength (570 and 880 nm) spectrophotometer (B-Hemoglobin Analyser; Hemocue Ltd, UK) as described by the manufacturer's instructions. A CV of 2.7% (see Appendix E) represented the precision of measurement.

2.11.3.2 Haematocrit (Hct)

Hct was determined using the GEM Premier 3000 analyser (GEM Premier 3000 blood gas analyser, Instrumentation Laboratory, UK) which measured the electrical conductivity of 170 μL of whole blood (σ_{blood}) and relating it to the Hct (in %) and the plasma conductivity (σ_{plasma}) using Equation 2.1. A CV of 5.0% (see Appendix E) represented the precision of measurement.

Equation 2.1: $\sigma_{\text{blood}}/\sigma_{\text{plasma}} = (1 - \text{Hct}/100)/(1 + \text{Hct}/100)$

2.12 HYDRATION ANALYSES

Hydration status was analysed using freezing point depression (Gonotec Cryoscopic Osmometer Osmomat 030; YSI Limited, UK); where the total osmolality of 50 μl of the aqueous solution under investigation was determined by comparative measurements of its freezing point to that of distilled water and calibration solutions as per the manufacturer's recommended guidelines. The interassay CV was 0.5% (see Appendix E).

CHAPTER THREE

STUDY ONE

*The reliability and construct validity of soccer skill tests that measure indices of
passing, shooting and dribbling performances*

3.1 INTRODUCTION

Soccer is a team sport that incorporates the simultaneous execution of technical performances (i.e., skills) throughout high intensity intermittent exercise. Considering that a disproportionate amount of goals are scored in the last 15 min of a match (Reilly, 2003), the maintenance of technical proficiency throughout the full duration of exercise can be considered vital to success in a sport where the main aim is to score more goals than your opponent. Although a number of exercise simulations have been developed to standardise the physiological demands of match-play (e.g., Nevill *et al.*, 1993; Drust *et al.*, 2000; Nicholas *et al.*, 2000; Thatcher and Batterham, 2004; Kingsley *et al.*, 2005), relatively few studies have included the performance of skills throughout exercise; this might be attributable to a lack of reliable soccer skills testing procedures.

Fitts and Posner (1967) suggested that both the speed and precision of motor skills can influence the overall quality of performance. In less technically proficient or fatigued individuals, one of these aspects of skilled performance is sacrificed in a manner that will allow preservation of the other; a phenomenon referred to as the *speed-accuracy trade-off*. For example, Ali *et al.* (2007b) initially reported that shooting performance was maintained after 90 min of exercise; however, when slower shots were excluded from the analysis significant reductions in shooting performances became evident. Nevertheless, a skilled action that is performed at sub-optimal speeds and/or with reduced precision can still be effective providing that the outcome is successful. Consequently, speed, precision and success can

provide independent measurement outcomes when assessing the proficiency of sporting skills.

Reliability has been defined as the reproducibility of values produced from repeated trials performed by the same individuals (Hopkins, 2000). Given that tests which are designed to replicate specific areas of sports performance are commonly used to investigate the influence of nutritional interventions (e.g., Kingsley *et al.*, 2005; Ali *et al.*, 2007a; Currell *et al.*, 2009), it is important to know the reliability associated with specific tests. Furthermore, the reliability of such tests should be determined prior to validity (the extent to which a test measures what it purports to measure) because validity is compromised if consistent values do not result from repeated measurements (Atkinson and Nevill, 1998). Information concerning whether a test can differentiate between individuals perceived to be of different standards, known as construct validity, would also be useful to those involved in interventional research; however, it is rare for authors to provide data on both the reliability and construct validity of proposed testing procedures.

Timed dribbling tasks have been used by previous authors to assess the soccer skill response to a number of interventions (e.g., McGregor *et al.*, 1999; Ostojic and Mazic, 2002). Mirkov *et al.* (2008) provided data on the reliability of ball dribbling speed; yet assessing soccer skill performance by the sole indicator of speed, limits the ecological validity of a test that is to be used to evaluate the technical performances of a skill where possession can be won or lost as a result of a lack of control. Although some would argue that a faster time on such tests would represent a more skilled action, this is not necessarily the case from an applied perspective.

For example, a skilled dribbler is able to keep the ball close to the desired position while travelling at high speed and a lack of ball control will increase the likelihood of losing possession of the ball. Consequently, the ability to quantify the actual ball position in relation to desired position (precision) and the ability to complete the desired task without mistakes (success rate) are additional measurement outcomes that provide further information about the proficiency of this technical action.

A commonly used alternative to timed dribbling tasks are skill tests that rely on criterion-based outcomes; where technical performances are scored in terms of accuracy and penalty points are awarded for errors (e.g., Northcott *et al.*, 1999; Ali *et al.*, 2007a; Currell *et al.*, 2009). Although the reliability of selected criterion-based tests have previously been examined in both male (Ali *et al.*, 2007a) and female soccer players (Ali *et al.*, 2008), the measurement outcomes from these tests are difficult to contextualise; for example, the outcome to passing and shooting accuracy is assessed in seconds and points, respectively. Therefore, these tests provide outcomes that have limited practical application. Information concerning measures of technical proficiency derived from continuous data, such as ball speed, precision (i.e., ball impact represented by the distance from a target) and success of skills, would enable players and coaches alike to directly compare performances between players of different standards and to published literature when players have been subjected to different conditions (e.g., physiological fatigue or different environmental conditions). Additionally, the value of an intervention can be evaluated more effectively if the outcome measure is calculated in ecologically valid units. For example, if a hypothetical intervention is shown to cause an improvement in the precision of passing by 20 cm a coach can interpret this outcome as

meaningful or not. Despite the fact that more sensitive measures of skilled actions have been used in other sports (e.g., Young *et al.*, 2010), the dominance of criterion-based skill tests within this code of football has led to a dearth of literature that quantifies soccer skill responses to modifying factors such as exercise and supplementation protocols.

In summary, the lack of tests that measure soccer skill performance in terms of continuous data (as opposed to discrete data) led to the development of a new soccer skills testing battery that uses video analysis procedures to assess passing, shooting and dribbling skills in a protocol that requires decision making and visual searching in each attempt. The aim of this study was to examine the test-retest reliability of these tests and to determine whether the tests could differentiate between players of different standards (construct validity). The null hypotheses associated with this study, were: (1) there will be no difference in skilled performances between tests undertaken on repeated occasions and (2) there will be no difference in skilled performances according to playing standard.

3.2 METHODS

3.2.1 Participants

Twenty outfield soccer players (age: 19 ± 1 years, height: 1.77 ± 0.01 m, mass: 71.8 ± 2.4 kg) participated in the study after approval from a University ethics committee. Players from a University reserve team (Recreational: $n=10$, age: 21 ± 1 years, height: 1.81 ± 0.02 m, mass: 75.5 ± 2.3 kg), and from a British Championship team (Professional: $n=10$, age: 18 ± 2 years, height: 1.73 ± 0.02 m, mass: 68.0 ± 4.0 kg) were recruited. The players were informed about the potential risks of the study and gave written informed consent for their participation; parental consent was obtained where players were less than 18 years of age. Participants were recruited on the basis that they had no injuries, were non-diabetic, did not smoke, and were regularly participating in match-play with their respective teams.

3.2.2 Study design

This study consisted of two parts: (1) test-retest reliability and (2) construct validity. Test-retest reliability was examined in the 20 players, which is representative of the number of players in a soccer squad and is congruent with the number of participants in studies previously published within this domain (e.g., Mirkov *et al.*, 2008; Currell *et al.*, 2009). Construct validity was then evaluated using two player groups, equal in number and distinguishable by playing standard (Professional players vs. Recreational players). In order to reduce anticipated trial order effects, players attended one familiarisation trial before completing the two main trials (T1

and T2) on separate days. Main trials were separated by no longer than two days. To minimise the effects of circadian variation, T2 commenced within one hour of the start time of T1 and players were asked to refrain from strenuous physical activity and caffeine consumption during the two days before all testing sessions. At the completion of the study, participants gave their verbal confirmation that they had complied with all instructions.

3.2.3 Main trial procedures

After adhering to a standardised diet, players arrived at the testing site where their mass (model 770; Seca Ltd, Birmingham, UK) and stature (Portable Stadiometer; Holtain Ltd, Wales, UK) were measured following the void of both bladder and bowels. A 20-min standardised warm-up (consisting of running, dynamic stretching and ball skills) and 10 practice attempts of the passing, shooting and dribbling tests preceded each main trial. Each main trial took approximately 47 min to complete and required participants to execute a total of 28 passes, 8 shots, and 10 dribbles. Passes and shots were performed in bouts of four attempts, whereas dribbles were performed singularly. At least 30 s of recovery separated each individual kick, and shots were performed before and after seven bouts of passing, which were separated by 5.5 min. Dribbles were performed in the periods between passing bouts.

3.2.4 Skills testing and analyses

Specific procedures for the passing, shooting, and dribbling tests are explained in chapter 2.

3.2.5 Statistical analyses

Statistical analysis was carried out using SPSS software (Version 16.0; SPSS Inc., USA). All results were reported as the mean \pm standard error of the mean and the level of statistical significance was set at $P \leq 0.05$. All data were assessed for normality by the calculation of z scores for skewness and kurtosis data as per previously described methods (Vincent, 1995). Systematic bias in the repeatability between trials was assessed using paired sample t -tests and the magnitude of bias was determined with the mean ratio from ratio limits of agreement (RLOA) analysis, which were derived from log transformed data. Because a range of statistical methods have been used to assess random error in reliability studies, and each method has its own merits, a selection of statistical methods have been completed to determine the repeatability between trials for all outcome measures. Relative reliability was determined using Pearson's correlation coefficients (r) and intraclass correlation coefficients (ICC), which were calculated using the two way random method previously described by Weir (2005). Due to heteroscedastic nature of human performance data and to allow greater comparison with previous and future research, RLOA were also presented. Absolute reliability was determined using coefficient of variance (CV) values, limits of agreement analysis (LOA: Bland and Altman, 1986) and standard error of measurement (SEM) with 95% confidence intervals (95% CI), which were calculated independently of the ICC. Using the SEM data, the minimum differences needed to be considered real (MD) were derived as per the methods outlined by Weir (2005). Independent sample t -tests and mean split analyses were used to determine criterion validity, where analyses were performed by playing standard (Professional players vs. Recreational players).

3.3 RESULTS

3.3.1 Systematic bias between trials

Mean results for T1 and T2 were similar in all measurement outcomes (speed, precision and success) for all skill tests (passing, shooting and dribbling) ($P > 0.111$; Table 1). The mean bias ranged from -8.7% in shooting success to +3% in shooting precision; however, the majority of outcome measures produced absolute mean biases of less than 5% (Table 3.1).

3.3.2 Random error in measurement outcomes

Reliability statistics for average ball speed, precision and success in passing, shooting and dribbling are presented in Tables 3.2 and 3.3. Average ball speed was identified as the most reliable outcome measure during passing and dribbling, with moderate to moderately strong relative reliability (passing, dribbling; being ICC: 0.76, 0.78 and r : 0.76, 0.78) and tight test-retest absolute reliability (passing, dribbling; being SEM: $1.0 \text{ m}\cdot\text{s}^{-1}$, $0.1 \text{ m}\cdot\text{s}^{-1}$; CV: 6.5%, 2.4%; LOA: $-3.2 - 2.2 \text{ m}\cdot\text{s}^{-1}$, $-0.4 - 0.3 \text{ m}\cdot\text{s}^{-1}$ and RLOA: $0.958 \times/\div 1.091$, $0.993 \times/\div 1.039$). Significant relationships existed in the precision of all skills confirming relative reliability in these outcomes (ICC: 0.38 – 0.77; r : 0.50 – 0.77). In terms of precision, absolute reliability was better in dribbling (SEM: 3 cm; CV: 4.6%; LOA: $-7.9 - 7.9 \text{ cm}$; and RLOA: $1.000 \times/\div 1.068$) when compared with passing (SEM: 4 cm; CV: 10.0%; LOA: $-12.9 - 10.4 \text{ cm}$; and RLOA: $0.956 \times/\div 1.147$) and shooting (SEM: 39 cm;

CV: 23.5%; LOA: -96.6 – 118.1 cm; and RLOA: 1.030 \times/\div 1.356). Moderate correlations existed for the success rates in passing, shooting and dribbling, with ICC and r values ranging from 0.38 to 0.44 (Table 3.1). Absolute reliability indices for success rates varied, with SEM ranging from 3% (dribbling) to 13% (shooting), CV values ranging from 2.2% (dribbling) to 14.4% (shooting), and RLOA ranging from 0.996 \times/\div 1.035 (dribbling) to 0.913 \times/\div 1.265 (shooting). MD calculations (Table 3.2) show that the skill tests can identify absolute changes in velocity, precision and success greater than 2.7 $\text{m}\cdot\text{s}^{-1}$, 12 cm and 25% (passing), 4.3 $\text{m}\cdot\text{s}^{-1}$, 107 cm and 37% (shooting), and 0.4 $\text{m}\cdot\text{s}^{-1}$, 8 cm and 8% (dribbling).

3.3.3 Construct validity

Data for average ball speed, precision and success in passing, shooting and dribbling performance outcome measures by playing standard (Professional players and Recreational players) are presented in Table 3.4.

Mean data suggests that passes performed by Professional players were 14% faster ($P=0.040$), 17% more precise ($P=0.016$), and 20% more successful ($P=0.018$) than the Recreational players (Table 3.4). Professional players exhibited a superior level of performance relative to the mean obtained from all participants in 90, 80 and 70% of cases for pass speed, precision, and percentage success, respectively (Table 3.4).

Mean shot speeds were similar between Professional and Recreational players ($P=0.685$; Table 3.4); however, shots taken by Professionals were 37% more accurate than those of the Recreational players ($P=0.048$). Additionally, shots taken

by the Professional players tended to be more successful than those taken by the Recreational players ($P=0.067$; Table 3.4). The majority of Professional players performed better than the mean obtained from all participants (Table 3.4).

Mean dribbling speed did not differ between Professional and Recreational players ($P=0.444$); however, Professional players were 3.4% more successful than their Recreational counterparts ($P=0.010$; Table 3.4). Professional players tended to exhibit more precision than the Recreational players in their dribbling ($P=0.062$); however statistical significance was not achieved. Individual performances of the Professional players were superior to the mean obtained from all participants in 80, 70 and 100% of cases for dribble speed, precision, and percent success, respectively (Table 3.4).

Table 3.1: Systematic bias between trials for the passing, shooting and dribbling tests

Skill	Variable	T1	T2	Mean	t-test (P-value)	RLOA (mean ratio)
Passing	Speed (m·s ⁻¹)	12.8 ± 0.4	12.3 ± 0.4	12.4 ± 0.5	0.111	0.958
	Precision (cm)	35 ± 1	34 ± 2	35 ± 1	0.374	0.956
	Success (%)	56 ± 3	58 ± 3	57 ± 2	0.661	1.017
Shooting	Speed (m·s ⁻¹)	16.8 ± 0.5	16.6 ± 0.4	16.7 ± 0.3	0.682	0.990
	Precision (cm)	112 ± 7	123 ± 14	117 ± 9	0.390	1.030
	Success (%)	70 ± 3	65 ± 4	68 ± 3	0.248	0.913
Dribbling	Speed (m·s ⁻¹)	4.2 ± 0.1	4.1 ± 0.1	4.1 ± 0.1	0.483	0.993
	Precision (cm)	51 ± 1	51 ± 1	51 ± 1	0.987	1.000
	Success (%)	97 ± 1	97 ± 1	97 ± 1	0.654	0.996

P-value determined from test-retest data using paired sample t-test for all measurement outcomes (n=20).

Table 3.2: Relative reliability statistics for the passing, shooting and dribbling tests

Skill	Variable	ICC	r
Passing	Speed (m·s ⁻¹)	0.76**	0.76**
	Precision (cm)	0.51**	0.53*
	Success (%)	0.43*	0.44 ⁺
Shooting	Speed (m·s ⁻¹)	0.32 ⁺	0.33
	Precision (cm)	0.38*	0.50*
	Success (%)	0.37*	0.38
Dribbling	Speed (m·s ⁻¹)	0.78**	0.78**
	Precision (cm)	0.77**	0.77**
	Success (%)	0.40*	0.41 ⁺

* Significant correlation between trials 1 and 2 ($P \leq 0.05$)

** Significant correlation between trials 1 and 2 ($P \leq 0.01$)

⁺ Trend for a significant correlation between trials 1 and 2 ($0.05 < P \leq 0.075$)

Table 3.3: Absolute reliability statistics for the passing, shooting and dribbling tests

Skill	Variable	Mean	CV (%)	SEM	95% CI	LOA (mean bias \pm 2SD)	RLOA (mean bias \times/\div 2SD)	MD
Passing	Speed (m·s ⁻¹)	12.4 \pm 0.5	6.5	\pm 1.0	\pm 1.9	-3.2 – 2.2	0.958 \times/\div 1.091	\pm 2.7
	Precision (cm)	35 \pm 1	10.0	\pm 4	\pm 8	-12.9 – 10.4	0.956 \times/\div 1.147	\pm 12
	Success (%)	57 \pm 2	11.7	\pm 9	\pm 17	-23.3 – 25.8	1.017 \times/\div 1.191	\pm 25
Shooting	Speed (m·s ⁻¹)	16.7 \pm 0.3	6.9	\pm 1.5	\pm 3.0	-4.5 – 4.1	0.990 \times/\div 1.107	\pm 4.3
	Precision (cm)	117 \pm 9	23.5	\pm 39	\pm 76	-96.6 – 118.1	1.030 \times/\div 1.356	\pm 107
	Success (%)	68 \pm 3	14.4	\pm 13	\pm 25	-41.8 – 31.8	0.913 \times/\div 1.265	\pm 37
Dribbling	Speed (m·s ⁻¹)	4.1 \pm 0.1	2.4	\pm 0.1	\pm 0.3	-0.4 – 0.3	0.993 \times/\div 1.039	\pm 0.4
	Precision (cm)	51 \pm 1	4.6	\pm 3	\pm 6	-7.9 – 7.9	1.000 \times/\div 1.068	\pm 8
	Success (%)	97 \pm 1	2.2	\pm 3	\pm 9	-8.1 – 7.3	0.996 \times/\div 1.035	\pm 8

Table 3.4: Criterion validity data for the passing, shooting and dribbling tests

Skill	Variable	Group	Mean	Group %	
				Below mean	Above mean
Passing	Speed (m·s ⁻¹)	Professional	13.4 ± 0.4*	10	90
		Recreational	11.7 ± 0.6	60	40
	Precision (cm)	Professional	32 ± 1*	80	20
		Recreational	37 ± 2	30	70
		Professional	62 ± 2*	30	70
		Recreational	52 ± 3	60	40
Shooting	Speed (m·s ⁻¹)	Professional	16.8 ± 0.3	30	70
		Recreational	16.6 ± 0.6	60	40
	Precision (cm)	Professional	99 ± 3*	90	10
		Recreational	134 ± 17	40	60
		Professional	73 ± 4*	30	70
		Recreational	62 ± 4	60	40
Dribbling	Speed (m·s ⁻¹)	Professional	4.2 ± 0.1	20	80
		Recreational	4.1 ± 0.1	50	50
	Precision (cm)	Professional	48 ± 1*	70	30
		Recreational	53 ± 2	40	60
		Professional	99 ± 1*	0	100
		Recreational	95 ± 1	60	40

* Significantly different from the Recreational group ($P \leq 0.05$)

+ Trend for a significant difference from the Recreational group ($0.05 < P \leq 0.075$)

3.4 DISCUSSION

The purpose of this study was to examine the reliability of a new battery of soccer skill tests that incorporate the assessment of the speed, precision and success of passing, shooting and dribbling skills and also to determine whether these tests could differentiate between players of different standards. Small non-significant biases existed for the test-retest data from all measurement outcomes. Moderate to moderately strong relative reliability was confirmed in at least one outcome measure for all skill tests. The absolute reliability statistics were similar or tighter than those produced by previous soccer skill tests. Consistent with perceptions regarding technical proficiency, Professional players performed better in the skills tests than Recreational players, which supports the construct validity of these tests.

As recommended by Atkinson and Nevill (1998), a range of reliability statistics have been presented to enable wider comparison to past, current and future literature. The magnitude of the test-retest mean bias was relatively small in all cases and less than 5% in most measurement outcomes (Table 3.1). Systematic biases were non-significant in all measurement outcomes (speed, precision and success) for passing, shooting and dribbling. These findings demonstrate that these measurement outcomes were not systematically influenced by factors such as learning or fatigue between trials.

Relative reliability statistics (ICC and r) were moderate to moderately strong and absolute reliability, when expressed in dimensionless terms (CV and RLOA), were relatively tight in all outcomes (speed, precision and success) obtained from passing

and dribbling (Tables 3.2 and 3.3, respectively). However, similar to previous research (Ali *et al.*, 2007a), the measurement outcomes to shooting performances were found to demonstrate more variation than the corresponding measurement outcomes to other skills (Tables 3.2 and 3.3).

Despite difficulties in making like-for-like comparison between skill tests that produce different measurement outcomes, a degree of comparison is possible when reliability has been reported in dimensionless units. In this respect, the shooting test used in this study was more reproducible than the Loughborough Soccer Shooting Test (LSST) reported by Ali *et al.* (2007a), where relative reliability for shooting success and precision (in comparison with ICC and r values for points scored) and absolute reliability (in comparison with CV and RLOA for points scored) were more reproducible for the current test. Interestingly, similar test-retest reliability data were reported for the shooting speed in both tests.

Although the variation in shot precision might appear to be relatively high in comparison to generally accepted standards (e.g., Nevill and Atkinson, 1997), values for precision and success in shooting ($1.030 \times \div 1.356$ and $0.913 \times \div 1.265$, respectively) were similar to the Astrand rhyming test (Nevill and Atkinson, 1997) and better than points scored in the LSST ($1.06 \times \div 4.29$; Ali *et al.*, 2007a). Tests of shooting proficiency that use moving balls as opposed to stationary balls introduce more variation in performance. In addition, the unpredictability of target location, introduced by the random lighting system in the current study, required the players to perform visual searching and adjustment to their response provides further sources of variation. Regardless of the possible influence that these two sources of

variation could have had on the test-retest reliability, these components better replicate the shooting skills performed during match-play over and above tests that require kicks to be aimed towards targets that determine the number of points scored. Interestingly, the shooting success values observed in this study reflected those of the senior Championship team from which the Professional players used in this study were sampled from, where 62% of 471 shots were on target or resulted in goals during 20 consecutive home games (see Appendix F4); thus enhancing the ecological validity of the shooting test.

Reproducibility of the Loughborough Soccer Passing Test (LSPT) has previously been reported in males (Ali *et al.*, 2007a) and females (Ali *et al.*, 2008). Although the outcomes from the LSPT (time taken, time penalties for incorrect actions and total time) are not easily aligned to the outcome measures from the current test (i.e., speed, precision and success), the relative reliability of these outcomes appear reasonably comparable. Comparing the precision of passing in the current test with the total time from the LSPT (representing a global marker of precision) demonstrated that the absolute reliability (CV and RLOA) was better in the current protocol. For example, corresponding CV and RLOA values for precision of passing were 10.0% and $0.956 \times/\div 1.147$ (Table 3.3) in the current protocol; comparable values for the LSPT were reported as 14.4% and $0.92 \times/\div 1.32$ (males; Ali *et al.*, 2007a), and 17.0% and $0.96 \times/\div 1.42$ (females; Ali *et al.*, 2008).

Soccer skill proficiency has previously been assessed using timed dribbling tasks (Abt *et al.*, 1998; McGregor *et al.*, 1999; Ostojic and Mazic, 2002; Currell *et al.*, 2009). Currell *et al.* (2009) have recently reported a dribbling task with a CV of

2.2% in the speed of dribbling. Although reliability statistics for the success and precision of dribbling were not presented by these authors, this value is similar to the CV for the speed of dribbling reported in the current study (2.4%; Table 3.3). McGregor *et al.* (1999) used a timed-dribbling task to examine the effect of fluid abstinence on soccer skill and found that a 5% decline in performance resulted from the completion of an intermittent exercise simulation in a fasted and fluid-restricted group. The decline in skilled performance that occurred in the no-fluid trial was attributed to mechanisms of fatigue associated with dehydration (e.g., Bangsbo *et al.*, 2006). Unfortunately, no data were presented to evaluate the quality of dribbling (e.g., information concerning whether or not all dribbles performed were free of errors was not included). Also, hypohydration has been associated with a decline in sprint performance in the latter stages, and on completion, of intermittent exercise (Baker *et al.*, 2007; Ali *et al.*, 2010); therefore, it is possible that this change in dribbling speed actually reflected a decrease in running speed rather than a change in skill performance. From an applied perspective, information regarding success rates and precision might be beneficial because dribbling possession can be lost due to a lack of ball control. In the present study, dribbling success was found to vary between players of different playing standards who commenced the test in a physiological state similar to that recommended to team sports players.

The current study also provides measures of relative reliability and absolute reliability for the average speed, precision and success of dribbling, which could be used to inform future intervention studies. MD calculations suggest that these procedures can detect interventions that cause changes in the speed, precision and success of passing ($2.7 \text{ m}\cdot\text{s}^{-1}$, 12 cm and 25%), shooting ($4.3 \text{ m}\cdot\text{s}^{-1}$, 107 cm and

37%) and dribbling ($0.4 \text{ m}\cdot\text{s}^{-1}$, 8 cm and 8%), respectively. Therefore, studies that assess soccer skills should consider using skill tests that evaluate speed, precision and success to express the overall quality of skilled performances.

It has been suggested that less skilled players will modify either the speed or precision of motor skills in a manner that will allow the preservation of the other; a phenomenon referred to as the *speed-accuracy trade-off* (Fitts and Posner, 1967). Professional players in this study performed passes that were 14% faster ($P=0.040$), 17% more precise ($P=0.016$), and 20% more successful ($P=0.018$) than their Recreational counterparts (Table 3.4). Shots taken by Professional players were 37% more accurate ($P=0.048$) than shots performed by players of a lower playing standard (Table 3.4). Dribbling performances were 3% more successful in the Professional players ($P=0.010$; Table 3.4). Furthermore, examining the distribution of the players' performances about the mean of the 20 players involved in the study enabled the classification of technical proficiency relative to the performance of the group as a whole (all participants). As expected, the technical superiority of the Professional players was observed in the majority of measurement outcomes. Therefore, the skill tests (passing, shooting and dribbling) that are described in this study were able to distinguish between soccer players who participate at different playing standards (Recreational players vs. Professional players) in at least one of the measurement outcomes (speed, precision or success).

As far as the authors are aware, this is the first soccer skill testing battery that provides quantitative data of a continuous nature (as opposed to discrete data obtained from criterion-based techniques) that describes the speed, precision and

success rate of technical performances, which are executed under conditions requiring visual searching and decision making. Nevertheless, some comparison is possible between the values produced in this study with previous literature. For example, the shot speeds recorded in the present study were slightly lower than those observed previously in male soccer players (Ali *et al.*, 2007a). Part of the reason for these differences is explained by differences in the technology used to measure this outcome. Ali *et al.* (2007a) used a speed gun to measure shot speed, which measures ball speed at a particular point in flight, whereas the current study used video analysis and defines the average ball speed throughout the whole flight. Additionally, it is possible that these differences might partly reflect variations in the target size between the two studies which could have impacted on the *speed-accuracy trade-off*.

Although it has been suggested that passing accuracy may be able to differentiate between passing performances in players of different standards (Ali *et al.*, 2007a), quantitative data to support this statement has previously been unavailable. These findings clearly demonstrate that differences between Professional and Recreational players in indices of passing performance equal approximately 20% (Table 3.4). It is therefore plausible that variations in the speed, precision and success of passes observed between Professional and Recreational players in the current study might have accounted for the previously observed differences in passing performances between elite and non-elite male soccer players (Ali *et al.*, 2007a); however, due to the lack of measurement of these variables in criterion-based tests, this assumption is somewhat speculative.

Only two studies to date that have provided data about the accuracy of kicking assessed by means other than criterion-based measures. Finnoff *et al.* (2002) reported a median deviation of approximately 90 cm over a 6.1 m distance, whereas the use of methods more comparable to those used in this study yielded deviations of 80-90 cm when elite Australian football players kicked a ball towards a target that was 16 m away (Young *et al.*, 2010). Although the latter data reflects the shooting accuracy of the Professional players in the current study, differences in the code of the football and the omission of match-specific cognitive processes (such as decision making and visual searching) while kicking, limit the like-for-like comparison of precision data. Despite these differences, the video digitisation procedures used in the current study and in that of Young *et al.* (2010) provide a viable alternative to the criterion-based outcome measures that have previously dominated soccer skill research. Therefore, future research should seek to incorporate these methods of analysis when quantifying the skilled response to modifying factors, such as nutritional interventions, in team sports players.

According to Williams and Reilly (2000), proficient skill performance is affected by cognitive factors such as decision making and game intelligence. When performing passing and shooting in this study, the randomised lighting system used for target identification incorporated perceptual abilities, such as decision making and visual searching. Although the direct involvement of these cognitive aspects of performance on the skills performed were unable to be determined, the development of a sensitive measure of soccer skill performance that can differentiate between playing standard and that incorporates perceptual skills, thus representing the demands of competitive match-play, increases the ecological validity of the tests.

It has been proposed that a minimum number of 40 participants are required in order to determine the reliability of a test (Atkinson and Nevill, 1998). This recommendation for a large sample size ($n > 40$) was based on the determination of limits of agreement, where sample data is extrapolated to a given population; however, given the difficulties in achieving participation rates of homogenous groups, this sample size is not always possible. Consequently, it has been common for the reliability of soccer skills tests to be determined with fewer individuals (e.g., Ali *et al.*, 2008; Mirkov *et al.*, 2008; Currell *et al.*, 2009). The present study incorporated 20 players, which is representative of the number of players in most soccer squads and also congruent with previous reliability research in this field (e.g., Mirkov *et al.*, 2008). Nevertheless, the limits of agreement presented in this study should be viewed with some caution. Interestingly, when additional reliability analyses (see Appendix F5) were performed independently for Professional players and Recreational players (i.e., $n=10$ per group as per the criterion validity analyses), irrespective of the statistics used test-retest reliability was similar to that presented despite the reduction in subject number.

In summary, the protocols used in this study provide outcomes derived from continuous data (as opposed to discrete data) concerning the measurement of the speed, precision and success of soccer passing, shooting and dribbling skills. Test-retest reliability is reported in familiarised male soccer players. Furthermore, the tests can distinguish between players of different standards. Consequently, these tests have potential application for researchers who wish to examine the effects of factors such as supplementation protocols, strength and conditioning regimes, and/or other interventions aimed at altering performance in soccer players.

CHAPTER FOUR

STUDY TWO

A soccer match simulation that incorporates technical actions and replicates the metabolic demands of match-play.

4.1 INTRODUCTION

Soccer is a high intensity intermittent sport which is normally played over ninety minutes, split into two forty-five minute halves that are separated by a 15 min half-time period. As one of the world's most popular sports, the impact of findings from soccer research are relatively wide-reaching; consequently several exercise protocols have been developed to replicate the demands of competition (e.g., Nevill *et al.*, 1993; Drust *et al.*, 2000; Nicholas *et al.*, 2000; Kingsley *et al.*, 2005). The primary purpose of these simulations is to control the movement requirements and thereby standardise the physiological demands. In doing so, the variation in responses that usually exists between matches is limited and the effects of exercise become more repeatable. The most obvious benefit of simulation protocols is that they allow for more prominent effects to be identified in sometimes subtle physiological changes that result from supplementation protocols, strength and conditioning regimes, and/or other performance altering interventions.

Soccer is primarily aerobic in nature (Bangsbo, 1994a); however, performance is heavily influenced by anaerobic actions such as those involved in the execution of skills. Notational analysis has evaluated the number of different soccer skills undertaken throughout match-play with the most frequently occurring actions being passing and dribbling (Reilly and Holmes, 1983; Luhtanen, 1994; Rampinini *et al.*, 2009a). As the aim of soccer is to score more goals than the opposition, shooting is a crucial skill (Stone and Oliver, 2009). However, the inclusion of ball skills throughout exercise protocols that aim to replicate the demands of match-play is rare; this is somewhat surprising because proficiency in ball skills is likely to

determine success because longer passing sequences have been shown to produce more goals in successful teams (Hughes and Franks, 2005) and technical aspects of game-play appear more important than the performance of high intensity physical activity in determining success (Di Salvo *et al.*, 2007).

Several motorised treadmill protocols have been used to simulate soccer (e.g., Drust *et al.*, 2000; Thatcher and Batterham, 2004); however, the unidirectional nature of movement performed on treadmills and the inability to induce maximal running speeds limit the validity of these protocols. A commonly used free-running intermittent exercise simulation protocol is the Loughborough Intermittent Shuttle Test (LIST; Nicholas *et al.*, 2000). The LIST has been extensively used to examine the effects of various ergogenic aids on exercise performance (Nicholas *et al.*, 1995; Morris *et al.*, 2003; Erith *et al.*, 2006). The original version of the LIST included 75 min of intermittent activity and a shuttle run to exhaustion. However, the omission of game-specific skills, some of which have been found to have energy consuming consequences (Reilly and Ball, 1984) and have the potential to cause additional physiological demand (e.g., muscle damage from high speed eccentric activity during kicking), reduces the ecological validity of the LIST.

Relatively few protocols exist that have incorporated the performance of soccer skills throughout exercise (e.g., Northcott *et al.*, 1999; Currell *et al.*, 2009; Williams *et al.*, 2010) as opposed to those that have included skilled actions before and after exercise (e.g., McGregor *et al.*, 1999; Ostojic and Mazic, 2002; Lyons *et al.*, 2006b; Ali *et al.*, 2007b). Furthermore, no study to date has examined the validity of such protocols by comparing the demands of simulated and actual soccer match-play.

This is surprising considering that valid comparisons require the same population to be examined under both conditions (Drust *et al.*, 2007). Therefore, the aim of this study was to use a single subject population to compare the physiological, movement and skilled demands of a new exercise protocol named the soccer match simulation which required the performance of passing, shooting, and dribbling skills throughout to the demands of actual match-play. The null hypothesis associated with this study was that there will be no differences in any indices of physiological, metabolic and skilled responses between the two modes of exercise performed.

4.2 METHODS

4.2.1 Participants

Ten soccer players (age: 15 ± 1 years, height: 1.74 ± 0.01 m, mass: 64.3 ± 1.2 kg, estimated $\dot{V}O_{2\max}$: 55.8 ± 0.9 ml·kg⁻¹·min⁻¹) from a British Championship team volunteered to participate in the study. Following approval by a University ethics committee, all players participated in both soccer match simulation (SMS) and actual match-play (match) trials. The potential risks of the study were explained and written informed consent was obtained from the players (and parents/guardians if players < 18 years) prior to participation. Players were recruited on the basis that they had no injuries, were non-diabetic, did not smoke, and had regularly participated in training with a soccer team of at least centre of excellence standard for twelve months prior to the study starting.

4.2.2 Study design

All players attended three preliminary visits: The first two sessions incorporated familiarisation of the specific main trial procedures and the remaining visit served to estimate maximal aerobic capacity via the multistage fitness test (MSFT; Ramsbottom *et al.*, 1988) in order to calculate the running speeds used in the SMS. The match and SMS trials were completed within 4 ± 1 days of each other and all players were asked to refrain from strenuous physical activity and caffeine consumption in the two days preceding all testing sessions. Additionally, players recorded all food consumed in the two days before each main trial. Food records

were subsequently analysed using commercially available software (CompEat version 5.8.0; Nutrition Systems, UK). All players gave verbal confirmation that they had complied with these instructions on completion of the study.

4.2.3 Main trial procedures

On arrival at the laboratory the players emptied their bowels and provided a mid-flow urine sample. Urine osmolality was subsequently measured by freezing point depression (Gonotec Cryoscopic Osmometer Osmomat 030; YSI Limited, UK). A standardised 1470 kJ meal (Energy content: 62% carbohydrates, 25% fats, 13% proteins) and 500 ml of a fluid-electrolyte beverage were provided before the participant's mass (model 770; Seca Ltd, Birmingham, UK) and stature (Portable Stadiometer; Holtain Ltd, Wales, UK) were measured. Players then remained in a rested state for approximately 120 min before commencing a standardised warm-up (consisting of running, dynamic stretching and ball skills) that preceded exercise. Main trial procedures are illustrated in Figure 4.1.

4.2.4 Soccer match simulation (SMS)

The SMS was performed on a synthetic running track in an indoor training facility with an air temperature of $16.8 \pm 0.4^{\circ}\text{C}$, an ambient pressure of 764 ± 1 mmHg and a humidity of $66 \pm 3\%$. Specific main trial procedures for the SMS are explained in detail in chapter 2; however, the outcomes for the skill tests were not determined for this study.

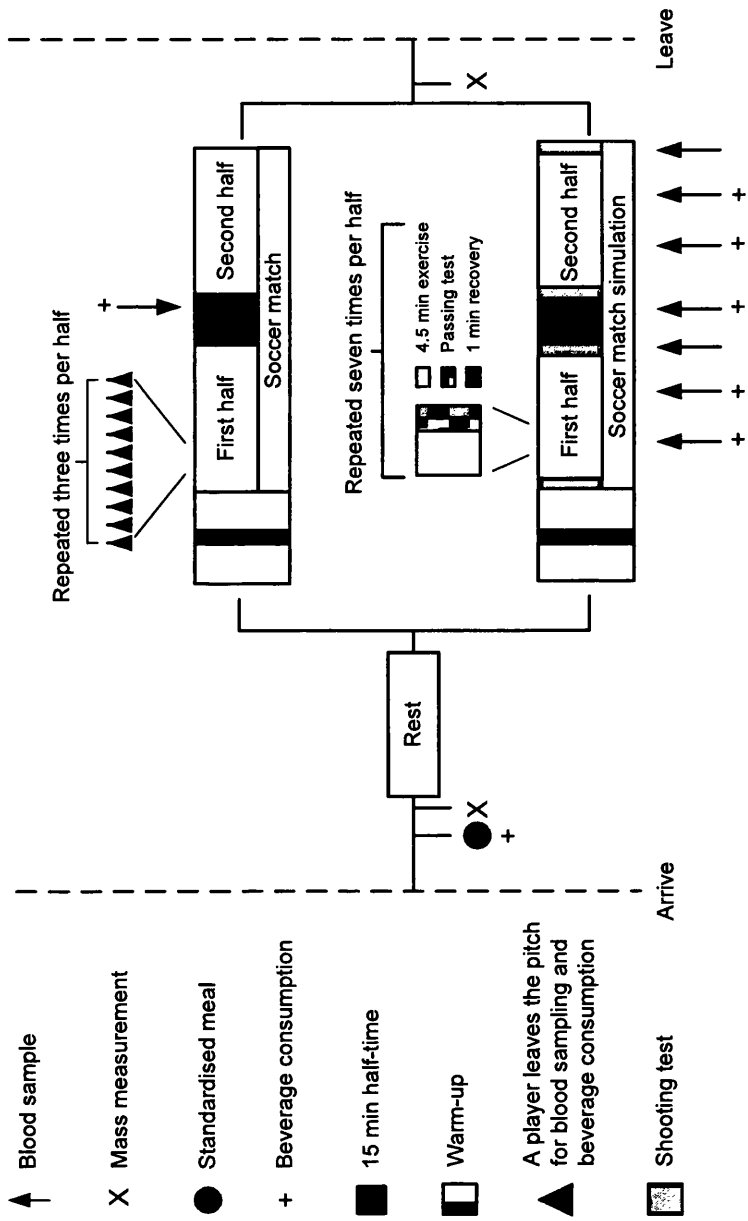


Figure 4.1: Main trial procedures for the match and SMS

4.2.5 Match

The same players who completed the SMS (termed the test team) played a game against a local rival team of similar playing standard (i.e., all previous results between the teams differed by only one goal). Procedures for this protocol are explained in chapter 2 and the match, which was an additional fixture added to both teams competitive calendar for the purpose of this study, took place in an environment that was familiar to all players involved (i.e., the venue used was shared by both teams on home match-days) and approximately 100 spectators attended. Environmental conditions during match-play were 12°C (air temperature), 749 mmHg (barometric pressure) and 80% (relative humidity).

4.2.6 Match analysis

Notational analysis data from the test team was collected using three cameras (DCR-HC96E; Sony Ltd, UK); two cameras were positioned such that the whole pitch was in view at all times and the third camera that tracked on-the-ball activity was positioned in an elevated viewpoint overlooking the half-way line. Match footage was analysed using specialist software (SportsCode; Sportstecinternational.com) which has been shown to be a reliable alternative to more sophisticated player tracking systems (Davies *et al.*, 2008). Player movements were classified according to predefined operational definitions (Davies *et al.*, 2008), with movements being categorised as one of five movement types (i.e., walking, jogging, striding, sprinting/dribbling or backwards jogging), which were exclusive to all others. Movement demands are expressed as the percentage of total exercise time that each

modality represents whereas skilled demands reflect the total number of on-the-ball actions performed throughout match-play. In addition, on-the-ball activities were determined, as previously described, during four competitive league matches played by the test team at the home venue (control games). These analyses were performed in order to compare the technical requirements of the experimental match with normal league matches using a within-participant design. All analyses were performed by a coder who had extensive experience using the software with a team competing in the British Championship. Intra-observer reliability was examined by analysing the physical and skilled demands of one player throughout the full duration of the match on two separate occasions (separated by no longer than 7 days). The variation between these data was within the 10% limit recommended by Reed and Hughes (2006); specifically, CV outcomes on these two occasions were 0% (total count of on-the-ball skills), 1.3% (walking), 0.2% (jogging), 9.8% (stride), 3.0% (sprint/dribble) and 5.2% (backwards jogging).

4.2.7 Blood sampling

Blood samples were taken throughout exercise (SMS: 15, 30, 45, 60, 75, 90 min; match: 0-15, 15-30, 30-45, 45-60, 60-75, 75-90 min) and at half-time. Whole blood samples were analysed using portable lactate (Lactate-Pro; Arkray, Japan) and glucose (Medisense Optium Xceed Glucose monitor; Abbott Laboratories, USA) analysers which were calibrated in accordance with the manufacturer's guidelines before all trials.

4.2.8 Physiological measurements

Heart rate (HR) was continuously recorded throughout each trial using short-range telemetry (Polar S610; Polar, Finland). Body mass (BM) losses were calculated as urine corrected differences in mass between pre and post-exercise measurements.

4.2.9 Fluid intake

An initial bolus of fluid (500 ml) was consumed with the standardised meal, and additional fluid was consumed during the trials at a rate of $14 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$ BM. Equal volumes were consumed 10 min prior to commencing each half of exercise and once every 15 min throughout exercise. In both exercise protocols players consumed a carbohydrate-free electrolyte beverage which was flavoured with a commercially available fruit cordial (Carbohydrate content $< 0.1 \text{ g} \cdot \text{L}^{-1}$) and contained $23 \text{ mmol} \cdot \text{L}^{-1}$ sodium and $14 \text{ mmol} \cdot \text{L}^{-1}$ chloride. In the month before the familiarisation sessions began players ingested water at a rate of $14 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$ BM during training sessions in order to promote gastric tolerance to this rate of fluid ingestion.

4.2.10 Statistical analyses

Statistical analysis was carried out using SPSS software (Version 16.0; SPSS Inc., USA). All data were reported as the mean \pm standard error of the mean and the level of statistical significance was set at $P \leq 0.05$. All data were assessed for normality by the calculation of *z* scores for skewness and kurtosis data as per previously described methods (Vincent, 1995). For variables with single time-points, limits of agreement

(LOA) ranges were calculated (Bland and Altman, 1986) to describe the magnitude of bias, inter-trial differences were evaluated using paired samples t-tests and inter-trial coefficient of variance (CV) were determined to assess random error. Two way repeated measures analyses of variance (ANOVA; within-participants factors: time of sample x trial) were used where data contained multiple time-points during main trials. Mauchly's test was consulted and Greenhouse–Geisser correction was applied if the assumption of sphericity was violated. If a significant *P*-value was identified for the interaction effect (trial x time), trial was deemed to have influenced the response and simple main effect analyses were performed. Significant main effects of time (time of sample) were further investigated using multiple pairwise comparisons with Bonferroni confidence interval adjustment.

4.3 RESULTS

Anthropometric characteristics did not differ between trials ($P>0.05$) and the players arrived at the testing sessions in a similarly hydrated state on both trials; being, $568 \pm 7 \text{ mOsmol} \cdot \text{kg H}_2\text{O}^{-1}$. The calculated daily diet was similar between trials; consisting of $9.0 \pm 1.0 \text{ MJ} \cdot \text{d}^{-1}$, of which $54 \pm 2\%$, $28 \pm 2\%$ and $17 \pm 1\%$ of energy intake was obtained from carbohydrates, fats, and proteins, respectively.

4.3.1 Demands of exercise

Tables 4.1 and 4.2 present the movement and technical demands of the SMS compared to the match and previously published values. The proportion of time that participants spent undertaking low intensity activities (walking), moderate intensity activities (jogging and striding) and high intensity activities (sprinting and dribbling) were similar during the SMS and match trials, being 38% and $37 \pm 1\%$ ($P=0.06$), 57 and $58 \pm 1\%$ ($P=0.29$) and 5% and $5 \pm 0\%$ ($P=0.92$) for SMS and match respectively. The number of technical actions performed during the match were similar to those recorded in the control games (Table 4.2), where the between-match CV for the number of on-the-ball activities performed during the control matches was 8.0% . Although these values are representative of data collected during match-play in professional players (Table 4.2), the number of on-the-ball activities during match (52 ± 6) was less than SMS (93). Sprint velocities reduced throughout the SMS trial with sprints in the last 15 min being slower than the first 15 min (75-90 min, 0-15 min: $5.74 \pm 0.07 \text{ m} \cdot \text{s}^{-1}$, $5.94 \pm 0.09 \text{ m} \cdot \text{s}^{-1}$; time effect: $F_{(5, 45)} = 3.733$, $P=0.007$).

Table 4.1: The percentage of time spent in each movement modality throughout 90 min of simulated (SMS) and actual (match) match-play.

Activity	SMS	Match	LOA Range
Walk (% time)	38	37 ± 1	-2.1 – 4.2
Sprint (% time)	5	5 ± 1	-2.4 – 2.4
Jog (% time)	49	47 ± 1	-4.5 – 7.9
Stride (% time)	8	11 ± 1	-5.0 – -0.7

Table 4.2: Distribution of technical actions throughout 90 min of play in the match organised for the purpose of this study (match), control matches, simulation (SMS) and published data for Italian Serie A players (Rampinini *et al.*, 2009a) and for English Premier League players (Bloomfield *et al.*, 2007).

Technical action	Total amount				
	Match	Control matches	SMS	Rampinini <i>et al.</i> (2009a)	Bloomfield <i>et al.</i> (2007)
Ball involvements	52 ± 6	46 ± 5	93	35 - 45	111 ± 77
Passes	34 ± 4	24 ± 4	56	23 - 32	n/a
Clearances	2 ± 1	3 ± 1	n/a	n/a	n/a
Interceptions	6 ± 1	5 ± 1	n/a	n/a	n/a
Blocks	1 ± 0	1 ± 1	n/a	n/a	n/a
Crosses	1 ± 0	1 ± 0	n/a	n/a	n/a
Shots	1 ± 0	1 ± 0	16	1 - 2	< 5
Dribbles	n/a	n/a	19	n/a	18 ± 18

Data from match, control matches and Bloomfield *et al.* (2007) matches are mean ± SD. Data from Rampinini *et al.* (2009a) reference are range. Non-significant differences between match and control match data ($P > 0.05$). n/a signifies that values are not available.

4.3.2 Physiological responses

Mean HR in the SMS and the match were 158 ± 4 beats·min⁻¹ and 160 ± 3 beats·min⁻¹ ($P=0.587$), which represented $77 \pm 2\%$ and $78 \pm 2\%$ of maximal values ($P=0.587$), respectively. Peak HR data were also similar between trials (SMS, match: 197 ± 3 beats·min⁻¹, 197 ± 4 beats·min⁻¹, $P=0.935$), representing $96 \pm 1\%$ and $96 \pm 2\%$ ($P=0.935$) of maximal values for the SMS and match respectively. The average 5 s HR response for all players throughout both trials is illustrated in Figure 4.2. Lower and upper LOA ranges (with CV data) for mean and peak HR between trials were $-19.4 - 15.4$ beats·min⁻¹ (2.6%) and $-14.3 - 14.7$ beats·min⁻¹ (1.6%), respectively.

Blood lactate concentrations peaked at 15 min of exercise and decreased from this sample onwards (time effect: $F_{(6, 54)} = 3.208$, $P=0.009$) and the pattern of response was similar between trials (time x trial interaction effect: $F_{(6, 54)} = 0.527$, $P=0.786$, Figure 4.3). However, differences existed between trials for mean blood lactate concentrations (trial effect: $F_{(1, 9)} = 5.839$, $P=0.039$, Figure 4.3), with values at 15 min being $60 \pm 23\%$ higher during the SMS when compared to the match ($P=0.042$).

Blood glucose concentrations were also similar between trials (time x trial interaction effect: $F_{(6, 54)} = 1.847$, $P=0.170$, Figure 4.3); however, a significant reduction from 15 min values occurred at 60 min (time effect: $F_{(6, 54)} = 8.961$, $P<0.001$). Lower and upper LOA ranges (with CV data) for mean lactate and glucose concentrations between trials were $-3.7 - 8.5$ mmol·L⁻¹ (34.4%) and $-0.9 - 0.7$ mmol·L⁻¹ (5.0%), respectively. Fluid intake was similar between trials (SMS,

match: 1.85 ± 0.08 L, 1.85 ± 0.09 L, $P=0.493$), however, BM losses in the SMS exceeded that of the match (SMS, match: 1.7 ± 0.2 kg, 0.6 ± 0.2 kg, $P=0.005$).

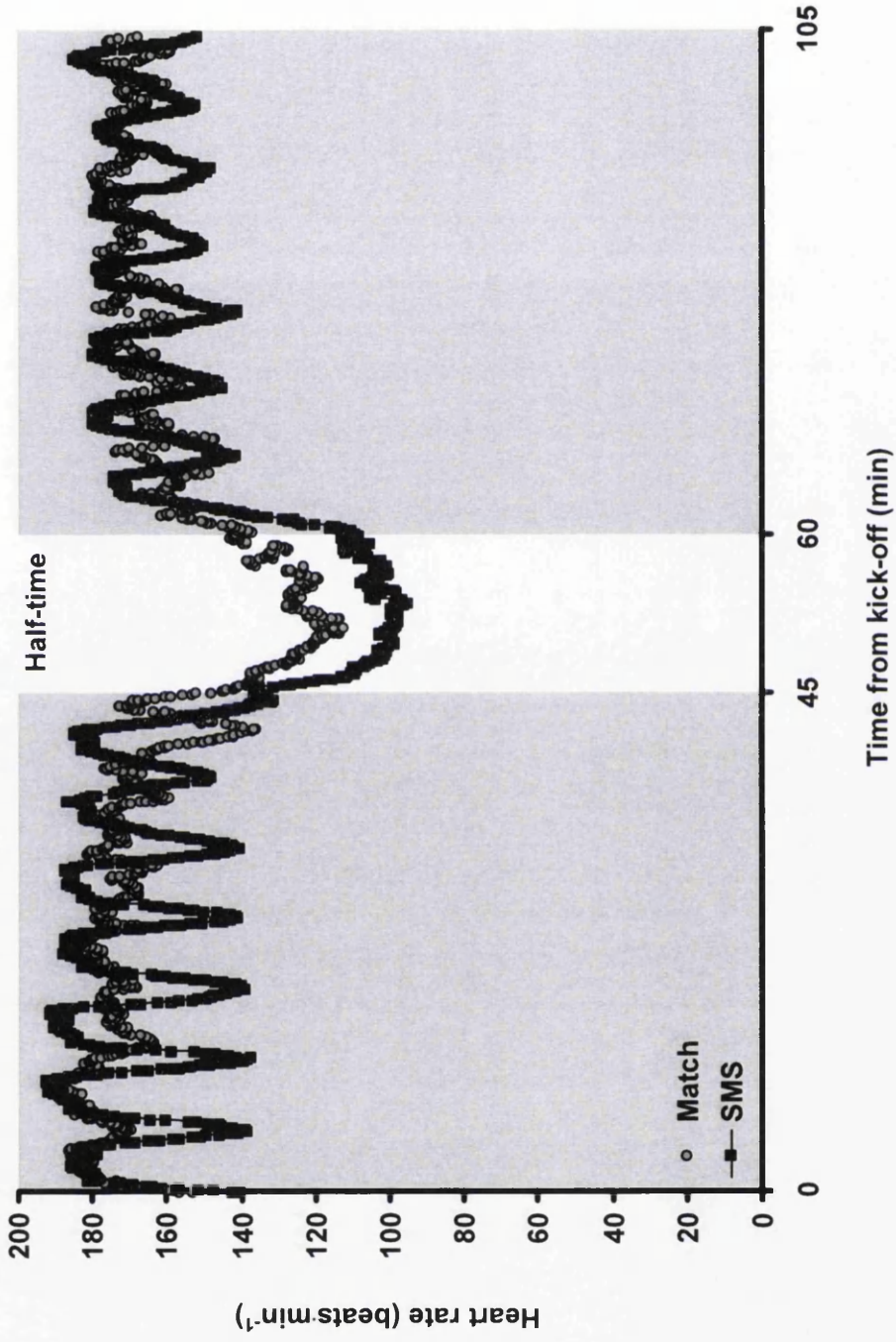


Figure 4.2: Average 5 s HR data for 10 players completing simulated (SMS) and actual (match) match-play

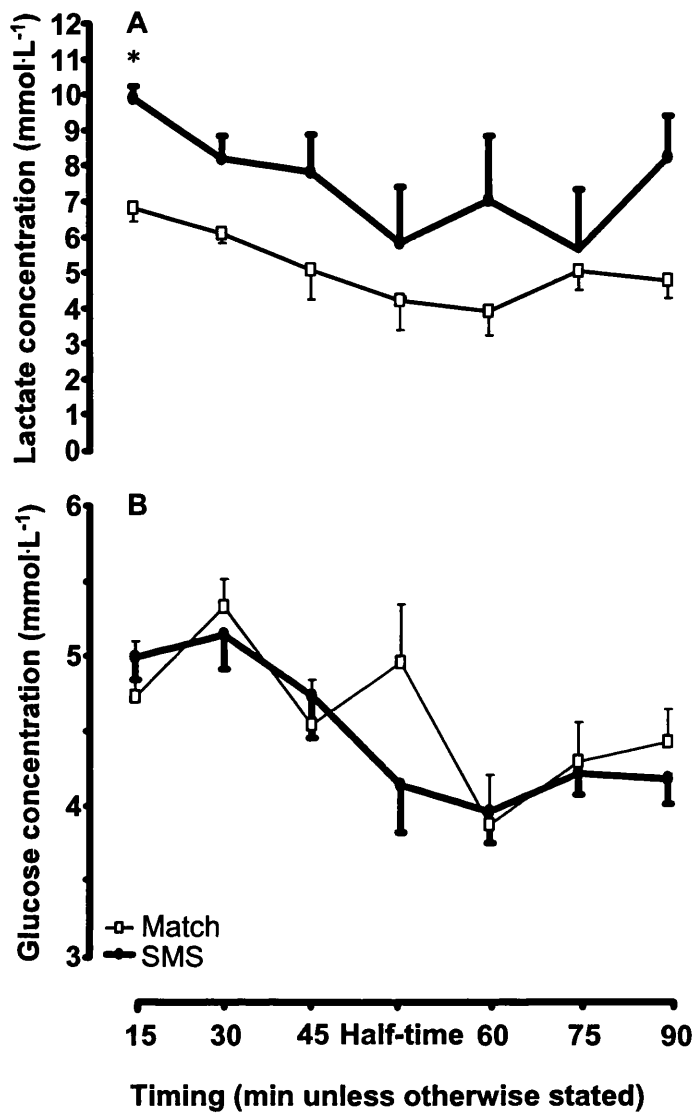


Figure 4.3: Blood lactate concentrations (A) and blood glucose concentrations (B) throughout simulated (SMS) and actual (match) match-play. * Difference between values for SMS and match trials at 15 min ($P \leq 0.05$).

4.4 DISCUSSION

The primary aim of this study was to determine whether a soccer match simulation that incorporated technical actions (i.e., skills) was representative of the demands of actual match-play in terms of the physiological, movement and technical responses elicited by soccer players. Total time spent undertaking low intensity activities (walking), moderate intensity activities (jogging and striding) and high intensity activities (sprinting and dribbling) were similar during the SMS and match. Heart rates and blood glucose concentrations during the SMS were representative of match-play. Although blood lactate concentrations followed a similar pattern during the SMS and match, blood lactate concentrations at 15 min of exercise were higher in SMS when compared to match. Notably, the reduction in blood glucose concentrations that occurred during the initial stages of the second half of exercise during the match was also present at the corresponding time-point in the SMS.

Throughout both trials, mean and peak HR values were representative of the intensities previously observed in match-play (Bangsbo, 1994b; 1994a; Krstrup *et al.*, 2006). However, the lack of a like-for-like comparison of HR data between trials (Figure 4.2) is explained by the unpredictable nature of activity that soccer match-play requires when compared to the repeated patterns of activity performed in the SMS. Nevertheless, based on CV and LOA data for mean and peak HR, the SMS replicated the demands of the match; furthermore no differences existed between trials in either peak (SMS, match: $197 \pm 3 \text{ beats}\cdot\text{min}^{-1}$, $197 \pm 3 \text{ beats}\cdot\text{min}^{-1}$, $P=0.935$) or mean HR (SMS, match: $158 \pm 4 \text{ beats}\cdot\text{min}^{-1}$, $160 \pm 3 \text{ beats}\cdot\text{min}^{-1}$, $P=0.587$). Consequently, physiological variables that are associated with exercise

intensity were similar between the SMS and the match, and were also representative of the values previously observed during soccer match-play (Krustrup *et al.*, 2006).

The variation in the demands placed on individual players, and their response to them, makes the study of actual matches too variable to realistically expect noticeable changes to be observed following interventions. The alternative is to use an analogue of soccer which reflects the movement patterns and physiological demands of the sport whilst ensuring the repeatability of the exercise protocol. The audible signals used in the SMS were effective in standardising movement modalities (except for sprinting and technical actions in which maximal performance was encouraged); consequently, limited opportunities exist to use self-pacing strategies. Although the total number of physical and skilled movements remains consistent between repeated SMS trials, the blood lactate concentrations during the initial stages of exercise (i.e., 0-15 min) were higher during the SMS when compared to actual match-play. This findings probably reflects an inability to alter the duration of recovery between successive exercise bouts of high intensity exercise during the SMS, whereas self-pacing strategies allow blood lactate concentrations to be moderated during the initial stages of match-play. In addition, it is important to acknowledge that the design of the SMS meant that blood samples were taken within 2 min of high intensity activity and that blood lactate concentrations taken during soccer-specific exercise are largely dependent on prior activity in the immediate pre-sampling period (Bangsbo, 1994b). Nevertheless, values elicited by the SMS reflected those that have been previously observed in soccer players (Krustrup *et al.*, 2006).



Mean blood glucose concentrations during the SMS were representative of the values achieved during the match trial, and in previously published literature (Krustrup *et al.*, 2006). However, in comparison with initial values, a reduction in blood glucose concentrations in the order of $17 \pm 4\%$ and $19 \pm 5\%$ at the onset of the second half of exercise (termed exercise-induced rebound glycaemic response) was observed in both the match and SMS trials, respectively. This is the first study to identify an exercise-induced rebound glycaemic response during simulated and actual match-play whilst players are routinely receiving a carbohydrate-free fluid-electrolyte beverage. Considering that previous researchers have incorporated less frequent blood sampling than employed during this study (e.g., Bishop *et al.*, 1999; Ostojic and Mazic, 2002; Clarke *et al.*, 2008), it is possible that the exercise-induced rebound glycaemic response has not been identified previously due to a lack of sampling resolution. It is therefore recommended that future researchers aim to increase the resolution of their metabolic data when examining the physiological and skill responses to high intensity intermittent exercise.

The implications of the exercise-induced rebound glycaemic response are difficult to ascertain; however, it is possible that the drop in blood glucose concentrations during the initial stages of the second half might have adversely affected the quality of soccer performance during this period; especially considering the role that blood glucose plays in cerebral metabolism (Duelli and Kuschinsky, 2001). In respect to cognitive function, Bandelow *et al.* (2010) recently demonstrated that higher blood glucose concentrations were associated with faster visual discrimination, faster fine-motor speed and faster psycho-motor speed after soccer match-play in the heat. Although the specific mechanism for the reduction in blood glucose concentrations

at the onset of the second half of exercise are unclear, it is plausible that the cessation of activity during the half-time break may have led to an array of physiological changes. During this time, reductions in circulating catecholamines lessen the inhibition of the hormone insulin, which in combination with restorative processes that aim to increase muscle glycogen concentrations post-exercise (i.e., translocation of GLUT-4 receptors to the muscle membrane), probably enhanced the uptake of available blood glucose on recommencing exercise. As measurements of insulin and catecholamine concentrations were absent in this study, one can only speculate as to the exact mechanisms involved; nevertheless, the exercise-induced rebound glycaemic response presents itself as a future research opportunity to all involved in sports that incorporate a prolonged rest period between successive exercise bouts.

The final score of the match (one goal to nil victory to the test team) exemplifies the competitive nature of the event, similar to all previous meetings between the two teams, a single goal decided the outcome. While acknowledging that factors such as the nature of the game (i.e., friendly or competitive), and venue (i.e., home or away) can influence physiological responses to competition (Drust *et al.*, 2007), the match trial was a highly competitive encounter between two local rivals at a venue which allowed each team to receive home support. In support of this, the notational analysis data of the test team obtained during the match closely replicated the demands faced by the same team whilst competing in their domestic league (Table 4.2) and also represented the technical responses that have been observed in players competing in the Italian Serie A (Rampinini *et al.*, 2009a). These data were determined for one experimental match and four control games and various factors

can influence movement and technical actions during soccer match-play (Drust *et al.*, 2007); therefore, these findings should be interpreted with some caution. Nevertheless, the technical responses of the test team reflect the responses that have been observed in professional players competing in the Italian Serie A (Rampinini *et al.*, 2009a). Furthermore, physiological responses were representative of published literature that has incorporated the examination of competitive fixtures in soccer players (Krustrup *et al.*, 2006).

A general consensus exists that top level outfield players cover distances in the region of 10-12 km per game with the majority of distance covered by walking and low intensity running (Reilly and Thomas, 1976; Withers *et al.*, 1982; Ekblom, 1986; Rienzi *et al.*, 2000; Mohr *et al.*, 2003; Di Salvo *et al.*, 2007); however, in comparison to their senior counterparts, the movement demands of junior soccer players during match-play has received relatively little attention. Notational analysis data collected during the match trial identified that junior players also spent the majority of total exercise time engaging in low and moderate intensity locomotion; ($37 \pm 1\%$ and $58 \pm 1\%$, respectively). This finding supports previous data from Brazilian youth soccer players during match-play (Pereira Da Silva *et al.*, 2007). Throughout the full duration of the SMS, participants covered a total distance of 10.1 km; of which walking (38%), jogging (49%) and striding (8%) accounted for the greatest proportions of total exercise time. Consequently, the SMS replicates the physical demands of soccer match-play and replicates movement in a manner that corresponds to previously published values (Reilly and Thomas, 1976; Withers *et al.*, 1982; Rienzi *et al.*, 2000; Di Salvo *et al.*, 2007).

The omission of a half-time period and the lack of inclusion of soccer skills throughout exercise limit the ecological validity of the original version of the LIST. The exercise protocol used in this study was a modified version of the LIST which was adapted to include additional movement components that further replicated the demands of soccer match-play and has previously been found to be reliable in familiarised soccer players (Kingsley *et al.*, 2005). In addition, the SMS also incorporates soccer-specific skills and a half-time period; which further enhances the ecological validity of the protocol.

Only one study to date has aimed to directly assess the validity of an exercise protocol that was designed to mimic the physiological demands of a soccer match (Thatcher and Batterham, 2004). Using a treadmill-based protocol, Thatcher and Batterham (2004) identified similar heart rate responses between male soccer players who participated in 90 min of simulated and actual soccer match-play. The exclusion of technical actions throughout this protocol combined with the unidirectional pattern of activity performed limit the ecological validity of this exercise simulation. As previous authors have assessed the validity of their simulation by comparison of physiological and physical responses to data collected in different subject populations (Drust *et al.*, 2000; Nicholas *et al.*, 2000; Williams *et al.*, 2010), study 2 is the first study that uses the same participants to examine the validity of an exercise protocol that incorporates the performance of skilled actions.

Relatively few studies have incorporated ball skills throughout soccer-specific exercise protocols (Rampinini *et al.*, 2008; Ali and Williams, 2009; Currell *et al.*, 2009; Foskett *et al.*, 2009). This is somewhat surprising considering the energy

consuming consequence of such actions (Reilly and Ball, 1984), and the potential that technical aspects of the game have in determining the result of a fixture. The SMS incorporates skills such as passing, shooting and dribbling, throughout two halves of soccer-specific exercise which were separated by a 15-min half-time period. Although the total amount of on-the-ball movements during the SMS were greater in number than what were performed during the match, the SMS reflects the total count of on-the-ball activities reported during matches played in the English Football Association Premier League, being 111 ± 77 (Bloomfield *et al.*, 2007) and can provide outcome measures that demonstrate test-retest reliability and construct validity (study 1).

The pattern of activity performed in the SMS enabled the consumption of fluid throughout exercise in such a way that adheres to published guidelines (e.g., Convertino *et al.*, 1996) and reflects the hydration regimes advocated by sports teams. In addition, the protocol allows researchers to administer interventions without compromising movement demands or gastric tolerance. Despite fluid intake being similar in both trials, more body mass was lost during the SMS when compared to match-play. It is likely that this finding reflects differences in the environmental conditions that were associated with the test locations, where the SMS was undertaken in an indoor training facility and the match was played outdoors. Nevertheless, mass losses observed in the SMS and match were similar to those observed by previous authors (Bangsbo *et al.*, 2006).

This study demonstrates that the SMS is a tool that simulates soccer-specific activity whilst monitoring physiological responses. In addition, its design enables the

measurement of skilled performances throughout soccer-specific activity. When such data are required, the layout of the SMS can incorporate video cameras that enable the assessment of technical performances throughout the full duration of a soccer match.

In conclusion, the SMS elicited similar physiological, movement and skilled demands to soccer match-play. Therefore, the SMS is a tool that replicates the demands of soccer match-play while maintaining standardisation. The SMS has potential application to researchers who wish to examine the effects of various ergogenic aids and strength and conditioning regimes that aim to improve performance in soccer players.

CHAPTER FIVE

STUDY THREE

The effects of fatigue on soccer skills performed during a soccer match simulation

5.1 INTRODUCTION

Physical performance has been observed to decline in the latter stages of real (Mohr *et al.*, 2003; Di Salvo *et al.*, 2007; Rampinini *et al.*, 2009a) and simulated (Rahnama *et al.*, 2003) soccer match-play, where soccer-related fatigue is associated with a diminished work rate (Di Salvo *et al.*, 2007; Rampinini *et al.*, 2009a), declining muscular force output (Rahnama *et al.*, 2003), and reduced performance in high intensity exercise (Mohr *et al.*, 2003). However, limited research exists concerning the effects of fatigue on the technical performances (i.e., skills) involved in soccer. This is somewhat surprising considering that a disproportionate number of goals are scored in the last 15 min of a match (Reilly, 2003), suggesting that a relationship exists between match-related fatigue and technical proficiency (Ostojic and Mazic, 2002).

The majority of studies that have examined the effects of exercise on the performance of isolated soccer skills have tended to assess technical proficiency before and after exercise (e.g., McGregor *et al.*, 1999; Ostojic and Mazic, 2002; Lyons *et al.*, 2006b; Ali *et al.*, 2007b) but not during. Moreover, previous studies have employed exercise protocols that are not representative of demands of match-play because they do not include soccer-specific movement patterns or a half-time period (Nicholas *et al.*, 2000; Lyons *et al.*, 2006b; Ali *et al.*, 2007b). Consequently, little evidence exists to evaluate the effects of soccer-specific exercise on skills performed throughout match-play.

Rampinini *et al.* (2008) observed reductions in short passing performance throughout match-play that were attributed to the accumulated effects of match-related fatigue. However, Currell *et al.* (2009) observed no detriment to kicking performance that was assessed at six time-points throughout exercise. Although skills were performed at six time-points throughout exercise, the use of criterion-based outcome measures (i.e., outcomes were scored in terms of accuracy and time faults were added for errors), which is a common approach in soccer skill research (e.g., Ali *et al.*, 2007a; Rampinini *et al.*, 2008; Stone and Oliver, 2009), might limit the validity of these findings and probably explains the lack of agreement between authors. Despite more sensitive measures of skill assessment having been used in other codes of football (e.g., Young *et al.*, 2010), no data collected by means other than criterion-based outcomes, currently exists concerning the effects of match-related fatigue on soccer skills performed during exercise.

In summary, evidence exists to suggest that fatigue may contribute to impaired technical performances during exercise; however, the effects of soccer-specific exercise on the technical aspects of the game remain to be fully elucidated. Therefore, the aim of this study was to use the reliable skill tests (study one) in conjunction with the validated soccer match simulation protocol (study two), to determine whether soccer-specific exercise would influence the quality of passing, shooting and dribbling skills performed throughout the full duration of a soccer match. The null hypothesis associated with this study was that exercise would not influence the performance of soccer skills when passes, shots and dribbles were assessed throughout exercise.

5.2 METHODS

5.2.1 Participants

Following approval from a University ethics committee, fifteen soccer players (age: 18 ± 1 years, height: 1.77 ± 0.01 m, mass: 71.1 ± 2.5 kg, estimated $\dot{V}O_{2\max}$: 57.3 ± 0.7 ml·kg⁻¹·min⁻¹) from a British Championship team participated in the study. The potential risks of the study were explained and written informed consent was obtained from the players (and parents/guardians if players < 18 years) prior to participation. Players were recruited on the basis that they had no injuries, were non-smokers and had regularly participated in training with their club for at least twelve months before commencing the study.

5.2.2 Study design

This study consisted of two parts: (1) Test-retest reliability and (2) The effects of exercise on soccer skills. Study one (chapter 3) demonstrated the test-retest reliability of the soccer skills tests used in the soccer match simulation (SMS), whereas study two validated the SMS protocol against the demands of match-play; consequently, the test-retest reliability of the physiological, metabolic and performance responses to the SMS had not previously been investigated. With this in mind, a subset of 10 participants (age: 17 ± 1 years, height: 1.76 ± 0.02 m, mass: 68.6 ± 2.5 kg, estimated $\dot{V}O_{2\max}$: 57.5 ± 1.0 ml·kg⁻¹·min⁻¹), completed one half of the SMS protocol on two separate occasions (T1 and T2; each separated by no longer than 14 days). Unfortunately, due to the competitive demands of the players,

not all of those involved in the investigation into the effects of fatigue on soccer skills were able to participate while adhering to the study controls outlined below; nevertheless, test-retest reliability has previously been investigated with a similar number of participants in studies previously published within this domain (e.g., Currell *et al.*, 2009).

On confirmation of the test-retest reliability of the physiological, metabolic and performance responses to the SMS, the effect of exercise on soccer skills was examined in fifteen participants that attended at least four preliminary visits before completing the one SMS main trial. Maximum oxygen uptake was estimated on the first visit using the multistage fitness test (MSFT; Ramsbottom *et al.*, 1988) in order to calculate the running speeds used in the main trial. The remaining visits were used to familiarise participants with the exercise and skill tests involved in the SMS. All familiarisation sessions aimed to reduce anticipated trial order effects.

Participants were asked to refrain from strenuous physical activity and caffeine consumption during the two days before all testing sessions. At the completion of the study, participants gave their verbal confirmation that they had complied with all instructions.

5.2.3 Main trial procedures

Participants arrived at the testing site at 10:15 hours in pairs according to their estimated aerobic capacity (within 0.5 decimal levels on MSFT). On arrival, participants proceeded to empty their bowels and bladder prior to measurements of

mass (model 770; Seca Ltd, Birmingham, UK) and stature (Portable Stadiometer; Holtain Ltd, Wales, UK) being taken. Participants then rested for approximately 20 min before providing a pre-exercise blood sample. A 20-min standardised warm-up (consisting of running, dynamic stretching and ball skills) was completed before starting the SMS at 11:00 hours. On completion, blood samples were taken and BM was measured. Main trial procedures are illustrated in Figure 5.1.

5.2.4 Soccer match simulation (SMS)

Players completed the SMS protocol explained in chapter 2. Blood samples were taken before exercise (pre-exercise), at half-time, and at 15, 30, 45, 60, 75 and 90 min of exercise. Environmental conditions were measured at the start of exercise (ETHG-912; Oregon Scientific, USA; Temperature: $20.3 \pm 0.5^{\circ}\text{C}$; Barometric pressure: 755 ± 2 mmHg; Humidity: $65 \pm 2\%$). Heart rate (HR) was continuously recorded throughout exercise (Polar S610; Polar, Finland) and values were categorized into four HR zones (HR zone 1: $<70\%$ HRmax, HR zone 2: $70\text{-}79\%$ HRmax, HR zone 3: $80\text{-}89\%$ HRmax, and HR zone 4: $90\text{-}100\%$ HRmax) to represent the proportion of exercise spent at each relative exercise intensity. Ratings of perceived exertion (RPE; Borg, 1973) were obtained after each block of exercise and sprint times were measured (Brower timing gates; Utah, USA). Equal volumes of a fluid-electrolyte beverage, containing $23 \text{ mmol}\cdot\text{L}^{-1}$ sodium and $14 \text{ mmol}\cdot\text{L}^{-1}$ chloride and flavoured with a commercially available fruit cordial (Carbohydrate content $< 0.15 \text{ g}\cdot\text{L}^{-1}$), was consumed during the trial at 10 min prior to commencing each half and after 15, 30, 60 and 75 min of exercise (overall rate of fluid consumption was $14 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$ body mass; BM).

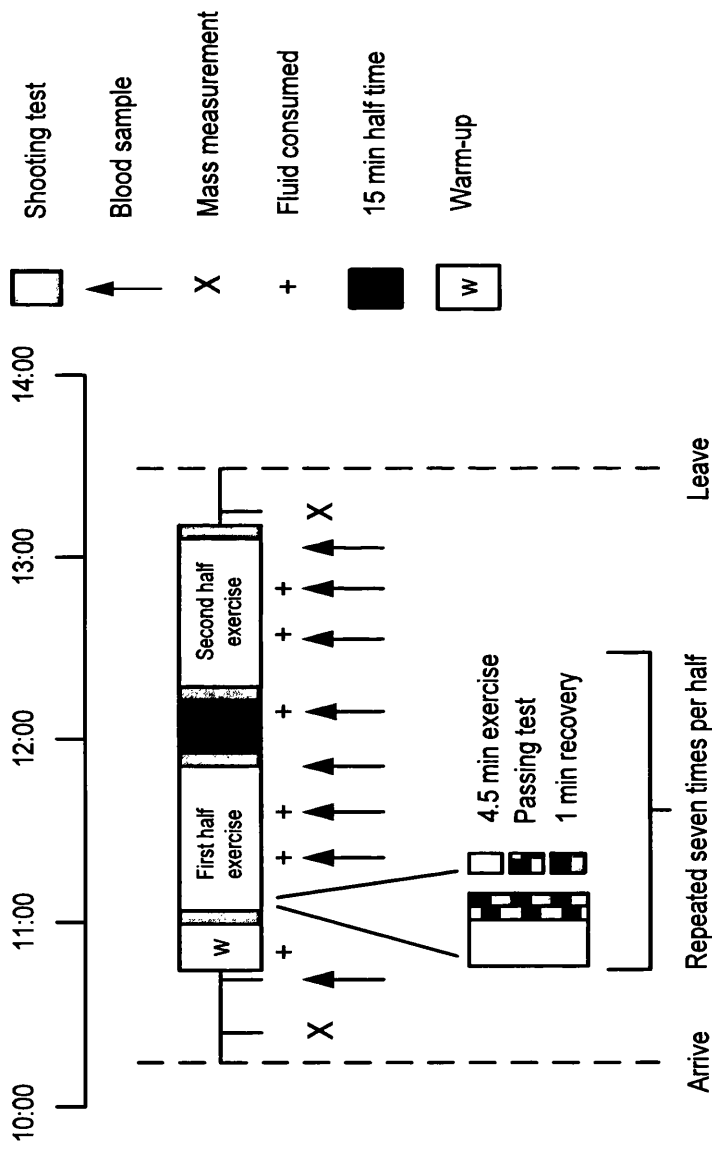


Figure 5.1: Schematic of the main trial procedures

5.2.5 Skills testing

Specific procedures for the execution and analysis of the skills tests are explained in chapter 2.

5.2.6 Blood sampling and analyses

Fingertip blood samples were taken at rest (pre-exercise), 10 min into half time (half-time) and every 15 min during exercise (first half: 15, 30, 45 min; second half: 60, 75, 90 min). Blood lactate concentrations were analysed using a portable micro-volume lactate analyser (Lactate-Pro; Arkray, Japan). Before the trial, the analyser was calibrated in accordance with the manufacturer's guidelines.

5.2.7 Statistical analyses

Statistical analysis was carried out using SPSS software (Version 16.0; SPSS Inc., USA). All results were reported as the mean \pm standard error of the mean and the level of statistical significance was set at $P \leq 0.05$. Normality of data was assessed by the calculation of z scores for skewness and kurtosis data as per previously described methods (Vincent, 1995). For test-retest reliability, systematic bias between T1 and T2 was assessed using paired samples t-tests (between data with single time-points), and a two way repeated measures ANOVA (within-participant factors: trial x time of sample) was used between data with multiple time-points. Absolute reliability was determined using coefficient of variance (CV) values and limits of agreement (LOA; Bland and Altman, 1986). One way repeated measures

analyses of variance (ANOVAs; within-participants factor: time of sample) were used to determine the effects of exercise on the skills performed at multiple time-points. Mauchly's test was consulted and Greenhouse–Geisser correction was applied if the assumption of sphericity was violated. Significant main effects of time (time of sample) were further investigated using multiple pairwise comparisons with Bonferroni confidence interval adjustment.

5.3 RESULTS

5.3.1 Test-retest reliability of physiological variables elicited during the SMS

Mean HR (T1, T2: 170 ± 2 beats·min⁻¹, 169 ± 1 beats·min⁻¹, CV = 2.6%, $P=0.089$) and peak HR (T1, T2: 198 ± 2 beats·min⁻¹, 194 ± 2 beats·min⁻¹, CV = 2.3%, $P=0.708$) were similar between trials. Similarly, trial averages for blood lactate concentrations (T1, T2: 8.3 ± 0.8 mmol·L⁻¹, 8.1 ± 0.9 mmol·L⁻¹, trial effect: $F_{(1,9)} = 0.046$, $P=0.834$), sprint velocities (T1, T2: 5.8 ± 0.1 m·s⁻¹, 5.8 ± 0.1 m·s⁻¹, trial effect: $F_{(1,9)} = 0.031$, $P = 0.865$) and sweat losses (T1, T2: 1.0 ± 0.1 kg, 1.0 ± 0.1 kg; $P=0.845$) did not differ between T1 and T2. Lower and upper LOA were -17 – 15 beats·min⁻¹, -17 – 9 beats·min⁻¹, -0.5 – 0.5 kg, -6.2 – 5.8 mmol·L⁻¹, and -0.5 – 0.5 m·s⁻¹ for mean HR, peak HR, sweat losses, mean lactate concentrations and mean sprint velocities, respectively.

5.3.2 Effect of exercise on skilled performance

Shot precision was significantly affected by exercise (time of sample effect: $F_{(3,42)} = 3.134$, $P=0.035$; Figure 5.2) with deviations from the target being 31 ± 16 cm and 38 ± 16 cm greater at the end of the first and second halves respectively when compared with the correspondent pre-half values. Shots taken after exercise were $26 \pm 4\%$ less accurate than those taken before exercise. Shooting success was $70 \pm 3\%$ and remained unchanged throughout the trial (time of sample effect: $F_{(3,42)} = 1.323$, $P=0.280$; Figure 5.2). Although exercise did not influence shot speed throughout

the trial (time of sample effect: $F_{(3,42)} = 2.142$, $P=0.109$, Figure 5.2) being 16.8 ± 0.2 $\text{m}\cdot\text{s}^{-1}$, shots in the second half were slower than shots in the first half (First half, Second half: 17.3 ± 0.3 $\text{m}\cdot\text{s}^{-1}$, 16.6 ± 0.3 $\text{m}\cdot\text{s}^{-1}$, $P=0.012$).

Passing precision remained unchanged during exercise (time of sample effect: $F_{(5,70)} = 0.477$, $P=0.792$; Table 5.1), and between halves ($P=0.816$), with the mean value throughout the protocol being 33 ± 1 cm. Similarly, passing success was maintained throughout exercise (time of sample effect: $F_{(5,70)} = 0.769$, $P=0.575$; Table 5.1), and between halves ($P=0.785$), with the mean value throughout the protocol being $61 \pm 2\%$. However, the speed of passing was significantly reduced over 90 min of exercise (time of sample effect: $F_{(5,70)} = 3.209$, $P=0.011$; Table 5.1). Although Bonferroni *post-hoc* analyses were unable to identify the precise location of these differences, passes in the latter stages of the protocol (i.e., 75-90 min) were $8 \pm 4\%$ slower than those in the initial stages (i.e., 0-15 min). Additionally, pass speed reduced in the second half compared to passes performed in the first half (First half, Second half: 13.0 ± 0.5 $\text{m}\cdot\text{s}^{-1}$, 12.2 ± 0.5 $\text{m}\cdot\text{s}^{-1}$, $P=0.039$; Table 5.1)

Dribbling precision was not influenced by exercise (time of sample effect: $F_{(5,70)} = 1.126$, $P=0.355$; Table 5.1), with the mean deviation throughout the protocol being 52 ± 1 cm. Similarly, dribbling success and average ball speed were maintained during exercise (time of sample effect: $F_{(5,70)} = 0.901$, $P=0.485$; $F_{(1,14)} = 0.008$, $P=0.932$ respectively; Table 5.1). Values of dribbling precision, success and average ball speed remained consistent between the first and second halves of the SMS ($P=0.516$, $P=0.345$, $P=0.879$, respectively; Table 5.1)

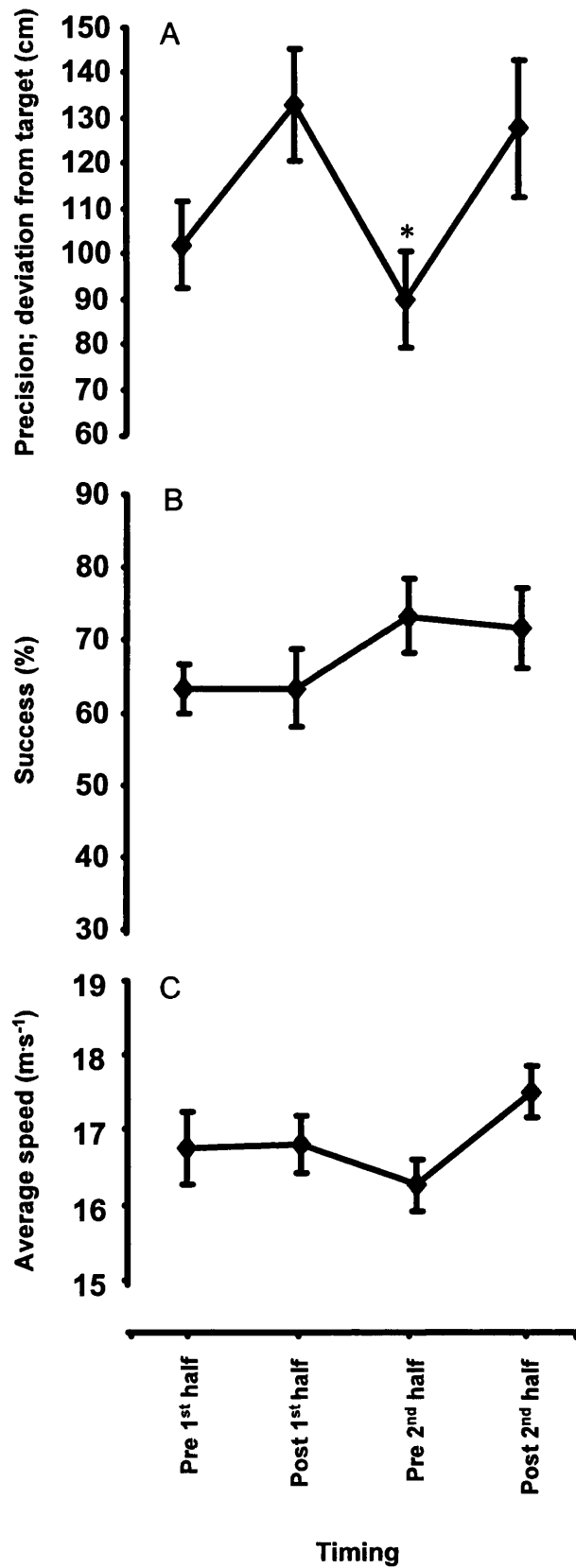


Figure 5.2: Precision (A), success (B) and average speed (C) values for shooting.
 * Represents significant difference compared to post 1st half value ($P \leq 0.05$).

5.3.3 Physiological demand and exercise intensity

Blood lactate concentrations were elevated above resting values from 15 min of exercise (time of sample effect: $F_{(3,39)} = 30.395$, $P < 0.001$; Table 5.1) with values at 90 min being $6.7 \pm 0.7 \text{ mmol}\cdot\text{L}^{-1}$. Similarly, rate of perceived exertion was elevated throughout exercise (time of sample effect: $F_{(1,20)} = 156.259$, $P < 0.001$, Table 5.1).

Sprint speed reduced over the course of the protocol (time of sample effect: $F_{(3,37)} = 7.469$, $P < 0.01$) with sprints in the final stages of exercise being $5 \pm 1\%$ slower than those in the initial stages (75-90 min vs. 0-15 min: $5.8 \pm 0.1 \text{ m}\cdot\text{s}^{-1}$ vs. $6.1 \pm 0.1 \text{ m}\cdot\text{s}^{-1}$, $P = 0.049$; Table 5.1). During the SMS mean HR was $163 \pm 2 \text{ beats}\cdot\text{min}^{-1}$ and peak HR was $199 \pm 2 \text{ beats}\cdot\text{min}^{-1}$; furthermore the proportion of time spent at each relative intensity was $10 \pm 2\%$, $20 \pm 1\%$, $38 \pm 4\%$ and $32 \pm 6\%$ for HR zones 1-4 respectively. The mean volume of fluid ingested was $1490 \pm 50 \text{ ml}$ and BM declined from initial values with average sweat losses of $2.0 \pm 0.1 \text{ kg}$ ($P < 0.01$).

Table 5.1: Physiological, metabolic and performance responses to the SMS

Variable	Timing throughout protocol (min unless otherwise stated)									
	Pre-exercise	0-15	15-30	30-45	Half-time	45-60	60-75	75-90	First Half	Second Half
Passing precision (cm)	n/a	32±2	34±3	33±2	n/a	34±2	33±2	30±2	32±2	33±1
Passing success (%)	n/a	63±3	58±6	61±4	n/a	58±3	62±5	68±5	61±3	62±2
Passing velocity (m·s ⁻¹)	n/a	13.3±0.5	13.2±0.5	12.7±0.6	n/a	12.2±0.5	12.3±0.5	12.1±0.6	13.0±0.5	12.2±0.5*
Dribbling precision (cm)	n/a	51±2	52±2	53±2	n/a	51±2	55±2	52±3	52±2	53±2
Dribbling success (%)	n/a	91±2	91±3	91±3	n/a	92±2	92±2	96±2	91±2	93±2
Dribbling velocity (m·s ⁻¹)	n/a	4.2±0.1	4.2±0.1	4.1±0.1	n/a	4.1±0.1	4.3±0.1	4.1±0.1	4.2±0.1	4.2±0.1
Blood lactate concentration (mmol·L ⁻¹)	2.4±0.2	10.4±0.8	9.6±0.9 ⁺	8.6±0.9 ⁺	3.5±0.2 ⁺	6.5±0.4 ⁺	6.3±0.3 ⁺	6.7±0.7 ⁺	9.5±0.8	6.5±0.4*
Rate of perceived exertion (units)	6±1	13±1	15±1 ⁺	16±1 ⁺	6±1	15±1 ⁺	17±1 ⁺	18±1 ⁺	15±1	16±1*
15 m sprint speed (m·s ⁻¹)	n/a	6.1±0.1	5.8±0.1 ⁺	5.8±0.1 ⁺	n/a	5.9±0.1 ⁺	5.9±0.1	5.8±0.1 ⁺	5.9±0.1	5.8±0.1

*Significant difference compared to corresponding first half value ($P \leq 0.05$)

+ Significant difference compared to corresponding 0-15 min value ($P \leq 0.05$)

5.4 DISCUSSION

The primary finding of this study was that fatigue induced by a soccer-specific exercise protocol, which included ball skills throughout exercise, caused a reduction in passing and shooting performances, specifically throughout the second half. Additionally, physiological, metabolic and performance responses to the SMS were similar between repeated trials. Therefore, the SMS is a suitable measurement tool for examining the physiological, metabolic and performance (both physical and skilled) responses to interventions in soccer players.

The results demonstrate that soccer-specific fatigue influences the performance of skills throughout simulated match-play. More specifically, pass speed and shooting precision decreased throughout exercise. These findings are in general agreement with previous research, where modifications in speed and/or precision of sports skills occur under fatiguing conditions (Kellis *et al.*, 2006; Ali *et al.*, 2007b) and exemplifies the importance of measuring the precision and the speed of skills. These data provide additional evidence for a *speed-accuracy trade-off* (Fitts and Posner, 1967) where participants modify the speed and/or precision associated with sports skills in order to maintain performance.

Some studies have reported reductions in physical performances between the first and second halves of a soccer match (Di Salvo *et al.*, 2007); however, few studies have evaluated temporal changes in the technical aspects of match-play. These results show that the speed of passing and shooting reduced between halves. Although this finding reflects declining performance, the extent to which ball speed

impacts on success during match-play remains unclear. Nevertheless, skills performed in the second half of match-play have been observed to be less successful than skills performed in the first half (Burgess *et al.*, 2006). This is the first study to evaluate the decay in the quality of skills performed during soccer-specific exercise using sensitive measures of assessment as previous studies have tested skills before and after exercise (McGregor *et al.*, 1999; Ostojic and Mazic, 2002; Ali *et al.*, 2007b) and/or used criterion-based outcomes (Ali *et al.*, 2007b; Rampinini *et al.*, 2008; Ali and Williams, 2009; Currell *et al.*, 2009).

Throughout actual match-play, Rampinini *et al.* (2008) observed reductions in short passing performances. However, both Currell *et al.* (2009) and Ali *et al.* (2009) have reported that kicking performances remained unchanged throughout simulated match-play. Inconsistencies between authors may be explained by the use of criterion-based outcome measures (i.e., outcomes were scored in terms of accuracy and time faults were added for errors) that are common in soccer skill research (e.g., Northcott *et al.*, 1999; Ali *et al.*, 2007b; Rampinini *et al.*, 2008; Currell *et al.*, 2009; Stone and Oliver, 2009; Ali *et al.*, 2010). The current study describes the influence of soccer-specific fatigue on skilled performance in units that have strong ecological validity rather than criterion-based measurements, hence comparisons with previous research is difficult. However, unpublished observations taken from the senior members of the club, from which the junior players used in this study were recruited from, suggest that the shooting success values observed were representative of those players who participated in 20 league games (see Appendix F4). Notably, the disagreement that exists between researchers concerning technical responses to

fatigue might be alleviated with the introduction of more sensitive and ecologically valid outcome measures.

The findings from this study, in combination with that of previous authors (Abt *et al.*, 1998; McGregor *et al.*, 1999), suggest that soccer dribbling is more resilient to the effects of match-related fatigue than other skills involving greater peak muscular activity. McGregor *et al.* (1999) showed that fluid abstinence during intermittent exercise resulted in a 5% decline in the performance of a timed dribbling task. Although this earlier research highlights a potential decline in skilled performance resulting from dehydration (Bangsbo *et al.*, 2006), dribbling performance remained unchanged in players who were in a physiological state that is more representative of that advocated by sports teams (i.e., consumed a carbohydrate-free solution throughout exercise). No change in any indices of dribbling performance were observed during the SMS despite reductions in sprint speed; highlighting the potential shortcomings of timed dribble tests whose outcomes are heavily influenced by sprint speed (McGregor *et al.*, 1999; Ostojic and Mazic, 2002). In addition, this study employed a standardised diet and two days of rest before participants began the SMS. It can, therefore, be assumed that these participants started exercise in a physiological state that is generally recommended for team sports players; thus, enhancing the ecological validity of the findings.

Although other exercise protocols exist that simulate soccer match-play (Drust *et al.*, 2000; Nicholas *et al.*, 2000), the ecological validity of these simulations is limited by the omission of backwards and sideways movements, the lack of game specific skills, and the failure to include a half-time period. The physiological and

movement demands of the SMS have previously been validated against match-play in a single group of participants (study two). Moreover, the SMS incorporates skills such as passing, shooting and dribbling at frequencies similar to those observed in the English Premier League (Bloomfield *et al.*, 2007) while players complete two halves of soccer-specific exercise that are separated by a 15 min half-time period. Moreover, participants also covered a distance (10.1 km) that represents the average distances covered by players during soccer matches (Bangsbo *et al.*, 1991; Rienzi *et al.*, 2000; Mohr *et al.*, 2003; Di Salvo *et al.*, 2007), the responses of HR and blood lactate concentrations reflect those observed during match-play (Krustrup *et al.*, 2006) and the proportion of time spent in the relative exercise intensities (HR zones 1-4) agreed with previous findings (Tauler *et al.*, 2008). In addition, the SMS was repeatable as demonstrated by the lack of differences between the physiological, metabolic and performance responses elicited in two SMS trials.

The mechanisms of match-related fatigue involved in soccer are likely to be multifaceted in origin, where muscle damage could influence proprioception and glucose transportation into active muscle; nevertheless, compromised fibre-specific muscle glycogen levels (Krustrup *et al.*, 2006), hypohydration (Ostojic and Mazic, 2002; Bangsbo *et al.*, 2006), and reduced blood glucose concentrations have all been proposed as possible contributors. Throughout the current study, fluid was consumed in accordance with published guidelines (Convertino *et al.*, 1996); therefore, although mass losses occurred throughout exercise, it is unlikely that the effects of exercise on skilled performance reflect changes in fluid balance. Glucose is the principal energy source for cerebral metabolism and the brain is dependent on a continuous supply of circulating blood glucose (Duelli and Kuschinsky, 2001). It

is plausible, therefore, that exercise can cause skill decrements due to reductions in the integrity of the central nervous system (Ross and Leveritt, 2001). However, as no measure of cerebral or muscle glucose concentrations were taken, although attractive, this mechanism remains somewhat speculative.

According to Williams and Reilly (2000), proficient skill performance is affected by cognitive factors such as decision making and game intelligence. When performing passing and shooting, the randomised lighting system used for target identification in this study incorporated perceptual abilities, such as decision making and visual searching. Although we were unable to determine the direct involvement of these cognitive aspects of performance on the skills performed, the decrement in passing and shooting skills observed have occurred when players were aiming the ball towards a specific target; which is similar to match-play when passes or shots are aimed towards opponents or areas of the goal deemed to increase the possibility of scoring, respectively.

Royal *et al.* (2006) suggested that elite athletes may be more resilient to the physiological stresses that occur during competition, and thus better able to maintain technical proficiency. The players used in this study had at least one years playing and training experience with a British Championship team; despite training and playing on three occasions per week during the competitive season, reductions in passing and shooting performance were still observed over the course of the protocol. As the decline in skill has been found to be more severe in novices than seniors (Lyons *et al.*, 2006a), it remains to be elucidated whether the effects of fatigue on skilled performances observed throughout exercise in junior players in

this study and others (e.g., Rampinini *et al.*, 2008) also impact on senior level players.

In summary, despite dribbling performance being maintained, a decline in soccer passing and shooting skills was observed throughout the full duration of the SMS; therefore practitioners should be aware that passing and shooting are susceptible to fatigue during soccer match-play. Future research should focus on interventions that attenuate such reductions in skilled performance. Additionally, the repeatability of the physiological, metabolic and performance responses elicited during the SMS were demonstrated. Therefore, the SMS protocol may be a valuable measurement tool when studying the effects of interventions on soccer players.

CHAPTER SIX

STUDY FOUR

*The influence of carbohydrate on soccer skills performed during a soccer match
simulation*

6.1 INTRODUCTION

There is a large market for sports drinks that rely on research supporting improved exercise capacity by consuming carbohydrates (e.g., Coyle *et al.*, 1983; Nicholas *et al.*, 1995). The ergogenic effects of carbohydrate supplementation are generally attributed to the maintenance of blood glucose and the sparing of muscle glycogen. Interestingly, during soccer match-play, the number of goals scored increases as the game approaches its end (Reilly, 2003). Although physiological fatigue could partially explain this phenomenon, decrements in decision making and motor skill performance probably contribute to this finding; however, there have been relatively few attempts to consider the impact of nutrition on the performance of sporting skills completed during exercise as opposed to fatigue.

There is an increasing number of reports that the provision of sugar can influence cognitive functioning (e.g., Davis *et al.*, 1992; Benton *et al.*, 2003). Furthermore, supplementation with a 5.5% carbohydrate solution has been demonstrated to improve cognitive performance during a choice reaction task that was completed after prolonged steady-state running, even though exercise did not lead to a hypoglycaemic response in these participants (Collardeau *et al.*, 2001). Therefore, carbohydrate consumption can enhance cognitive and motor skill performance at rest and following continuous activity, even when the participants remain euglycaemic.

Various skills that are associated with high intensity intermittent sports have been reported to decline during or following exercise (McGregor *et al.*, 1999; Welsh *et*

al., 2002; Winnick *et al.*, 2005; Lyons *et al.*, 2006b; Oliver *et al.*, 2008; Rampinini *et al.*, 2008). Therefore, it is biologically plausible that enhancing carbohydrate availability might improve central nervous system function and attenuate this loss of motor skill performance; however, the research that investigates the influence of carbohydrate supplementation on soccer skill performance during simulated or actual match-play has produced equivocal findings.

Zeederberg *et al.* (1996) observed no measurable benefit of ingesting a 6.9% glucose-polymer on motor skill performance executed during soccer match-play. It is possible that the variation in the physical demands, and responses to these demands, makes the study of skilled performance during actual matches too variable to detect changes following interventions. Carbohydrate provision was reported to improve performance in a timed soccer dribbling test, as decrements observed in a placebo group were attenuated in a group supplemented with a 7% carbohydrate-electrolyte beverage (Ostojic and Mazic, 2002). However, it is difficult to assess whether these findings reflected differences in movement speed or skilled performance.

It has been reported that consuming a 6.4% carbohydrate-electrolyte beverage during exercise enabled participants to better maintain shooting skill following exercise but did not influence the outcome of a passing test (Ali *et al.*, 2007b); a finding which has since been confirmed when passing has also been assessed throughout intermittent exercise (Ali and Williams, 2009). However, the participants started these trials in a compromised glycogen state and the skill tests used criterion scoring methods (i.e., outcomes were scored in terms of accuracy and time faults

were added for errors); consequently, it is difficult to assess the ecological validity of these findings.

In summary, the administration of carbohydrate and/or carbohydrate-electrolyte solutions have been demonstrated to improve cognitive function and attenuate the reduction of some sports related skills following prolonged exercise; however, the influence of exogenous carbohydrate on the performance of soccer skills during soccer-specific exercise is not clear. This is somewhat surprising considering the influence that skilled actions have in defining success and the potential beneficial effects of carbohydrate supplementation on the function of the central nervous system. Therefore, the aim of this study was to consider whether ingestion of a carbohydrate-electrolyte beverage would influence the quality of the performance of soccer skills when assessed before, during, and after a soccer-specific exercise simulation. The null hypothesis associated with this study was that there would be no difference in the performance of soccer skills executed throughout exercise between conditions of carbohydrate-electrolyte and fluid-electrolyte ingestion.

6.2 METHODS

6.2.1 Participants

Fifteen soccer players (age: 18 ± 1 years, height: 1.77 ± 0.05 m, mass: 69.7 ± 2.2 kg, estimated $\dot{V}O_{2\max}$: 57.3 ± 0.9 ml·kg⁻¹·min⁻¹) from a British Championship team completed all of the study requirements, which was approved by a University ethics committee. All players were informed about the potential risks of the study and gave written informed consent for their participation. Written consent was obtained from a parent or guardian when participants were less than 18 years of age. Participants were recruited on the basis that they had no injuries, were non-diabetic, and had regularly participated in training with their club for at least twelve months before the start of the study.

6.2.2 Study design

Participants attended five preliminary visits before completing two main trials. Maximum oxygen uptake was estimated on the first visit using the multistage fitness test (MSFT; Ramsbottom *et al.*, 1988) in order to calculate the running speeds of the exercise protocol used in the main trials. Maximum 15-m sprint speeds were measured during the second visit. The remaining visits were used to familiarise participants with the exercise protocol and the skills tests. All familiarisation sessions aimed to reduce anticipated trial order effects.

Two main trials (CHO and PL) were completed in a randomised, double-blind and cross-over fashion, separated by 9 ± 2 days. Participants were asked to refrain from strenuous physical activity and caffeine consumption during the two days before all testing sessions. Additionally, participants recorded all food consumption for the two days before each main trial. Food records were subsequently analysed using commercially available software (CompEat version 5.8.0; Nutrition Systems, UK). At the completion of the study, all participants gave their verbal confirmation that they had complied with all instructions.

6.2.3 Main trial procedures

Participants were paired according to estimated aerobic capacity (within 0.5 decimal levels on MSFT) and arrived at the testing site at 08:15 hours, following an overnight fast. On arrival, participants proceeded to empty their bowels and bladder prior to a resting blood sample being taken. At 08:50 hours, participants consumed a standardised breakfast, consisting of a 1470 kJ meal (Energy content: 62% carbohydrates, 25% fats, 13% proteins) and 500 ml of the treatment beverage. Body mass (BM; model 770: Seca Ltd, Birmingham, UK) and stature (Portable Stadiometer; Holtain Ltd, Wales, UK) were then measured. Participants then proceeded to rest for approximately 100 min before a pre-exercise blood sample was taken. A 20-min standardised warm-up (consisting of running, dynamic stretching and ball skills) was completed before the soccer match simulation (SMS) commenced. After completing the exercise and skills protocol, blood samples were taken and BM was measured. A schematic of the procedures for both main trials is presented in Figure 6.1.

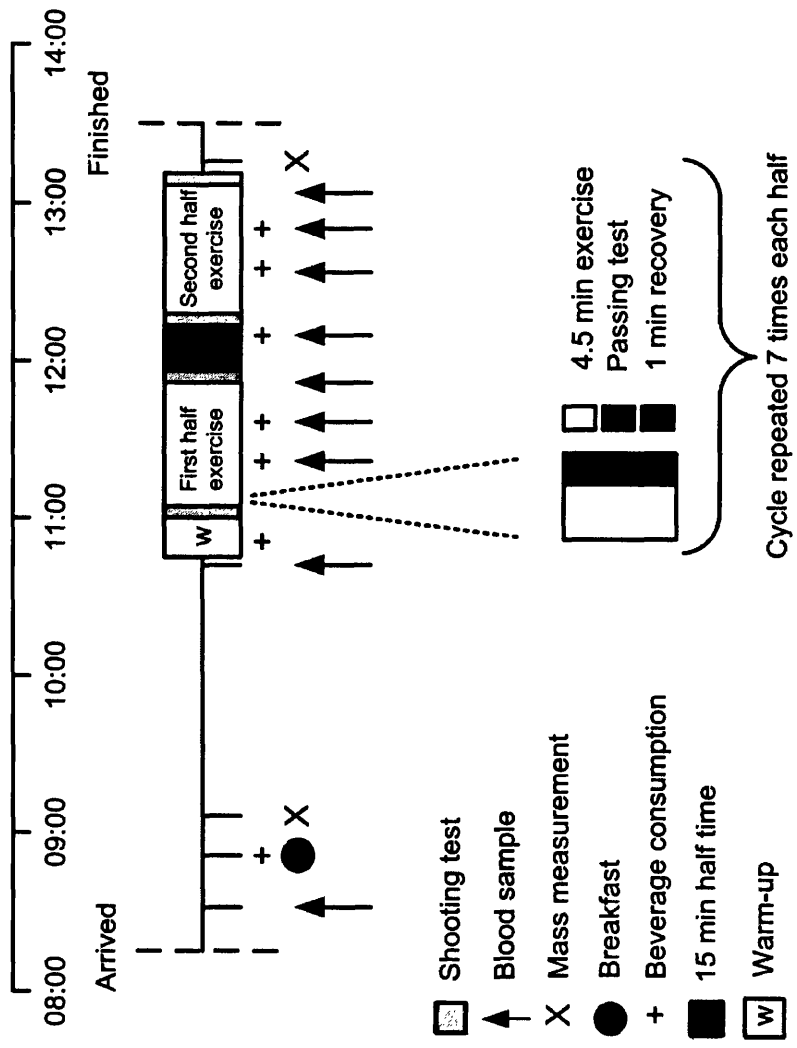


Figure 6.1: Schematic of the main trial procedures

6.2.4 Soccer match simulation (SMS)

Specific trial procedures for the exercise and skills protocol are explained in chapter 2. Blood samples were taken at rest, before exercise (pre-exercise), at half-time, and at 15, 30, 45, 60, 75 and 90 min of exercise. Environmental conditions were measured at the start of all exercise sessions (ETHG-912; Oregon Scientific, USA). Heart rate (HR) was continuously recorded throughout each trial using short-range telemetry (Polar S610; Polar, Finland) and rate of perceived exertion (RPE) values (Borg, 1973) were obtained after each block of exercise. Sprint times were measured throughout the protocol (Brower timing gates; Utah, USA).

6.2.5 Experimental beverages

An initial bolus of the treatment beverage (500 ml) was consumed with breakfast and additional fluid was consumed during the trial at a rate of $14 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$ BM. Equal volumes of fluid were consumed at 10 min prior to commencing each half and after 15, 30, 60 and 75 min of exercise. During the carbohydrate trial (CHO), a carbohydrate-electrolyte beverage containing 6% sucrose, $23 \text{ mmol} \cdot \text{L}^{-1}$ sodium and $14 \text{ mmol} \cdot \text{L}^{-1}$ chloride was consumed. The placebo (PL) beverage was equimolar in terms of electrolytes but void of carbohydrate. Sweetness of the PL beverage was maintained by an energy free artificial sweetener. Both CHO and PL beverages were flavoured with a commercially available fruit cordial (Carbohydrate content $< 0.15 \text{ g} \cdot \text{L}^{-1}$). The drinks were indistinguishable by taste and texture and were consumed from identical containers. Following completion of the second main trial, the participants reported that they were unable to distinguish between the experimental

beverages. During the familiarisation sessions the participants ingested water at a rate of $14 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$ BM in order to promote gastric tolerance to this rate of fluid ingestion.

6.2.6 Skills testing

Specific procedures for the execution and analysis of skills testing are explained in chapter 2. In addition to these analyses, a further speed-precision index (SP index) was calculated using Equation 6.1. This equation is a modification of Fitts' law (Fitts, 1954); a model that integrates speed, accuracy, target size and distance to the target, and is similar to that used in previous skill research (Vergauwen *et al.*, 1998). As an overall representation of skilled performance, a speed-precision-success (SPS) index was calculated by multiplying the mean SP indexes by the proportion of successful skills completed. Higher values represent greater speed, precision and success of skills.

$$\text{Equation 6.1: SP Index} = \frac{\text{Speed}}{(\text{Log}_2 ((\text{Precision}/\text{Target}) + 1)) + 15} \times 100$$

Where speed is expressed in $\text{m}\cdot\text{s}^{-1}$, precision represents values of deviations from the target or cone (cm) and target size was constant at 50 cm for passes, 10 cm for shots and 300 cm for dribbles. A higher index indicates greater speed and precision of skill.

6.2.7 Blood sampling and analyses

Blood pH, lactate concentrations, glucose concentrations, and haematocrit (Hct) were analysed immediately (GEM Premier 3000 blood gas analyser, Instrumentation Laboratory, UK) from fingertip blood samples that were taken using 170 μL heparinised capillary tubes (Instrumentation Laboratory, UK) at rest, pre-exercise, every 15 min throughout exercise (first half: 15, 30, 45 min; second half: 60, 75, 90 min), and 10 min into half time (half-time). Haemoglobin (Hb) concentrations (HemoCue AB, Sweden) were also measured at each time-point whereas indices of acid-base balance (e.g., standard and actual blood bicarbonate and base excess) were retrospectively calculated from data collected from the pre-exercise time-point onwards in accordance with the manufacturer's instructions (equations 6.2 through 6.7).

Equation 6.2: Actual bicarbonate (HCO_3^-) = $10^{(\text{pH} + \log(\text{pCO}_2) - 7.608)}$

Equation 6.3: Standard bicarbonate ($\text{HCO}_3^- \text{ std}$) = $25 + 0.78 \times \text{BE} + 0.002 \times \text{Hgb} (\text{SO}_2\text{c} - 100)$

Equation 6.4: Base excess (BE) = $(1 - 0.014 \times \text{Hgb}) \times [\text{HCO}_3^- - 24 + (1.63 \times \text{Hgb} + 9.5) \times (\text{pH} - 7.4)]$

Equation 6.5: $\text{Hgb} = 0.31 \times 40$

Equation 6.6: Oxygen saturation (SO_2c) = $100 / [1 + (23400 / ((\text{pO}_2\text{pp} \times 3) + (150 \times \text{pO}_2\text{pp})))]$

Equation 6.7: $\text{pO}_2\text{pp} = \text{pO}_2 \times 2.718^{(((\text{pO}_2/26.7)^{0.184}) + 0.003 \times \text{BE} - 2.2) \times (7.4 - \text{pH})}$

Where pO_2pp = Partial pressure of oxygen in blood at pH of 7.4 and HCO_3^- , $\text{HCO}_3^- \text{ std}$ and BE are in $\text{mmol} \cdot \text{L}^{-1}$.

6.2.8 Hydration markers

Changes from resting plasma volume were estimated before and after exercise using previously described methods (Dill and Costill, 1974). Additional blood samples at pre-exercise and at 90 min were centrifuged at $4000 \times g$ for 15 min and the

osmolality of 50 μ L of plasma was measured by freezing point depression (Gonotec Cryoscopic Osmometer Osmomat 030; YSI Limited, UK).

6.2.9 Statistical analyses

Statistical analysis was carried out using SPSS software (Version 13.0; SPSS Inc., USA). All results were reported as the mean \pm standard error of the mean and the level of statistical significance was set at $P \leq 0.05$. All data were assessed for normality by the calculation of z scores for skewness and kurtosis data as per previously described methods (Vincent, 1995). Paired sample t -tests were used to compare participant anthropometrics, environmental conditions, nutritional intake, mean and peak HR and sweat losses between trials. Two way repeated measures analysis of variance (ANOVA; within-participant factors: treatment x time of sample) were used where data contained multiple time-points during each main trial. Mauchly's test was consulted and Greenhouse–Geisser correction was applied if the assumption of sphericity was violated. If a significant P -value was identified for the interaction effect (time x treatment), CHO supplementation was deemed to have influenced the exercise response and simple main effect analyses were performed. Significant main effects of time (time of sample) were further investigated using multiple pairwise comparisons with Bonferroni confidence interval adjustment.

6.3 RESULTS

Environmental conditions were similar during both trials; ambient temperature being 20.7 ± 0.4 and $20.1 \pm 0.4^\circ\text{C}$, barometric pressure being 761 ± 1 and 761 ± 2 mmHg, and humidity being 62 ± 2 and $65 \pm 2\%$, for CHO and PL respectively. The calculated daily diet comprised of $11.2 \pm 0.9 \text{ MJ}\cdot\text{d}^{-1}$, of which 52 ± 1 , 30 ± 1 , $18 \pm 1\%$ of energy intake was obtained from carbohydrates, fats, and proteins, respectively. No differences existed between trials for macronutrient content and energy intake.

6.3.1 Effect of carbohydrate supplementation on skilled performance

Shooting precision was not influenced by supplementation (treatment effect: $F_{(1,14)} = 0.002$, $P=0.967$) or exercise (time of sample effect: $F_{(3,42)} = 0.143$, $P=0.934$; Figure 6.2), being 125 ± 5 cm from the centre of the target. Similarly, success rates in shooting remained unchanged throughout both trials, being $75 \pm 2\%$. Supplementation affected shot speed over the duration of the protocol (time x treatment interaction effect: $F_{(3,42)} = 3.793$, $P=0.017$). As exercise progressed the decrease in shot speed during the PL trial ($-10.5 \pm 0.1\%$) was attenuated in the CHO trial ($-5.2 \pm 0.1\%$). Following exercise, shot speed was $9.7 \pm 0.1\%$ higher in the CHO trial than the PL trial (Figure 6.2).

Exercise (time of sample effect: $F_{(3,42)} = 3.127$, $P=0.036$) and treatment ($F_{(1,14)} = 8.208$, $P=0.012$) influenced $\text{SPS}_{\text{Shooting}}$ index. The decline in the $\text{SPS}_{\text{Shooting}}$ index between the initial and final shooting assessments was $23.1 \pm 0.1\%$ during the PL

trial ($P=0.014$); this decline was attenuated by CHO ingestion ($11.8 \pm 0.1\%$ decline, $P=0.552$; Figure 6.2).

Passing precision was not affected by exercise (time of sample effect: $F_{(5,70)} = 0.839$, $P=0.527$) or supplementation (treatment effect: $F_{(1,14)} = 0.351$, $P=0.563$; Table 6.1), being 31 ± 1 cm from the centre of the target. Similarly, exercise and supplementation did not influence passing success (time of sample effect: $F_{(5,70)} = 0.883$, $P=0.497$; treatment effect: $F_{(1,14)} = 0.001$, $P=0.972$; Table 6.1), being $71 \pm 1\%$. The main effects of time ($F_{(5,70)} = 0.132$, $P=0.985$) and treatment ($F_{(1,14)} = 0.364$, $P=0.556$) for pass speed were non-significant (Table 6.1). Similarly, the SPS_{Passing} index was not influenced by exercise or supplementation (time of sample effect: $F_{(5,70)} = 0.834$, $P=0.530$, treatment effect: $F_{(1,14)} = 0.001$, $P=0.995$).

Dribbling precision was not influenced by exercise (time of sample effect: $F_{(5,70)} = 1.894$, $P=0.106$) or supplementation (treatment effect: $F_{(1,14)} = 0.008$, $P=0.931$), with the mean deviation being 51 ± 1 cm from the centre of the cone. Similarly, the main effects of treatment and time of sample were non-significant for dribbling success ($F_{(1,14)} = 0.079$, $P=0.783$; $F_{(1,14)} = 0.405$, $P=0.844$, respectively) and average ball speed during dribbling ($F_{(1,14)} = 0.008$, $P=0.932$; $F_{(5,70)} = 0.924$, $P=0.471$, respectively; Table 6.1). The $SPS_{\text{Dribbling}}$ index tended to be greater in the last 15 min of the CHO trial when compared to the PL trial; however, these trends did not reach statistical significance (Table 6.1).

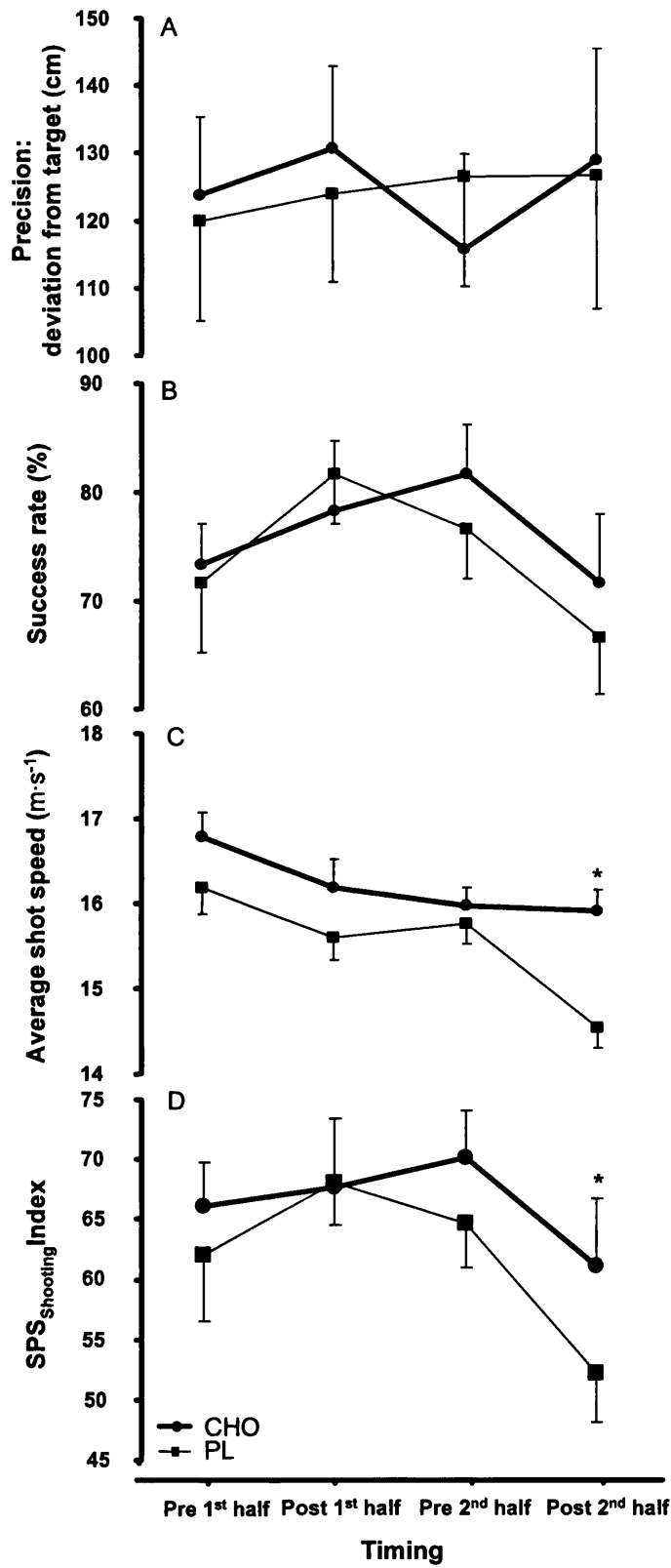


Figure 6.2: Precision (A), success (B), average speed (C), and SPS index (D) values for shooting during the carbohydrate (CHO) and placebo (PL) trials. * Represents significant difference ($P < 0.01$) between treatments

Table 6.1: Precision, success, average speed and Speed-Precision-Success (SPS) index values for passing and dribbling during the carbohydrate (CHO) and placebo (PL) trials

Skill	Variable	Treatment	Timing (min)					
			0-15	15-30	30-45	45-60	60-75	75-90
Passing	Precision (cm)	CHO	35±2	35±2	39±3	34±3	40±3	35±2
		PL	36±3	36±3	38±3	32±3	33±2	37±3
	Success (%)	CHO	61±1	68±1	67±1	51±1	59±1	70±1
		PL	58±1	64±1	63±1	68±1	70±1	61±1
	Speed (m·s ⁻¹)	CHO	11.6±0.4	11.8±0.5	11.9±0.6	11.8±0.5	11.5±0.4	11.7±0.3
		PL	11.5±0.3	11.7±0.4	11.3±0.4	11.9±0.5	11.9±0.5	11.8±0.5
	SPS Index	CHO	44±4	51±3	51±6	39±6	42±4	52±4
		PL	42±4	49±5	46±5	52±5	53±4	46±4
Dribbling	Precision (cm)	CHO	52±2	51±2	52±2	51±2	50±2	50±1
		PL	53±2	52±2	52±2	51±2	50±2	50±2
	Success (%)	CHO	96±2	96±1	92±3	96±1	94±2	96±2
		PL	95±2	92±2	97±1	92±1	98±1	92±2
	Speed (m·s ⁻¹)	CHO	3.9±0.1	4.0±0.1	3.8±0.1	3.9±0.1	3.9±0.1	4.0±0.1
		PL	3.8±0.1	3.9±0.1	4.0±0.1	3.9±0.1	3.9±0.1	3.9±0.1
	SPS Index	CHO	25±1	25±1	23±1	24±1	24±1	25±1
		PL	23±1	24±1	26±1	24±1	25±1	24±1

SPS Index: Speed-precision-success Index; CHO: carbohydrate trial; PL: placebo trial

6.3.2 Physiological demand and exercise intensity

Mean and peak HR values were not influenced by supplementation (CHO, PL: 145 ± 2 , 146 ± 2 beats·min⁻¹, $P=0.745$; CHO, PL: 187 ± 1 , 188 ± 2 beats·min⁻¹, $P=0.754$). RPE rose significantly over time reaching 16 ± 1 units at 90 min of exercise (time of sample effect: $F_{(5,70)} = 60.301$, $P<0.001$); however, supplementation did not influence RPE during the SMS (treatment effect: $F_{(1,14)} = 0.003$, $P=0.958$), indicating that the overall intensity of the protocol remained consistent between trials. Sprint speed reduced over the course of the protocol (time of sample effect: $F_{(5,70)} = 11.714$, $P<0.001$), with $2.0 \pm 0.1\%$ and $3.3 \pm 0.1\%$ reductions in CHO and PL trials, respectively (Figure 6.3). However, supplementation did not influence the pattern of response (time x treatment interaction effect: $F_{(1,14)} = 0.015$, $P=0.685$). Although the mean volume of fluid ingested was 1970 ± 48 ml, BM declined from initial values in both trials. Average sweat loss was greater during the CHO trial (2.4 ± 0.2 kg) than the PL trial (2.1 ± 0.1 kg; $P=0.025$).

6.3.3 Blood metabolites

Supplementation influenced the pattern of response in blood glucose concentrations (time x treatment interaction effect: $F_{(8,112)} = 5.220$, $P=0.002$). Following CHO ingestion, blood glucose concentration increased by $11.6 \pm 0.1\%$ above rest at pre-exercise, and remained elevated until 60 min, when concentrations declined by 1.9 ± 0.3 mmol·L⁻¹ from the half-time value. Conversely, blood glucose concentrations

were similar at rest and pre-exercise during the PL trial, before peaking after 15 min of exercise, and gradually declining thereafter (Figure 6.4).

Blood lactate concentrations were elevated above resting values from 15 min of exercise (time of sample effect: $F_{(8,112)} = 49.761$, $P < 0.001$); however, supplementation did not influence the blood lactate response to exercise (time x treatment interaction effect: $F_{(8,112)} = 1.291$, $P = 0.255$; Figure 6.4). Similarly, exercise caused reductions in blood pH (time of sample effect: $F_{(8,112)} = 15.657$, $P < 0.001$; Figure 6.4) that were not influenced by supplementation (time x treatment interaction effect: $F_{(8,112)} = 1.560$, $P = 0.669$). Interestingly, blood pH recovered to pre-exercise values from 30 min onwards ($P > 0.05$).

6.3.4 Acid-base balance

Base excess (time of sample effect: $F_{(7,98)} = 52.026$, $P < 0.001$), standard blood bicarbonate (time of sample effect: $F_{(7,98)} = 53.783$, $P < 0.001$) and actual blood bicarbonate (time of sample effect: $F_{(7,98)} = 53.961$, $P < 0.001$) were depressed at each time-point throughout exercise (Figure 6.5); however, supplementation did not influence these markers during the SMS (Base excess treatment effect: $F_{(1,14)} = 0.021$, $P = 0.887$, standard blood bicarbonate treatment effect: $F_{(1,14)} = 0.014$, $P = 0.908$, actual blood bicarbonate treatment effect: $F_{(1,14)} = 0.086$, $P = 0.774$).

6.3.5 Hydration markers

Although the protocol influenced estimated changes in plasma volume (main effect of time: $F_{(8,112)} = 9.101$, $P < 0.001$), values were not different from pre-exercise values at any time-point and supplementation did not affect the pattern of response (time x treatment interaction effect: $F_{(8,112)} = 0.898$, $P = 0.521$). Plasma osmolality was not influenced by supplementation (treatment effect: $F_{(1,14)} = 0.430$, $P = 0.523$) or exercise (time of sample effect: $F_{(1,14)} = 1.787$, $P = 0.203$), being 287 ± 4 and 294 ± 4 mosmol \cdot kg $_{H_2O}^{-1}$ at rest and following exercise, respectively.

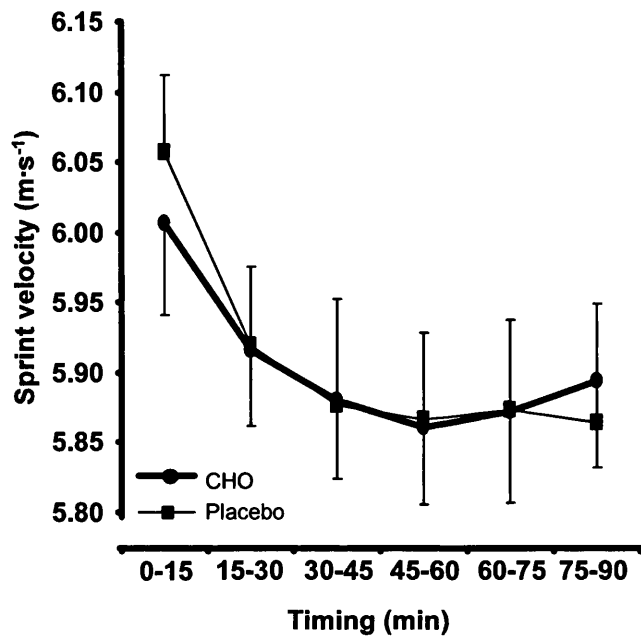


Figure 6.3: Sprint velocities during the carbohydrate (CHO) and placebo (PL) trials

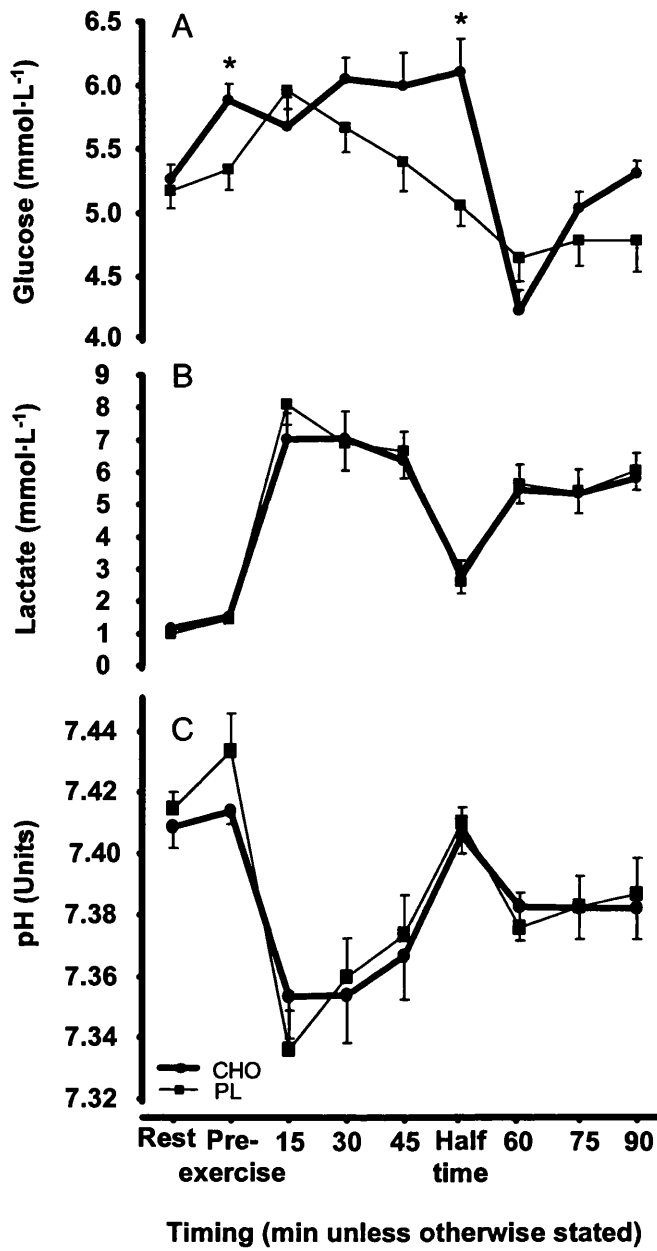


Figure 6.4: Blood glucose concentrations (A), lactate concentrations (B), and pH (C) during the carbohydrate (CHO) and placebo (PL) trials. * Represents significant difference ($P < 0.01$) between treatments

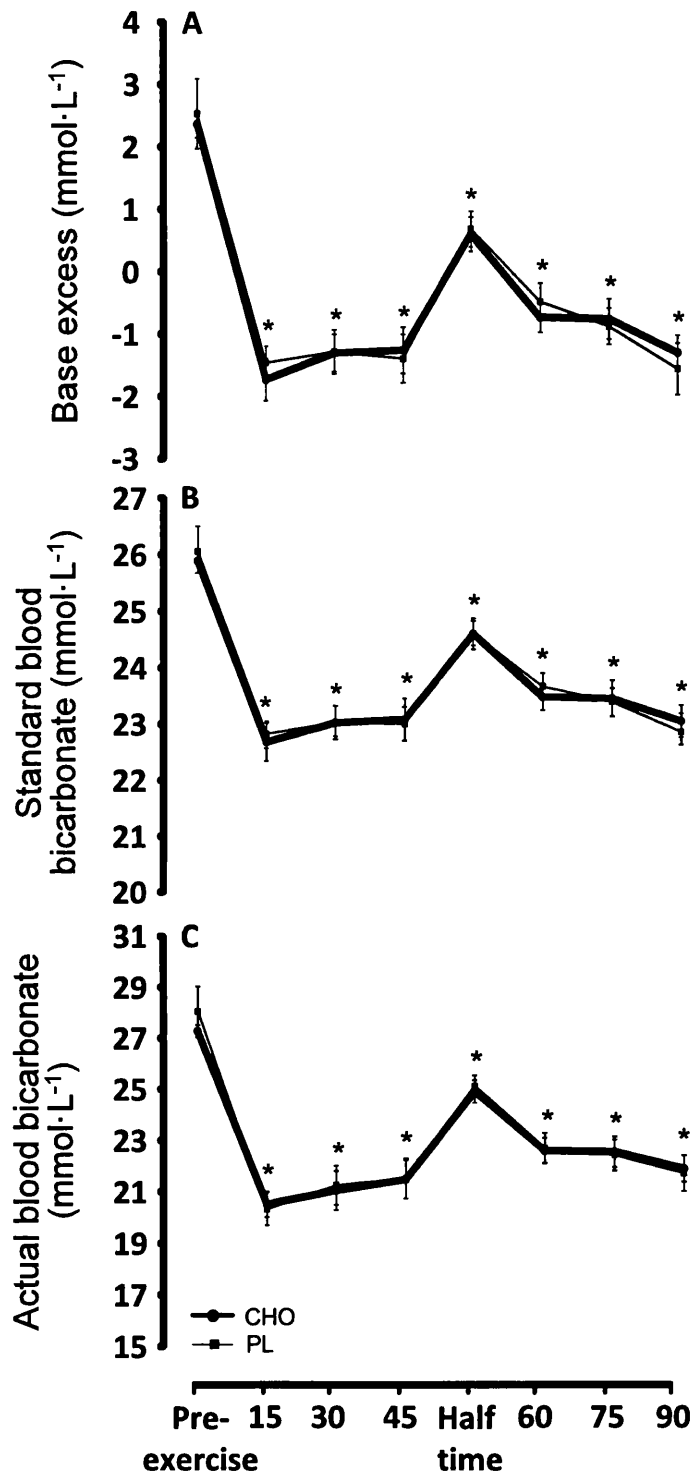


Figure 6.5: Base excess (A), standard blood bicarbonate (B), and actual blood bicarbonate (C) during the carbohydrate (CHO) and placebo (PL) trials. * Represents significant difference ($P < 0.01$) compared to corresponding pre-exercise value.

6.4 DISCUSSION

The main finding of this study was that supplementation with a 6% carbohydrate-electrolyte solution attenuated the decline in shooting performance that occurred at the end of a soccer-specific exercise and skill protocol, where shot speed and shooting performance were improved by approximately 10% at the end of exercise compared to a placebo. Precision, success rate, ball speed, and performance of passing and dribbling were maintained throughout exercise in both trials. Although the current carbohydrate supplementation strategy elevated blood glucose concentrations throughout the first half of exercise, a significant decline in blood glucose concentrations was observed, following half-time, at 15 min into the second half of exercise.

Exercise did not significantly influence precision, success, ball speed, or performance in passing or dribbling at any time during the protocol. However, average shot speed declined throughout the exercise protocol without a loss of shooting precision in the placebo trial. Reduced shot velocities under fatiguing conditions have previously been reported (Kellis *et al.*, 2006; Ali *et al.*, 2007b). This finding provides evidence for a *speed-accuracy trade-off* (Fitts and Posner, 1967), where participants sacrificed shot speed to ensure that accuracy was maintained over the duration of the trial. Additionally, the SPS_{shooting} index, an overall index of shooting performance, was significantly lower at the end of exercise.

Participants covered a distance (10.1 km) that corresponds to distances covered by players during soccer matches (Bangsbo *et al.*, 1991; Rienzi *et al.*, 2000; Mohr *et*

al., 2003; Di Salvo *et al.*, 2007) and the responses of HR, sprint speed, blood lactate concentration, and blood pH were reflective of match-play (Krustrup *et al.*, 2006); consequently, observations from the present study suggest that actions involved in determining success in soccer, such as shooting, are compromised under fatiguing situations. In support of this, fatigue has been previously reported to occur towards the end of soccer match-play (Reilly and Thomas, 1979; Bangsbo *et al.*, 1991; Rienzi *et al.*, 2000; Mohr *et al.*, 2003; Di Salvo *et al.*, 2007) and throughout the SMS (study 3).

Carbohydrate supplementation attenuated the reduction in shot speed and the SPS_{shooting} index, where improvements of approximately 10% were observed in both variables at the final time-point when the participants received CHO compared with PL. As glucose is the principal energy source for cerebral metabolism, the brain is dependent on a continuous supply of circulating blood glucose (Duelli and Kuschinsky, 2001). It is therefore plausible that exogenous carbohydrate might have enhanced skill performance by preserving the integrity of the central nervous system (Ross and Leveritt, 2001). In support of this hypothesis, blood glucose concentrations were higher at selected time-points in CHO when compared with PL. However, as no measure of cerebral glucose levels were taken, although attractive, this mechanism remains somewhat speculative. Furthermore, the current study used a placebo solution that supplied the same amount of electrolytes as the CHO solution. Supplementation did not influence plasma osmolality; therefore, it is likely that the ergogenic effects reported above were caused by exogenous carbohydrate rather than any influence on hydration or ionic balance.

One of the main reasons for including carbohydrates in sports drinks is to increase exogenous carbohydrate oxidation during exercise. Commercial sports drinks generally include carbohydrates at concentrations between 6% and 8%. However, the type of carbohydrate that is included varies greatly between manufacturers. Combining carbohydrates (e.g., glucose and fructose) in a drink has been suggested to increase carbohydrate oxidation rates (Jeukendrup and Jentjens, 2000); consequently, many sports drinks now include 2 or 3 carbohydrates (including glucose, maltodextrins, fructose and sucrose). Sucrose is a disaccharide of glucose and fructose that has the potential to utilise multiple intestinal transport mechanisms. Although few studies have investigated the oxidation of ingested sucrose during exercise, these investigations demonstrate that exogenous carbohydrate oxidation rates are similar to those following the consumption of glucose (Jeukendrup and Jentjens, 2000). Furthermore, peak exogenous carbohydrate oxidation rates during exercise are similar when carbohydrate is consumed in the form of sucrose (Jentjens *et al.*, 2005) or maltodextrins (Wallis *et al.*, 2005). Consequently, sucrose promotes high exogenous oxidation rates that are comparable to those of glucose and maltodextrins and, therefore, the efficacy of these carbohydrates may be similar.

After supplementation with carbohydrates, blood glucose concentrations rose by approximately 12% when sampled at the pre-exercise time-point, and remained elevated until 60 min. However, an unexpected outcome of this study was that ingesting carbohydrate-electrolyte beverages, in a manner that adheres to published guidelines (e.g., Convertino *et al.*, 1996) and is similar to supplementation regimes that are commonly used by competitive teams, caused a transient decrease in blood glucose concentrations 15 min into the second half of exercise. This study confirms

the occurrence of an exercise-induced rebound glycaemic response, first identified in study two (albeit under conditions of a fluid-electrolyte ingestion opposed to carbohydrate-electrolyte ingestion), during team sports such as soccer. Unlike other studies that have investigated the effects of carbohydrate supplementation during exercise that simulates high intensity intermittent exercise (e.g., Nicholas *et al.*, 1999; Ali *et al.*, 2007b), the SMS protocol included a half-time recovery period and collected blood samples at frequent intervals during exercise (i.e., every 15 min and at half-time). Furthermore, the plasma glucose responses to exercise while consuming exogenous glucose and sucrose are similar (Jentjens *et al.*, 2005); therefore, it is unlikely that this finding is limited to drinks that contain sucrose alone.

It is probable that consuming a carbohydrate of relatively high glycaemic-index during the half-time break caused blood glucose and insulin concentrations to be elevated at the onset of exercise. With the onset of exercise at the start of the second half, the combined effect of an increase in glucose uptake by exercising muscles (due to the translocation of GLUT-4 transporters to the muscle membrane) and exposure of tissues to insulin caused the rate of disappearance to exceed the rate of appearance and resulted in a transient fall in blood glucose concentrations. Although average blood glucose concentrations at 60 min were above a criteria value of $3.5 \text{ mmol}\cdot\text{L}^{-1}$, which has been referred to as “rebound hypoglycemia” when exercise manipulations have been used to promote hypoglycaemic responses (e.g., DeMarco *et al.*, 1999), it is not clear if the timing of this sample was optimal to measure minimum blood glucose concentrations. In addition, the physiological effects of this

rapid reduction in blood glucose concentrations (~30% of half-time values) are unclear.

In this study the rebound glycaemic response was not associated with a detectable decline in skill; however, it should be noted that passing was the only skill that was tested at this time-point. It is possible that the drop in blood glucose concentrations during the second half of exercise might have negated any ergogenic effect of carbohydrate supplementation during this period of exercise. Consequently, there is scope to investigate carbohydrate supplementation strategies that have the potential to maintain elevated blood glucose concentrations throughout the duration of the game. Specifically, supplementation strategies should focus on maintaining elevated blood glucose concentrations during the second half of play, when skill was demonstrated to decline.

The finding that carbohydrate supplementation attenuated the loss of shooting performance following a prolonged period of intermittent exercise is in agreement with Ali *et al.* (2007b). Interestingly, these authors were only able to identify differences in shooting performance when slower shots were excluded from the analysis. This suggests that participants modified shot speed to maintain accuracy and supports the current finding that fatigue influenced shot speed. In the current study, all participants began both main trials having refrained from strenuous exercise for two days and were fed a pre-exercise meal. Consequently, it can be assumed that these participants started exercise in a physiological state that is generally recommended for team sport players; therefore, enhancing the ecological validity of these findings.

Despite benefits in skill being identified, no effect of CHO supplementation on sprint performance occurred. This finding supports those of Northcott *et al.* (1999); however, other studies have noticed improvements in sprint performance with CHO supplementation during intermittent exercise (Welsh *et al.*, 2002; Winnick *et al.*, 2005; Ali *et al.*, 2007b). These equivocal findings might be a function of the number of sprints completed; Welsh *et al.* (2002) and Winnick *et al.* (2005) observed improved sprinting performance following CHO supplementation in a basketball simulation requiring the completion of 40 sprints. Ali *et al.* (2007b) also observed improved sprinting performance in participants with compromised glycogen stores following CHO supplementation; however, it is possible that starting exercise with compromised glycogen stores adversely affected sprint performance.

Using comparable methods to those used in this study, Rampinini *et al.* (2009b) have reported that blood bicarbonate is depressed from pre-exercise values following intermittent exercise. Data from the present study supports this observation (Figure 6.5); however, in addition to evaluating acid-base balance before and after exercise, this is the first study to provide information concerning the transient changes in blood bicarbonate and base excess that occur during simulated soccer match-play. Interestingly, although buffering capacity was reduced throughout the full duration of exercise, blood pH stabilised after 30 min. Therefore, interventions that improve buffering capacity may be of benefit to soccer players.

In summary, CHO supplementation attenuated a fatigue-induced decline in soccer shooting performance; therefore, the CHO supplementation strategy was successful in improving skills that are directly related to success in soccer. However, the specific skills of passing and dribbling were not influenced by fatigue. Similar to the response observed in study two, a sharp decline in blood glucose concentrations occurred in all but one of the participants supplemented with CHO at 60 min of exercise. As cognitive processes are crucial to the performance of skilled actions undertaken in competitive team sports, and the provision of sufficient glucose is vital for cognitive function, it is possible that more effective CHO supplementation strategies could be developed to maximise skilled performances during high intensity intermittent exercise.

CHAPTER SEVEN

STUDY FIVE

The effects of carbohydrate ingestion prior to and during soccer match-play

7.1 INTRODUCTION

Soccer is a high intensity intermittent team sport played over 90 min that consists of two 45-min halves, which are separated by a half-time recovery period. Over the duration of a match, muscle glycogen becomes compromised in specific fibres (Krustrup *et al.*, 2006) and blood glucose concentrations fall to levels that might impair cognitive function (Shephard and Leatt, 1987). Consequently, players are often encouraged to consume carbohydrates throughout a match in an effort to spare muscle glycogen and maintain blood glucose concentrations for the full duration of exercise. A number of studies have examined the effects of carbohydrate supplementation on metabolic responses during simulated (e.g., Nicholas *et al.*, 1995; Clarke *et al.*, 2008) and actual soccer match-play (e.g., Zeederberg *et al.*, 1996; Ostojic and Mazic, 2002). It has been generally suggested that blood glucose concentrations are better maintained in the latter stages of soccer-specific exercise when a carbohydrate supplement is ingested (Ostojic and Mazic, 2002; Clarke *et al.*, 2008). However, differences in the exercise protocol employed and the fact that blood samples have not been taken at regular intervals during exercise mean that the pattern of blood glucose response during soccer match-play is unclear.

It is well known that consuming a high-glycaemic index carbohydrate in the hour before exercise can lower blood glucose levels 15-30 min after starting exercise (e.g., Costill *et al.*, 1977; Chryssanthopoulos *et al.*, 1994; Jentjens *et al.*, 2003; Jentjens and Jeukendrup, 2003). Free fatty acid inhibition is a likely contributor to increased carbohydrate utilisation during an isolated bout of exercise completed soon after carbohydrate ingestion (Costill *et al.*, 1977). However, the influence of

carbohydrate supplementation on the glycaemic response to a bout of exercise that is completed after a passive recovery from a previous bout of exercise has received little attention. This is somewhat surprising as most team sports include a half-time break and, therefore, follow this pattern of activity.

The half-time break is often considered crucial in team sports for primarily tactical reasons; however, the half-time can also be viewed as a recovery period following the first half, a period of preparation before the second half, an opportunity to provide exogenous fluids, and a transition between the two halves of play. Despite the potential for a period of recovery between two bouts of exercise to influence physiological responses, it has not been common practice for exercise simulations that aim to replicate the demands of high intensity intermittent sports (such as soccer) to include a half-time recovery period (e.g., Nicholas *et al.*, 1995; McGregor *et al.*, 1999; Drust *et al.*, 2000; Ali and Williams, 2009; Foskett *et al.*, 2009; Ali *et al.*, 2010). Therefore, the ecological validity of studies aiming to replicate the demands of team sports might be improved by including a half-time break (e.g., Bishop *et al.*, 1999; Kingsley *et al.*, 2005; Clarke *et al.*, 2008).

The findings from chapters 4 and 6 identified that a sharp reduction in blood glucose concentrations occurred after the onset of exercise following a half-time recovery period. Although the mechanisms of this response remain to be elucidated, it is probable that increased glucose uptake, due to the translocation of GLUT-4 transporters to the muscle membrane, and exposure of tissues to insulin caused the rate of disappearance of blood glucose to exceed the rate of appearance; the net effect being a transient fall in blood glucose concentrations (termed the exercise-

induced rebound glycaemic response) at the onset of exercise at the start of the second half.

In summary, compromising glucose availability has the potential to negatively influence motor skills and cognitive function which are vital for optimum performance in intermittent sports, such as soccer. Although soccer players are often encouraged to consume carbohydrate-electrolyte solutions, carbohydrate supplementation has been recently reported to result in an exercise-induced rebound glycaemic response while players completed a soccer-specific exercise protocol. However, data with sufficient resolution are not currently available to establish the existence of this phenomenon during actual soccer match-play while carbohydrate-containing beverages are routinely being ingested; therefore, the aim of the current study was to investigate metabolic responses to carbohydrate ingestion prior to and during soccer match-play. The null hypothesis associated with this study was that there would be no difference in the metabolic responses of soccer players who consumed carbohydrate-electrolyte or fluid-electrolyte beverages prior to, and during soccer match-play.

7.2 METHODS

7.2.1 Participants

Ten soccer players (age: 16 ± 1 years, height: 1.74 ± 0.02 m, mass: 65.1 ± 1.9 kg, estimated $\dot{V}O_{2\max}$: 58.4 ± 0.6 ml·kg⁻¹·min⁻¹) from a British Championship team volunteered and completed all of the study requirements. Following approval by a University ethics committee, the players were informed about the potential risks of the study and written informed consent was obtained prior to participation. Players were recruited on the basis that they had no injuries, were non-diabetic, and had regularly participated in training with their club for at least twelve months before the start of the study.

7.2.2 Study design

Players attended a preliminary visit, where the procedures of the main trials were explained and maximum oxygen uptake was estimated using the multistage fitness test (MSFT; Ramsbottom *et al.*, 1988). Two main trials (CHO and PL), separated by one week, were completed in a counter-balanced, randomised, double-blind and cross-over fashion. Players were asked to refrain from strenuous physical activity and caffeine consumption in the two days preceding all testing sessions. Additionally, players recorded all food consumed in the two days before each main trial. Food records were subsequently analysed using commercially available software (CompEat version 5.8.0; Nutrition Systems, UK). All players gave verbal

confirmation that they had complied with these instructions on completion of the study.

7.2.3 Main trial procedures

On arrival at the laboratory at 17:00 hours the players emptied their bowels and provided a mid-flow urine sample. Urine osmolality was subsequently measured by freezing point depression (Gonotec Cryoscopic Osmometer Osmomat 030; YSI Limited, UK). A resting capillary blood sample was then taken at 17:30 hours before players consumed a standardised 1470 kJ meal (Energy content: 62% carbohydrates, 25% fats, 13% proteins) and 500 ml of the treatment beverage. Body mass (BM; model 770: Seca Ltd, Birmingham, UK) and stature (Portable Stadiometer; Holtain Ltd, Wales, UK) were then measured. Players then remained in a rested state for approximately 90 min before commencing a 30-min standardised warm-up (consisting of running, dynamic stretching and ball skills) that preceded the match kick-off at 19:30 hours. Main trial procedures are illustrated in Figure 7.1.

7.2.4 Match

Two soccer matches between the players participating in the study (test team) and an opposing team similar in playing standard were arranged for this study. Procedures for each match are detailed in chapter 2 and players from both teams and the referee were the same in each main trial. Heart rate (HR) was continuously recorded throughout exercise using Team Polar transmitters (Polar, Finland) and values were categorized into four HR zones (HR zone 1: <70% HR_{max}, HR zone 2: 70-79%

HRmax, HR zone 3: 80-89% HRmax, and HR zone 4: 90-100% HRmax) to represent the proportion of match-play spent at each relative exercise intensity. Environmental conditions were measured at kick-off (ETHG-912; Oregon Scientific, USA).

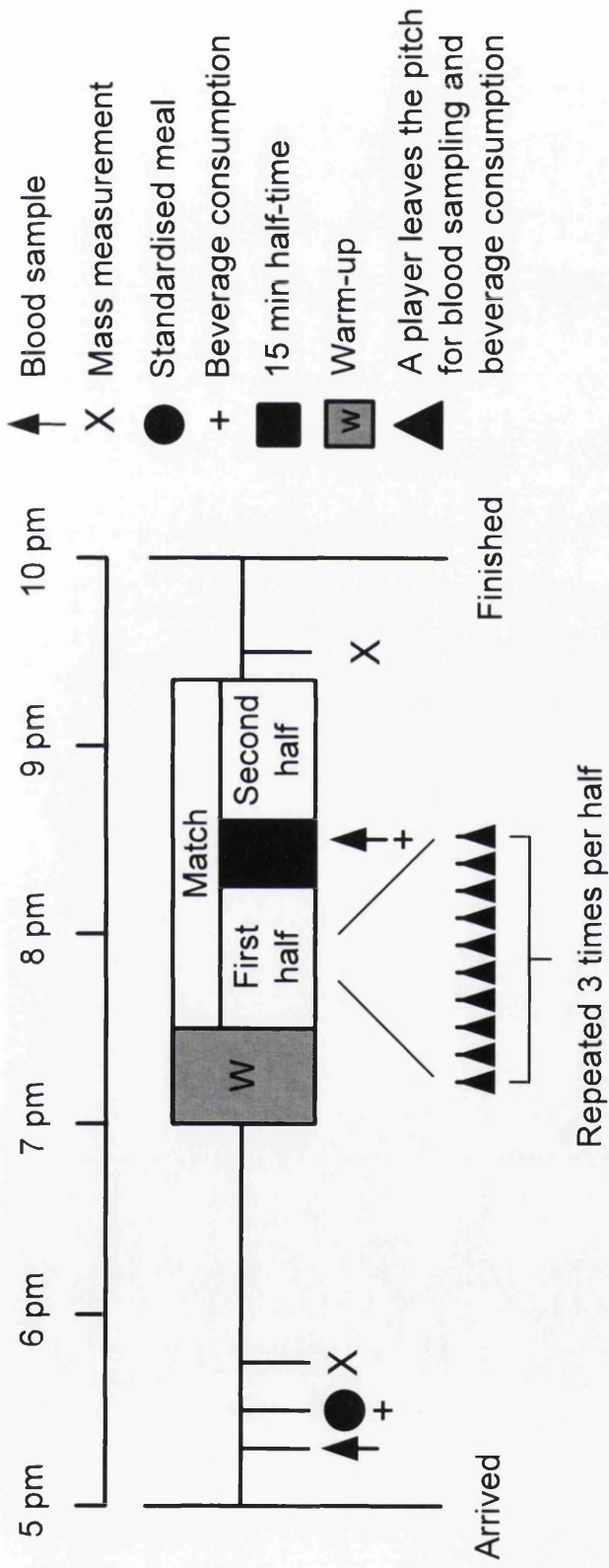


Figure 7.1: Schematic of the main trial procedures

7.2.5 Experimental beverages

An initial bolus of the treatment beverage (500 ml) was consumed at 17:30 hours with the standardised meal, and additional fluid was consumed during the trial at a rate of $14 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$ BM. Equal volumes of fluid were consumed 10 min prior to commencing each half and on every occasion that the players left the pitch for blood sampling during match-play. During the CHO trial, a carbohydrate-electrolyte beverage containing 6% sucrose, $23 \text{ mmol} \cdot \text{L}^{-1}$ sodium and $14 \text{ mmol} \cdot \text{L}^{-1}$ chloride was consumed. The PL beverage was equimolar in terms of electrolytes but void of carbohydrate. Sweetness of the PL beverage was maintained by an energy free artificial sweetener. Both CHO and PL beverages were flavoured with a commercially available fruit cordial (Carbohydrate content $< 0.15 \text{ g} \cdot \text{L}^{-1}$). The drinks were indistinguishable by taste and texture and consumed from identical containers. Following completion of the second main trial, the players reported that they were unable to distinguish between the experimental beverages. During the month before the familiarisation session, players ingested water at a rate of $14 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$ BM during training sessions in order to promote gastric tolerance to this rate of fluid ingestion.

7.2.6 Blood sampling and analyses

Fingertip blood samples were taken at rest, 10 min into half time (half-time) and every 15 min during match-play (first half: 0-15, 15-30, 30-45 min; second half: 45-60, 60-75, 75-90 min). Glucose concentrations were analysed immediately from

whole blood (Medisense Optium Xceed Glucose monitor; Abbott Laboratories, USA). Blood lactate concentrations were analysed using a portable micro-volume lactate analyser (Lactate-Pro; Arkray, Japan). Before both trials, the analysers were calibrated in accordance with the manufacturers' guidelines.

7.2.7 Statistical analyses

Statistical analysis was carried out using SPSS software (Version 16.0; SPSS Inc., USA). All data were reported as the mean \pm standard error of the mean and the level of statistical significance was set at $P \leq 0.05$. All data were assessed for normality by the calculation of *z* scores for skewness and kurtosis data as per previously described methods (Vincent, 1995). Paired sample *t*-tests were used to compare environmental conditions, nutritional intake, urine osmolality and HR variables. Two way repeated measures analysis of variance (ANOVA; within-participant factors: treatment x time of sample) were used where data contained multiple time-points during each main trial. Mauchly's test was consulted and Greenhouse–Geisser correction was applied if the assumption of sphericity was violated. If a significant *P*-value was identified for the interaction effect (time x treatment), CHO supplementation was deemed to have influenced the exercise response and simple main effect analyses were performed. Significant main effects of time (time of sample) were further investigated using multiple pairwise comparisons with Bonferroni confidence interval adjustment.

7.3 RESULTS

Environmental conditions were similar during both trials; with ambient temperature being $5.5 \pm 0.1^\circ\text{C}$, barometric pressure being 761 ± 1 mmHg, and humidity being $64 \pm 4\%$. Players arrived in a similar hydration state on both occasions (CHO, PL: 570 ± 140 mOsmol $\cdot\text{kg}_{\text{H}_2\text{O}}^{-1}$, 420 ± 130 mOsmol $\cdot\text{kg}_{\text{H}_2\text{O}}^{-1}$, $P=0.349$). The calculated daily diet comprised of 11.6 ± 0.6 MJ $\cdot\text{d}^{-1}$, of which $53 \pm 2\%$, $31 \pm 2\%$ and $16 \pm 1\%$ of energy intake was obtained from carbohydrates, fats, and proteins, respectively.

7.3.1 Physiological demand and exercise intensity

Mean and peak HR values were not influenced by supplementation and no differences existed between trials in the percentage of time spent in each HR Zone during match-play (Table 7.1). The mean volume of fluid ingested was 1874 ± 40 ml and average sweat losses were similar between trails (CHO, PL: 1.2 ± 0.1 , 1.0 ± 0.1 kg; $P=0.291$).

Table 7.1: Heart rate (HR) response to match-play during the carbohydrate (CHO) and placebo (PL) trials

Variable	CHO	PL	<i>P-value</i>
Peak HR (beats·min ⁻¹)	196 ± 3	193 ± 2	0.150
Mean HR (beats·min ⁻¹)	158 ± 3	157 ± 2	0.641
HR zone 1 (%)	12 ± 2	13 ± 4	0.660
HR zone 2 (%)	25 ± 4	28 ± 6	0.136
HR zone 3 (%)	47 ± 4	45 ± 8	0.532
HR zone 4 (%)	17 ± 5	14 ± 6	0.558

HR zone values present the percentage of match-play spent in each heart rate zone. HR zones are derived from maximum HR values (HRmax), where HR zone 1: <70% HRmax, HR zone 2: 70-79% HRmax, HR zone 3: 80-89% HRmax, and HR zone 4: 90-100% HRmax. *P-value* from paired samples t-test.

7.3.2 Blood metabolites

Supplementation influenced the pattern of response in blood glucose concentrations (time x treatment interaction effect: $F_{(7,63)} = 2.182, P=0.048$). CHO ingestion elevated blood glucose concentration by $30 \pm 12\%$ above rest at the end of the first half (30-45 min); however, re-starting exercise, caused a $40 \pm 4\%$ decrease in blood glucose concentration when compared to pre half-time values (30-45 min: $6.85 \pm 0.42 \text{ mmol}\cdot\text{L}^{-1}$ vs. 45-60 min: $3.94 \pm 0.27 \text{ mmol}\cdot\text{L}^{-1}$, $P=0.002$). Conversely, blood glucose concentrations peaked between 15-30 min and were lower than this value in all samples thereafter during the PL trial (Figure 7.2).

Blood lactate concentrations were elevated above rest during the first 15 min of exercise (time of sample effect: $F_{(7,63)} = 9.748, P<0.001$) and remained elevated throughout exercise. Supplementation did not influence the pattern of response (time x treatment interaction effect: $F_{(7,63)} = 0.934, P=0.487$; Figure 7.2). In the final 15-min of the match, lactate concentrations were $5.0 \pm 0.7 \text{ mmol}\cdot\text{L}^{-1}$.

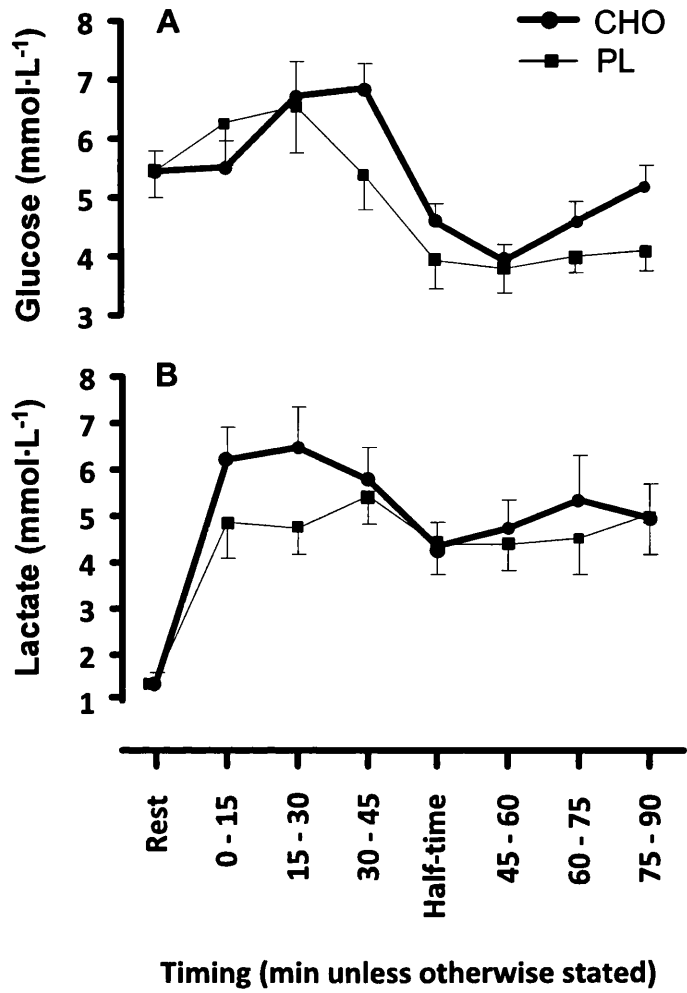


Figure 7.2: Blood glucose concentrations (A) and blood lactate concentrations (B) during the carbohydrate (CHO) and placebo (PL) trials

7.4 DISCUSSION

The primary finding of this study was that the provision of exogenous carbohydrates before and during soccer match-play, in the form of a 6% carbohydrate-electrolyte solution, did not attenuate an exercise-induced rebound glycaemic response when exercise was re-started after a half-time recovery period. Blood glucose concentrations were approximately 30% higher during the last third of the first half after supplementation in CHO when compared with the PL trial; however, on re-starting exercise after a passive half-time period, blood glucose concentrations decreased by approximately 40% from the pre half-time values. This is the first study to document an exercise-induced rebound glycaemic response during competitive play of a team sport, such as soccer, while carbohydrate-electrolyte beverages are routinely being consumed.

The consumption of a high-glycaemic index carbohydrate within the hour of exercise can result in blood glucose responses that reach hypoglycaemic levels ($3.5 \text{ mmol}\cdot\text{L}^{-1}$) in 15-30 min after starting exercise (Costill *et al.*, 1977; Chryssanthopoulos *et al.*, 1994; Jentjens *et al.*, 2003; Jentjens and Jeukendrup, 2003). The normal physiological response to ingesting carbohydrates that increase blood glucose concentrations is an upregulation in the synthesis and secretion of insulin within the beta cells of the islets of Langerhans. The actions of insulin on cell metabolism include decreased lipolysis and increased glucose uptake in liver, skeletal muscle, and fat cells. Consequently, starting exercise when circulatory insulin levels are high (e.g., within 15-30 min of consuming a high-glycaemic index carbohydrate) can cause a net reduction in blood glucose concentrations through

increased muscle glucose uptake via GLUT-4 translocation (Thorell *et al.*, 1999) and increased carbohydrate utilisation through free fatty acid inhibition (Costill *et al.*, 1977).

The transient nature of the hypoglycaemic response during prolonged exercise is partly explained by a stimulation of counter-regulatory hormones, including cortisol, growth hormone and catecholamines (Astrand and Rodahl, 1986). For example, epinephrine has hyperglycaemic effects via the stimulation of glycconeogenesis and increasing liver glucose output as well as directly inhibiting insulin release (Nonogaki, 2000). Although the incidence of rebound hypoglycaemia has not been specifically reported to occur during the onset of high intensity intermittent sports, it is likely that consuming a high-glycaemic index carbohydrate within 30 min of starting this type of activity will elicit a similar glycaemic response as rebound hypoglycaemia is not dependent on exercise intensity (Achten and Jeukendrup, 2003).

However, the effects of insulin and counter-regulatory hormones on the glycaemic response to intermittent match-play following a half-time break (passive recovery) had not been previously reported. These results demonstrate that the delivery of a carbohydrate-electrolyte solution 2 hours prior to starting the match, during half-time, and every 15 min during match-play initially elevated blood glucose concentrations; however, on re-starting exercise following the 15-min half-time period blood glucose concentrations dropped sharply. Although the initial phase of glucose uptake during the recovery from exercise appears to be insulin-independent (Price *et al.*, 1994), an acute bout of exercise increases insulin sensitivity by

increasing glucose uptake in skeletal muscle and decreasing hepatic glucose production during the ensuing recovery period (Stephens *et al.*, 2007). As the physiological responses to both matches were similar (heart rate and blood lactate concentrations) it is probable that the locally-mediated factors responsible for the insulin-independent uptake of glucose were similar between both trials; consequently, consumption of relatively high-glycaemic index carbohydrates during exercise and half-time did not afford any protective benefit from the transient fall in blood glucose concentrations observed after exercise had restarted.

The effect of carbohydrates on exercise performance has been extensively researched since the early 1970's. Although early research suggested otherwise (Foster *et al.*, 1979), there is no convincing evidence to suggest that exercise-induced rebound hypoglycaemia is associated with reduced exercise performance (Jentjens *et al.*, 2003; Jentjens and Jeukendrup, 2003; Hargreaves *et al.*, 2004); however, it must be noted that only physical, and not technical performances have been assessed while participants are in a state of rebound hypoglycaemia. Moreover, no other study has identified an exercise-induced rebound glycaemic response after ingesting CHO during competitive match-play of a team sport, such as soccer. One explanation for the identification of this glycaemic response is the amount of blood samples taken in the current study (i.e., every 15 min during match-play and at half-time). Previous research has incorporated less frequent blood sampling during soccer-specific exercise (Bishop *et al.*, 1999; Ostojic and Mazic, 2002; Clarke *et al.*, 2008); therefore, it is possible that these researchers have not identified this pattern of response due to a lack of sampling resolution.

In support of the current finding, a similar response was identified initially in chapter 4, (study 2) whereby players who participated in actual soccer match-play that included a 15-min half-time break and required the consumption of a fluid-electrolyte beverage throughout exercise, also experienced a decrease in blood glucose concentrations compared to pre half-time values on restarting the second half. Interestingly, the exercise-induced rebound glycaemic response observed in chapter 4 occurred under conditions of ingestion of a fluid-electrolyte beverage that was void of any carbohydrate. Consequently, it may be the inclusion of the half-time recovery period between two bouts of exercise that causes this response. Therefore, if ecological validity is desired, then it is necessary to ensure that the half-time period is incorporated in exercise simulations designed to replicate the demands of soccer match-play.

The final match scores reflected the competitive nature of both matches, where one goal separated the teams on both occasions. HR and blood lactate responses were comparable to previously published values for soccer match-play (Krustrup *et al.*, 2006); furthermore, the proportion of time spent in the relative exercise intensities (HR zones 1-4) were similar between trials and agreed with previously reported values (Tauler *et al.*, 2008). The supplementation regime was similar to published nutritional guidelines on fluid replacement (Convertino *et al.*, 1996) and congruent with strategies currently recommended for soccer players (Clarke *et al.*, 2008). Consequently, the findings from the present study suggest that current carbohydrate-fluid replacement strategies result in a decline in blood glucose concentrations during the second half of soccer match-play. The effects of this exercise-induced

rebound glycaemic response on competitive match-play in team sports, such as soccer, remain to be elucidated.

Blood glucose is the principal energy source for cerebral metabolism (Duelli and Kuschinsky, 2001); therefore, it is possible that the drop in blood glucose concentrations during the second half of exercise might adversely affect the quality of skilled movements executed during this period. It is difficult to ascertain whether this effect was evident in the current study as match-play poses difficulties in terms of experimental control. Nevertheless, findings from study 4 (chapter 6) demonstrated that shooting skill declined in the second half of a soccer-specific exercise protocol. Consequently, there is scope to investigate supplementation regimes that aim to maintain elevated blood glucose concentrations throughout the duration of the match.

In conclusion, a 6% carbohydrate-electrolyte beverage ingested 2 hours before and throughout soccer match-play did not attenuate a sharp decline in blood glucose concentrations in the first 15 min of exercise following the half-time break. These findings suggest that carbohydrate-fluid supplementation regimes that are recommended for high intensity intermittent sports teams result in an exercise-induced rebound glycaemic response during soccer. It is possible that more effective carbohydrate supplementation strategies could be developed to maintain elevated blood glucose concentrations throughout soccer match-play.

CHAPTER EIGHT

GENERAL DISCUSSION

8.0 GENERAL DISCUSSION

The aim of this research was twofold: (1) to develop a soccer-specific exercise protocol that enabled the technical proficiency of soccer passing, shooting and dribbling skills, which were performed throughout exercise, to be assessed in terms of continuous data (as opposed to discrete data obtained from criterion-based techniques), and (2) to use the newly developed protocol and analysis procedures to examine the effects of exercise and acute carbohydrate-electrolyte supplementation on the performance of soccer skills throughout the duration of a simulated match.

Data from study 1 demonstrated that small non-significant biases existed between the speed, precision, and success (determined by video analysis) of passes, shots and dribbles performed on two separate days. Moderate to moderately strong relative reliability was confirmed in at least one outcome measure for all skill tests. The absolute reliability statistics were stronger than those produced by previous soccer skill tests. Consistent with perceptions regarding technical proficiency, Professional players performed better in the skills tests than Recreational players, which supports the construct validity of these tests.

Study 2 validated the soccer match simulation (SMS), which is a soccer-specific exercise protocol that includes, throughout exercise, the passing, shooting and dribbling tests deemed to be reliable in study 1. The physiological and movement demands of the SMS were representative of those observed during actual match-play in a single group of familiarised soccer players. Consequently, the SMS was

effective in replicating the physiological responses that were elicited during a single soccer match.

Study 3 identified that fatigue induced by participation in the SMS negatively influenced passing and shooting performances of familiarised male soccer players during the second half of exercise.

The main finding of study 4 was that supplementation with a 6% carbohydrate-electrolyte solution attenuated the decline in shooting performance that occurred at the end of the SMS, where shot speed and shooting performance were improved at the end of exercise compared to a fluid-electrolyte placebo trial. Interestingly, although the carbohydrate supplementation strategy elevated blood glucose concentrations throughout the first half of exercise, a significant decline in blood glucose concentrations was observed at 15 min into the second half of exercise (termed exercise-induced rebound glycaemic response).

Study 5 aimed to examine whether the glycaemic response observed in simulated soccer match-play, while players routinely ingested a carbohydrate-containing beverage, was present in actual match-play. Results identified that the provision of exogenous carbohydrates before, and during, soccer match-play, in the form of a 6% carbohydrate-electrolyte solution, did not attenuate an exercise-induced rebound glycaemic response when exercise was re-started after a half-time recovery period.

The findings from this series of studies are collectively discussed in this chapter. Where appropriate, conclusions regarding current understanding are included and recommendations for future investigations aimed at evaluating the performance of soccer skills are presented.

8.1 THE USE OF A NEW EXERCISE PROTOCOL THAT SIMULATES SOCCER-SPECIFIC ACTIVITY AND INCORPORATES TECHNICAL ACTIONS THROUGHOUT EXERCISE.

8.1.1 Measuring soccer skill performance

Soccer is a high intensity intermittent sport in which success is determined by the scoring of more goals than an opposing team within the allotted time-frame and while adhering to the games rules. Although physiological prerequisites for predicting success in soccer have previously been identified (for a review see Shephard, 1999), the ability to maintain the proficient execution of soccer skills throughout the full duration of a match can also be considered a crucial determinant of success. Therefore, a number of skills tests have been developed by researchers to measure the “quality” of various technical actions in soccer (see Table 1.1).

The skill tests developed in this thesis are stronger in terms of relative and absolute reliability when compared to existing methods that are currently employed within this area of research. While acknowledging the difficulties in making like-for-like comparisons between skill tests that produce different measurement outcomes, the shooting test used in this study was more reproducible than the Loughborough

Soccer Shooting Test (LSST) reported by Ali *et al.* (2007a); with relative reliability for shooting success and precision (in comparison with intraclass correlation coefficients; ICC and r values for points scored) and absolute reliability (in comparison with coefficient of variance; CV, and ratio limits of agreement; RLOA, for points scored) being more reproducible for the current test. Interestingly, similar test-retest reliability data were reported for the shooting speed in both tests.

Although the outcomes from the Loughborough Soccer Passing Test (LSPT; time taken, time penalties for incorrect actions and total time) are not easily aligned to the outcome measures from the tests developed in this thesis (i.e., speed, precision and success), the relative reliability of these outcomes appear reasonably comparable. Comparing the precision of passing with the total time from the LSPT (representing a global marker of precision) demonstrated that the absolute reliability (CV and RLOA) was better in the current protocol as CV and RLOA values for precision of passing were 10.0% and $0.956 \times \pm 1.147$ (Table 3.3), respectively, in the current protocol while values for the LSPT were reported as 14.4% and $0.92 \times \pm 1.32$ (males; Ali *et al.*, 2007a), and 17.0% and $0.96 \times \pm 1.42$ (females; Ali *et al.*, 2008). Consequently, the battery of tests developed in this thesis offer reliable alternatives to those commonly used when examining technical responses in soccer players.

Information concerning measures of technical proficiency derived from continuous data, such as ball speed, precision (i.e., ball impact represented by the distance from a target) and the success of skills, provides data of greater ecological validity than that resulting from criterion-based outcome tests when comparing performances between players of different standards and/or to published values when players have

been subjected to different conditions (e.g., physiological fatigue or different environmental conditions). For example, the LSPT devised by Ali *et al.* (2007a) has been extensively used to examine the influence of a number of interventions on soccer passing performance in both male and female players (Ali *et al.*, 2007b; Ali and Williams, 2009; Foskett *et al.*, 2009; Ali *et al.*, 2010); however, the criterion scoring methods used in this protocol assess passing performances in terms of points scored and/or units of time. Therefore, the application of findings from the LSPT is limited due to a lack of ecological validity.

A 20-m timed sprint-dribble devised by McGregor *et al.* (1999) has also been used to assess technical proficiency. A 2.4% reduction in body mass (BM) due to fluid abstinence during a soccer-specific exercise protocol caused a 5% reduction in dribbling performance relative to a fluid-provision trial. In this test of soccer skill, which has also been employed by other authors (e.g., Ostojic and Mazic, 2002), the main performance variable is speed, with no concern for the “quality” of the dribble. From an applied perspective, it is not true to assume that a faster time on such tests would represent a more skilled action as a skilled dribbler is able to keep the ball close to the desired position while travelling at a high speed; consequently, a lack of ball control will increase the likelihood of losing possession of the ball. Therefore, the ability to quantify the actual ball position in relation to a desired position (precision) and the ability to complete the desired task without mistakes (success rate) are measurement outcomes of additional interest to the researcher, coach or player, that provide further information about the proficiency of this technical action. The skill tests incorporated within the SMS are the first to provide such data as

independent outcome measures in relation to passes, shots and dribbles performed by soccer players.

To date, quantitative and continuous data that describes the speed, precision, and success rate of technical performances executed under conditions requiring visual searching and decision making, has been scarce. Nevertheless, the shot speeds recorded throughout this thesis were slightly lower than those observed previously in male soccer players (Ali *et al.*, 2007a). This lack of agreement may be explained by differences in the technology used to measure this outcome; for example, Ali *et al.* (2007a) used a speed gun to measure shot speed, which measures ball speed at a particular point in flight, whereas the current methods used video analysis and defines the average ball speed throughout the full flight. Additionally, it is possible that these differences might partly reflect variations in the target size between the two studies which could have impacted on the *speed-accuracy trade-off*.

According to Williams and Reilly (2000), proficient skill performance is affected by cognitive factors such as decision making and game intelligence. When performing passing and shooting, the randomised lighting system used for target identification in this thesis incorporated perceptual abilities, such as decision making and visual searching. Although the direct involvement of these cognitive aspects of performance on the skills executed were unable to be determined, the development of a sensitive measure of soccer skill performance that can differentiate between playing standard and that incorporates perceptual skills, thus representing the demands of competitive match-play, increases the ecological validity of the tests used and the findings produced.

The usage of lighting systems in comparison to stimuli that are greater in sports-specificity have previously been questioned in reactive agility sprint tests that afford a greater advantage to players with superior anticipation, reaction time and pattern recognition skills (Sheppard *et al.*, 2006). The randomised lighting system employed in this study enabled target identification when participants performed either passing or shooting skills. As the outcome measures used in the current battery of skills tests were not dependent on total performance time (providing that passes and shots were executed from within the action zone), it is unclear as to the direct involvement of these cognitive factors in the skills tests employed. Nevertheless, the benefit of using a lighting system is that the timing of the target identification signal is controlled and repeatable; using humans to provide the stimulus (e.g., verbal target identification as per Ali *et al.*, 2007a) can introduce variation between repeated trials which may influence skilled outcomes.

Differences in the analysis methods employed make the like-for-like comparison of data between that presented in this thesis to existing soccer skill research difficult; nevertheless, the data presented concerning the reliability (study 1), the validity (studies 1 and 2), and application (studies 3 and 4) of such methods provide strong evidence that alternatives do exist to the previously employed criterion-based outcome measures when assessing the technical proficiency of soccer players. Therefore, researchers are encouraged to incorporate methods similar to those demonstrated to be reliable and show construct validity in this thesis, as the value of an intervention can be evaluated more effectively if the outcome measure is calculated in ecologically valid units.

8.1.2 Simulating soccer-specific exercise

Study 2 validated a new exercise protocol, named the SMS, that replicated the demands of match-play and incorporated the skills tests found to be reliable in study 1. Although the total count of technical actions performed throughout the SMS exceeded that which were performed during a single soccer match (study 2), the number of technical actions were still comparable to previously published literature (Bloomfield *et al.*, 2007). Moreover, the SMS elicited physiological variables associated with exercise intensity that: replicated the responses observed during match-play (study 2), were similar across multiple trials (studies 2, 3, and 4), and were congruent with previously published literature (Krustrup *et al.*, 2006).

An exercise simulation that has commonly been used to replicate the physiological and movement responses of soccer players is the Loughborough Intermittent Shuttle Test (LIST; Nicholas *et al.*, 2000) which consists of 75 min of intermittent activity followed by a run of alternating intensity until volitional exhaustion. Surprisingly, despite the extensive use of the LIST in interventional research (e.g., Nicholas *et al.*, 1995; Nicholas *et al.*, 2000; Morris *et al.*, 2003; Erith *et al.*, 2006), no previous data exists concerning the validity of responses of simulated to actual match-play in a study design that uses a single subject population. Furthermore, only one study to date has aimed to directly assess the validity of any exercise protocol that was designed to mimic the physiological demands of a soccer match (Thatcher and Batterham, 2004). However, the exclusion of technical actions throughout this protocol in combination with the unidirectional pattern of activity performed on the

treadmill limit the ecological validity of physiological data derived from players participating in this simulation.

It is a more common approach for authors to validate the demands of an exercise simulation against the physiological and physical responses elicited by a different subject population (e.g., Drust *et al.*, 2000; Nicholas *et al.*, 2000; Williams *et al.*, 2010); consequently, the data presented in study 2 is unique in the fact that the same participants were used to validate a soccer-specific exercise protocol that, unlike the LIST, includes a half-time period and game specific skills.

The variation in demands, and responses to these demands, limit the use of actual soccer match-play in interventional research; consequently, exercise simulations that elicit controlled and repeatable physiological responses are favoured. However, despite the importance of soccer skills to determining the outcome of a competitive fixture, it has not been common practice for researchers to incorporate the performance of technical actions throughout such simulations. Nevertheless, of the previous authors that have incorporated the performance of soccer skills into exercise simulations, such skill tests have generally been assessed before and after exercise; consequently, limited information exists regarding the potential time-course of decay of skilled actions during a match.

McGregor *et al.* (1999) required participants to perform a timed dribbling task before and after 90 min of soccer-specific exercise. Similarly, Ali *et al.* (2007b) investigated the ergogenic potential of carbohydrate-electrolyte provision relative to a non-electrolyte placebo beverage on passing and shooting skills performed before

and after a modified LIST protocol. Consequently, despite some authors having investigated the effects of exercise and various ergogenic aids on the quality of skilled performances in soccer (McGregor *et al.*, 1999; Ali *et al.*, 2007b), assessing skills before and after exercise, as used in earlier research in this field, fails to fully replicate the demands of soccer match-play in which skills are performed throughout exercise.

The development of the SMS aimed to further the recent work that has sought to address the problem of a lack of soccer skills performance during intermittent exercise (e.g., Rampinini *et al.*, 2008; Ali and Williams, 2009; Currell *et al.*, 2009; Foskett *et al.*, 2009; Ali *et al.*, 2010). Although previous authors have required male and female soccer players to perform a passing task every 15 min throughout a 90 min modified LIST protocol (Ali and Williams, 2009; Ali *et al.*, 2010), the failure to include a half-time period within the protocol may elicit physiological responses that are not indicative of those that occur during actual match-play. This claim is substantiated by the pattern of response in blood glucose concentrations observed in studies 2, 4, and 5, that may be influenced in part by the cessation of activity during the half-time recovery period.

It is possible that previous researchers have failed to incorporate skilled actions within soccer-specific exercise simulations due to the skill level of the potential subject becoming a limiting factor for participation in protocols that incorporate technical performances. Consequently, researchers investigating the physiological responses of younger and/or a lower standard of player during simulated soccer match-play (where the technical proficiency may not be as high as in older and/or

higher standard of player, respectively), might wish to consider the type of skills tests (if any) incorporated within their choice of exercise simulation.

In summary, the SMS is a valid simulation of soccer match-play that incorporates reliable soccer skills tests throughout the full duration of a match that are capable of distinguishing between players of different standards. Consequently, the SMS has potential utility in studies investigating the effects of various interventions on performance in familiarised soccer players.

8.2 FACTORS AFFECTING THE PERFORMANCE OF SOCCER SKILLS DURING EXERCISE

8.2.1 Match-related fatigue

Studies 3 and 4 demonstrated that prolonged intermittent soccer-specific exercise influenced the quality of performance of soccer skills. Although relatively few studies have examined the effect of exercise on soccer skills performed throughout the duration of a match, these findings are in agreement with the data of Currell *et al.* (2009) who observed that kicking accuracy was compromised throughout an exercise simulation that required stationary balls to be kicked towards a target approximately every 15 min. Similarly, Ali and Williams (2009) identified that performance in a criterion-based passing test (i.e., LSPT) was reduced in the last 15 min of a 90 min exercise protocol that excluded a half-time recovery period. Although the results of such studies are questionable on the basis of methodological limitations regarding the ecological validity of the skills tests used and the pattern of

activity performed, the available data used in conjunction with that presented in trials 3 and 4, suggest that exercise influences the performance of soccer skills in familiarised male soccer players.

The findings from this thesis, in combination with that of previous authors (Abt *et al.*, 1998; McGregor *et al.*, 1999), suggest that soccer dribbling is more resilient to the effects of match-related fatigue than either passing or shooting. Although the specific reason for this finding requires further elucidation, differences in the influence of fatigue on skills with varying degrees of peak muscular activity, and/or variations in the distance that the ball travels between touches when performing the different skills may offer explanations. Nevertheless, despite McGregor *et al.* (1999) initially identifying that fluid abstinence during intermittent exercise resulted in a 5% decline in dribbling performance, players who were in a physiological state that is more representative of that advocated by sports teams (i.e., consumed a carbohydrate-free solution throughout exercise) maintained their times on the sprint-dribbling task. As dribbling performance was maintained during the SMS throughout studies 3 and 4, despite reductions in sprint speed occurring, these observations may highlight the potential shortcomings of timed dribble tests whose outcomes are heavily influenced by sprint speed (McGregor *et al.*, 1999; Ostojic and Mazic, 2002).

Although the specific mechanisms of performance deterioration in technical actions performed during exercise remain to be elucidated, it is apparent that a *speed accuracy trade-off* exists under conditions of match-related fatigue. Despite previous research having identified that factors associated with match-related fatigue

may be responsible for skill deterioration (e.g., dehydration; McGregor *et al.*, 1999), data from study 4 also suggests that blood glucose concentrations might play a role.

8.2.2 Blood glucose concentrations

Study 4 demonstrated that routine provision of a carbohydrate-electrolyte beverage positively influenced the performance of soccer skills throughout the second half of exercise. Although the specific mechanisms of this response were not clear, the findings from study 4 agree with previous findings (Northcott *et al.*, 1999; Ostojic and Mazic, 2002; Ali *et al.*, 2007b; Currell *et al.*, 2009) as consumption of a carbohydrate-electrolyte beverage during exercise has previously been found to enable participants to better maintain performance in shots taken post-exercise (Ali *et al.*, 2007b; Currell *et al.*, 2009) but did not influence the outcome of a passing task (Ali *et al.*, 2007b). Moreover, the exercise intervention studies presented in this thesis utilised participants who commenced, and maintained throughout exercise, a state which resembles that of the hydro-nutritional practices advocated by sports teams. Therefore, the ecological validity of these results are greater than studies involving fasted and previously glycogen-depleted players that ingest carbohydrates during exercise (e.g., Ali *et al.*, 2007b; Ali and Williams, 2009).

Ali & Williams (2009) suggested that to improve motor skill performance, a supply of exogenous carbohydrates must exceed a rate of $50 \text{ g}\cdot\text{h}^{-1}$; a statement which was based on the findings of previous authors (Northcott *et al.*, 1999; Welsh *et al.*, 2002). Consequently, fasted and previously glycogen-depleted participants were supplemented with $52 \text{ g}\cdot\text{h}^{-1}$ of carbohydrates. Interestingly, no benefit to LSPT

performance was observed pre, post, and throughout exercise (Ali and Williams, 2009); a finding which supports previous work from the same laboratory when passing was assessed before and after exercise and carbohydrates were supplied at a rate of $30 \text{ g}\cdot\text{h}^{-1}$ (Ali *et al.*, 2007b). However, post-exercise improvements in shooting performances were observed when the $30 \text{ g}\cdot\text{h}^{-1}$ carbohydrate dose was used when compared to a non-electrolyte placebo trial (Ali *et al.*, 2007b). Therefore, while acknowledging that the ecological validity of these findings are limited (due to the criterion-based skill tests used and the physiological state of the players before exercise), it appears that the effects of carbohydrate supplementation may vary according to the type of skill being performed.

In study 4, carbohydrate was supplemented throughout exercise at a rate of $59 \text{ g}\cdot\text{h}^{-1}$ which resulted in improvements in shooting performances at the end of simulated soccer match-play. Consequently, it appears that this dose of carbohydrate is effective when seeking to improve soccer shooting performances towards the end of a simulated soccer match. However, as the rate of carbohydrate provision remained constant throughout study 4, it is impossible to state whether this dose was optimal when seeking to maintain soccer skill proficiency in the latter stages of a match. Given the dose-response relationship that has previously been observed in the non-exercise setting between carbohydrate provision and cognitive function (Messier *et al.*, 1998), it remains to be determined whether higher doses of carbohydrates ingested during exercise will further improve the performance of skills.

A surprising outcome from studies 2 and 4 was the presence of a reduction in blood glucose concentrations compared to pre half-time values at the onset of exercise in

the second half of exercise during simulated match-play. This transient lowering of blood glucose concentrations was termed the exercise-induced rebound glycaemic response and was also confirmed to occur in actual match-play (study 5). It has consistently been reported that consumption of a high-glycaemic index carbohydrate in the hour before exercise can lower blood glucose levels 15-30 min after starting exercise (Jentjens *et al.*, 2003; Jentjens and Jeukendrup, 2003); although, the potential performance effects of this reduced blood glucose concentration remain unclear with some authors identifying reduced performance (Foster *et al.*, 1979) whereas others disagree (Jentjens *et al.*, 2003; Jentjens and Jeukendrup, 2003). Nevertheless, this thesis presents the first data concerning a reduction in blood glucose concentrations that are not attenuated by the consumption of carbohydrate-electrolyte beverages before and during match-play, but appear more likely to result from the interaction between a period of recovery that separates two successive exercise bouts.

Studies involving non-exercising participants have demonstrated that almost immediate reductions in cognitive performance occur when blood glucose concentrations fall below $3.4 \text{ mmol}\cdot\text{L}^{-1}$ (Holmes *et al.*, 1984; Stevens *et al.*, 1989; Widom and Simonson, 1990; Fanelli *et al.*, 1993; Fanelli *et al.*, 1994a; Fanelli *et al.*, 1994b; Veneman *et al.*, 1994; Maran *et al.*, 1995; Evans *et al.*, 2000; Maran *et al.*, 2000). Although the exercise-induced rebound glycaemic response observed at the 60 min time-point in study 4 (chapter 6) caused a 30% reduction in blood glucose concentrations compared to half-time values, the mean blood glucose concentration of the group did not breach the $3.4 \text{ mmol}\cdot\text{L}^{-1}$ threshold at which cognitive

performance has previously been found to be impaired. Consequently, this may explain the maintenance of skilled performance at the 60 min time-point.

However, it should be noted that passing was the only skill assessed when blood glucose concentrations were found to be minimal. Given that more complex skills have been found to be more susceptible to modification when compared to simple motor tasks (Holmes *et al.*, 1986; Deary *et al.*, 2003), it is possible that the rapid drop in blood glucose concentrations observed throughout this thesis in the initial stages of restarting exercise after half-time may have a greater impact on more complex skills. This claim is substantiated by the fact that shooting performances post-exercise were compromised in a placebo trial where blood glucose concentrations were $4.8 \pm 0.2 \text{ mmol}\cdot\text{L}^{-1}$, whereas passing performances remained unaffected. Therefore, further research is warranted into examining the effects of the exercise-induced rebound glycaemic response on the full array of skills performed in soccer.

Despite the mean blood glucose concentration of the group not reaching the levels previously reported to cause cognitive impairments (i.e., $3.4 \text{ mmol}\cdot\text{L}^{-1}$), analysis of individual data throughout this thesis suggests that certain participants were more susceptible than others to the exercise-induced rebound glycaemic response (see Appendix I5; participants 2 and 12 in the carbohydrate trial of study 4 breached the $3.4 \text{ mmol}\cdot\text{L}^{-1}$ threshold at 60 min). This finding is supported by the inter-individual differences in the susceptibility to rebound hypoglycaemia that have previously been reported when comparable doses of pre-exercise carbohydrates have been provided (Jentjens and Jeukendrup, 2003). Consequently, an individual approach should be

taken when determining whether strategies aiming to provide exogenous carbohydrates while increasing fluid delivery during exercise are indeed optimal. Moreover, on rapid restoration of euglycaemia the recovery of cognitive function following hypoglycaemia is not immediate (with delays of up to 90 min being reported before cognitive functioning is restored to pre-hypoglycaemic levels; Tallroth *et al.*, 1990; Evans *et al.*, 2000). Therefore, it is plausible to speculate that even transient reductions in blood glucose concentrations may have consequences for cognitive function, and technical actions, performed throughout the remainder of the match.

Throughout studies 2, 4 and 5, the half-time period, which is often considered crucial in team sports for primarily tactical reasons, appeared to influence blood glucose concentrations on recommencing exercise in the second half. Although the possible performance effects of reduced blood glucose concentrations are unclear, it also remains to be elucidated whether the effects of restarting soccer-specific exercise whilst in a state of energy restoration differ according to the physical or skilled nature of the task being performed as previous authors have only considered performance in terms of endurance or time-trial assessments (Foster *et al.*, 1979; Jentjens *et al.*, 2003; Jentjens and Jeukendrup, 2003).

8.3 DIRECTIONS FOR FUTURE RESEARCH

It is important to acknowledge that the results presented within this thesis relate only to the interventions and technical actions performed. Throughout studies 1, 3 and 4, technical proficiency was examined in soccer passing, shooting and dribbling skills using methods of video analysis. Only Young *et al.* (2010) have attempted to quantify components of kicking accuracy using continuous outcome measures (as opposed to discrete outcomes). However, despite differences in the code of football examined, the video digitisation procedures employed by Young *et al.* (2010), and in the skills tests developed and used throughout this thesis, provide alternative methods to the criterion-based outcome measures that have previously dominated soccer skill research. Therefore, future research should seek to incorporate similar outcome measures when quantifying the skilled response to modifying factors, such as nutritional interventions, in team sports players. Moreover, this is the first soccer skill testing battery that provides quantitative data of a continuous nature (as opposed to discrete data obtained from criterion-based techniques) that describes the speed, precision and success rate of technical performances, which are executed under conditions requiring visual searching and decision making.

Although the analyses used were shown to demonstrate reliability and construct validity, numerous other skills are performed throughout match-play in addition to the technical actions considered in this thesis (e.g., heading, crossing, tackling etc.; see Table 1.2); with the technical proficiency of attempts at each skill possibly contributing to success. Consequently, future research should seek to incorporate further technical actions that are involved in soccer into testing protocols which

analyse performance in terms of continuous data that demonstrates high ecological validity.

Studies 4 and 5 examined the influence of carbohydrate-electrolyte supplementation on physical, technical, and metabolic responses elicited during simulated and actual soccer match-play. Given the array of ergogenic aids used by soccer players (for a review see: Hespel *et al.*, 2006), future researchers should aim to examine the effects of different supplements on the performance of a wide range of soccer skills and also consider whether the combination of multiple supplements can elicit additive effects. For example, caffeine has been reported to enhance the absorption (Van Nieuwenhoven *et al.*, 2000) and oxidation (Yeo *et al.*, 2005) of co-ingested carbohydrates.

Considering that caffeine ingestion has consistently been reported to enhance visual information processing and reaction time during non-sports related tasks such as computer-based/pen-and-paper tests (Brice and Smith, 2001; Haskell *et al.*, 2005; Van Duinen *et al.*, 2005), caffeine supplementation may elicit performance benefits for athletes participating in team sports that require skilled performances, concentration, and cognitive function. However, this is yet to be established using skills tests that produce outcomes that are high in ecological validity and that produce outcomes derived from continuous as opposed to discrete data.

After supplementation with carbohydrates, blood glucose concentrations rose and were maintained throughout the first half of exercise; however, an unexpected outcome of this research was that ingestion of carbohydrate-electrolyte beverages, in

a manner that adheres to published guidelines (e.g., Convertino *et al.*, 1996) and is similar to supplementation regimes that are commonly used by competitive teams, was unable to attenuate a transient decrease in blood glucose concentrations 15 min into the second half of exercise (i.e., \approx 60 min time-point) in both simulated and actual match-play scenarios. Consequently, identification of the mechanisms responsible for the exercise-induced rebound glycaemic response presents itself as a future research opportunity to all involved in sports that incorporate a prolonged rest period between successive exercise bouts; specifically in team sports where carbohydrate-containing beverages are consumed in the intervening period.

The effects of a rapid reduction in blood glucose concentrations at the onset of exercise in the second half on technical, physical, and physiological responses are unclear. Although, the exercise-induced rebound glycaemic response was not associated with a detectable decline in skilled performance in study 4; it must be noted that passing was the only skill examined at the 60 min time-point. Considering that studies 3 and 4 identified resilience to performance deterioration which varied according to the type of skill being performed, it remains to be elucidated whether the exercise-induced rebound glycaemic response does in fact influence performance in the full spectrum of skills performed throughout soccer match-play.

Ali & Williams (2009) have suggested that the supply of exogenous carbohydrates must exceed a rate of $50 \text{ g}\cdot\text{h}^{-1}$ to elicit improvements in motor skill. Consequently, these authors supplemented fasted and previously glycogen-depleted participants with $52 \text{ g}\cdot\text{h}^{-1}$ of carbohydrates and observed no benefit to LSPT performance (Ali

and Williams, 2009); a finding which supports previous work from the same laboratory when carbohydrates were supplied at a rate of $30 \text{ g}\cdot\text{h}^{-1}$ (Ali *et al.*, 2007b). Although it could be interpreted that additional carbohydrate provision yields no benefit to soccer skill performance, data from study 4 (where improvements in shooting performance were observed when carbohydrates were consumed at a rate of $59 \text{ g}\cdot\text{h}^{-1}$) and previous research from the non-exercise setting where a dose-response relationship between carbohydrate provision and cognitive function has been observed (Messier *et al.*, 1998) would suggest otherwise. Therefore, the effects of different doses of carbohydrate provision on the quality of performance of soccer skills during exercise remain to be elucidated.

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Appendix A1: Ethical application (Study 1)

Swansea University
SPORTS SCIENCE, SCHOOL OF HUMAN SCIENCE
DEPARTMENTAL ETHICS ADVISORY COMMITTEE

APPLICATION FOR ETHICAL COMMITTEE APPROVAL OF A RESEARCH PROJECT

In accordance with Departmental Safety Policy, all research undertaken in the department must be approved by the Departmental Ethics Advisory Committee **prior to** data collection. **Applications for approval should be typewritten on this form using the template available in the Public Folders.** The researcher(s) should complete the form in consultation with the project supervisor. Where appropriate, the application must include the following appendices:

- (A) subject information sheet;
- (B) subject consent form;
- (C) subject health questionnaire.

1. Draft title of Project

The reliability and construct validity of soccer skill tests that measure passing, shooting, and dribbling

2. Names and Status of Research Team

Martin Carvalho – Undergraduate Student

Carlos Penas Ruiz – Undergraduate Student

Mark Russell – Postgraduate Student

Dr. Mike Kingsley – Dissertation Supervisor

3. Rationale

Soccer is the world's most popular sport (Bangsbo, 1994) in which success is determined by scoring more goals than your opponent. A lot of research has focused on player movement patterns during a match; with the literature demonstrating that top level outfield players cover distances in the region of 10-12 km per game (Reilly and Thomas, 1976; Di Salvo *et al.*, 2007). Most of this distance is covered by predominantly low intensity actions such as walking and jogging (Di Salvo *et al.*, 2007); thus 90% of a soccer match is estimated to be fuelled aerobically (Bangsbo, 1994); concerned mostly with movement "off the ball" and creating "space" for team mates or by tracking runs of opposition players (Reilly, 1996).

Despite the dominance of aerobic activities within a match, it is the anaerobic pathways involved in the execution of skills and powerful movements that can determine the outcome of a game. Analysis of midfielders from a local professional team (unpublished data from our laboratory) has revealed that, over a two season period, the most frequent motor skills performed were passing (~50%), tackling (~15%), dribbling (~15%), aerial challenges (~5%), and shooting (~5%). These high intensity involvements with the ball will be fuelled anaerobically and contribute directly to the outcomes of the game. Therefore, it is the anaerobic periods of play which may determine the

success of winning possession and the scoring or conceding of goals.

Although the importance of skilled actions in determining the success of a game is widely known, surprisingly few soccer skill tests have been developed, and even less have been assessed for their reliability. McGregor *et al.* (1999) devised a dribbling test in which a ball was dribbled as fast as possible between seven cones; each 3-m apart, spanning a total distance of 18-m. The critical variable being recorded to represent skilled performance was time, with no concern for the “quality” of the dribble. Although some would argue that a faster time on such tests would represent a more skilled action, no efforts are made to quantify the error associated with the action; for example, the deviation of the ball from specific markers or a player’s foot. More recently, tests using criterion based outcomes have become popular when assessing soccer skill. For example, Ali *et al.* (2007) used a selection of targets that the ball was passed or shot towards, and awarded or deducted points for success and failure respectively. Clearly, such an approach is limited by the large degree of variation that can exist before changes will be detected.

In summary, previous studies have used either criterion based outcomes or a timed dribbling task to assess soccer skill; both of which have their limitations. Proficient execution of skilled actions have the potential to determine the winner of a game, however, the lack of sensitivity of the soccer skill tests that are currently available make the small changes associated with supplementation studies impossible to detect consistently. As the quality of the skills passing, shooting and dribbling contribute directly to success in soccer, we aim to examine the reliability of a new battery of tests that quantitatively analyses the performance of these skills.

4. References

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5. Aims and Objectives

The aim of this study is to measure the reliability of a new protocol to measure soccer skill performance.

Null Hypotheses:

H0₁: There will be no difference in passing, shooting and dribbling skills when performed on two separate days.

6. Methodology

6.1 Study Design

The study will compare soccer skill tests that aim to measure passing, shooting and dribbling performance on two separate testing sessions. Prior to participation, all subjects will be informed about the study requirements, provided with subject information (Appendix B1) and asked to complete written consent (Appendix B2) and a pre-participation health questionnaire (ACSM, 1998; Appendix C).

Following approval by the University ethics committee and informed consent being attained from participants, recreational (n≈15) and semi-professional soccer players (n≈15), all aged between 18 and 35 years and all with more than two years playing experience, will be advised to record their dietary intake (representative of a normal training day; i.e., no caffeine or alcohol) and to refrain from strenuous resistance training for the 48 hours prior to any testing session.

Participants will be required to attend at least three testing sessions, one being an anthropometric and familiarisation session and the two main trials. During the main trials each participant is expected to complete a controlled warm up, consisting of dynamic stretching and light aerobic activity followed by two bouts of soccer skill assessment. Each bout incorporates 8 shots, 28 passes and then 11 dribbles (details for all skills outlined below) and is performed at the same time of day to minimise circadian variation. The passes, shots and dribbling skills will be continuously recorded and the outcomes from each skill will be subjected to quantitative analysis in order to determine the reliability of the test. This testing session will then be completed twice (2 x daily) on two separate testing days that are separated by one week.

15 min warm up	S	P	S	D
	Skill testing			

Figure 1: Overview of each main trial
S = Shooting test, P = Passing test, D = Dribbling test

6.2 Experimental Procedures

6.2.1 Preliminary Testing

Following satisfactory completion of a medical consent questionnaire and assurances to the tester that no muscle injury is present in any participant, a testing session aiming to familiarise each participant with the study protocol will be completed. On arrival at the laboratory, all participants will be asked to empty their bowels and void their bladder. Body mass (model 770; Seca Ltd, Birmingham, UK) and stature (Portable Stadiometer; Holtain Ltd, Wales, UK) will then be determined. A controlled 10 min warm up consisting of 3 min of light aerobic activity and 7 min of dynamic stretching will precede 5 min of skill based warming up. Maximal oxygen uptake using the protocol outlined by Ramsbottom *et al.* (1988) will then be completed following the determination of standing start 15-m sprint speed using an opto-electronic device (Brower, Utah).

6.2.2 Main Experimental Procedures

6.2.2.1 Skilled Performance Analysis

6.2.2.1.1 Passing

6.2.2.1.1.1 Layout of the Passing Test

Four targets (short left: SL, short right: SR, long left: LL, long right: LR) will be placed as shown in Figure 2, such that the centre of the targets are 4.2-m and 7.9-m from the centre of the action zone, for short and long targets respectively.

The targets are 2.0-m wide and 1.0-m high, constructed from a durable blue coloured banner (Charterbrook signs; Swansea, UK), and supported at each end by two counterbalanced poles. Each banner is marked with black calibration lines at 0.25-m intervals both horizontally and vertically, with a red target box measuring 0.5 x 0.25-m identifying the area to be aimed for. The rationale for the use of the target banner is twofold: firstly, the banners allow visible shock waves to help identify the time of ball impact, and secondly, the flexible nature of the banners prevent problems associated with ball rebound.

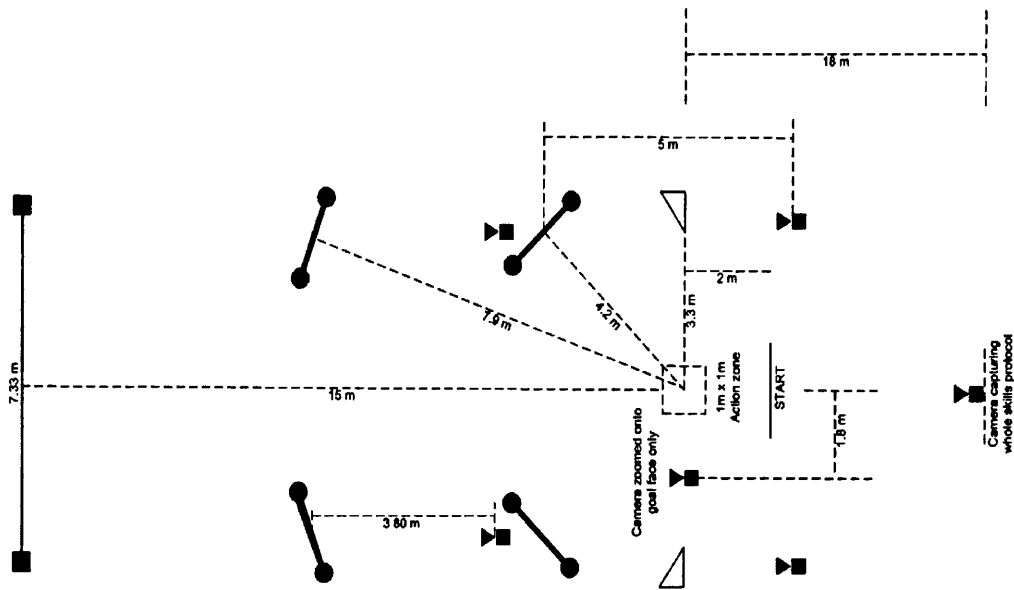


Figure 2: Setup of the passing and shooting test to be used in the study.

●—● Passing target, ■—■ Shooting target, ▽ CSDS, ▼ Video camera.

6.2.2.1.1.2 Instructions for the Passing Test

Participants commence the test from a stationary position with their leading foot on a start line marked 2.0-m from the centre of the action zone. The participants wait on the start line until the initiation of movement of an official Premier League ball (Total 90 Aerow Football: Size 5; Nike Inc, USA) down either a left or right (alternating between attempts) constant speed delivery system (CSDS). At which point, they begin to jog into the 1.0 x 1.0-m action zone. The CSDS consists of a modified ramp 0.68-m high and 1.43-m long (Mark 3 bowling ramp; Pete’s Pro Shop, UK). The ball is positioned on the edge of the decline, such that no external forces other than gravity are required to initiate its downward movement, maintaining a constant release velocity of $2.3 \text{ m}\cdot\text{s}^{-1}$ between attempts, thus ensuring standardisation and repeatability. As the ball passes the end of the CSDS, integrated motion sensors trigger the visual identification of the target to be aimed for in the upcoming pass by means of a lighting system that is specifically designed for this study. A delay of 0.4 s between the ball triggering the system and the light (consisting of a collection of bright light emitting diodes: LEDs) being illuminated will be used as pilot work found this to be the most appropriate time delay to enable the participants to perform visual searching and decision making processes whilst jogging into the action zone (similar to a soccer match when looking for space or team mates). As a result, a constant time difference of 0.2 s exists between light illumination and the ball entering the action zone. A time difference of 0.64 s exists between target identification and the ball reaching the centre of the action zone.

Participants will be instructed to pass the ball along the ground, and to aim at the centre of the red box within the target that was illuminated. No prior touch will be allowed to control the ball, which

enhances the ecological validity of the test (Dooan *et al.*, 2001). During each bout of pass testing, the order of passes is randomly determined, and 4 non-assessed practice passes follow the warm up (Figure 1) and precede the 28 assessed passes (7 sets of 4 passes). Passes are completed in sets of four with 30 s rest between each pass and each set is separated by 4 min of passive recovery. No restrictions will be placed on which foot should be used; therefore, participants kick with the foot that they feel is most suitable for the execution of the pass, while adhering to the instructions. All participants will be informed that passes can only be executed from within the action area, and as such, any pass completed from outside this area will be classified as an error. Additionally, any pass which missed the entire target will be classified as an error.

6.2.2.1.2 Shooting

6.2.2.1.2.1 Layout of the Shooting Test

Figure 2 also includes the layout of the shooting test. As passing and shooting skill tests will be integrated into the same area, the action zone is the same for both tests. Shots are taken from a distance of 15.0-m from the goal. The area of the shooting target will replicate a standard 11 aside adult soccer goal measuring 7.33-m x 2.44-m (FA Regulations). Transparent netting will be stretched across the back of the goal structure, to allow the location of ball impact to be readily identified. Horizontal and vertical calibration markers will be positioned at exact locations on each side of the goal. Four target rings (top left: TL, top right: TR, bottom left: BL and bottom right: BR), 0.1-m in diameter, will be positioned 1.0-m horizontally inside each post and 0.5-m vertically inside the upper and lower edges of the goal. Light emitting diodes (LEDs) are positioned so that, when illuminated, the lights shine through the centre of the rings and are easily visible from the centre of the action zone.

6.2.2.1.2.2 Instructions for the Shooting Test

Similar to the passing test, the participants will move towards the action zone when ball movement is initiated down the CSDS. The target will be identified by LEDs that become illuminated behind the goal when triggered by ball movement on either CSDS. Targets are positioned in the corners of the goal, as optimal ball placement to beat a goalkeeper is in the top and bottom corners (Ali *et al.*, 2007). The CSDS and lighting system ensure that the participants consistently receive the same time to undertake visual scanning and decision making before completing the shot. The participants will be informed to shoot, as accurately as possible, towards one of the four targets without a prior touch to control the ball. These instructions are based on the findings of Olsen *et al.* (1988), who observed that 70.5% of all shots are completed without an additional touch. Following the warm up, four practice shots will precede the 8 assessed shots (split into two 4 shot bouts completed before and after the passing test, Figure 1). Two shooting trials (made up of 4 shots; 2 from each CSDS), with a 30 s rest period between each shot will be completed. Shot targets are selected in a randomised order for each player. Similar to the passing test, participants are informed that shots could only be executed

from within the action area, and that either foot can be used. If the shot is not completed within the action area or the shot misses the goal area, then it will be recorded as an error.

6.2.2.1.3 Dribbling

6.2.2.1.3.1 Layout of the Dribbling Test

The layout of the dribbling test is similar to that employed by McGregor *et al.* (1999) and is illustrated in Figure 3. Start and finish lines will be placed 20-m apart and cones 2 through 7 are placed 3-m away from the preceding cone, with cones 1 and 7 being 1-m away from each end of the 20-m course.

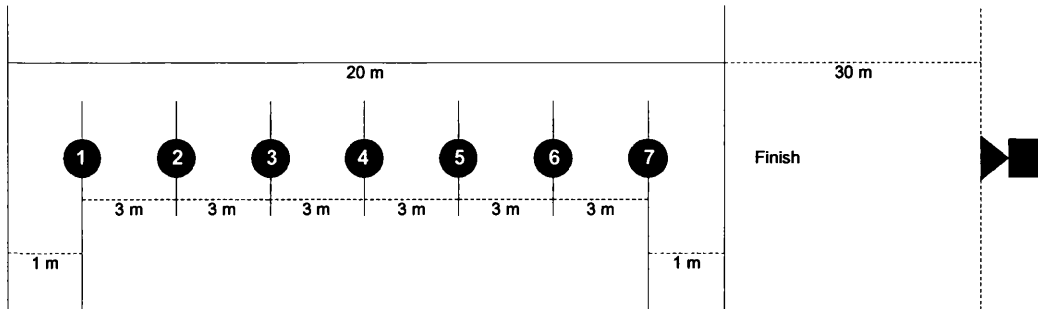


Figure 3: Setup of the dribbling test to be used in the study.

■ Video camera, ● cone.

6.2.2.1.3.2 Instructions for the Dribbling Test

Participants will be required to dribble the ball as accurately as possible through all of the cones in the shortest time possible. As accuracy is determined by deviation from the cone, participants will be instructed to dribble the ball as close to each cone as possible without making contact with the cone. Eleven dribbles are completed as per Figure 1 and 30 s rest is allowed between each dribble.

6.2.2.2 Video Capture and Digitisation

Six 50 Hz video cameras (DCR-HC96E; Sony UK Ltd, UK) will be placed in the positions marked in Figures 2 and 3. Cameras will be placed on tripods at heights of 0.5-m above the ground for the passing test and 1.5-m above the ground for capture of the shooting and dribbling tests. A Carl Zeiss Vario-Sonnar T* lens and maximal target to camera distances will be used in order to minimise parallax errors within the field of view. Each camera will be activated independently and then zoomed onto their respective target areas so that only the target image occupies the viewfinder, and these settings will be maintained thereafter. All cameras will be synchronised using an audio signal which precedes the first shooting assessment.

Following calibration procedures, video clips of all skills executed during the testing will be analysed. For passing and shooting, still images of the point of ball impact on the targets will be digitised

(VICON Peak Motus V9.2, VICON Motion Systems, USA). The outcome measure of passing and shooting precision will be calculated as the distance that the centre of the ball missed the centre of the target that participants were originally aiming towards. Average pass and shot velocities will be calculated using the conventional distance/time relationship and video footage of the time taken between initial impact with the ball and impact with the target. Success of passing and shooting is determined as the number of shots or passes that hit the target area expressed as a function of the total passes and shots taken. For dribbling, precision is represented by horizontal deviation of the ball from the cone and success is the number of cones successfully dribbled around; with all data collected from digitisation procedures.

6.2.2.3 Outcome Measures

Outcome measures of precision, percentage success, and ball velocity will be calculated for shooting, passing and dribbling. Shooting performance will be expressed as an average of the 8 shots taken in each shooting bout. Passing and dribbling performances will be expressed as an average of each bout.

6.3 Data Analysis Techniques

Data will be tabulated using commercially available software (Microsoft Excel 2003, Microsoft Inc, USA) and sampled for normality. Differences between trials will be evaluated using a Bonferroni corrected two-way repeated measures ANOVA and intra-class correlation coefficients will be calculated for each skill. Statistical tests will be carried out using statistical software (SPSS V16.0, SPSS Inc, USA) and significance set at $P \leq 0.05$.

6.4 Storage and Disposal of Data and Samples

All data collected will be treated and disposed of with utmost confidentiality and in strict accordance with the Data Protection Act. Data reported in the write up of this study will ensure that all individuals remain anonymous. On request individual participants will be able to view their own data at any point in the research process if they so wish. Data will only be stored on password restricted computers located in the Sports and Exercise Science Research Centre at Swansea University. May it be made clear that only authorised persons involved in this study (the named researchers M. Carvalho, C. Penas Ruiz, M. Russell and supervisor Dr M. Kingsley) will be able to access this data and will be solely responsible for the correct disposal of such data.

6.5 Dietary supplementation

No dietary supplementation regimes will be administered in this study.

7. Location of the Premises where the Research will be Conducted.

All testing will be supervised by Mark Russell (CPR/AED qualified) whilst on site at the Indoor Training Centre, Ashleigh Road, Sketty, Swansea.

8. Subject Risks and Discomforts

Whilst undergoing *voluntary* participation in this study, participants will experience no more discomfort than associated with any normal training session and are able to cease participation in the study at any time. Some muscular soreness localised in the quadriceps, hamstrings and gluteals may occur in the 24-48 hours following participation; however this is just part of the body's natural recovery. No psychological discomfort or stress will result as a part of this study.

The study does require that a certain level of soccer skill proficiency as 2 years of soccer playing experience is a pre-requisite for participation. Furthermore it is advised that any person with muscle or connective tissue damage in the musculature involved in completing the soccer skills does not participate, in fear of aggravating and delaying recovery from such an injury. Participants with any signs of cardiorespiratory distress prior to or during any test involvement will be instructed to cease participation in the whole study immediately.

9. Information Sheet and Informed Consent

The submission should be specific about the type of consent that will be sought:

Have you included a Subject Information Sheet for participants of the study? YES see Appendix B1

Have you included a Subject Consent Form for the participants of the study? YES see Appendix B1

10. Computers

Are computers to be used to store data? YES

If so, is the data registered under the Data Protection Act? YES

11. Student Declaration

Please read the following declarations carefully and provide details below of any ways in which your project deviates from them. Having done this, each student listed in section 2 is required to sign where indicated.

1. I have ensured that there will be no active deception of participants.
2. I have ensured that no data will be personally identifiable.
3. I have ensured that no participant should suffer any undue physical or psychological discomfort
4. I certify that there will be no administration of potentially harmful drugs, medicines or foodstuffs.
5. I will obtain written permission from an appropriate authority before recruiting members of any outside institution as participants.
6. I certify that the participants will not experience any potentially unpleasant stimulation or deprivation.
7. I certify that any ethical considerations raised by this proposal have been discussed in detail with my supervisor.
8. I certify that the above statements are true with the following exception(s):
9. All collected data will be destroyed immediately after completion of the project.

Student signature: (include a signature for each student in research team)

Date: 

12. Supervisor's Declaration

In the supervisor's opinion, this project (delete those that do not apply):

- ~~Does not raise any significant issues.~~
- Raises some ethical issues, but I consider that appropriate steps and precautions have been taken and I have approved the proposal.
- ~~Raises ethical issues that need to be considered by the Departmental Ethics Committee.~~
- ~~Raises ethical issues such that it should not be allowed to proceed in its current form.~~

Supervisor's signature: 

Date: 30/10/08

13. ETHICS COMMITTEE DECISION (COMMITTEE USE ONLY)

ETHICAL APPROVAL: GRANTED REJECTED (delete as appropriate)

The ethical issues raised by this project have been considered by members of the Departmental Ethical Approval Committee who made the following comments:

..... Note: Data must be deleted at end of study.

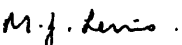
.....

.....

.....

.....

Please ensure that you take account of these comments and prepare a revised submission that should be shown to your supervisor/ resubmitted to the Department Ethical Approval Committee (delete as appropriate).

Signed:  Date: 31/10/08

(Chair, Departmental Ethics Advisory Committee)

Appendix A2: Ethical application (Study 2)

Swansea University
SPORTS SCIENCE, SCHOOL OF ENGINEERING
DEPARTMENTAL ETHICS ADVISORY COMMITTEE

APPLICATION FOR ETHICAL COMMITTEE APPROVAL OF A RESEARCH PROJECT

In accordance with Departmental Safety Policy, all research undertaken in the department must be approved by the Departmental Ethics Advisory Committee **prior to data collection. Applications for approval should be typewritten on this form using the template available in the Public Folders.** The researcher(s) should complete the form in consultation with the project supervisor. Where appropriate, the application must include the following appendices:

- (D) subject information sheet;
- (E) subject consent form;
- (F) subject health questionnaire.

1. Draft Title of Project

A soccer match simulation that incorporates technical actions and replicates the metabolic demands of match-play.

2. Names and Status of Research Team

Mark Russell – Postgraduate Student

Dr. Mike Kingsley – PhD Supervisor

3. Rationale

Soccer is a high intensity intermittent sport which is normally played over ninety minutes, split into two forty five minute halves that are each separated by a 15 min half-time period. As the world's most popular sport, the commercial value of findings from soccer research is extremely high; consequently a number of exercise protocols that aim to replicate the demands of competition have been developed (Nevill *et al.*, 1993; Nicholas *et al.*, 1995; Drust *et al.*, 2000; Nicholas *et al.*, 2000; Kingsley *et al.*, 2005). The primary reasons for developing an exercise simulation are to control the movement requirements and standardise the physiological demands. In doing so, the variation in responses that usually exists between matches is limited and the effects of exercise become repeatable. The most obvious benefit of simulation protocols is that they allow for more prominent effects to be identified in sometimes subtle physiological changes that result from supplementation protocols, strength and conditioning regimes, and/or other performance altering interventions.

Although soccer is primarily aerobic in nature, the outcome of a game is heavily influenced by anaerobic actions such as those involved in the execution of skills. Notational analysis has provided information concerning the total number of soccer skills performed throughout match-play with the most frequently utilised actions being passing and dribbling (Reilly and Holmes, 1983). As the primary aim of soccer is to score more goals than your opponent within the allotted time, shooting

can also be considered a crucial skill (Stone and Oliver, 2009). However, incorporating the performance of soccer skills throughout exercise protocols that aim to replicate the demands of a soccer match is rare; this is somewhat surprising considering the influence that soccer skills have in defining success.

The most commonly used intermittent exercise simulation is the Loughborough Intermittent Shuttle Test (LIST) which since its development has been extensively used to examine the effects of a number of ergogenic aids on exercise performance (Nicholas *et al.*, 1995; Nicholas *et al.*, 2000; Morris *et al.*, 2003; Erith *et al.*, 2006). The original version of the LIST consisted of 75 min of intermittent activity which was followed by a run to exhaustion. A free-running exercise simulation that replicated the movement demands of soccer was a valuable progression from unidirectional treadmill based protocols that had been used previously (Nevill *et al.*, 1993). However, the omission of game specific skills, some of which have been previously found to have an energy consuming consequence (Reilly and Ball, 1984), reduces the ecological validity of the LIST.

Relatively few protocols exist that have incorporated the performance of isolated soccer skills throughout exercise (Rampinini *et al.*, 2008; Currell *et al.*, 2009; Foskett *et al.*, 2009) as opposed to those that have included skilled actions before and after exercise (McGregor *et al.*, 1999; Ostojic and Mazic, 2002; Lyons *et al.*, 2006b; Ali *et al.*, 2007b). The authors are not aware of any data that directly compares the demands of simulated soccer match-play to the demands of actual match-play. Therefore, the aim of this study is to compare the physiological, movement and skilled requirements of a soccer match simulation that incorporates the physical and skilled components of a game to the demands of actual match-play in elite youth players.

4. References

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5. Aims and Objectives

The aim of this study is to measure the validity of physiological, skilled and physical demands of a 90 min soccer-match simulation to those of actual soccer match-play.

Null Hypotheses:

H0₁: *There will be no difference in physiological demands between the two exercise modalities.*

H0₂: *There will be no difference in skilled demands between the two exercise modalities.*

6. Methodology

6.1 Study Design

The study will compare the physiological (blood lactate and glucose concentrations, heart rate, core temperature and fluid losses) and physical demands (number of skilled actions and selected markers of player movement) of soccer match-play to the demands of a 90 min soccer-match simulation that incorporates intermittent exercise and skills. Players will undergo two main trials, where they will participate in a 90 min soccer match against an equally matched opposing team (University first team) and a soccer-specific exercise simulation that incorporates the performance of passing, shooting, and dribbling skills before, during and after exercise. Prior to each main trial the ten outfield players of the experimental team will swallow an intestinal pill system that measures core temperature and be subject to periodic blood sampling before, during and following exercise; therefore results will be presented for ten players each completing two main trials. Prior to any participation, all players will be informed about the study requirements, will have been provided with subject information

(Appendix B2), asked to provide written consent (Appendix B2) and/or parental consent where necessary (<18 years, Appendix B2) and will have completed a pre-participation health questionnaire (ACSM, 1998; Appendix C) in the presence of trained individuals.

Following approval by the University ethics committee and informed consent being attained, two squads of players aged between 14 and 25 years old, and all with two or more years playing experience, will be recruited. However, diabetics or smokers will not be recruited. Each player will be advised to record their dietary intake (representative of a normal training day; i.e., no caffeine or alcohol) for 48 hours prior to the first testing session and to replicate this in all subsequent sessions. Additionally, any strenuous exercise during this 48 hour period will be discouraged.

Participants will be required to attend two preliminary sessions and the two main trials; the first two sessions will enable the collection of anthropometric data and also allow familiarisation of the testing procedures to occur, whereas the remaining two trials will include the soccer match and the exercise simulation trial. During the main trials each participant will arrive at the laboratory 2.5 hours before commencing exercise. In addition to the ingestion of the core temperature measuring device, two hours prior to the game or simulation a standardised pre-exercise meal will be provided before performing a controlled warm up after a 90 min rest period. Players will undergo capillary blood sample collection at nine time-points throughout each main trial. All players will consume a fluid-electrolyte beverage throughout exercise. During both trials, a break of 15 min will separate the two halves of exercise, which are each approximately 45 min in duration, and all players involved will remain consistent between trials. No more than 14 days will separate the match and the simulation.

6.2 Experimental Procedures

6.2.1 Preliminary Testing

Following satisfactory completion of a medical consent questionnaire and informed consent being attained from participants and a parent/guardian (if necessary), two preliminary testing sessions will be completed. In both instances, arrival at the testing site will require participants to empty their bowels and void their bladder. In the first preliminary session, anthropometric measurements of body mass (model 770; Seca Ltd, Birmingham, UK) and stature (Portable Stadiometer; Holtain Ltd, Wales, UK) will then be determined. On completion, a controlled warm up that consists of 5 min of light aerobic activity and 10 min of dynamic stretching and sprints that progress to near maximal speeds, will be performed. After cessation of the warm up, each participant undertakes assessments of lower body power (i.e., 30-m sprint testing with 15-m split and vertical jumping for maximum height); measured using an opto-electronic device (Brower, Utah) and a jump mat (TKA 5106; Takei Scientific Instruments CO., Korea) respectively. Following a 10 min recovery period, maximal oxygen uptake will then be estimated using the protocol outlined by Ramsbottom *et al.* (1988). The remaining preliminary session serves to familiarise participants with the procedures of the main trials;

consequently, players will perform 90 min of an intermittent exercise simulation that incorporates the performances of passing, shooting and dribbling skills (detailed in section 6.2.2).

6.2.2 Main Experimental Procedures

On arrival at the laboratory players will be prompted to empty their bowels and provide a mid-flow urine sample. Urine osmolality will subsequently be measured by freezing point depression (Gonotec Cryoscopic Osmometer Osmomat 030; YSI Limited, UK). A resting blood sample will then be taken before players consume a standardised 1470 kJ meal (Energy content: 62% carbohydrates, 25% fats, 13% proteins) and 500 ml of a fluid-electrolyte beverage. At the same time as the ingestion of the pre-exercise meal, players will be required to swallow a small silicon coated ingestible pill that measures core temperature (CorTemp, Human Technologies International, California, USA). Body mass (model 770; Seca Ltd, Birmingham, UK) and stature (Portable Stadiometer; Holtain Ltd, Wales, UK) will then be measured. Players will remain in a rested state for approximately 90 min; on which a pre-exercise blood sample will be taken before players make a 5 min walk to an indoor training facility or an outdoor soccer pitch for the soccer-match simulation and the match trials respectively. On arrival, players will commence their final pre-exercise preparations before performing a standardised warm-up (consisting of running, dynamic stretching and ball skills) that precedes the start of exercise. Main trial procedures are illustrated in Figure 1.

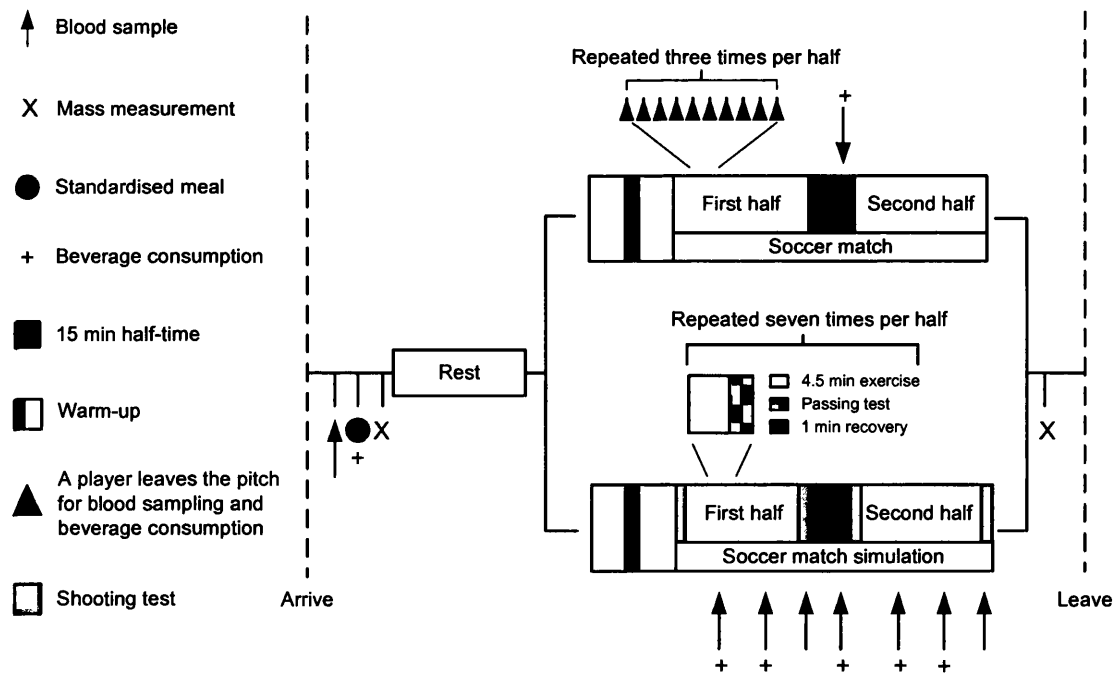


Figure 1: Main trial procedures for the soccer match and the soccer-match simulation.

Soccer Match Simulation (SMS)

The soccer-match simulation requires participants to perform soccer shooting, passing and dribbling skills throughout two 45 min halves of soccer-specific activity that are separated by a 15-min passive recovery period (half-time). The exercise protocol is similar to that devised by Nicholas *et al.* (2000) but subsequently adapted to include additional components that further replicate the movement demands of soccer match-play (Kingsley *et al.*, 2005). Movements will be dictated by audio signals from CDs and each participant will alternate between sprinting and dribbling during each cycle.

More specifically, exercise is made up of 4.5-min blocks that consists of 3 repeated cycles of three 20-m walks, one walk to the side, an alternating 15-m sprint or an 18-m dribble, a 4-s passive recovery period, five 20-m jogs at a speed corresponding to 40% $\dot{V}O_{2\max}$, one 20-m backwards jog at 40% $\dot{V}O_{2\max}$ and two 20-m strides at 85% $\dot{V}O_{2\max}$. A 2 min period incorporating the performance of soccer passing (1 min) and recovery (1 min) will follow all blocks of exercise (Figure 1). Seven blocks of intermittent activity and skills will be completed during each half of exercise. The participants cover a total distance of 10.1 km and will complete 56 passes, 16 shots, and 21 dribbles during the protocol.

Figure 2 shows the setup of the shooting and passing skill tests. Balls (Total 90 Aerow: size 5; Nike Inc, USA) will be released at a constant velocity of 2.3 m·s⁻¹ towards a 1.5 x 1.5-m square (action zone), where participants will be instructed to kick the ball. The participants kick towards one of four randomly determined targets (identified by a custom lighting system); consequently, the players are required to carry out visual searching and decision making during each attempt (similar to a soccer match when looking for space or other players). Motion sensors on the ball release mechanism ensure standardization and repeatability of each attempt; with a delay of 0.64 s between target identification and the ball reaching the centre of the action zone. Pilot work found this to be the most appropriate in player's of a similar standard.

Participants will commence the shooting and passing skill tests from a standing start before jogging into the action zone when the ball is released. The 2.0 x 1.0-m passing targets will be placed at distances of 4.2 m (short pass) and 7.9 m (long pass) away from the centre of the action zone. The shooting target is a standard 11-aside adult soccer goal measuring 7.33 x 2.44 m with transparent netting stretched across it. Four target lights are placed in the corners of the goal (positioned 1.0 m horizontally inside each post and 0.5 m vertically inside the upper and lower edges of the goal) as this has been identified as optimal ball placement to beat a goalkeeper when shooting (Ali *et al.*, 2007).

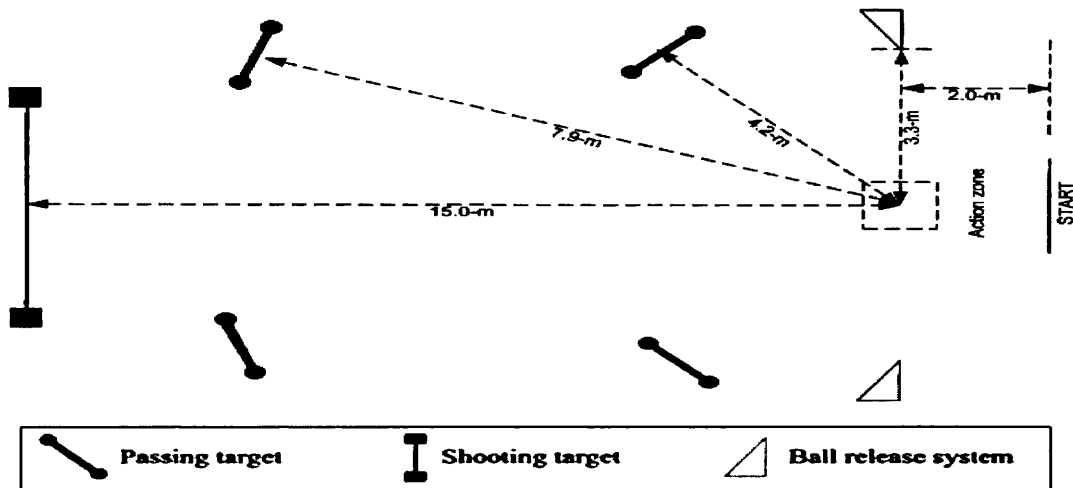


Figure 2: Schematic for the layout of the passing and shooting tests.

The participants will be instructed to aim passes at the centre of the target that is illuminated. When shooting, participants are instructed to kick the ball as accurately as possible at the illuminated target within the goal. The bouts of passing and shooting consist of four attempts, where the ball is alternately delivered from the right and left side of the action zone. To enhance ecological validity, no prior touches are allowed to control the ball (Olsen, 1988) and participants choose to kick the ball with the foot that they feel is most suitable to successfully complete the task.

The layout of the dribbling task is similar to that employed by McGregor *et al.* (McGregor *et al.*, 1999) with start and finish lines placed 20-m apart. Cones 2 through 7 are placed 3-m away from the preceding cone, and cones 1 and 7 are 1-m away from each end of the course. Participants will be instructed to dribble the ball as fast and as accurately as possible between all cones.

Soccer Match

A match will be organised between a test team (the same players who completed the soccer match simulation) and an equally matched opposing team. The match will be 90 min in duration, consisting of two 45-min halves that are separated by a 15-min passive recovery period (half-time) (Figure 1) and an official referee will be used. The match will be played with official balls (Total 90 Aerow: size 5; Nike Inc, USA) and take place on a floodlit grass pitch measuring 95 x 68 m that conforms to FA regulations.

The outfield players of the test team ($n=10$) are subject to periodic blood sampling and will leave the pitch on six occasions during match-play (i.e., once every 15 min). To ensure minimal disruption to the match, players will be removed individually and in an order that remains consistent between time-points. The match will be divided into six 15-min periods (first half: 0-15, 15-30, 30-45 min; second half: 45-60, 60-75, 75-90 min). Two minutes into each of these periods, the first player leaves the

pitch for blood sampling (i.e., after 2, 17, 32, 47, 62 and 77 min of match-play). When the first player returns to the match, the next player leaves the pitch; this sequence is continued until the 10 players have been sampled within each 15-min period.

In order to maintain the standard number of players on the pitch at all times, one utility player (deemed by coaching staff as able to fulfil all positional demands) will be used as a substitute. The substitute changes positions as different players leave the pitch for blood sampling. This player will not be subject to any analyses and will not play for the first two minutes of every 15-min period of the match.

Notational analysis data will be collected in order to compare the skilled and movement demands of actual match-play to the demands of the soccer-match simulation. Match footage will be analysed using specialist software (SportsCode; Sportstecinternational.com) which has been shown to be a reliable alternative to more sophisticated player tracking systems (Davies *et al.*, 2008). Footage of all outfield players (excluding the utility player) will be categorised according to five types of movement demands (walking, jogging, striding, sprinting/dribbling or backwards jogging); with each category being exclusive to all others. Movement demands will be expressed as the percentage of total exercise time that each modality represents. Skilled demands will reflect the total number of passes and the number of on-the-ball actions performed by the players throughout match-play. Data will be collected and analysed by a coder who has extensively used the software with an English League Championship team.

Both the match and the soccer-match simulation will be completed within the first half of the playing season and all players will be informed to refrain from strenuous physical activity and caffeine consumption in the two days preceding any testing sessions. Additionally, players will record all food consumed in the two days before each main trial. Food records will subsequently be analysed using commercially available software (CompEat version 5.8.0; Nutrition Systems, UK).

6.2.3 Experimental Beverages

During both main trials, the participants of the experimental team will drink an initial fluid bolus, containing 500 ml of a fluid-electrolyte beverage with the pre-exercise meal. Additionally, $14 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$ BM will be consumed over each half; one third of this volume consumed 10 min prior to commencing each half of exercise, and the remaining two thirds to be consumed between 0 and 15 and 15 and 30 min of each half when players are subjected to blood sampling procedures. Beverages will contain $23 \text{ mmol} \cdot \text{L}^{-1}$ sodium and $14 \text{ mmol} \cdot \text{L}^{-1}$ chloride and will be flavoured with a commercially available fruit cordial (Smartprice Lemon; ASDA, UK: CHO < 0.1 g/100 ml). During the month before the main trials, players of the experimental team will ingest water at a rate of $14 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$ BM during training in order to promote the gastric tolerance of this rate of fluid ingestion.

6.2.4 Physiological testing

Fingertip blood samples will be taken and analysed immediately for lactate and glucose concentrations using calibrated handheld devices (Lactate Pro; Arkray, Inc., Kyoto, Japan and Medisense Optium Glucose Meter, Abbott Diabetes Care, California, USA, respectively). Blood samples of the experimental team will be taken at time-points of rest, pre-exercise and following the start of exercise; between 0-15, 15-30, 30-45, half-time, 45-60, 60-75 and 75-90 min. HR will be recorded at rest and every 5 s during exercise using short range telemetry (Polar S610 HR monitor, Polar, Finland). Core temperature will be measured by means of a small ingestible pill that transmits a low frequency radio signal to an external data receiver/data logger (CorTemp, Human Technologies International, California, USA). Measurements of core temperature will be taken periodically throughout exercise.

6.3 Statistical analyses

Data will be tabulated using commercially available software (Microsoft Excel 2003, Microsoft Inc, USA) and sampled for normality. Statistical analysis will be carried out using SPSS software (Version 16.0; SPSS Inc., IL). All results are to be reported as the mean \pm standard error of the mean (SEM) and the level of statistical significance will be set at $P \leq 0.05$. A two way repeated measures analysis of variance (ANOVA) will establish if any significant effects exist in the physiological responses due to time or trial. Mauchly's test will be consulted and Greenhouse–Geisser correction is to be applied if the assumption of sphericity is violated. When differences are noted, a *post-hoc* Bonferroni correction is to be implemented to determine the location of these differences and limits of agreement will also be calculated via established methods (Bland & Altman, 1986).

6.5 Storage and Disposal of Data and Samples

All data collected will be treated and disposed of with utmost confidentiality and in strict accordance with the Data Protection Act. Data reported in the write up of this study will ensure that all individuals remain anonymous. On request individual participants will be able to view their own data at any point in the research process if they so wish. Data will only be stored on password restricted computers located in the Sports and Exercise Science Research Centre at Swansea University. May it be made clear that only authorised persons involved in this study (the named researchers M. Russell and supervisor Dr M. Kingsley) will be able to access this data and will be solely responsible for the correct disposal of such data.

6.5 Dietary supplementation

During the two main trials, the experimental team will be required to acutely consume a fluid-electrolyte beverage. An initial 500 ml fluid bolus will be consumed with a pre-exercise meal that consists of two slices of white toast and margarine spread. Thereafter, consumption of the beverage at a rate of $14 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$ BM will be required; one third of this volume is consumed 10 min prior to

commencing each half of exercise (i.e., during the warm up and half-time recovery period). The remaining two thirds will be consumed between 0 and 15 and 15 and 30 min of each half of exercise when players are subject to blood sampling. A solution containing 23 mmol·L⁻¹ sodium and 14 mmol·L⁻¹ chloride will be consumed which is to be flavoured with a commercially available fruit cordial (Smartprice Lemon; ASDA, UK: CHO < 0.1 g/100 ml). No adverse side effects of this supplementation regime are expected.

7. Location of the Premises where the Research will be Conducted.

All testing will be supervised by Mark Russell (CPR/AED qualified) whilst on site at the Sports Village, Sketty Lane, Swansea.

8. Subject Risks and Discomforts

Whilst undergoing *voluntary* participation in this study, participants will experience no more discomfort than associated with any normal soccer game and are able to cease participation in the study at any time. Some muscular soreness localised in the quadriceps, hamstrings and gluteals may occur in the 24-48 hours following participation; however this is just part of the body's natural recovery. No psychological discomfort or stress will result as a part of this study.

The study does require that a certain level of soccer skill proficiency as 2 years of soccer playing experience is a pre-requisite for participation. Furthermore, it is advised that any person with muscle or connective tissue damage in the musculature involved in completing the soccer skills does not participate, in fear of aggravating and delaying recovery from such an injury. Participants with any signs of cardiorespiratory distress prior to or during any test involvement will be instructed to cease participation in the whole study immediately.

The use of the ingestible core temperature monitor is associated with no known adverse side effects in healthy participants and has been used in a number of scientific research studies. In the event of an injury during the study that requires diagnosis by medical scanning equipment (i.e., MRI, X-Ray etc), it is necessary for players to consume a laxative to facilitate the removal of the ingestible pill prior to undergoing the scan. Evacuation of the pill from the body occurs via normal means.

9. Information Sheet and Informed Consent

The submission should be specific about the type of consent that will be sought:

Have you included a Subject Information Sheet for participants of the study? YES see Appendix B2

Have you included a Subject Consent Form for the participants of the study? YES see Appendix B2

10. Computers

Are computers to be used to store data? YES

If so, is the data registered under the Data Protection Act? YES

11. Student Declaration

Please read the following declarations carefully and provide details below of any ways in which your project deviates from them. Having done this, each student listed in section 2 is required to sign where indicated.

1. I have ensured that there will be no active deception of participants.
2. I have ensured that no data will be personally identifiable.
3. I have ensured that no participant should suffer any undue physical or psychological discomfort
4. I certify that there will be no administration of potentially harmful drugs, medicines or foodstuffs.
5. I will obtain written permission from an appropriate authority before recruiting members of any outside institution as participants.
6. I certify that the participants will not experience any potentially unpleasant stimulation or deprivation.
7. I certify that any ethical considerations raised by this proposal have been discussed in detail with my supervisor.
8. I certify that the above statements are true with the following exception(s):
9. All collected data will be destroyed immediately after completion of the project.

Student signature:



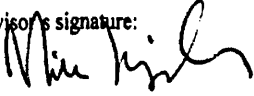
Date:

(include a signature for each student in research team)

12. Supervisor's Declaration

In the supervisor's opinion, this project (delete those that do not apply):

- ~~Does not raise any significant issues.~~
- Raises some ethical issues, but I consider that appropriate steps and precautions have been taken and I have approved the proposal.
- ~~Raises ethical issues that need to be considered by the Departmental Ethics Committee.~~
- ~~Raises ethical issues such that it should not be allowed to proceed in its current form.~~

Supervisor's signature: 

Date:

13. ETHICS COMMITTEE DECISION (COMMITTEE USE ONLY)

ETHICAL APPROVAL: GRANTED REJECTED (delete as appropriate)

The ethical issues raised by this project have been considered by members of the Departmental Ethical Approval Committee who made the following comments:

..... Note. Data must be deleted at end of study.

.....

.....

.....

.....

.....

Please ensure that you take account of these comments and prepare a revised submission that should be shown to your supervisor/ resubmitted to the Department Ethical Approval Committee (delete as appropriate).

Signed: 

Date:

(Chair, Departmental Ethics Advisory Committee)

Appendix A3: Ethical application (Study 3)

Swansea University
SPORTS SCIENCE, SCHOOL OF ENGINEERING
DEPARTMENTAL ETHICS ADVISORY COMMITTEE

APPLICATION FOR ETHICAL COMMITTEE APPROVAL OF A RESEARCH PROJECT

In accordance with Departmental Safety Policy, all research undertaken in the department must be approved by the Departmental Ethics Advisory Committee **prior to** data collection. **Applications for approval should be typewritten on this form using the template available in the Public Folders.** The researcher(s) should complete the form in consultation with the project supervisor. Where appropriate, the application must include the following appendices:

- (G) subject information sheet;
- (H) subject consent form;
- (I) subject health questionnaire.

1. Draft Title of Project

The effects of fatigue on soccer skills performed during a soccer match simulation

2. Names and Status of Research Team

Mark Russell – Postgraduate Student

Dr. Mike Kingsley – PhD Supervisor

3. Rationale

Physical performance has been observed to decline in the latter stages of a soccer match (Reilly and Thomas, 1979; Bangsbo *et al.*, 1991; Rienzi *et al.*, 2000; Mohr *et al.*, 2003); a phenomenon primarily associated with match-related fatigue that manifests its effects via a diminished work rate (Di Salvo *et al.*, 2007), a decline in muscular force output (Rahnama *et al.*, 2003), and reductions in the ability to perform high intensity exercise (Mohr *et al.*, 2003; Bangsbo *et al.*, 2006). However, little research exists concerning the effects of fatigue on the technical performances (i.e., skills) involved in soccer; this is somewhat surprising considering that a disproportionate number of goals are scored in the last 15 min of a match (Reilly, 2003), which suggests that a possible link between match-related fatigue and technical proficiency may exist (Ostojic and Mazic, 2002).

The majority of studies that have examined the effects of exercise on the performance of isolated soccer skills have tended to assess technical proficiency before and after exercise (e.g., McGregor *et al.*, 1999; Ostojic and Mazic, 2002; Lyons *et al.*, 2006b; Ali *et al.*, 2007b) but not during. Moreover, previous investigations into the effects of fatiguing exercise on soccer skills have failed to fully replicate the demands of a game by implementing exercise protocols that are not truly representative of match-play (Nicholas *et al.*, 2000; Lyons *et al.*, 2006b; Ali *et al.*, 2007b). Consequently, relatively little evidence exists concerning the effects of soccer-specific exercise on skills performed throughout simulated or actual match-play.

Rampinini *et al.* (2008) observed reductions in short passing performance throughout the duration of a soccer match that were attributed to the accumulated effects of match-related fatigue. However, in simulated match-play Currell *et al.* (2009) observed no detriment to kicking performance that was assessed at six time-points throughout exercise. Although these authors included soccer skills throughout exercise that was soccer-specific, the use of criterion-based outcome measures (i.e., outcomes were scored in terms of accuracy and time faults were added for errors) that are common in soccer skill research (Rampinini *et al.*, 2008; Stone and Oliver, 2009) may explain the lack of agreement between studies. Despite more sensitive measures of skill assessment having been used in other codes of football (Young *et al.*, 2010), no data collected by means other than criterion-based outcomes, currently exists concerning the effects of match-related fatigue on soccer skills performed during exercise.

In summary, evidence exists to suggest that fatigue may contribute to impaired technical performances during exercise; however the effects of soccer-specific exercise on the technical aspects of the game remain to be fully elucidated. Therefore, the aim of this study was to use the reliable skill tests (study one) in conjunction with the validated SMS protocol (study two), to determine whether soccer-specific exercise would influence the quality of passing, shooting and dribbling skills performed throughout the full duration of a soccer match.

5. Aims and Objectives

The aim of this study is to measure the validity of physiological, skilled and physical demands of a 90 min soccer-match simulation to those of actual soccer match-play.

Null Hypotheses:

H0₁: Exercise will not influence the speed, precision or success of soccer skills performed throughout exercise.

6. Methodology

6.1 Study Design

The study will examine the effects of match-related fatigue on the physiological (blood lactate concentrations, heart rate, and fluid losses), technical and physical responses (sprint speed) of soccer players. Players will undergo one main trial, where they will participate in a soccer-specific exercise simulation that incorporates the performance of passing, shooting, and dribbling skills before, during and after exercise. Prior to any participation, all players will be informed about the study requirements, will have been provided with subject information (Appendix B3), asked to provide written consent (Appendix B3) and/or parental consent where necessary (<18 years, Appendix B3) and will have completed a pre-participation health questionnaire (ACSM, 1998; Appendix C) in the presence of trained individuals.

Following approval by the University ethics committee and informed consent being attained, players aged between 14 and 25 years old, and all with two or more years playing experience, will be

recruited. However, diabetics or smokers will not be recruited. Each player will be advised to record their dietary intake (representative of a normal training day; i.e., no caffeine or alcohol) for 48 hours prior to the main trial. Additionally, any strenuous exercise during this 48 hour period will be discouraged.

Participants will be required to attend two preliminary sessions and the one main trial; the first two sessions will enable the collection of anthropometric data and also allow familiarisation of the testing procedures to occur, whereas the remaining trial will include the exercise simulation. Players will undergo capillary blood sample collection at nine time-points throughout each main trial. All players will consume water throughout exercise. During the main trial, a break of 15 min will separate the two halves of exercise, which are each approximately 47 min in duration.

6.2 Experimental Procedures

6.2.1 Preliminary Testing

Following satisfactory completion of a medical consent questionnaire and informed consent being attained from participants and a parent/guardian (if necessary), two preliminary testing sessions will be completed. In both instances, arrival at the testing site will require participants to empty their bowels and void their bladder. In the first preliminary session, anthropometric measurements of body mass (model 770; Seca Ltd, Birmingham, UK) and stature (Portable Stadiometer; Holtain Ltd, Wales, UK) will then be determined. On completion, a controlled warm up that consists of 5 min of light aerobic activity and 10 min of dynamic stretching and sprints that progress to near maximal speeds, will be performed. After cessation of the warm up, each participant undertakes assessments of lower body power (i.e., 30-m sprint testing with 15-m split and vertical jumping for maximum height); measured using an opto-electronic device (Brower, Utah) and a jump mat (TKA 5106; Takei Scientific Instruments CO., Korea) respectively. Following a 10 min recovery period, maximal oxygen uptake will then be estimated using the protocol outlined by Ramsbottom *et al.* (1988). The remaining preliminary session serves to familiarise participants with the procedures of the main trial; consequently, players will perform 90 min of an intermittent exercise simulation that incorporates the performances of passing, shooting and dribbling skills (detailed in section 6.2.2).

6.2.2 Main Experimental Procedures

On arrival at the laboratory players will be prompted to empty their bowels and provide a mid-flow urine sample. Body mass (model 770; Seca Ltd, Birmingham, UK) and stature (Portable Stadiometer; Holtain Ltd, Wales, UK) will then be measured. Players will remain in a rested state for approximately 20 min; on which a pre-exercise blood sample will be taken before players make a 5 min walk to an indoor training facility. On arrival, players will commence their final pre-exercise preparations before performing a standardised warm-up (consisting of running, dynamic stretching and ball skills) that precedes the start of exercise.

Soccer Match Simulation (SMS)

The soccer-match simulation requires participants to perform soccer shooting, passing and dribbling skills throughout two 47 min halves of soccer-specific activity that are separated by a 15-min passive recovery period (half-time). The exercise protocol is similar to that devised by Nicholas *et al.* (2000) but subsequently adapted to include additional components that further replicate the movement demands of soccer match-play (Kingsley *et al.*, 2005). Movements will be dictated by audio signals from CDs and each participant will alternate between sprinting and dribbling during each cycle.

More specifically, exercise is made up of 4.5-min blocks that consists of 3 repeated cycles of three 20-m walks, one walk to the side, an alternating 15-m sprint or an 18-m dribble, a 4-s passive recovery period, five 20-m jogs at a speed corresponding to 40% $\dot{V}O_{2\max}$, one 20-m backwards jog at 40% $\dot{V}O_{2\max}$ and two 20-m strides at 85% $\dot{V}O_{2\max}$. A 2 min period incorporating the performance of soccer passing (1 min) and recovery (1 min) will follow all blocks of exercise. Seven blocks of intermittent activity and skills will be completed during each half of exercise. The participants cover a total distance of 10.1 km and will complete 56 passes, 16 shots, and 21 dribbles during the protocol.

Figure 1 shows the setup of the shooting and passing skill tests. Balls (Total 90 Aerow: size 5; Nike Inc, USA) will be released at a constant velocity of $2.3\text{ m}\cdot\text{s}^{-1}$ towards a $1.5 \times 1.5\text{-m}$ square (action zone), where participants will be instructed to kick the ball. The participants kick towards one of four randomly determined targets (identified by a custom lighting system); consequently, the players are required to carry out visual searching and decision making during each attempt (similar to a soccer match when looking for space or other players). Motion sensors on the ball release mechanism ensure standardization and repeatability of each attempt; with a delay of 0.64 s between target identification and the ball reaching the centre of the action zone. Pilot work found this to be the most appropriate in player's of a similar standard.

Participants will commence the shooting and passing skill tests from a standing start before jogging into the action zone when the ball is released. The $2.0 \times 1.0\text{-m}$ passing targets will be placed at distances of 4.2 m (short pass) and 7.9 m (long pass) away from the centre of the action zone. The shooting target is a standard 11-aside adult soccer goal measuring $7.33 \times 2.44\text{ m}$ with transparent netting stretched across it. Four target lights are placed in the corners of the goal (positioned 1.0 m horizontally inside each post and 0.5 m vertically inside the upper and lower edges of the goal) as this has been identified as optimal ball placement to beat a goalkeeper when shooting.

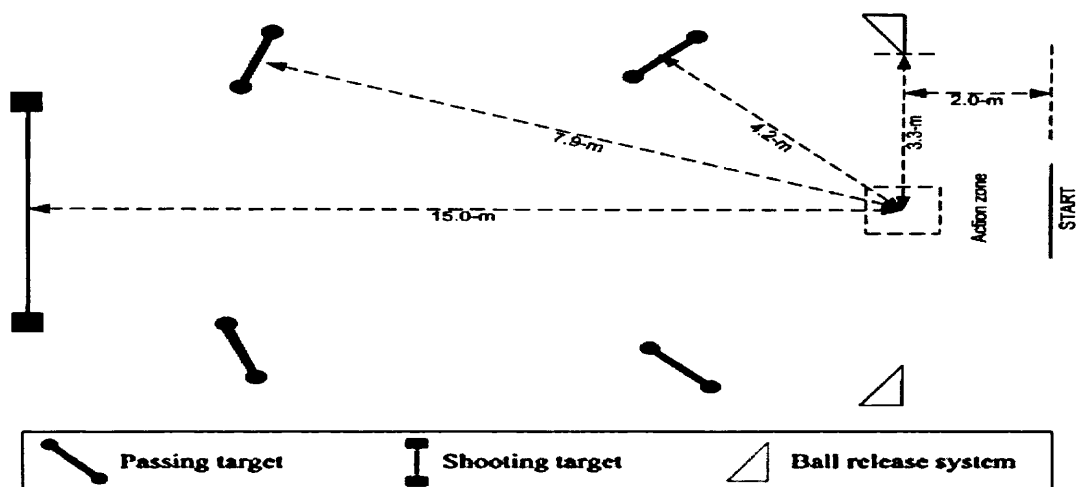


Figure 1: Schematic for the layout of the passing and shooting tests.

The participants will be instructed to aim passes at the centre of the target that is illuminated. When shooting, participants are instructed to kick the ball as accurately as possible at the illuminated target within the goal. The bouts of passing and shooting consist of four attempts, where the ball is alternately delivered from the right and left side of the action zone. To enhance ecological validity, no prior touches are allowed to control the ball (Olsen, 1988) and participants choose to kick the ball with the foot that they feel is most suitable to successfully complete the task.

The layout of the dribbling task is similar to that employed by McGregor *et al.* (McGregor *et al.*, 1999) with start and finish lines placed 20-m apart. Cones 2 through 7 are placed 3-m away from the preceding cone, and cones 1 and 7 are 1-m away from each end of the course. Participants will be instructed to dribble the ball as fast and as accurately as possible between all cones.

6.2.3 Physiological testing

Fingertip blood samples will be taken and analysed immediately for lactate concentrations using calibrated handheld devices (Lactate Pro; Arkray, Inc., Kyoto, Japan). Blood samples will be taken at time-points of pre-exercise and following the start of exercise at 15, 30, 45, half-time, 60, 75 and 90 min. HR will be recorded at rest and every 5 s during exercise using short range telemetry (Polar S610 HR monitor, Polar, Finland).

6.3 Statistical analyses

Data will be tabulated using commercially available software (Microsoft Excel 2003, Microsoft Inc, USA) and sampled for normality. Statistical analysis will be carried out using SPSS software (Version 16.0; SPSS Inc., IL). All results are to be reported as the mean \pm standard error of the mean (SEM) and the level of statistical significance will be set at $P \leq 0.05$. A one way repeated measures analysis of variance (ANOVA) will establish if any significant effects exist in the physiological

responses due to time. Mauchly's test will be consulted and Greenhouse–Geisser correction is to be applied if the assumption of sphericity is violated. When differences are noted, a *post-hoc* Bonferroni correction is to be implemented to determine the location of these differences and limits of agreement will also be calculated via established methods (Bland & Altman, 1986).

6.6 Storage and Disposal of Data and Samples

All data collected will be treated and disposed of with utmost confidentiality and in strict accordance with the Data Protection Act. Data reported in the write up of this study will ensure that all individuals remain anonymous. On request individual participants will be able to view their own data at any point in the research process if they so wish. Data will only be stored on password restricted computers located in the Sports and Exercise Science Research Centre at Swansea University. May it be made clear that only authorised persons involved in this study (the named researchers M. Russell and supervisor Dr M. Kingsley) will be able to access this data and will be solely responsible for the correct disposal of such data.

6.5 Dietary supplementation

During the main trial, the experimental team will be required to acutely consume water. Consumption of water during exercise will be at a rate of $14 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$ BM; one third of this volume is consumed 10 min prior to commencing each half of exercise (i.e., during the warm up and half-time recovery period). The remaining two thirds will be consumed between 0 and 15 and 15 and 30 min of each half of exercise when players are subject to blood sampling. No adverse side effects of this supplementation regime are expected.

7. Location of the Premises where the Research will be Conducted.

All testing will be supervised by Mark Russell (CPR/AED qualified) whilst on site at the Sports Village, Sketty Lane, Swansea.

8. Subject Risks and Discomforts

Whilst undergoing *voluntary* participation in this study, participants will experience no more discomfort than associated with any normal soccer game and are able to cease participation in the study at any time. Some muscular soreness localised in the quadriceps, hamstrings and gluteals may occur in the 24-48 hours following participation; however this is just part of the body's natural recovery. No psychological discomfort or stress will result as a part of this study.

The study does require that a certain level of soccer skill proficiency as 2 years of soccer playing experience is a pre-requisite for participation. Furthermore, it is advised that any person with muscle or connective tissue damage in the musculature involved in completing the soccer skills does not participate, in fear of aggravating and delaying recovery from such an injury. Participants with any signs of cardiorespiratory distress prior to or during any test involvement will be instructed to cease participation in the whole study immediately.

9. Information Sheet and Informed Consent

The submission should be specific about the type of consent that will be sought:

Have you included a Subject Information Sheet for participants of the study? YES see Appendix B3

Have you included a Subject Consent Form for the participants of the study? YES see Appendix B3

10. Computers

Are computers to be used to store data? YES

If so, is the data registered under the Data Protection Act? YES

11. Student Declaration

Please read the following declarations carefully and provide details below of any ways in which your project deviates from them. Having done this, each student listed in section 2 is required to sign where indicated.

1. I have ensured that there will be no active deception of participants.
2. I have ensured that no data will be personally identifiable.
3. I have ensured that no participant should suffer any undue physical or psychological discomfort
4. I certify that there will be no administration of potentially harmful drugs, medicines or foodstuffs.
5. I will obtain written permission from an appropriate authority before recruiting members of any outside institution as participants.
6. I certify that the participants will not experience any potentially unpleasant stimulation or deprivation.
7. I certify that any ethical considerations raised by this proposal have been discussed in detail with my supervisor.
8. I certify that the above statements are true with the following exception(s):
9. All collected data will be destroyed immediately after completion of the project.

Student signature: 

Date:

(include a signature for each student in research team)

12. Supervisor's Declaration

In the supervisor's opinion, this project (delete those that do not apply):

- ~~Does not raise any significant issues.~~
- Raises some ethical issues, but I consider that appropriate steps and precautions have been taken and I have approved the proposal.
- ~~Raises ethical issues that need to be considered by the Departmental Ethics Committee.~~
- ~~Raises ethical issues such that it should not be allowed to proceed in its current form.~~

Supervisor's signature: *Mike Kirk*

Date:

13. ETHICS COMMITTEE DECISION (COMMITTEE USE ONLY)

ETHICAL APPROVAL: GRANTED REJECTED (delete as appropriate)

The ethical issues raised by this project have been considered by members of the Departmental Ethical Approval Committee who made the following comments:

..... *note. Data must be deleted at end of study.*

.....

.....

.....

.....

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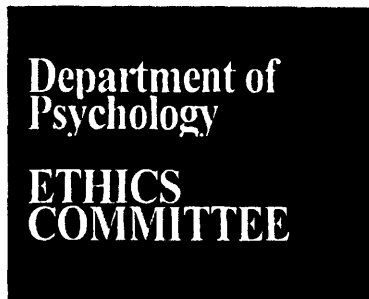
Please ensure that you take account of these comments and prepare a revised submission that should be shown to your supervisor/ resubmitted to the Department Ethical Approval Committee (delete as appropriate).

Signed: *M. J. Dennis*

Date:

(Chair, Departmental Ethics Advisory Committee)

Appendix A4: Ethical application (Study 4)



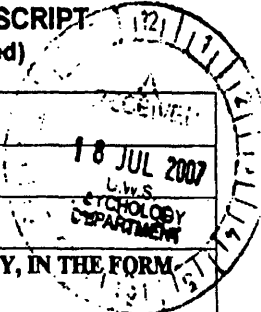
Memo

To: Professor David Benton and Mr. Mike Kingsley
From: Dr. Phil Tucker, on behalf of Ethics Committee
Copy:
Date: Thursday, 26th July, 2007
Re: The impact of carbohydrate energy, in the form of sucrose, on soccer skills

Your proposed study, "The impact of carbohydrate energy, in the form of sucrose, on soccer skills", has now been reviewed. Provided the information obtained is kept absolutely confidential and that no personally identifiable is entered on computer, it was agreed that no substantive ethical issues are raised and you may therefore proceed with your study.

PT ✓

Application for Ethical Approval
PLEASE COMPLETE THE FORM USING TYPESCRIPT
 (hand-written applications will not be considered)



Name	David Benton / Mike Kingsley
Address	Psychology / Sports Science
E-mail address	d.benton@swansea.ac.uk
Title of Proposed Research	THE IMPACT OF CARBOHYDRATE ENERGY, IN THE FORM OF SUCROSE, ON SOCCER SKILLS
Type of Researcher (please tick)	<input type="checkbox"/> Undergraduate student <input type="checkbox"/> Postgraduate student <input checked="" type="checkbox"/> Member of staff

1. Briefly describe the main aims of the research you wish to undertake. Please use non-technical language wherever possible.
 To see if the provision of carbohydrate energy during exercise will facilitate motor skills and maintain the cognitive functioning required for decision making.

2. Briefly describe the overall design of the project
 Cross over design with subjects taking either a sucrose drink or a placebo

3. Briefly describe the methods of data collection and analysis. Please describe all measures to be employed (e.g., questionnaire responses, reaction times, accuracy, skin conductance responses, etc.). If questionnaire or interviews are to be used, please provide the questionnaire / interview questions and schedule.
 Shuttle run is performed to mimic playing soccer. At various times a test of soccer skills will be taken. At the end memory, the ability to sustain attention and reaction times will be measured. Blood samples will be taken.

4. Location of the proposed research (i.e., Departmental labs, schools, etc)
 Sports centre - Sketty Lane

5. Describe the participants: give the age range, gender, inclusion and exclusion criteria, and any particular characteristics pertinent to the research project.
 Young fit and active highly-skilled soccer players will be recruited. They will have no history of cardiovascular disease, diabetes, respiratory, liver or gastro-intestinal disease and will not be currently taking medication. Blood pressure will be in the normal range. Only non-smokers will be recruited.

6. How will the participants be selected and recruited?
 Subject pool.
 General public
 Other. Club standard football papers. Swansea City have in principle allowed access to their

youth team although most subjects will be local club / university players

7. What procedures (e.g., interviews, computer-based learning tasks, etc.) will be carried out on the participants?

At various times a test of soccer skills will be taken. At the end a test of memory, the ability to sustain attention and reaction times will be measured.

8. What potential risks to the participants do you foresee and how do you propose to ameliorate/deal with potential risks? For instance, provide contact details of Student Counseling services and relevant community support organizations, etc.

As the subjects are young fit males, who exercise regularly, the task will make no demands in addition to those that they regularly freely undertake. Should distress be apparent then the study will be stopped immediately.

Those taking blood will have received relevant training.

9. What potential risks to the interests of the researchers do you foresee and how will you ameliorate/deal with potential risks?

Dealing with body fluids. Appropriate injections will be administered to the researcher, for example for hepatitis. Rubber gloves will be worn. Waste material will be placed in 'sin-bins' and burnt.

10. How will you brief and debrief participants? (Please attach copy of debrief information to be given to participants)

See attached sheets

11. Will informed consent be sought from participants? Yes (Please attach a copy of the consent form)

No

If no, please explain below:

12. If there are doubts about participants' abilities to give informed consent, what steps have you taken to ensure that they are willing to participate?

None

13. If participants are under 18 years of age, please describe how you will seek informed consent. If the proposed research is to be conducted in a school, please describe how you will seek general consent from the relevant authorities and attach a copy of any written consent.

NA

14. How will consent be recorded?

A consent sheet will be signed and the forms kept in a locked filing cabinet.

penalty? No

16. How do you propose to ensure participants' confidentiality and anonymity?
By not recording their names or other identifying characteristic in the data file. All reported measures will be averages for a group.

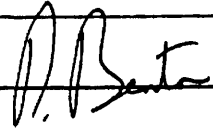
17. Please describe which of the following will be involved in your arrangements for storing data:

- Manual files (e.g. paper documents or X-rays)
- Home or other personal computer
- X University computer
- Private company or work-based computer
- Laptop computer
- Other (please define)

Please explain, for each of the above, the arrangements you will make for the security of the data (please note that any data stored on computer must have password protection as a minimum requirement):
Data will be anonymous and the computer password protected

18. Will payments or subject pool credits be made to participants? Yes X
No

If yes, please specify quantities involved (e.g., £5 or 1 hour credits):
£60 in total for attending for four half days

Applicant's signature:  Date: 17/7/07

**CHECKLIST OF ATTACHMENTS:
PLEASE REMEMBER TO ATTACH COPIES OF EACH OF THE FOLLOWING
(WHERE RELEVANT)**

INCOMPLETE APPLICATIONS WILL NOT BE CONSIDERED

- Copy of Participant Information Sheet
- Copy of Consent Form
- Copy of Participant debrief
- Copy of any questionnaires and/or interview schedules to be employed

N Copy of written consent from local authorities (e.g., schools)

N If your proposed research is with 'vulnerable' groups (e.g., children, people with developmental disorder), please attach a copy of your clearance letter from the Criminal Records Bureau (if UK) or equivalent non-UK clearance.

Departmental Ethics Committee Use Only

Members of the Departmental Ethics Committee have considered the ethical issues raised by this project, and have the following comments:

Approved

Please ensure that you take account of these comments and prepare a revised submission that should be either shown to your supervisor (if you are an undergraduate or postgraduate student) or resubmitted (if you are a member of staff) to the Departmental Ethics Committee.

Signed on behalf of Departmental Ethics Committee:

Philip Tan

Date: 25-7-07

Experiment Management System (EMS; 'the electronic subject pool')

EMS Approval Code: N/A

Date of Expiry: N/A

Appendix A5: Ethical application (Study 5)

Swansea University
SPORTS SCIENCE, SCHOOL OF HUMAN SCIENCE
DEPARTMENTAL ETHICS ADVISORY COMMITTEE

APPLICATION FOR ETHICAL COMMITTEE APPROVAL OF A RESEARCH PROJECT

In accordance with Departmental Safety Policy, all research undertaken in the department must be approved by the Departmental Ethics Advisory Committee **prior to data collection. Applications for approval should be typewritten on this form using the template available in the Public Folders.** The researcher(s) should complete the form in consultation with the project supervisor. Where appropriate, the application must include the following appendices:

- (J) subject information sheet;
- (K) subject consent form;
- (L) subject health questionnaire.

1. Draft Title of Project

The effect of a 6% carbohydrate-electrolyte solution consumed during soccer match play on blood glucose and lactate concentrations.

2. Names and Status of Research Team

John Norman – Undergraduate Student

Sean Evans – Undergraduate Student

Mark Russell – Postgraduate Student

Dr. Mike Kingsley – Dissertation Supervisor

3. Rationale

Soccer is a high intensity intermittent sport that requires athletes to perform prolonged and repeated bouts of continuous and intermittent activity. The intermittent nature of activity involved in competitive soccer leads to the onset of fatigue, which has been shown to manifest its effects in the later stages of the game and has also been identified as a limiting factor to performance (Krustrup *et al.*, 2005; Rampinini *et al.*, 2008).

One of the primary contributors of fatigue during soccer games is the depletion of intramuscular and liver glycogen, which is often associated with decreased blood glucose concentrations. A reduction in blood glucose concentrations can subsequently impair a variety of cognitive and psychomotor tasks even when muscle glycogen stores are not challenged. Therefore, it is widely accepted that the ingestion of a carbohydrate drink before, during, and after exercise can counteract the effects of fatigue by raising blood glucose levels. Although supplementation with carbohydrate-electrolyte drinks has been demonstrated to improve exercise capacity at the end of game simulations (Ali *et al.*, 2007), the influence of this supplementation regime on blood glucose levels throughout actual game play is currently unknown.

Recent results from our laboratory using young academy soccer players performing a soccer specific exercise and skill simulation, similar to that devised by Nicholas *et al.* (2000), indicates an association between reduced blood glucose concentrations and impaired skill performance. Furthermore, the results of this study indicate an incidence of rebound hypoglycaemia in the vast majority of the participants tested whilst ingesting a 6% carbohydrate-electrolyte solution in a manner similar to that recommended and utilised during match play. It is therefore necessary to investigate the influence of regimentally consuming a 6% carbohydrate-electrolyte solution during a soccer match on blood glucose and lactate concentrations. Investigating this phenomenon has the potential to influence carbohydrate electrolyte supplementation strategies for soccer players.

4. References

Ali, A., Williams, C., Nicholas, C.W. and Foskett, A. (2007). The influence of carbohydrate-electrolyte ingestion on soccer skill performance. *Medicine and Science in Sports and Exercise*, **11**, 1969-1976.

Krustrup, P., Mohr, M., Steensberg, A., Bencke, J., Kjer, M. and Bangsbo, J. (2006). Muscle and blood metabolites during a soccer game: Implications for sprint performance. *Medicine and Science in Sports and Exercise*, **38**, 1165-1174.

Nicholas, C.W., Nuttall, F.E. and Williams, C. (2000). The Loughborough Intermittent Shuttle Test: A field test that simulates the activity pattern of soccer. *Journal of Sports Sciences*, **18**, 97-104.

Rampinini, E., Impellizzeri, F., Franco, M., Castagna, C., Azzalin, A., Bravo, A.F. and Wisloff, U. (2008). Effect of match-related fatigue on short-passing ability in young soccer players. *Medicine and Science in Sports and Exercise*, **40**, 934-942.

Zeederberg, C., Leach, L., Estelle, V.L., Noakes, T.D., Dennis, S.C. and Hawley, J.A. (1996). The effect of carbohydrate ingestion on motor skill proficiency of soccer players. *International Journal of Sport Nutrition*, **6**, 348-355.

5. Aims and Objectives

The aim of this study is to measure the blood glucose and lactate response to a 6% carbohydrate-electrolyte supplement administered before and during a soccer match.

Null Hypotheses:

H₀₁: *There will be no difference in blood glucose levels between the two treatments.*

H₀₂: *There will be no difference in blood lactate levels between the two treatments*

6. Methodology

6.1 Study Design

The study will compare the heart rate (HR), blood lactate and glucose responses of players supplemented with either a carbohydrate or an artificially sweetened placebo beverage before and during a soccer match. Two experimental matches arranged for this study will be played between two teams consisting of elite academy players (experimental team) and University first team players

(opposition team). Ten outfield players of the experimental team will have their blood sampled at periodic time-points before and throughout each game, therefore results will be presented for ten players. Prior to any participation, all players will be informed about the study requirements, will have been provided with subject information (Appendix B5), asked to provide written consent (Appendix B5) and/or parental consent where necessary (<18 years, Appendix B5) and will have completed a pre-participation health questionnaire (ACSM, 1998; Appendix C) in the presence of trained individuals.

Following approval by the University ethics committee and informed consent being attained, two squads of players aged between 14 and 25 years old, and all with two or more years playing experience, will be recruited. However, diabetics or smokers will not be recruited. Each player will be advised to record their dietary intake (representative of a normal training day; i.e., no caffeine or alcohol) for 48 hours prior to the first testing session and to replicate this in all subsequent sessions. Additionally, any strenuous exercise during this 48 hour period will be discouraged.

Participants will be required to attend three testing sessions, one being an anthropometric and familiarisation session and the two main trials. During the main trials each participant will arrive at the laboratory 2.5 hours before kick off. Two hours before the game, a standardised pre-match meal will be provided before commencing a controlled 30 min warm up prior to kick off. Capillary blood samples of the experimental team will be taken at nine time-points throughout each main trial. Additionally, the experimental team will consume either a carbohydrate-electrolyte (CHO) or placebo (PL) treatment beverage throughout the game. A break of 15 min will separate two 45 min halves and players of both teams, together with the referee and assistant referees, will remain consistent in both main trials. Both matches will be separated by 7 days.

6.2 Experimental Procedures

6.2.1 Preliminary Testing

Following satisfactory completion of a medical consent questionnaire and informed consent being attained from participants and a parent/guardian (if necessary), a preliminary testing session will be completed. On arrival at the testing site, all participants will be asked to empty their bowels and void their bladder. Anthropometric measurements of body mass (model 770; Seca Ltd, Birmingham, UK) and stature (Portable Stadiometer; Holtain Ltd, Wales, UK) will then be determined. A controlled warm up that consists of 5 min of light aerobic activity and 10 min of dynamic stretching and sprints that progress to near maximal speeds, will then be completed. After cessation of the warm up, each participant undertakes 15-m sprint testing from a standing start; measured using an opto-electronic device (Brower, Utah). Following a 10 min recovery period, maximal oxygen uptake will then be estimated using the protocol outlined by Ramsbottom *et al.* (1988).

6.2.2 Main Experimental Procedures

Within a week of the preliminary testing session, the first of two matches organised for the purpose of this study will be played. Players of both teams will arrive at the laboratory 2.5 hours before kick off. On arrival and following voiding of both bladder and bowels, all players of the experimental team remain seated for 15 min before providing a pre-meal blood sample. Two hours before kick off, both teams receive a standardised 1470 kJ pre-match meal (Carbohydrate: 48 %, Fat: 9 %, Protein: 8 %), with the addition of 500 ml of the treatment beverage for the experimental team. The opposition team can consume fluid *ad libitum* but are encouraged to monitor their fluid intake in the first trial and replicate it for the second. Ninety minutes post-ingestion of the pre-match meal, players of the experimental team provide a post-meal blood sample. Both teams can then commence a standardised 30 min warm up consisting of light aerobic work, dynamic stretching and running that progresses to near maximal velocities.

The match kicks off 2 hours post ingestion of the pre-match meal. Both matches are to be played on the same grass pitch (that conforms to FA regulations), and during both games ten outfield players from the experimental team will have their blood sampled periodically. Players will be removed individually from the game in order to limit the influence of their absence on the match being played. A 1 min period of blood sampling occurs every 15 min for each player of the experimental team that data is collected for. In every 15 min block of the game, each player is removed once for the purpose of blood sampling and beverage administration. Player's will be numbered according to position and this number dictates the order of sampling; this order will be maintained throughout the study. The opposition team consists of a standard 10 outfield players and one goalkeeper. However, the experimental team utilises an additional outfield player; a "universal" player. The "universal" player will fulfill the role of the player that is off the field having a blood sample, in other words, if a defender is removed for blood sampling the "universal" player acts as a defender. If a standard 10 man outfield formation was adopted by the experimental team, they would find themselves a player down for the majority of the game; which could potentially alter the values of work done by the remaining players beyond that typically encountered in match play. When blood sampling is completed for each 15 min block, the "universal" player then leaves the pitch to sustain balance of the teams. In order to fully represent the demands of a game, the "universal" player is not subject to any analysis. In both matches, each team will be instructed to maintain a 4-4-2 formation, such that there are four defenders, four midfielders and two strikers and a 15 min passive recovery period will separate the two halves.

6.2.3 Experimental Beverages

During both main trials, the participants of the experimental team will drink an initial fluid bolus, containing 500 ml of the treatment beverage with the pre-match meal. Additionally, $14 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$ BM will be consumed over each half; one third of this volume consumed 10 min prior to commencing each half of exercise, and the remaining two thirds to be consumed between 0 and 15 and 15 and 30

min of each half when players leave the pitch to have their blood taken. In the carbohydrate trial (CHO), a carbohydrate-electrolyte beverage containing 6% sucrose, 23 mmol·L⁻¹ sodium and 14 mmol·L⁻¹ chloride will be consumed. The placebo (PL) beverage is equimolar in terms of electrolytes but void of any carbohydrate. Sweetness of the PL beverage is maintained by an energy free artificial sweetener. Both CHO and PL beverages will be flavoured with a commercially available fruit cordial (Smartprice Blackcurrant; ASDA, UK: CHO < 0.1 g/100 ml). Each trial is counterbalanced such that 5 players of the experimental team consume CHO in the first trial and 5 consume PL; an order which is then reversed in the second trial. Each trial will be completed in a double blind and randomised crossover fashion and both drinks will be indistinguishable by taste and consumed from identical containers. Following completion of the second main trial, the participants will verbally report whether they were able to distinguish between the two experimental beverages. During the month before the main trials, players of the experimental team will ingest water at a rate of 14 ml·kg⁻¹·h⁻¹ BM during training in order to promote the gastric tolerance of this rate of fluid ingestion.

6.2.4 Physiological testing

6.2.4.1 Blood sampling and analysis

Fingertip blood samples will be taken and analysed immediately for lactate and glucose concentrations using calibrated handheld devices (Lactate Pro; Arkray, Inc., Kyoto, Japan and Medisense Optium Glucose Meter, Abbott Diabetes Care, California, USA, respectively). Blood samples of the experimental team will be taken at times pre-meal, post-meal and between 0-15, 15-30, 30-45, recovery, 45-60, 60-75 and 75-90 min.

6.2.4.2 Heart rate

HR will be recorded at rest and every 5 s during each match using short range telemetry (Polar S610 HR monitor, Polar, Finland).

6.3 Statistical analyses

Data will be tabulated using commercially available software (Microsoft Excel 2003, Microsoft Inc, USA) and sampled for normality. Statistical analysis will be carried out using SPSS software (Version 16.0; SPSS Inc., IL). All results are to be reported as the mean ± standard deviation (SD) and the level of statistical significance will be set at $P \leq 0.05$. A two way repeated measures analysis of variance (ANOVA) will establish if any significant effects exist in the physiological responses due to time or treatment. Mauchly's test will be consulted and Greenhouse–Geisser correction is to be applied if the assumption of sphericity is violated. When differences are noted, a *post-hoc* Bonferroni correction is to be implemented to determine the location of these differences.

6.7 Storage and Disposal of Data and Samples

All data collected will be treated and disposed of with utmost confidentiality and in strict accordance with the Data Protection Act. Data reported in the write up of this study will ensure that all individuals remain anonymous. On request individual participants will be able to view their own data at any point in the research process if they so wish. Data will only be stored on password restricted computers located in the Sports and Exercise Science Research Centre at Swansea University. May it be made clear that only authorised persons involved in this study (the named researchers J. Norman, S. Evans, M. Russell and supervisor Dr M. Kingsley) will be able to access this data and will be solely responsible for the correct disposal of such data.

6.5 Dietary supplementation

During the two main trials, the experimental team will be required to acutely consume a 6% CHO beverage. Carbohydrate will be administered in the form of sucrose from standard table sugar. An initial 500 ml fluid bolus will be consumed with a pre-match meal that consists of two slices of white toast and margarine spread. Consumption of the treatment beverages at a rate of $14 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$ BM will be required; one third of this volume is consumed 10 min prior to commencing each half of the match (i.e., during warm up and recovery period). The remaining two thirds will be consumed between 0 and 15 and 15 and 30 min of each half when players leave the pitch to have their blood taken. In the CHO trial, a solution of 6% sucrose, $23 \text{ mmol} \cdot \text{L}^{-1}$ sodium and $14 \text{ mmol} \cdot \text{L}^{-1}$ chloride will be consumed. The PL beverage is equimolar in terms of electrolytes but void of any carbohydrate. Sweetness is maintained in the PL beverage by an energy free artificial sweetener. Both CHO and PL beverages are to be flavoured with a commercially available fruit cordial (Smartprice Blackcurrant; ASDA, UK: CHO < 0.1 g/100 ml). No adverse side effects of this supplementation regime are expected.

7. Location of the Premises where the Research will be Conducted.

All testing will be supervised by Mark Russell (CPR/AED qualified) whilst on site at the Sports Village, Sketty Lane, Swansea.

8. Subject Risks and Discomforts

Whilst undergoing *voluntary* participation in this study, participants will experience no more discomfort than associated with any normal game and are able to cease participation in the study at any time. Some muscular soreness localised in the quadriceps, hamstrings and gluteals may occur in the 24-48 hours following participation; however this is just part of the body's natural recovery. No psychological discomfort or stress will result as a part of this study.

The study does require that a certain level of soccer skill proficiency as 2 years of soccer playing experience is a pre-requisite for participation. Furthermore it is advised that any person with muscle or connective tissue damage in the musculature involved in completing the soccer skills does not

participate, in fear of aggravating and delaying recovery from such an injury. Participants with any signs of cardiorespiratory distress prior to or during any test involvement will be instructed to cease participation in the whole study immediately.

9. Information Sheet and Informed Consent

The submission should be specific about the type of consent that will be sought:

Have you included a Subject Information Sheet for participants of the study? YES see Appendix B5

Have you included a Subject Consent Form for the participants of the study? YES see Appendix B5

10. Computers

Are computers to be used to store data? YES

If so, is the data registered under the Data Protection Act? YES

11. Student Declaration

Please read the following declarations carefully and provide details below of any ways in which your project deviates from them. Having done this, each student listed in section 2 is required to sign where indicated.

1. I have ensured that there will be no active deception of participants.
2. I have ensured that no data will be personally identifiable.
3. I have ensured that no participant should suffer any undue physical or psychological discomfort
4. I certify that there will be no administration of potentially harmful drugs, medicines or foodstuffs.
5. I will obtain written permission from an appropriate authority before recruiting members of any outside institution as participants.
6. I certify that the participants will not experience any potentially unpleasant stimulation or deprivation.
7. I certify that any ethical considerations raised by this proposal have been discussed in detail with my supervisor.
8. I certify that the above statements are true with the following exception(s):
9. All collected data will be destroyed immediately after completion of the project.

Student signature: 

Date:

12. Supervisor's Declaration

In the supervisor's opinion, this project (delete those that do not apply):

- Does not raise any significant issues.
- Raises some ethical issues, but I consider that appropriate steps and precautions have been taken and I have approved the proposal.
- ~~Raises ethical issues that need to be considered by the Departmental Ethics Committee.~~
- ~~Raises ethical issues such that it should not be allowed to proceed in its current form.~~

Supervisor's signature:



Date:

30/10/08

13. ETHICS COMMITTEE DECISION (COMMITTEE USE ONLY)

ETHICAL APPROVAL:

GRANTED

REJECTED

(delete as appropriate)

The ethical issues raised by this project have been considered by members of the Departmental Ethical Approval Committee who made the following comments:

Note: Please provide name of CHO product.
(Supply details in b.S.)

Please ensure that you take account of these comments and prepare a revised submission that should be shown to your supervisor/ resubmitted to the Department Ethical Approval Committee (delete as appropriate).

Signed:



Date: 11/10/08

(Chair, Departmental Ethics Advisory Committee)

Appendix B1: Informed Consent (Study 1)

DEPARTMENT OF SPORTS SCIENCE SUBJECT INFORMATION SHEET

Date: October 2008

Contact Details:

Dr Mike Kingsley,

Sport and Exercise Science Research Centre, Swansea University, Singleton Park,
Swansea, SA2 8PP.

Tel: 01792 513310

Email: m.i.c.kingsley@swansea.ac.uk

Mark Russell,

Sport and Exercise Science Research Centre, Swansea University, Singleton Park,
Swansea, SA2 8PP.

Tel: 01792 602826

Martin Carvalho (07818400598)

Carlos Penas Ruiz (07906199161)

1. Study title

The reliability of a new soccer skill testing protocol that incorporates dribbling, passing and shooting assessments.

2. Invitation paragraph

You are being invited to take part in a research study. Before you decide whether to participate, it is important for you to understand why the research is being performed and what it will involve. Please take time to read the following information carefully and discuss it with friends, relatives and your GP if you wish. Ask us if there is anything that it is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

3. What is the purpose of this study?

The purpose of this research is to determine the reliability of a new soccer skills test (i.e., how repeatable the test is on different occasions).

4. Why have I been chosen?

You have been selected as a possible participant in this investigation because you are physically active and are considered healthy. As soccer players you will understand how important it is to determine new ways in which training can be tailored to your specific sporting needs. This study will go some way towards providing this information. Through your participation and training backgrounds you are the perfect participants for undertaking a study of this kind. However if at any time you

feel unhappy with the way the study is progressing you are free to withdraw.

5. What will happen to me if I take part?

If you decide to take part you will need to attend three separate testing sessions. The first session is for you to get used to what is coming up in the two main trials. In the first session we will measure your 15-m sprint speed and estimate your maximal oxygen uptake following a controlled warm up. You will then practice the skill test of dribbling, passing and shooting. The two main trials will consist of two skill assessment bouts. In each bout you will complete a total of 8 shots, 28 passes and 11 dribbles which will all be filmed and analysed after. A break of one hour separates the two bouts during which you will be able to relax. More formal information regarding the study design is available on request.

6. What are the possible disadvantages of taking part?

Exercise has negligible risk in healthy adults, although there is a possibility that certain physiological changes may occur during the exercise tests. They include abnormal blood pressure, fainting and disorders of the heart. You may suffer the effects of syncope (fainting) immediately post exercise and are therefore asked to continue moving post-test in order to reduce the chance of this occurring. Some temporary muscle soreness may be experienced 24-48 hours following the completion of the testing sessions. This particularly may be localised to the quadriceps, hamstrings and gluteal areas. You will complete a medical questionnaire to provide written consent with the option of withdrawing from the study at any point.

7. What are the possible benefits of taking part?

Through participating in this study you will gain an insight into the world of sports science research as well as gaining accurate measurements of your estimated maximal oxygen uptake, 15-m sprint speed and football skill proficiency. You will receive feedback on all of your results if you request. A formal explanation and interpretation of your results can be arranged with advice on how you will be able to make use of these results.

8. Will my taking part in the study be kept confidential?

All information that is collected about you during the course of the study will be kept strictly confidential within the research team. Any information about you that leaves the research team will have your name and address removed so that you cannot be identified by it.

**DEPARTMENT OF SPORTS SCIENCE
SUBJECT CONSENT FORM**

Contact Details:

Dr Mike Kingsley,

Sport and Exercise Science Research Centre, Swansea University, Singleton Park,
Swansea, SA2 8PP. Tel: 01792 513310. Email: m.i.c.kingsley@swansea.ac.uk

Mark Russell,

Sport and Exercise Science Research Centre, Swansea University, Singleton Park,
Swansea, SA2 8PP. Tel: 01792 602826

Martin Carvalho (07818400598)

Carlos Penas Ruiz (07906199161)

1. Study title

The reliability and construct validity of soccer skill tests that measure passing,
shooting, and dribbling

Please initial

box

- 1. I confirm that I have read and understood the information sheet dated/...../..... (version number) for the above study and have had the opportunity to ask questions.

- 2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected.

- 3. I understand that sections of any of data obtained may be looked at by responsible individuals from the University of Wales Swansea or from regulatory authorities where it is relevant to my taking part in research. I give permission for these individuals to have access to these records.

- 4. I agree to take part in the above study.

Name of Subject Date Signature

Person taking consent Date Signature

Researcher Date Signature

Appendix B2: Informed Consent (Study 2)

DEPARTMENT OF SPORTS SCIENCE SUBJECT INFORMATION SHEET

Date : October 2009

Contact Details:

Dr Mike Kingsley,

Sport and Exercise Science Research Centre, Swansea University, Singleton Park,
Swansea, SA2 8PP.

Tel: 01792 513310

Email: m.i.c.kingsley@swansea.ac.uk

Mark Russell,

Sport and Exercise Science Research Centre, Swansea University, Singleton Park,
Swansea, SA2 8PP.

Tel: 01792 606758

1. Study title

A soccer match simulation that incorporates technical actions and replicates the metabolic demands of match-play.

2. Invitation paragraph

You are being invited to take part in a research study. Before you decide whether to participate, it is important for you to understand why the research is being performed and what it will involve. Please take time to read the following information carefully and discuss it with friends, relatives and your GP if you wish. Ask us if there is anything that it is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

3. What is the purpose of this study?

The purpose of this study is to compare the demands of an exercise simulation to the demands of a soccer match.

4. Why have I been chosen?

You have been selected as a possible participant in this investigation because you are physically active and are considered healthy. As soccer players you will understand how important it is to determine new ways in which training can be tailored to your specific sporting needs. This study will go some way towards providing this information. Through your participation and training backgrounds you are the perfect participants for undertaking a study of this kind. However if at any time you feel unhappy with the way the study is progressing you are free to withdraw.

5. What will happen to me if I take part?

If you decide to take part you will need to attend three separate testing sessions. The first session is for you to get used to what is coming up in the two main trials. In the first session we will measure your 15-m sprint speed and estimate your maximal oxygen uptake following a controlled warm up. In the subsequent two sessions you will play in a soccer match and perform a soccer-match simulation that incorporates intermittent exercise and the performance of skills. During the two trials your blood will be sampled and aspects of your performances will be filmed for analysis. In addition you will be required to swallow a small silicon coated pill that contains a micro-transmitter that provides information on your body's core temperature.

6. What are the possible disadvantages of taking part?

Exercise has negligible risk in healthy adults, although there is a possibility that certain physiological changes may occur during exercise. They include abnormal blood pressure, fainting and disorders of the heart. You may suffer the effects of syncope (fainting) immediately post-exercise and are therefore asked to continue moving post-exercise in order to reduce the chance of this occurring. Some temporary muscle soreness may be experienced 24-48 hours following the completion of the testing sessions. This particularly may be localised to the quadriceps, hamstrings and gluteal areas. You will complete a medical questionnaire to provide written consent with the option of withdrawing from the study at any point. The use of the ingestible core temperature monitor is associated with no known adverse side effects in healthy participants and has been used in a number of scientific research studies. In the event of an injury during the study that requires diagnosis by medical scanning equipment (i.e., MRI, X-Ray etc), it is necessary for you to consume a laxative to facilitate the removal of the ingestible pill prior to undergoing the scan otherwise the pill will leave the body via normal means.

7. What are the possible benefits of taking part?

Through participating in this study you will gain an insight into the world of sports science research as well as gaining accurate measurements of your estimated maximal oxygen uptake, 15-m sprint speed and football skill proficiency. You will receive feedback on all of your results if you request it. A formal explanation and interpretation of your results can be arranged with advice on how you will be able to make use of these results.

8. Will my taking part in the study be kept confidential?

All information that is collected about you during the course of the study will be kept strictly confidential within the research team. Any information about you that leaves the research team will have your name and address removed so that you cannot be identified by it.

**DEPARTMENT OF SPORTS SCIENCE
SUBJECT CONSENT FORM**

Contact Details:

Dr Mike Kingsley,

Sport and Exercise Science Research Centre, Swansea University, Singleton Park,
Swansea, SA2 8PP.

Tel: 01792 513310

Email: m.i.c.kingsley@swansea.ac.uk

Mark Russell,

Sport and Exercise Science Research Centre, Swansea University, Singleton Park,
Swansea, SA2 8PP.

Tel: 01792 606758

1. Study title

A soccer match simulation that incorporates technical actions and replicates the metabolic demands of match-play.

Please initial

box

1. I confirm that I have read and understood the information sheet dated/...../..... (version number) for the above study and have had the opportunity to ask questions.

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected.

3. I understand that sections of any of data obtained may be looked at by responsible individuals from the University of Wales Swansea or from regulatory authorities where it is relevant to my taking part in research. I give permission for these individuals to have access to these records.

4. I agree to take part in the above study.

Name of Subject Date Signature

Person taking consent Date Signature

Researcher Date Signature

Appendix B3: Informed Consent (Study 3)

DEPARTMENT OF SPORTS SCIENCE SUBJECT INFORMATION SHEET

Date : October 2009

Contact Details:

Dr Mike Kingsley,

Sport and Exercise Science Research Centre, Swansea University, Singleton Park,
Swansea, SA2 8PP.

Tel: 01792 513310

Email: m.i.c.kingsley@swansea.ac.uk

Mark Russell,

Sport and Exercise Science Research Centre, Swansea University, Singleton Park,
Swansea, SA2 8PP.

Tel: 01792 606758

1. Study title

The effects of fatigue on soccer skills performed during a soccer match simulation

2. Invitation paragraph

You are being invited to take part in a research study. Before you decide whether to participate, it is important for you to understand why the research is being performed and what it will involve. Please take time to read the following information carefully and discuss it with friends, relatives and your GP if you wish. Ask us if there is anything that it is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

3. What is the purpose of this study?

The purpose of this study is to determine whether exercise influences the quality of soccer skills.

4. Why have I been chosen?

You have been selected as a possible participant in this investigation because you are physically active and are considered healthy. As soccer players you will understand how important it is to determine new ways in which training can be tailored to your specific sporting needs. This study will go somewhat towards providing this information. Through your participation and training backgrounds you are the perfect participants for undertaking a study of this kind. However if at any time you feel unhappy with the way the study is progressing you are free to withdraw.

5. What will happen to me if I take part?

If you decide to take part you will need to attend three separate testing sessions. The first two sessions is for you to get used to what is coming up in the main trial. In the first session we will measure your 15-m sprint speed and estimate your maximal oxygen uptake following a controlled warm up. In the subsequent session you will perform a soccer-match simulation that incorporates intermittent exercise and the performance of skills. During the trial your blood will be sampled and aspects of your performances will be filmed for analysis.

6. What are the possible disadvantages of taking part?

Exercise has negligible risk in healthy adults, although there is a possibility that certain physiological changes may occur during exercise. They include abnormal blood pressure, fainting and disorders of the heart. You may suffer the effects of syncope (fainting) immediately post-exercise and are therefore asked to continue moving post-exercise in order to reduce the chance of this occurring. Some temporary muscle soreness may be experienced 24-48 hours following the completion of the testing sessions. This particularly may be localised to the quadriceps, hamstrings and gluteal areas. You will complete a medical questionnaire to provide written consent with the option of withdrawing from the study at any point.

7. What are the possible benefits of taking part?

Through participating in this study you will gain an insight into the world of sports science research as well as gaining accurate measurements of your estimated maximal oxygen uptake, 15-m sprint speed and football skill proficiency. You will receive feedback on all of your results if you request it. A formal explanation and interpretation of your results can be arranged with advice on how you will be able to make use of these results.

8. Will my taking part in the study be kept confidential?

All information that is collected about you during the course of the study will be kept strictly confidential within the research team. Any information about you that leaves the research team will have your name and address removed so that you cannot be identified by it.

**DEPARTMENT OF SPORTS SCIENCE
SUBJECT CONSENT FORM**

Contact Details:

Dr Mike Kingsley,

Sport and Exercise Science Research Centre, Swansea University, Singleton Park,
Swansea, SA2 8PP.

Tel: 01792 513310

Email: m.i.c.kingsley@swansea.ac.uk

Mark Russell,

Sport and Exercise Science Research Centre, Swansea University, Singleton Park,
Swansea, SA2 8PP.

Tel: 01792 606758

1. Study title

The effects of fatigue on soccer skills performed during a soccer match simulation

Please initial

box

- 1. I confirm that I have read and understood the information sheet dated/...../..... (version number) for the above study and have had the opportunity to ask questions.

- 2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected.

- 3. I understand that sections of any of data obtained may be looked at by responsible individuals from the University of Wales Swansea or from regulatory authorities where it is relevant to my taking part in research. I give permission for these individuals to have access to these records.

- 4. I agree to take part in the above study.

Name of Subject Date Signature

Person taking consent Date Signature

Researcher Date Signature

Appendix B4: Informed Consent (Study 4)

BACKGROUND INFORMATION

The study at Swansea University is looking at the influence of taking a sugar containing drink on football skills throughout a match. The study involves running, jogging and walking (in a gym) in a similar way to playing a game of football. You should only take part if you regularly play football and have no history of heart, lung, liver or gut problems and do not suffer with diabetes. Similarly if you are currently taking drugs prescribed by your doctor, or are a smoker, you should not take part.

You will be asked to come to the university gym on five mornings. You will be asked to take a shuttle run that involves walking, jogging, running, backward running, zigzag sprinting and sprinting as instructed by a recording. This will take place for two 45 min periods separated by a ten minute half-time. At various times soccer skills will be assessed including passing, dribbling and shooting. Several blood samples will be taking for analysis. At the end of the shuttle run measures of reaction times and attention will be taken.

Only if you are totally happy should you agree to take part. The experimenters will not inform your club if you decide not to take part. The measures of football skill will not be given to your club. Even if you start you are free to drop out at any point.

If before agreeing to take part you have any questions or concerns you should discuss them with the experimenters. You can phone or email or we can arrange a meeting so we can talk one to one.

The only way that the best advice can be offered to sportsmen and women is by carrying out this type of study. Your help will be greatly appreciated and with luck it will allow us to offer advice that will help you and others to perform to the best of your ability.

Mike Kingsley
Phone 01792 293310
Email M.I.C.Kingsley@swansea.ac.uk

David Benton
01792 295607
d.benton@swansea.ac.uk

AGREEMENT TO TAKE PART IN A STUDY OF FOOTBALL SKILLS

- | | YES | NO |
|---|--------------------------|--------------------------|
| 1) I have read about the study and any questions have been answered | <input type="checkbox"/> | <input type="checkbox"/> |
| 2) I have enough information to allow me decide whether I should take part | <input type="checkbox"/> | <input type="checkbox"/> |
| 3) I understand that I do not need to take part and can withdraw at any time. | <input type="checkbox"/> | <input type="checkbox"/> |
| 4) I understand that my individual results will not be given to my club | <input type="checkbox"/> | <input type="checkbox"/> |
| 5) I am fit enough to take part and there is no medical reason for me not to take part. | <input type="checkbox"/> | <input type="checkbox"/> |

Tick only one of these

I agree to take part in the study

- | YES | NO |
|--------------------------|--------------------------|
| <input type="checkbox"/> | <input type="checkbox"/> |

NAME

SIGNED

ADDRESS

PHONE

.....

.....

Appendix B5: Informed Consent (Study 5)

DEPARTMENT OF SPORTS SCIENCE SUBJECT INFORMATION SHEET

Date : October 2008

Contact Details:

Dr Mike Kingsley,

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Mark Russell,

Sport and Exercise Science Research Centre, Swansea University, Singleton Park,
Swansea, SA2 8PP.

Tel: 01792 602826

John Norman (07534986126)

Sean Evans (07974203195)

1. Study title

The effects of carbohydrate ingestion prior to and during soccer match play.

2. Invitation paragraph

You are being invited to take part in a research study. Before you decide whether to participate, it is important for you to understand why the research is being performed and what it will involve. Please take time to read the following information carefully and discuss it with friends, relatives and your GP if you wish. Ask us if there is anything that it is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

3. What is the purpose of this study?

The purpose of this study is to see how your blood glucose and lactate levels change during a match in response to a carbohydrate-electrolyte drink.

4. Why have I been chosen?

You have been selected as a possible participant in this investigation because you are physically active and are considered healthy. As soccer players you will understand how important it is to determine new ways in which training can be tailored to your specific sporting needs. This study will go some way towards providing this information. Through your participation and training backgrounds you are the perfect participants for undertaking a study of this kind. However if at any time you feel unhappy with the way the study is progressing you are free to withdraw.

5. What will happen to me if I take part?

If you decide to take part you will need to attend three separate testing sessions. The first session is for you to get used to what is coming up in the two main trials. In the first session we will measure your 15-m sprint speed and estimate your maximal oxygen uptake following a controlled warm up. In the subsequent two sessions you will play in a soccer match whilst drinking one of two drinks; both of which taste the same. During the matches your blood will be sampled.

6. What are the possible disadvantages of taking part?

Exercise has negligible risk in healthy adults, although there is a possibility that certain physiological changes may occur during the exercise tests. They include abnormal blood pressure, fainting and disorders of the heart. You may suffer the effects of syncope (fainting) immediately post exercise and are therefore asked to continue moving post-test in order to reduce the chance of this occurring. Some temporary muscle soreness may be experienced 24-48 hours following the completion of the testing sessions. This particularly may be localised to the quadriceps, hamstrings and gluteal areas. You will complete a medical questionnaire to provide written consent with the option of withdrawing from the study at any point.

7. What are the possible benefits of taking part?

Through participating in this study you will gain an insight into the world of sports science research as well as gaining accurate measurements of your estimated maximal oxygen uptake, 15-m sprint speed and football skill proficiency. You will receive feedback on all of your results if you request. A formal explanation and interpretation of your results can be arranged with advice on how you will be able to make use of these results.

8. Will my taking part in the study be kept confidential?

All information that is collected about you during the course of the study will be kept strictly confidential within the research team. Any information about you that leaves the research team will have your name and address removed so that you cannot be identified by it.

**DEPARTMENT OF SPORTS SCIENCE
SUBJECT CONSENT FORM**

Contact Details:

Dr Mike Kingsley,

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Swansea, SA2 8PP.

Tel: 01792 602826

John Norman (07534986126)

Sean Evans (07974203195)

1. Study title

The effects of carbohydrate ingestion prior to and during soccer match play.

Please initial

box

- 1. I confirm that I have read and understood the information sheet dated/...../..... (version number) for the above study and have had the opportunity to ask questions.

- 2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected.

- 3. I understand that sections of any of data obtained may be looked at by responsible individuals from the University of Wales Swansea or from regulatory authorities where it is relevant to my taking part in research. I give permission for these individuals to have access to these records.

- 4. I agree to take part in the above study.

Name of Subject Date Signature

Person taking consent Date Signature

Researcher Date Signature

Appendix C: Health Questionnaire (All studies)

AHA/ACSM Health/Fitness Facility Preparticipation Screening Questionnaire

Please assess your health needs by marking all true statements.

History:

You have had:

- a heart attack
- heart surgery
- cardiac catheterization
- coronary angioplasty (PTCA)
- pacemaker/implantable cardiac defibrillator/rhythm disturbance
- heart valve disease
- heart failure
- heart transplantation
- congenital heart disease

Symptoms:

- You experienced chest discomfort with exertion.
- You experience unreasonable breathlessness.
- You experience dizziness, fainting, blackouts.
- You take heart medications.

Other health issues:

- You have musculoskeletal problems.
- You have concerns about the safety of exercise.
- You take prescription medication(s).
- You are pregnant.

If you marked any of the statements in this section, consult your healthcare provider before engaging in exercise. You may need to use a facility with a medically qualified staff.

Cardiovascular Risk Factors:

- You are a man older than 45 years.
- You are a woman older than 55 years or you have had a hysterectomy or you are post menopausal.
- You smoke.
- Your blood pressure is > 140/90.
- You don't know your blood pressure.
- You take blood pressure medication.
- Your blood cholesterol level is > 240 mg/dl.
- You don't know your cholesterol level.
- You have a close blood relative who had a heart attack before age 55 (father or brother) or age 65 (mother or sister).
- You are physically inactive (ie, you get < 30 minutes of physical activity on at least 3 days per week).
- You are > 20 pounds overweight.

If you marked 2 or more of the statements in this section, consult your healthcare provider before engaging in exercise. You might benefit by using a facility with a professionally qualified exercise staff to guide your exercise programme.

None of the above is true.

You should be able to exercise safely without consulting your healthcare provider in almost any facility that meets your exercise programme needs.

Appendix D: CV values – Skill analysis

Table D1: Raw data for CV analysis of passes performed

Analysis	Deviation (cm)					
	Pass 1	Pass 2	Pass 3	Pass 4	Pass 5	Pass 6
1	31	29	74	80	46	17
2	31	29	74	80	46	17
3	31	29	74	80	46	17
4	31	30	74	80	46	17
5	31	29	74	80	46	17
6	31	29	74	80	46	17
7	30	29	74	80	46	17
8	31	29	74	80	46	17
9	31	29	74	80	46	17
10	31	30	74	80	46	17
MEAN	31	29	74	80	46	17
SD	0	0	0	0	0	0
CV (%)	1	1	0	0	0	1
MEAN DIFF	GRAND MEAN	OVERALL CV (%)				
0.2	46.2	0.36%				

Table D2: Raw data for CV analysis of shots performed

Analysis	Deviation (cm)					
	Shot 1	Shot 2	Shot 3	Shot 4	Shot 5	Shot 6
1	38	615	711	550	171	263
2	38	615	713	550	170	263
3	38	614	713	550	171	264
4	38	614	713	551	171	263
5	38	614	712	550	171	264
6	36	614	712	550	170	263
7	38	612	713	550	171	264
8	38	615	713	550	170	263
9	38	615	713	549	171	263
10	36	614	716	550	170	262
MEAN	37	614	713	550	170	263
SD	1	1	1	1	1	1
CV (%)	1	0	0	0	0	0
MEAN DIFF	GRAND MEAN	OVERALL CV (%)				
0.8	391.3	0.21%				

Table D3: Raw data for CV analysis of dribbles performed

Analysis	Deviation (cm)					
	Dribble 1	Dribble 2	Dribble 3	Dribble 4	Dribble 5	Dribble 6
1	30	82	74	19	103	15
2	30	82	74	20	103	15
3	30	82	73	20	103	15
4	30	82	73	20	103	15
5	30	82	74	20	103	15
6	30	82	74	20	103	15
7	30	82	74	20	103	15
8	30	82	74	19	103	15
9	30	82	74	20	103	15
10	30	82	74	20	103	15
MEAN	30	82	74	20	103	15
SD	0	0	0	0	0	0
CV (%)	0	0	0	1	0	0
MEAN DIFF	GRAND MEAN	OVERALL CV (%)				
0.1	53.9	0.20%				

Appendix E: CV values – Physiological analyses

Table E1: Raw data for CV analysis of blood glucose concentrations between the handheld (Optium) and laboratory (YSI) analysers

Blood Glucose (mmol/L)				
Sample	Optium	YSI		
1	4.7	5.00		
2	4.8	4.54		
3	5.2	4.98		
4	5.1	4.95		
5	4.8	5.03		
6	5.0	4.82		
7	4.8	4.75		
8	4.9	5.03		
9	5.1	4.95		
10	4.9	4.82		
MEAN	4.9	4.89	Difference between devices	
SD	0.2	0.16		0.87%
CV (%)	3.3	3.19		

Table E2: Raw data for CV analysis of blood lactate concentrations between the handheld (Lactate-Pro) and laboratory (YSI) analysers

Blood Lactate (mmol/L)				
Sample	Lactate-Pro	YSI		
1	0.8	0.84		
2	0.8	0.86		
3	0.9	0.92		
4	0.8	0.84		
5	0.8	0.81		
6	0.8	0.86		
7	0.9	0.91		
8	0.9	0.89		
9	0.8	0.83		
10	0.8	0.84		
MEAN	0.8	0.86	Difference between devices	
SD	0.1	0.1		3.38%
CV (%)	5.8	4.19		

Table E3: Raw data for interassay CV analyses of blood pH, glucose, lactate, haematocrit, pH, pCO₂ and pO₂ values using the Gem Premier 3000 analyser

Sample	pH	Glu (mmol/L)	Lac (mmol/L)	Hct (%)	pH	PCO ₂ (kPa)	PO ₂ (kPa)
1	7.45	6	1.1	41	7.45	5.6	10.3
2	7.46	6.1	1.1	43	7.46	5.3	11.6
3	7.43	5.8	1.1	46	7.43	5.7	11.2
4	7.44	6.2	1	44	7.44	5.6	11.3
5	7.47	6.4	1.1	48	7.47	5.3	11.1
6	7.43	6	1.1	43	7.43	5.7	11.5
7	7.46	6.2	1	43	7.46	5.5	12.1
8	7.45	5.9	1	42	7.45	5.6	11.1
9	7.43	6	1	44	7.43	5.9	10
10	7.43	6	1	42	7.43	5.9	10.5
MEAN	7.45	6.1	1.1	44	7.45	5.6	11.1
SD	0.02	0.2	0.1	2	0.02	0.2	0.6
CV (%)	0.20	2.8	5.0	5	0.20	3.7	5.8

Table E4: Raw data for interassay CV analysis of osmolality

Sample	Osmolality (Osmol/kg)
1	0.292
2	0.295
3	0.292
4	0.292
5	0.292
6	0.292
7	0.293
8	0.295
9	0.295
10	0.293
MEAN	0.293
SD	0.001
CV (%)	0.468

Table E5: Raw data for interassay CV analysis of haemoglobin

Sample	Hb
1	144
2	134
3	135
4	141
5	142
6	137
7	137
8	142
9	134
10	136
MEAN	138
SD	4
CV (%)	3

Appendix F1: Raw Data – Study 1 – Participant anthropometrics

Table F1: Raw data of player anthropometrics involved in study 1

Player	Mass (kg)	Height (m)	Age (years)
1	80.7	1.67	26
2	66.0	1.74	16
3	66.1	1.78	14
4	55.7	1.66	16
5	64.0	1.76	16
6	69.2	1.81	15
7	97.9	1.81	28
8	63.4	1.67	15
9	58.5	1.75	16
10	58.6	1.69	15
11	81.8	1.89	20
12	64.1	1.73	23
13	71.3	1.78	20
14	66.8	1.78	18
15	75.3	1.78	21
16	82.4	1.83	22
17	71.5	1.81	21
18	85.3	1.88	21
19	82.8	1.79	20
20	74.1	1.83	21
MEAN	71.8	1.77	19
SD	10.7	0.06	4
SEM	2.4	0.01	1

Appendix F2: Raw Data – Study 1 – Skill variables ($n = 20$)

Table F2: Raw data of shooting performances (speed, precision and success) between two trials from study 1

Player	Shooting					
	Speed (m/s)		Precision (cm)		Success (%)	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
1	15.6	16.3	124	54	63	50
2	20.1	16.6	117	115	75	75
3	17.5	16.8	112	124	88	75
4	15.1	16.5	95	86	63	75
5	18.0	17.9	67	121	75	50
6	15.6	15.1	123	91	88	88
7	21.0	16.3	117	72	88	100
8	16.9	15.9	110	78	75	75
9	16.5	16.3	98	95	63	75
10	17.8	15.3	75	130	75	50
11	19.3	15.8	178	255	75	38
12	14.6	18.8	154	316	38	38
13	15.4	14.9	105	136	88	88
14	15.5	14.8	72	86	50	50
15	16.5	17.3	136	165	63	75
16	16.1	18.9	112	115	88	50
17	13.3	13.7	165	79	50	63
18	14.8	17.1	114	155	75	75
19	16.9	16.4	90	83	50	75
20	19.8	21.5	82	109	75	38
MEAN	16.8	16.6	112	123	70	65
SD	2.0	1.7	30	63	15	18
SEM	0.5	0.4	7	14	3	4

Table F3: Raw data of passing performances (speed, precision and success) between two trials from study 1

Player	Passing					
	Speed (m/s)		Precision (cm)		Success (%)	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
1	10.7	11.1	30	39	57	54
2	15.5	14.8	30	26	61	68
3	15.5	11.5	32	26	64	68
4	14.1	12.8	29	31	68	71
5	13.1	12.5	33	27	61	79
6	14.1	12.8	35	32	61	61
7	13.8	12.2	44	33	43	57
8	14.1	12.8	32	37	57	46
9	14.5	11.8	31	31	64	64
10	15.5	15.7	29	30	75	64
11	12.8	14.1	41	50	39	36
12	13.6	14.1	46	44	39	36
13	10.7	10.0	40	33	54	54
14	10.3	10.1	36	34	50	64
15	12.4	14.4	36	27	43	68
16	10.9	12.3	36	25	54	71
17	11.3	10.4	44	45	39	43
18	10.3	9.9	34	40	64	57
19	9.3	8.2	30	36	71	54
20	14.5	15.2	38	35	64	39
MEAN	12.8	12.3	35	34	56	58
SD	2.0	2.0	5	7	11	12
SEM	0.4	0.4	1	2	2	3

Table F4: Raw data of dribbling performances (speed, precision and success) between two trials from study 1

Player	Dribbling					
	Speed (m/s)		Precision (cm)		Success (%)	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
1	4.1	3.8	45	50	100	94
2	4.0	4.0	46	47	98	100
3	4.2	3.8	42	47	98	100
4	4.3	4.0	45	49	98	100
5	4.0	4.2	46	42	98	98
6	4.0	3.8	49	50	100	96
7	4.4	4.4	54	49	96	98
8	4.4	4.3	53	54	98	100
9	4.1	4.1	53	55	100	100
10	4.1	4.2	44	45	100	98
11	4.0	4.0	62	60	100	90
12	4.3	4.4	57	49	94	96
13	4.2	4.2	60	65	100	96
14	3.4	3.6	57	53	100	98
15	4.9	4.5	45	46	86	94
16	4.5	4.5	47	43	88	90
17	3.9	4.2	46	47	100	98
18	4.2	4.1	50	55	96	94
19	4.0	4.1	51	46	96	94
20	4.4	4.5	58	60	96	100
MEAN	4.2	4.1	51	51	97	97
SD	0.3	0.3	6	6	4	3
SEM	0.1	0.1	1	1	1	1

Appendix F3: Raw Data – Study 1 – Skill variables (Professional $n = 10$, Recreational $n = 10$)

Table F5: Raw data for criterion validity analyses for shooting performances (speed, precision and success) for professional players from study 1

Player	Shooting		
	Speed (m/s)	Precision (cm)	Success (%)
	Mean of 2 Trials	Mean of 2 Trials	Mean of 2 Trials
1	16.8	89	56
2	18.4	116	75
3	17.1	118	81
4	15.9	90	69
5	17.9	89	63
6	15.3	104	88
7	16.8	93	94
8	16.4	94	75
9	16.8	97	69
10	16.8	97	63
MEAN	16.8	99	73
SD	0.9	11	12
SEM	0.3	3	4

Table F6: Raw data for criterion validity analyses for passing performances (speed, precision and success) for professional players from study 1

Player	Passing		
	Speed (m/s)	Precision (cm)	Success (%)
	Mean of 2 Trials	Mean of 2 Trials	Mean of 2 Trials
1	10.9	35	55
2	15.2	28	64
3	13.6	29	66
4	13.4	30	70
5	12.8	30	70
6	13.4	33	61
7	13.0	38	50
8	13.4	34	52
9	12.9	31	64
10	15.6	29	70
MEAN	13.4	32	62
SD	1.3	3	7
SEM	0.4	1	2

Table F7: Raw data for criterion validity analyses for dribbling performances (speed, precision and success) for professional players from study 1

Player	Dribbling		
	Speed (m/s)	Precision (cm)	Success (%)
	Mean of 2 Trials	Mean of 2 Trials	Mean of 2 Trials
1	4.0	48	97
2	4.4	45	99
3	4.2	47	99
4	3.5	47	99
5	4.7	44	98
6	4.5	50	98
7	4.1	52	97
8	4.1	53	99
9	4.0	54	100
10	4.4	44	99
MEAN	4.2	48	99
SD	0.3	4	1
SEM	0.1	1	0

Table F8: Raw data for criterion validity analyses for shooting performances (speed, precision and success) for recreational players from study 1

Player	Shooting		
	Speed (m/s)	Precision (cm)	Success (%)
	Mean of 2 Trials	Mean of 2 Trials	Mean of 2 Trials
11	18.1	211	56
12	16.7	235	38
13	15.2	120	88
14	15.1	79	50
15	17.0	152	69
16	17.1	113	69
17	13.5	117	56
18	16.0	134	75
19	16.6	88	63
20	20.4	91	56
MEAN	16.6	134	62
SD	1.9	52	14
SEM	0.6	16	4

Table F9: Raw data for criterion validity analyses for passing performances (speed, precision and success) for recreational players from study 1

Player	Passing		
	Speed (m/s)	Precision (cm)	Success (%)
	Mean of 2 Trials	Mean of 2 Trials	Mean of 2 Trials
11	13.4	45	38
12	13.9	45	38
13	10.4	36	54
14	10.2	35	57
15	13.4	32	55
16	11.6	30	63
17	10.8	44	41
18	10.1	37	61
19	8.7	33	63
20	14.8	36	52
MEAN	11.7	37	52
SD	2.0	6	10
SEM	0.6	2	3

Table F10: Raw data for criterion validity analyses for dribbling performances (speed, precision and success) for recreational players from study 1

Player	Dribbling		
	Speed (m/s)	Precision (cm)	Success (%)
	Mean of 2 Trials	Mean of 2 Trials	Mean of 2 Trials
11	4.0	61	95
12	4.0	53	95
13	4.0	62	98
14	4.1	55	99
15	4.1	46	90
16	3.9	45	89
17	4.4	47	99
18	4.3	53	95
19	4.1	49	95
20	4.1	59	98
MEAN	4.1	53	95
SD	0.2	6	3
SEM	0.1	2	1

Appendix F4: Additional shooting notational analysis

Table F11: Summary of shooting data from 20 matches played by a professional team in one season

Total	471
Miss %	38.85
Success %	61.15

**Appendix F5: Additional reliability analyses – Study 1 –
Skill variables (Professional $n = 10$, Recreational $n = 10$)**

Table F12: Summary of skilled performance measures with Pearson's correlation coefficients (r), coefficients of variation (CV), limits of agreement (LOA) and ratio limits of agreement (RLOA) for passing, shooting and dribbling tests between two trials (T1 and T2) and by playing level.

Skill	Variable	Group	Mean	r	CV (%)	LOA Range	RLOA	
							Mean ratio	Agreement ratio
Passing	Speed ($m\ s^{-1}$)	Professional	13.4±0.4 ^c	0.60 ⁺	7.3	-3.8 – 1.2	0.909	1.082
		Recreational	11.7±0.6	0.94 ⁺	5.6	-1.9 – 2.3	1.010	1.079
		All	12.4±0.5	0.76 [~]	6.5	-3.2 – 2.2	0.958	1.091
	Precision (cm)	Professional	32±1 ^c	0.14	9.8	-12.4 – 9.7	0.957	1.141
		Recreational	37±2	0.55	10.1	-13.8 – 11.7	0.959	1.161
		All	35±1	0.53 [~]	10.0	-12.9 – 10.4	0.956	1.147
	Success (%)	Professional	62±2 ^c	0.43	8.1	-16.3 – 20.6	1.034	1.135
		Recreational	52±3	0.23	16.0	-30.1 – 30.9	1.000	1.241
		All	57±2	0.44 ⁺	11.7	-23.3 – 25.8	1.017	1.191
Shooting	Speed ($m\ s^{-1}$)	Professional	16.8±0.3	0.25	6.4	-4.8 – 2.6	0.941	1.090
		Recreational	16.6±0.6	0.51	7.4	-3.5 – 4.9	1.042	1.108
		All	16.7±0.3	0.33	6.9	-4.5 – 4.1	0.990	1.107
	Precision (cm)	Professional	99±3 ^c	0.61 ⁺	22.4	-86.8 – 72.1	0.915	1.375
		Recreational	134±17	0.62 ⁺	24.8	-94.4 – 152.5	1.160	1.321
		All	117±9	0.50 ⁺	23.5	-96.6 – 118.1	1.030	1.356
	Success (%)	Professional	73±4 ^{tc}	0.51	10.9	-32.3 – 24.7	0.933	1.188
		Recreational	62±4	0.19	18.6	-51.4 – 38.9	0.893	1.335
		All	68±3	0.38	14.4	-41.8 – 31.8	0.913	1.265
Dribbling	Speed ($m\ s^{-1}$)	Professional	4.1±0.1	0.57	2.6	-0.4 – 0.3	0.979	1.038
		Recreational	4.2±0.1	0.91 ⁺	2.2	-0.3 – 0.4	1.008	1.037
		All	4.1±0.1	0.78 [~]	2.4	-0.4 – 0.3	0.993	1.039
	Precision (cm)	Professional	48±1 ^{tc}	0.64 ⁺	4.1	-5.9 – 7.8	1.020	1.063
		Recreational	53±2	0.79 [~]	5.1	-9.7 – 7.9	0.981	1.072
		All	51±1	0.77 [~]	4.6	-7.9 – 7.9	1.000	1.068
	Success (%)	Professional	99±1 ^c	0.41	1.6	-5.9 – 5.5	0.998	1.025
		Recreational	95±1	0.37	2.8	-10.2 – 9.0	0.994	1.045
		All	96±1	0.41 ⁺	2.2	-8.1 – 7.3	0.996	1.035

^c Significantly different from the recreational group in the mean of both trials ($P \leq 0.05$)

^{tc} Trend for a significant difference from the recreational group in the mean of both trials ($0.05 < P \leq 0.075$)

^{*} Significant correlation between trials 1 and 2 ($P \leq 0.05$)

^{**} Significant correlation between trials 1 and 2 ($P \leq 0.01$)

⁺ Trend for a significant correlation between trials 1 and 2 ($0.05 < P \leq 0.075$)

Table F13: Intraclass correlation coefficients (ICC), standard error of measurement (SEM) with 95% confidence intervals (95% CI), and the minimal differences needed to be considered real (MD) for the passing, shooting and dribbling tests between trials (T1 and T2) and by playing level.

Skill	Variable	Group	ICC	SEM	95% CI	MD
Passing	Speed	Professional	0.60*	± 0.9 m s ⁻¹	± 1.8 m s ⁻¹	± 2.5 m s ⁻¹
		Recreational	0.87**	± 0.8 m s ⁻¹	± 1.5 m s ⁻¹	± 2.1 m s ⁻¹
		All	0.76**	± 1.0 m s ⁻¹	± 1.9 m s ⁻¹	± 2.7 m s ⁻¹
	Precision	Professional	0.11	± 4 cm	± 8 cm	± 11 cm
		Recreational	0.48 ⁺	± 5 cm	± 9 cm	± 13 cm
		All	0.51**	± 4 cm	± 8 cm	± 12 cm
	Success	Professional	0.43	± 7 %	± 13 %	± 18 %
		Recreational	0.23	± 11 %	± 22 %	± 31 %
		All	0.43*	± 9 %	± 17 %	± 25 %
Shooting	Speed	Professional	0.17	± 1.3 m s ⁻¹	± 2.6 m s ⁻¹	± 3.7 m s ⁻¹
		Recreational	0.51 ⁺	± 1.5 m s ⁻¹	± 3.0 m s ⁻¹	± 4.2 m s ⁻¹
		All	0.32 ⁺	± 1.5 m s ⁻¹	± 3.0 m s ⁻¹	± 4.3 m s ⁻¹
	Precision	Professional	0.57	± 29 cm	± 57 cm	± 79 cm
		Recreational	0.47 ⁺	± 45 cm	± 88 cm	± 123 cm
		All	0.38*	± 39 cm	± 76 cm	± 107 cm
	Success	Professional	0.45	± 10 %	± 20 %	± 28 %
		Recreational	0.19	± 16 %	± 31 %	± 45 %
		All	0.37*	± 13 %	± 25 %	± 37 %
Dribbling	Speed	Professional	0.54*	± 0.1 m s ⁻¹	± 0.3 m s ⁻¹	± 0.4 m s ⁻¹
		Recreational	0.86**	± 0.1 m s ⁻¹	± 0.3 m s ⁻¹	± 0.4 m s ⁻¹
		All	0.78**	± 0.1 m s ⁻¹	± 0.3 m s ⁻¹	± 0.4 m s ⁻¹
	Precision	Professional	0.63*	± 2 cm	± 4 cm	± 7 cm
		Recreational	0.78**	± 3 cm	± 6 cm	± 9 cm
		All	0.77**	± 3 cm	± 6 cm	± 8 cm
	Success	Professional	0.38	± 2 %	± 4 %	± 6 %
		Recreational	0.34	± 4 %	± 8 %	± 10 %
		All	0.40*	± 3 %	± 9 %	± 8 %

NOTE: ICC variables have no measurement units

* Significant correlation between trials 1 and 2 ($P \leq 0.05$)

** Significant correlation between trials 1 and 2 ($P \leq 0.01$)

⁺ Trend for a significant correlation between trials 1 and 2 ($0.05 < P \leq 0.075$)

Appendix G1: Raw Data – Study 2 – Participant anthropometrics

Table G1: Raw data of player anthropometrics involved in study 2

Player	Mass (kg)	Height (m)	Age (years)	Estimated Aerobic Capacity (ml/kg/min)
1	61.5	1.72	15	55.8
2	64.2	1.72	15	55.8
3	64.5	1.82	15	55.7
4	67.9	1.73	15	57.5
5	66.7	1.73	15	55.4
6	61.2	1.71	16	57.5
7	65.4	1.78	16	51.3
8	66.3	1.74	16	55.4
9	68.8	1.78	15	58.2
10	56.1	1.65	15	55.8
MEAN	64.3	1.74	15	55.8
SD	3.8	0.05	1	1.9
SEM	1.2	0.01	1	0.6

Appendix G2: Raw Data – Study 2 – Pre-trial diet and urine analyses

Table G2: Pre SMS trial dietary and osmolality data

Player	Energy contribution			Total Calories	MJ/d	Urine osmolality (mOsmol/kg)
	% Fat	% CHO	% Protein			
1	16	60	16	504	2.1	207.5
2	28	58	14	2761	11.6	377
3	31	52	17	2236	9.4	751.5
4	39	46	15	1896	7.9	383.5
5	28	58	14	2650	11.1	197
6	31	50	19	2541	10.6	393
7	21	58	21	2537	10.6	448.5
8	28	55	17	3091	12.9	374.5
9	41	40	19	1994	8.3	760
10	37	41	22	1869	7.8	363.5
MEAN	30	52	17	2208	9.2	426
STDEV	8	7	3	720	3.0	191
SEM	2	2	1	228	1.0	61

Table G3: Pre Match trial dietary and osmolality data

Player	Energy contribution			Total Calories	MJ/d	Urine osmolality (mOsmol/kg)
	% Fat	% CHO	% Protein			
1	21	63	16	1693	7.1	818
2	22	64	14	2116	8.9	711
3	23	58	19	1506	6.3	894
4	42	43	14	2313	9.7	398
5	17	65	18	2294	9.6	943
6	27	57	16	2325	8.8	363
7	16	62	22	1605	6.7	100
8	34	50	16	3335	14.0	1066
9	43	47	10	3794	15.9	753
10	21	61	19	2267	9.5	363
MEAN	27	57	16	2325	8.8	641
STDEV	10	8	3	776	4.3	315
SEM	3	3	1	259	1.4	100

Table G4: Average data for pre-trial dietary and osmolality data

	Energy contribution			Total Calories	MJ/d	Urine osmolality (mOsmol/kg)
	% Fat	% CHO	% Protein			
MEAN	28	54	17	2263	9.0	533
STDEV	9	8	3	728	3.6	276
SEM	2	2	1	167	0.8	62

Appendix G3: Raw Data – Study 2 – Notational analyses

Table G5: Test-retest reliability analyses of the percentage time of physical activities performed during the match trial.

Activity	T1	T2	% diff
walk	37.7	38.2	-1.3
jog	49.3	49.2	0.2
stride	11.8	10.7	9.8
sprint/dribble	6.3	6.5	-3.0
back jog	5.6	5.3	5.2
test	0.6	0.6	0

Table G6: Percentage of time in each movement modality throughout the Match trial

Player	Intensity		
	Low	Medium	High
1	35.5	59.8	4.6
2	38.8	55.3	3.3
3	36.9	62.5	4.5
4	37.4	57.3	3.7
5	36.4	58.9	4.5
6	35.3	60.2	4.8
7	34.5	60.4	5.7
8	37.3	59.3	5.4
9	39.8	51.2	7.6
10	37.2	56.4	6.3
MEAN	37	58	5
SD	2	3	1
SEM	1	1	0

Table G7: Total number of on-the-ball actions in the Match trial

Player	Passes	Clearances	Interceptions	Blocks	Crosses	Shots	Ball involvements
1	33	0	13	0	1	1	48
2	34	10	10	2	0	0	68
3	47	2	5	1	2	0	62
4	35	6	2	4	0	0	58
5	43	1	10	0	0	0	61
6	23	0	1	2	0	2	31
7	56	2	6	0	1	3	83
8	31	0	7	0	2	1	46
9	16	1	1	0	4	1	32
10	17	1	6	0	2	0	29
MEAN	33.5	2.3	6.1	0.9	1.2	0.8	51.8
STDEV	12.8	3.2	4.1	1.4	1.3	1.0	17.8
SEM	4.1	1.0	1.3	0.4	0.4	0.3	5.6

Appendix G4: Raw Data – Study 2 – Physiological data

Table G8: Average HR variables throughout the Match and SMS trials

Player	Match		SMS	
	Mean	Peak	Mean	Peak
1	160	197	158	197
2	161	209	165	207
3	165	202	161	198
4	159	190	136	179
5	157	203	167	199
6	160	197	158	197
7	170	201	163	204
8	140	176	145	194
9	166	198	166	198
10	162	196	162	198
MEAN	160	197	158	197
SD	8	9	10	7
SEM	3	4	4	3

Table G9: Blood lactate concentrations (mmol/L) throughout the SMS trial

Player	Time of sample (min unless stated)						
	15	30	45	Half-time	60	75	90
1	9.3	13.0	7.0	5.0	10.1	6.4	4.6
2	9.0	5.6	5.1	3.1	13.8	4.6	7.3
3	10.1	8.0	21.3	5.7	5.2	3.6	13.3
4	11.6	3.8	2.0	3.2	3.7	3.0	5.6
5	17.0	18.9	10.7	20.8	6.1	10.1	12.1
6	8.0	4.2	5.9	3.4	11.3	3.2	9.8
7	10.9	7.4	6.0	2.9	6.4	12.9	17.3
8	5.9	7.2	4.2	3.0	2.3	2.9	0.8
9	5.2	2.8	4.0	5.2	3.6	2.6	3.1
10	12.0	11.0	11.9	6.1	8.0	7.0	8.4
MEAN	9.9	8.2	7.8	5.8	7.1	5.6	8.2
SD	3.4	4.9	5.6	5.4	3.7	3.5	5.0
SEM	1.1	1.6	1.8	1.7	1.2	1.1	1.6

Table G10: Blood lactate concentrations (mmol/L) throughout the Match trial

Player	Time of sample (min unless stated)						
	15	30	45	Half-time	60	75	90
1	5.4	10.1	8.3	5.3	5.0	7.7	1.3
2	5.7	3.6	2.1	1.9	1.7	3.0	3.8
3	13.2	2.2	2.4	2.1	5.6	2.1	2.4
4	3.9	5.1	8.4	5.1	4.8	9.0	9.1
5	6.7	9.2	4.2	4.9	2.4	1.9	8.6
6	4.7	6.1	5.0	5.7	4.9	5.6	3.1
7	6.1	7.9	6.1	5.1	2.2	2.7	4.0
8	6.8	3.7	3.4	1.8	2.8	4.3	6.1
9	6.7	6.0	4.9	4.1	3.9	5.0	4.8
10	9.0	7.0	5.9	6.0	5.9	9.0	4.7
MEAN	6.8	6.1	5.1	4.2	3.9	5.0	4.8
SD	2.6	2.5	2.2	1.6	1.5	2.7	2.5
SEM	0.8	0.8	0.7	0.5	0.5	0.9	0.8

Table G11: Blood glucose concentrations (mmol/L) throughout the SMS trial

Player	Time (min unless stated)						
	15	30	45	Half-time	60	75	90
1	4.5	5.6	5.0	4.6	4.5	4.1	4.2
2	4.4	4.2	3.9	4.2	3.4	3.9	3.9
3	4.8	4.3	4.2	4.2	4.1	4.6	4.8
4	5.5	4.8	5.2	4.6	4.0	4.4	4.8
5	6.9	7.4	5.3	4.1	3.7	4.2	4.2
6	4.7	4.9	4.8	4.9	4.4	5.1	4.6
7	5.5	5.9	4.7	3.8	3.8	4.5	4.1
8	5.0	5.3	5.8	3.8	3.7	3.9	2.9
9	3.5	4.0	3.8	3.5	3.3	3.4	3.6
10	5.5	5.3	5.1	3.9	5.0	4.3	4.9
MEAN	5.0	5.1	4.7	4.1	4.0	4.2	4.2
SD	0.9	1.0	0.7	0.4	0.5	0.5	0.6
SEM	0.3	0.3	0.2	0.1	0.2	0.1	0.2

Table G12: Blood glucose concentrations (mmol/L) throughout the Match trial

Player	Time (min unless stated)						
	15	30	45	Half-time	60	75	90
1	5.0	6.1	4.7	4.4	3.9	4.2	4.6
2	4.7	3.5	3.9	3.8	3.8	4.2	3.5
3	3.4	4.1	4.4	5.1	3.4	3.8	5.0
4	5.1	6.0	6.9	6.6	5.2	4.7	5.0
5	5.2	5.7	3.9	4.4	4.0	5.0	5.1
6	5.8	7.4	4.6	5.8	4.5	5.4	4.3
7	4.6	5.9	5.0	5.0	3.2	3.2	3.2
8	4.0	4.4	3.7	4.6	3.9	4.6	4.6
9	3.4	4.1	3.1	4.4	2.8	4.3	4.4
10	6.3	6.3	5.5	5.6	4.2	3.6	4.6
MEAN	4.7	5.3	4.5	5.0	3.9	4.3	4.4
SD	0.9	1.2	1.1	0.8	0.7	0.7	0.6
SEM	0.3	0.4	0.3	0.3	0.2	0.2	0.2

Table G13: Raw data for mass change calculations during the SMS trial

Player	Mass Pre (kg)	Mass Post (kg)	Urine (L)	Fluid In (L)	Net mass loss (kg)
1	61.5	60.6	0.5	1.79	1.69
2	64.2	62.4	0.4	1.85	2.75
3	64.5	63.9	0.7	1.85	1.22
4	67.9	67.4	0.0	1.93	1.93
5	66.7	65.7	0.6	1.90	1.79
6	61.2	60.5	0.4	1.79	1.63
7	65.4	64.3	1.2	1.87	1.27
8	66.3	65.4	0.1	1.89	2.19
9	68.8	68.2	0.6	1.94	1.44
10	56.1	55.1	0.8	1.68	1.35
MEAN	64.3	63.4	0.5	1.85	1.7
SD	3.8	3.9	0.4	0.08	0.5
SEM	1.2	1.2	0.1	0.03	0.1

Table G14: Raw data for mass change calculations during the Match trial

Player	Mass Pre (kg)	Mass Post (kg)	Urine (L)	Fluid In (L)	Net mass loss (kg)
1	63.5	63.0	0.3	1.83	2.0
2	64.0	65.5	0.7	1.84	-0.3
3	65.0	65.0	0.5	1.87	1.4
4	67.5	68.0	0.8	1.92	0.6
5	66.0	67.5	0.4	1.89	0.0
6	61.5	63.0	0.4	1.79	-0.1
7	65.0	66.0	0.6	1.87	0.2
8	66.0	67.5	0.0	1.89	0.4
9	70.0	70.5	0.4	1.97	1.0
10	56.0	57.0	0.5	1.68	0.1
MEAN	64.5	65.3	0.5	1.85	0.5
SD	3.8	3.7	0.2	0.08	0.7
SEM	1.2	1.2	0.1	0.02	0.2

Appendix H1: Raw Data – Study 3 – Participant anthropometrics (n = 15)

Table H1: Raw data of player anthropometrics involved in study 3 (influence of exercise on skilled performance trial)

Player	Mass (kg)	Height (m)	Age (years)	Estimated Aerobic Capacity (ml/kg/min)
1	67.4	1.77	16	57.1
2	65.7	1.77	16	60.6
3	53.8	1.67	16	57.8
4	66.9	1.72	14	57.5
5	77.8	1.81	16	54.4
6	68.9	1.70	15	61.3
7	79.1	1.83	16	57.5
8	57.5	1.70	16	57.5
9	82.9	1.83	20	55.8
10	73.0	1.79	20	57.5
11	71.4	1.81	20	57.1
12	72.3	1.75	23	50.6
13	91.8	1.82	23	50.6
14	65.7	1.76	26	58.9
15	72.3	1.80	15	61.6
MEAN	71.1	1.77	18	57.3
SD	9.5	0.05	4	3.3
SEM	2.5	0.01	1	0.7

Table H2: Raw data of player anthropometrics involved in study 3 (test-retest reliability trial)

Player	Mass (kg)	Height (m)	Age (years)	Estimated Aerobic Capacity (ml/kg/min)
1	67.40	1.77	16	57.1
2	65.70	1.77	16	60.6
3	53.80	1.67	16	57.8
5	77.80	1.81	16	54.4
6	68.90	1.70	15	61.3
7	79.10	1.83	16	57.5
8	57.50	1.70	16	57.5
11	71.40	1.81	20	57.1
12	72.30	1.75	23	50.6
15	72.30	1.80	15	61.6
MEAN	68.6	1.76	17	57.5
SD	8.0	0.06	3	3.3
SEM	2.5	0.02	1	1.0

Appendix H2: Raw Data – Study 3 – Test-retest reliability of physiological variables

Table H3: Average HR variables throughout the two SMS trials (test-retest reliability)

Player	HR (bpm)			
	T1		T2	
	Mean	Peak	Mean	Peak
1	169	195	170	193
2	182	205	167	196
3	170	195	163	191
5	172	204	176	198
6	181	205	167	188
7	172	196	177	188
8	170	200	171	196
11	163	194	171	192
12	160	198	164	201
15	164	192	168	200
MEAN	170	198	169	194
SD	7	5	5	5
SEM	2	2	1	1

Table H4: Blood lactate concentrations (mmol/L) throughout the two SMS trials (test-retest reliability)

Player	Blood lactate concentration (mmol/L)							
	T1			T2			MEAN	
	15	30	45	15	30	45	T1	T2
1	11.6	10.6	17.9	7.1	7.3	9.4	13.4	7.9
2	8.9	7.9	6.0	8.9	7.9	6.0	7.6	7.6
3	8.1	6.9	5.8	6.7	5.6	5.4	6.9	5.9
5	6.6	5.7	5.4	5.4	5.6	6.9	5.9	6.0
6	11.7	11.0	11.0	10.9	7.9	6.6	11.2	8.5
7	7.8	6.2	6.2	7.6	9.7	8.4	6.7	8.6
8	6.3	5.9	7.0	6.4	6.0	7.0	6.4	6.5
11	11.6	9.0	7.0	12.8	23.0	11.0	9.2	15.6
12	10.4	9.6	6.8	7.4	6.6	9.3	8.9	7.8
15	8.1	7.1	6.3	7.9	7.2	6.3	7.2	7.1
MEAN	9.1	8.0	7.9	8.1	8.7	7.6	8.3	8.1
SD	2.1	2.0	3.8	2.2	5.2	1.8	2.4	2.8
SEM	0.7	0.6	1.2	0.7	1.6	0.6	0.8	0.9

Table H5: Mean 15 m sprint velocities throughout the two SMS trials (test-retest reliability)

Player	Average 15 m sprint velocities (m/s)								
	T1			T2			MEAN		
	15	30	45	15	30	45	T1	T2	
1	6.1	5.9	5.7	6.0	5.8	5.7	5.9	5.9	
2	6.1	6.1	6.0	6.1	6.1	6.0	6.1	6.1	
3	6.3	6.1	6.0	6.1	6.0	6.0	6.1	6.0	
5	6.0	5.4	5.9	5.9	5.4	5.2	5.8	5.5	
6	5.9	5.9	5.8	6.0	5.8	5.9	5.9	5.9	
7	6.2	6.2	4.4	6.0	5.9	5.8	5.6	5.9	
8	6.1	5.3	3.9	6.0	5.3	5.4	5.1	5.6	
11	6.3	6.0	6.0	6.0	5.5	5.3	6.1	5.6	
12	5.8	5.7	5.6	5.9	5.5	5.5	5.7	5.6	
15	6.2	6.1	6.2	6.2	6.1	6.2	6.2	6.2	
MEAN	6.1	5.9	5.5	6.0	5.7	5.7	5.8	5.8	
SD	0.2	0.3	0.8	0.1	0.3	0.3	0.3	0.2	
SEM	0.1	0.1	0.2	0.0	0.1	0.1	0.1	0.1	

Table H6: Raw data for mass change calculations during T1 of the test-retest reliability study

Player	T1				
	Mass Pre (kg)	Mass Post (kg)	Urine (L)	Fluid In (L)	Net mass loss (kg)
1	67.4	67.3	0.0	0.71	0.8
2	65.7	65.2	0.0	0.69	1.2
3	53.8	53.6	0.0	0.56	0.8
5	77.8	77.1	0.0	0.82	1.5
6	68.9	68.6	0.0	0.72	1.0
7	79.1	78.8	0.0	0.83	1.1
8	57.5	57.1	0.0	0.60	1.0
11	71.4	71.1	0.0	0.75	1.0
12	72.3	72.2	0.0	0.76	0.9
15	72.3	72.0	0.0	0.76	1.1
MEAN	68.6	68.3	0.0	0.72	1.0
SD	8.0	8.0	0.0	0.08	0.2
SEM	2.5	2.5	0.0	0.03	0.1

Table H7: Raw data for mass change calculations during T2 of the test-retest reliability study

Player	T2				
	Mass Pre (kg)	Mass Post (kg)	Urine (L)	Fluid In (L)	Net mass loss (kg)
1	66.9	67.0	0.0	0.70	0.6
2	65.7	65.3	0.0	0.67	1.1
3	55.2	54.9	0.0	0.58	0.9
5	77.2	77.1	0.0	0.81	0.9
6	67.2	66.7	0.0	0.71	1.2
7	78.9	78.4	0.0	0.83	1.3
8	57.7	57.0	0.0	0.61	1.3
11	70.8	70.5	0.0	0.73	1.0
12	72.6	72.4	0.0	0.76	1.0
15	71.9	71.7	0.0	0.73	0.9
MEAN	68.4	68.1	0.0	0.71	1.0
SD	7.6	7.7	0.0	0.08	0.2
SEM	2.4	2.4	0.0	0.03	0.1

Appendix H3: Raw Data – Study 3 – Skill variables

Table H8: Raw data for shot speeds throughout study 3

Player	Shooting speed (m/s)			
	Pre 1st half	Post 1st half	Pre 2nd half	Post 2nd half
1	19.2	15.5	18.0	17.2
2	14.8	16.1	13.6	16.7
3	16.0	17.5	15.5	18.3
4	14.1	16.2	15.6	17.1
5	17.3	14.1	17.8	15.7
6	16.3	15.7	15.2	16.1
7	18.4	18.4	17.9	18.0
8	17.6	16.6	15.9	16.5
9	13.8	17.1	16.9	20.2
10	18.2	19.7	17.8	19.6
11	13.9	18.2	15.7	16.5
12	19.9	18.3	14.6	19.1
13	17.6	15.9	16.1	18.0
14	17.4	15.3	16.4	15.8
15	16.8	17.4	16.9	17.8
MEAN	16.8	16.8	16.3	17.5
SD	1.9	1.5	1.3	1.4
SEM	0.5	0.4	0.3	0.4

Table H9: Raw data for shot precision throughout study 3

Player	Shooting precision (cm)			
	Pre 1st half	Post 1st half	Pre 2nd half	Post 2nd half
1	88	122	174	126
2	45	75	61	169
3	33	139	145	196
4	73	185	44	95
5	137	180	91	285
6	141	99	46	101
7	124	97	82	101
8	125	95	67	107
9	77	226	129	69
10	96	132	97	97
11	112	49	50	49
12	166	178	105	84
13	127	117	139	177
14	71	122	40	113
15	114	179	80	145
MEAN	102	133	90	128
SD	37	48	41	59
SEM	10	12	11	15

Table H10: Raw data for shot success throughout study 3

Player	Shooting success (%)			
	Pre 1st half	Post 1st half	Pre 2nd half	Post 2nd half
1	75	75	25	100
2	50	50	75	75
3	75	75	75	100
4	50	75	50	75
5	75	75	100	50
6	75	50	100	50
7	50	75	75	100
8	75	100	75	75
9	75	75	75	50
10	75	75	75	75
11	50	25	50	50
12	50	50	75	50
13	50	75	75	50
14	75	50	100	100
15	50	25	75	75
MEAN	63	63	73	72
SD	13	21	20	21
SEM	3	5	5	5

Table H11: Raw data for passing speed throughout study 3

Player	Passing speed (m/s)					
	15	30	45	60	75	90
1	12.9	12.0	12.3	12.4	13.0	11.6
2	10.5	11.3	10.5	10.3	10.5	11.6
3	15.0	14.1	14.4	10.6	10.3	13.0
4	14.7	12.7	12.7	12.2	12.6	13.0
5	13.1	15.3	12.2	13.8	13.1	15.7
6	13.0	12.1	10.7	10.9	11.3	11.7
7	13.1	17.1	17.7	15.7	15.7	16.3
8	13.3	13.2	12.7	12.2	12.3	12.1
9	14.4	14.4	14.6	13.5	15.2	13.6
10	17.5	16.1	17.3	15.4	15.9	14.1
11	11.1	11.9	10.1	9.7	9.5	9.4
12	10.2	9.5	9.6	10.8	10.9	10.6
13	13.7	13.3	13.1	13.1	12.1	11.1
14	13.9	12.1	12.1	11.5	9.2	9.2
15	12.7	12.6	10.2	10.6	12.3	9.1
MEAN	13.3	13.2	12.7	12.2	12.3	12.1
SD	1.8	2.0	2.5	1.8	2.1	2.2
SEM	0.5	0.5	0.6	0.5	0.5	0.6

Table H12: Raw data for passing precision throughout study 3

Player	Passing precision (cm)					
	15	30	45	60	75	90
1	45	38	46	30	31	44
2	30	25	33	43	40	25
3	28	16	29	32	38	37
4	33	35	27	35	36	15
5	31	32	39	36	39	33
6	35	50	39	34	31	31
7	36	27	23	30	20	32
8	26	41	20	21	35	18
9	39	33	30	30	24	28
10	35	21	22	41	27	24
11	31	36	42	44	48	30
12	19	25	42	29	31	17
13	28	34	24	33	28	43
14	33	64	38	49	34	44
15	27	27	33	27	35	35
MEAN	32	34	32	34	33	30
SD	6	12	8	7	7	9
SEM	2	3	2	2	2	2

Table H13: Raw data for passing success throughout study 3

Player	Passing success (%)					
	15	30	45	60	75	90
1	33	50	50	75	63	50
2	67	63	50	33	63	63
3	67	100	75	67	25	63
4	58	50	63	50	63	88
5	58	63	50	50	50	63
6	67	38	38	58	75	75
7	67	50	88	50	88	63
8	75	38	88	83	63	88
9	58	38	75	67	75	88
10	50	88	63	58	75	75
11	42	50	38	50	38	63
12	75	88	50	58	38	100
13	75	63	75	58	63	50
14	67	13	50	42	75	38
15	83	75	63	67	75	50
MEAN	63	58	61	58	62	68
SD	13	23	16	13	17	18
SEM	3	6	4	3	4	5

Table H14: Raw data for dribbling speed throughout study 3

Player	Dribbling speed (m/s)					
	15	30	45	60	75	90
1	4.1	4.1	3.7	3.8	3.8	3.9
2	3.5	3.5	3.4	3.4	3.8	3.7
3	4.0	4.3	4.3	4.3	4.5	4.4
4	3.5	3.8	4.1	3.8	4.3	4.1
5	3.8	4.2	3.7	3.7	4.0	3.7
6	4.6	4.2	4.1	4.4	4.8	4.6
7	3.8	4.2	3.8	3.7	3.6	3.7
8	4.3	4.4	4.5	4.3	4.6	4.3
9	4.7	4.7	4.2	4.6	4.0	4.1
10	4.2	4.4	4.0	4.0	4.5	3.3
11	5.1	5.5	4.8	4.9	5.3	4.9
12	4.3	4.1	4.5	4.5	4.4	4.3
13	4.3	4.3	4.5	4.0	4.1	4.6
14	5.0	4.5	4.6	4.9	4.6	4.6
15	3.1	3.3	3.6	3.7	3.8	3.6
MEAN	4.2	4.2	4.1	4.1	4.3	4.1
SD	0.6	0.5	0.4	0.5	0.5	0.5
SEM	0.1	0.1	0.1	0.1	0.1	0.1

Table H15: Raw data for dribbling precision throughout study 3

Player	Dribbling precision (cm)					
	15	30	45	60	75	90
1	50	53	49	53	56	50
2	43	43	48	43	46	41
3	48	49	49	44	53	40
4	51	56	50	44	63	51
5	59	68	59	59	64	76
6	54	64	45	60	47	45
7	58	54	69	65	66	62
8	50	46	46	49	51	46
9	62	53	52	56	53	52
10	47	45	56	45	46	52
11	46	50	61	53	60	56
12	62	61	69	67	62	74
13	53	54	58	42	56	52
14	38	40	40	42	57	41
15	49	48	44	43	42	49
MEAN	51	52	53	51	55	52
SD	7	8	9	9	8	11
SEM	2	2	2	2	2	3

Table H16: Raw data for dribbling success throughout study 3

Player	Dribbling success (%)					
	15	30	45	60	75	90
1	80	80	100	100	93	100
2	96	100	100	100	100	100
3	100	93	100	100	100	100
4	80	93	67	75	67	80
5	92	60	87	95	87	73
6	92	67	60	85	100	100
7	85	100	93	92	100	100
8	100	100	100	88	93	100
9	90	100	93	100	93	100
10	84	100	100	100	100	100
11	95	100	100	92	100	100
12	80	93	93	70	87	100
13	95	80	73	92	87	87
14	92	93	100	90	87	100
15	100	100	93	100	87	100
MEAN	91	91	91	92	92	96
SD	7	13	13	9	9	9
SEM	2	3	3	2	2	2

Appendix H4: Raw Data – Study 3 – Physiological variables

Table H17: Average HR variables throughout study 3

Player	HR (bpm)	
	Mean	Peak
1	160	195
2	171	205
3	159	195
4	165	200
5	164	204
6	169	205
7	162	196
8	164	200
9	163	199
10	163	199
11	163	199
12	163	199
13	163	199
14	163	199
15	156	192
MEAN	163	199
SD	4	4
SEM	1	1

Table H18: Blood lactate concentrations (mmol/L) throughout study 3

Player	Blood lactate (mmol/l)							
	Rest	15	30	45	Half-time	60	75	90
1	3.0	11.6	10.6	17.9	3.0	7.6	9.3	11.4
2	3.4	8.9	7.9	6.0	6.3	6.5	5.7	6.3
3	0.9	8.1	6.9	5.8	1.8	5.8	5.7	5.1
4	3.7	8.6	10.1	8.4	4.2	6.6	7.7	7.4
5	2.1	6.6	5.7	5.4	2.1	5.3	5.4	4.1
6	3.0	11.7	11.0	11.0	4.2	10.7	7.9	9.0
7	2.2	7.8	6.2	6.2	2.3	6.6	5.6	5.3
8	1.9	6.3	5.9	7.0	4.0	4.1	4.6	3.8
9	1.9	13.7	13.6	11.4	4.2	8.3	6.7	6.9
10	2.1	12.2	11.3	8.1	3.2	5.2	4.0	5.7
11	1.8	11.6	9.0	7.0	4.0	5.3	6.3	4.9
12	2.4	10.4	9.6	6.8	2.6	6.5	6.3	5.3
13	2.4	17.2	18.1	11.7	3.4	5.3	5.5	5.1
14	2.4	13.4	10.8	10.3	4.7	8.7	6.3	6.9
15	2.4	8.1	7.1	6.3	2.7	5.1	6.9	13.7
MEAN	2.4	10.4	9.6	8.6	3.5	6.5	6.3	6.7
SD	0.7	3.0	3.3	3.3	1.2	1.7	1.3	2.7
SEM	0.2	0.8	0.9	0.9	0.3	0.4	0.3	0.7

Table H19: Mean 15 m sprint velocities throughout study 3

Player	15 m sprint velocity (m/s)					
	15	30	45	60	75	90
1	6.0	5.9	5.7	5.9	6.0	6.0
2	6.1	6.1	6.0	5.9	6.0	5.9
3	6.3	6.1	6.0	6.0	6.0	6.0
4	5.9	5.7	5.6	5.7	6.0	5.9
5	6.0	5.4	5.9	5.8	5.7	5.7
6	5.9	5.9	5.8	6.0	5.9	5.9
7	6.2	6.2	5.8	6.1	6.4	6.2
8	6.1	5.3	5.3	5.7	5.6	5.6
9	6.4	6.0	6.4	6.4	6.2	6.0
10	6.1	5.3	5.3	5.3	5.2	5.2
11	6.3	6.0	6.0	6.0	6.0	5.9
12	5.8	5.7	5.6	5.6	5.6	5.6
13	5.9	5.6	5.5	5.4	5.2	4.9
14	6.2	5.8	5.8	6.0	5.6	5.5
15	6.2	6.1	6.2	6.3	6.4	6.4
MEAN	6.1	5.8	5.8	5.9	5.9	5.8
SD	0.2	0.3	0.3	0.3	0.4	0.4
SEM	0.0	0.1	0.1	0.1	0.1	0.1

Table H20: Raw data for mass change calculations throughout study 3

Player	Mass changes			
	Mass Pre (kg)	Mass Post (kg)	Fluid In (L)	Net mass loss (kg)
1	67.4	67.0	1.4	1.8
2	65.7	65.2	1.4	1.9
3	53.8	53.5	1.1	1.4
4	66.9	66.1	1.4	2.2
5	77.8	77.1	1.6	2.3
6	68.9	68.1	1.4	2.2
7	79.1	77.8	1.7	3.0
8	57.5	57.1	1.2	1.6
9	82.9	82.4	1.7	2.2
10	73.0	73.1	1.5	1.4
11	71.4	70.9	1.5	2.0
12	72.3	72.0	1.5	1.8
13	91.8	90.8	1.9	2.9
14	65.7	65.3	1.4	1.8
15	72.3	72.0	1.5	1.8
MEAN	71.1	70.6	1.5	2.0
SD	9.5	9.3	0.2	0.5
SEM	2.5	2.4	0.1	0.1

Table H21: RPE values throughout study 3

Player	RPE (units)							
	Rest	15	30	45	Half-time	60	75	90
1	6	2	5	7	6	9	12	14
2	6	13	18	19	6	17	18	19
3	6	15	16	17	6	15	16	17
4	6	14	16	17	6	17	17	17
5	6	13	17	19	6	15	18	19
6	6	12	14	16	6	14	15	16
7	6	14	18	17	6	15	16	17
8	6	13	14	16	6	14	17	17
9	6	12	15	16	6	14	16	17
10	6	16	18	18	6	16	18	19
11	6	16	18	18	6	17	18	19
12	6	14	16	17	6	16	18	19
13	6	14	16	17	6	16	18	19
14	6	17	19	20	6	16	19	20
15	6	12	15	16	6	14	16	17
MEAN	6	13	15	16	6	15	17	18
SD	0	3	3	3	0	2	2	2
SEM	0	1	1	1	0	1	0	0

Appendix I1: Raw Data – Study 4 – Participant anthropometrics

Table I1: Raw data of player anthropometrics involved in study 4 in both CHO and PL trials

Player	CHO			PI		
	Mass (kg)	Height (m)	Age (years)	Mass (kg)	Height (m)	Age (years)
1	72.0	1.81	20	70.40	1.81	20
2	72.4	1.75	23	71.00	1.75	23
3	78.0	1.83	16	78.00	1.84	16
4	62.8	1.81	16	62.20	1.79	16
5	68.5	1.77	16	67.90	1.77	16
6	72.4	1.79	20	71.50	1.78	20
7	66.8	1.77	16	66.70	1.77	16
8	68.6	1.70	15	68.40	1.70	15
9	65.7	1.76	26	66.30	1.76	26
10	78.7	1.81	16	77.80	1.81	16
11	66.0	1.72	14	66.00	1.72	14
12	60.2	1.70	16	59.50	1.71	16
13	55.8	1.67	16	55.20	1.67	16
14	73.2	1.80	15	72.40	1.80	15
15	93.8	1.82	23	91.50	1.82	23
MEAN	70.3	1.77	18	69.7	1.77	18
SD	9.0	0.05	4	8.6	0.05	4
SEM	2.3	0.01	1	2.2	0.01	1

Table I2: Raw data of estimated aerobic capacity values from multistage fitness test

Player	Estimated Aerobic Capacity (ml/kg/min)
1	57.1
2	50.6
3	57.5
4	60.1
5	57.1
6	57.5
7	60.6
8	61.3
9	58.9
10	54.4
11	57.5
12	57.5
13	57.8
14	61.6
15	50.6
MEAN	57.3
SD	3.3
SEM	0.9

Appendix I2: Raw Data – Study 4 – Pre-trial diet and urine analyses

Table I3: Pre-trial dietary data for CHO

Player	CHO			Total Calories	MJ/d
	Energy contribution				
	% Fat	% CHO	% Protein		
1	29	53	18	2667	11.2
2	17	62	21	1464	6.1
3	31	53	16	2266	9.5
4	27	58	15	1610	6.7
5	29	53	18	2667	11.2
6	29	53	18	2667	11.2
7	29	54	18	1883	7.9
8	32	52	16	3220	13.5
9	28	55	17	2892	12.1
10	23	57	20	1197	5.0
11	33	46	21	2162	9.0
12	34	49	17	2377	9.9
13	25	56	18	4689	19.6
14	31	50	18	6726	28.1
15	33	44	23	1522	6.4
MEAN	29	53	18	2667	11.2
STDEV	4	4	2	1416	5.9
SEM	1	1	1	366	1.5

Table I4: Pre-trial dietary data for PL

Player	PI			Total Calories	MJ/d
	Energy contribution				
	% Fat	% CHO	% Protein		
1	30	50	17	2695	11.3
2	26	56	18	1534	6.4
3	30	50	17	2695	11.3
4	33	53	15	3810	15.9
5	24	60	17	1916	8.0
6	30	50	17	2695	11.3
7	38	48	14	2549	10.7
8	33	51	16	2982	12.5
9	33	49	18	4433	18.5
10	2	34	24	2630	11.0
11	25	55	20	2413	10.1
12	48	34	18	2510	10.5
13	25	61	16	3802	15.9
14	29	57	16	2313	9.7
15	38	45	17	1448	6.1
MEAN	30	50	17	2695	11.3
STDEV	10	8	2	818	3.4
SEM	3	2	1	211	0.9

Table I5: Average pre-trial dietary data for both CHO and PL trials

Average of two trials					
	Energy contribution			Total	MJ/d
	%	%	%	Calories	
	Fat	CHO	Protein		
MEAN	30	52	18	2681	11.2
STDEV	8	6	2	1136	4.8
SEM	1	1	0	207	0.9

Appendix I3: Raw Data – Study 4 – Pre-trial environmental conditions

Table I6: Pre-trial environmental conditions for CHO and PL trials

Player	CHO			PI		
	Temp (°c)	Humidity (%)	Pressure (mmHg)	Temp (°c)	Humidity (%)	Pressure (mmHg)
1	16	69	760	20	71	747
2	22	69	766	20	74	761
3	20	57	750	21	64	757
4	19	60	757	20	60	772
5	22	59	770	16	69	760
6	20	63	769	20	65	759
7	21	60	763	20	60	772
8	21	60	763	20	74	759
9	22	60	756	21	63	755
10	22	60	761	22	46	770
11	22	60	761	20	74	759
12	22	60	758	20	63	769
13	20	74	761	20	71	757
14	21	63	755	20	71	757
15	20	65	759	22	60	756
MEAN	21	63	761	20	66	761
SD	2	5	5	1	8	7
SEM	0	1	1	0	2	2

Appendix I4: Raw Data – Study 4 – Skill variables

Table I7: Raw data for shot speeds throughout the CHO trial

Player	Shooting speed (m/s)			
	CHO			
	Pre 1st half	Post 1st half	Pre 2nd half	Post 2nd half
1	16.8	14.6	14.3	15.8
2	16.8	15.4	16.0	14.4
3	18.5	16.9	16.0	17.4
4	15.6	17.0	15.8	16.2
5	17.9	14.3	16.0	15.7
6	17.1	19.0	16.1	16.1
7	17.1	14.6	15.5	15.2
8	14.7	14.8	15.8	14.1
9	15.5	16.1	15.4	16.9
10	16.9	16.5	16.1	15.8
11	18.7	18.0	17.8	17.1
12	17.3	16.3	16.6	16.7
13	15.1	16.0	15.2	15.0
14	16.5	16.8	17.2	16.9
15	17.2	16.6	15.8	15.5
MEAN	16.8	16.2	16.0	15.9
SD	1.1	1.3	0.8	1.0
SEM	0.3	0.3	0.2	0.3

Table I8: Raw data for shot speeds throughout the PL trial

Player	Shooting speed (m/s)			
	PI			
	Pre 1st half	Post 1st half	Pre 2nd half	Post 2nd half
1	16.3	14.6	16.1	14.2
2	17.0	15.2	16.1	14.4
3	18.6	16.4	16.5	16.6
4	15.9	15.6	15.6	14.2
5	16.2	14.7	16.9	12.9
6	16.1	16.3	16.9	15.8
7	17.5	15.9	16.0	14.6
8	13.5	13.7	13.8	13.5
9	16.9	17.3	16.2	14.3
10	14.8	17.1	15.8	14.7
11	17.2	16.2	15.7	14.4
12	16.1	15.6	16.5	15.2
13	15.4	14.3	14.7	13.7
14	15.2	15.1	14.5	14.0
15	16.2	16.2	15.2	15.4
MEAN	16.2	15.6	15.8	14.5
SD	1.2	1.0	0.9	0.9
SEM	0.3	0.3	0.2	0.2

Table I9: Raw data for shot precision throughout the CHO trial

Player	Shooting precision (cm)			
	CHO			
	Pre 1st half	Post 1st half	Pre 2nd half	Post 2nd half
1	119	118	129	69
2	137	161	87	78
3	138	203	73	80
4	79	84	90	206
5	128	79	107	127
6	172	215	110	158
7	56	122	82	206
8	158	171	124	86
9	147	108	79	155
10	127	38	152	47
11	210	158	49	81
12	117	137	119	94
13	50	136	286	283
14	67	136	127	132
15	152	95	124	132
MEAN	124	131	116	129
SD	45	47	54	64
SEM	12	12	14	17

Table I10: Raw data for shot precision throughout the PL trial

Player	Shooting precision (cm)			
	PI			
	Pre 1st half	Post 1st half	Pre 2nd half	Post 2nd half
1	132	251	180	287
2	211	161	290	275
3	110	92	139	45
4	81	62	105	66
5	67	51	51	48
6	121	95	129	145
7	118	169	144	147
8	63	129	127	157
9	106	103	46	97
10	89	163	93	94
11	280	89	111	81
12	115	107	58	166
13	134	126	152	147
14	101	109	80	123
15	70	152	192	23
MEAN	120	124	127	127
SD	57	50	63	77
SEM	15	13	16	20

Table I11: Raw data for shot success throughout the CHO trial

Player	Shooting success (%)			
	CHO			
	Pre 1st half	Post 1st half	Pre 2nd half	Post 2nd half
1	75	75	75	25
2	75	50	100	50
3	75	75	75	50
4	75	75	75	75
5	50	100	100	50
6	75	50	100	75
7	75	50	100	75
8	75	75	100	100
9	50	100	75	100
10	50	100	50	50
11	75	25	50	75
12	100	100	100	100
13	75	100	75	50
14	75	100	75	100
15	100	100	75	100
MEAN	73	78	82	72
SD	15	25	18	25
SEM	4	6	5	6

Table I12: Raw data for shot success throughout the PL trial

Player	Shooting success (%)			
	PI			
	Pre 1st half	Post 1st half	Pre 2nd half	Post 2nd half
1	50	75	50	50
2	75	100	75	50
3	25	75	75	50
4	75	100	75	100
5	75	50	75	50
6	75	75	75	100
7	100	75	100	75
8	100	100	75	100
9	50	75	50	50
10	50	75	100	50
11	50	75	50	50
12	100	50	75	75
13	50	100	75	75
14	100	100	100	75
15	100	100	100	50
MEAN	72	82	77	67
SD	25	18	18	20
SEM	6	5	5	5

Table I13: Raw data for SPS_{shooting} index throughout the CHO trial

Player	SPS Shooting index			
	CHO			
	Pre 1st half	Post 1st half	Pre 2nd half	Post 2nd half
1	67	59	57	22
2	67	40	87	40
3	73	65	66	48
4	65	70	65	62
5	48	79	86	42
6	67	49	87	63
7	72	39	85	59
8	58	58	85	77
9	41	87	63	89
10	45	96	42	45
11	72	24	51	70
12	93	86	89	91
13	65	85	57	38
14	69	89	69	90
15	90	90	63	82
MEAN	66	68	70	61
SD	14	22	15	22
SEM	4	6	4	6

Table I14: Raw data for SPS_{shooting} index throughout the PL trial

Player	SPS Shooting index			
	PI			
	Pre 1st half	Post 1st half	Pre 2nd half	Post 2nd half
1	43	55	42	36
2	65	79	61	36
3	25	67	66	48
4	66	87	63	79
5	68	42	72	37
6	64	66	67	83
7	94	62	84	58
8	75	73	55	71
9	46	70	46	39
10	40	67	86	40
11	43	66	42	40
12	87	42	70	59
13	41	76	58	54
14	82	81	80	56
15	90	85	79	46
MEAN	62	68	65	52
SD	21	14	14	16
SEM	5	4	4	4

Table I15: Raw data for passing speed throughout the CHO trial

Player	Passing speed (m/s)					
	CHO					
	15	30	45	60	75	90
1	9.0	9.6	9.0	9.9	8.3	9.1
2	9.9	13.4	10.8	8.7	10.2	11.2
3	13.1	17.2	17.2	14.2	14.0	13.5
4	13.3	12.0	11.5	13.8	13.5	12.9
5	11.8	11.5	11.3	10.6	11.5	11.6
6	11.9	12.1	13.3	11.6	11.7	12.2
7	11.1	12.3	13.2	11.9	11.4	11.6
8	13.0	12.3	10.8	9.9	12.2	10.4
9	11.3	10.3	11.3	10.8	11.1	12.2
10	10.7	10.0	9.7	11.8	11.6	11.0
11	13.9	10.9	10.3	14.7	12.5	11.3
12	9.2	9.6	10.7	10.0	9.9	10.7
13	10.8	11.2	11.8	12.9	9.6	12.9
14	11.9	11.7	11.8	12.4	13.3	12.6
15	13.4	13.3	15.5	13.9	12.3	12.2
MEAN	11.6	11.8	11.9	11.8	11.5	11.7
SD	1.5	1.9	2.2	1.8	1.6	1.2
SEM	0.4	0.5	0.6	0.5	0.4	0.3

Table I16: Raw data for passing speed throughout the PL trial

Player	Passing speed (m/s)					
	PI					
	15	30	45	60	75	90
1	10.4	10.1	8.2	7.3	9.3	10.0
2	11.4	11.5	10.9	9.8	13.2	10.3
3	12.7	15.5	13.9	15.0	14.4	12.7
4	11.0	10.4	11.8	11.3	10.2	9.3
5	12.4	11.0	13.2	12.9	10.1	11.8
6	11.0	11.1	11.4	13.1	12.9	13.1
7	10.5	10.9	9.1	9.9	9.5	11.1
8	9.9	10.1	9.8	11.5	10.8	10.2
9	9.6	9.8	10.1	9.8	10.1	11.0
10	11.6	12.8	10.8	12.2	11.4	12.1
11	12.5	14.1	12.0	14.5	14.2	16.7
12	12.5	12.0	11.0	11.3	12.3	11.9
13	11.8	11.2	11.8	12.5	13.2	12.0
14	11.1	11.5	11.4	12.8	12.2	11.7
15	14.0	13.3	13.7	14.2	14.6	12.8
MEAN	11.5	11.7	11.3	11.9	11.9	11.8
SD	1.2	1.6	1.6	2.1	1.8	1.8
SEM	0.3	0.4	0.4	0.5	0.5	0.5

Table I17: Raw data for passing precision throughout the CHO trial

Player	Passing precision (cm)					
	CHO					
	15	30	45	60	75	90
1	29	41	46	34	55	38
2	38	36	44	31	50	27
3	39	32	41	45	39	44
4	29	28	33	29	35	38
5	36	34	27	45	41	28
6	39	43	49	27	25	36
7	38	24	34	33	28	26
8	29	24	47	57	34	52
9	44	37	51	31	50	45
10	49	46	42	46	41	47
11	44	36	37	40	58	37
12	33	28	20	22	44	19
13	29	57	52	20	51	28
14	23	30	23	34	22	29
15	31	30	32	24	29	29
MEAN	35	35	39	34	40	35
SD	7	9	10	10	11	9
SEM	2	2	3	3	3	2

Table I18: Raw data for passing precision throughout the PL trial

Player	Passing precision (cm)					
	PI					
	15	30	45	60	75	90
1	46	35	28	47	32	27
2	31	39	57	23	23	35
3	39	37	45	26	42	47
4	25	32	25	50	34	34
5	24	45	14	30	49	25
6	15	25	30	16	26	30
7	32	43	34	30	29	35
8	45	48	49	34	30	41
9	49	21	24	43	34	45
10	49	23	51	32	30	20
11	26	50	52	50	44	43
12	50	20	35	20	31	48
13	35	36	30	31	34	29
14	28	38	49	29	31	33
15	40	48	39	23	28	64
MEAN	36	36	38	32	33	37
SD	11	10	12	11	7	11
SEM	3	3	3	3	2	3

Table I19: Raw data for passing success throughout the CHO trial

Player	Passing success (%)					
	CHO					
	15	30	45	60	75	90
1	100	75	100	75	100	75
2	50	75	75	25	75	75
3	50	75	63	50	63	50
4	25	50	75	25	25	75
5	58	63	75	42	63	75
6	75	75	50	0	25	50
7	67	88	50	58	75	100
8	75	75	38	50	75	38
9	50	100	50	25	75	100
10	42	63	50	42	38	63
11	33	63	63	50	50	63
12	67	63	88	92	50	88
13	75	38	38	83	50	63
14	92	75	88	75	100	63
15	50	50	100	75	25	75
MEAN	61	68	67	51	59	70
SD	21	16	21	26	25	18
SEM	5	4	5	7	6	5

Table I20: Raw data for passing success throughout the CHO trial

Player	Passing success (%)					
	PI					
	15	30	45	60	75	90
1	50	75	50	50	75	50
2	50	50	25	75	100	50
3	42	63	50	75	63	38
4	75	50	50	25	50	50
5	83	75	100	75	50	75
6	75	75	100	100	75	50
7	75	50	75	83	88	63
8	50	25	50	67	75	50
9	50	75	75	100	100	75
10	33	88	50	75	63	88
11	83	38	38	33	50	63
12	42	88	75	83	63	63
13	75	63	75	67	63	100
14	67	50	50	67	63	50
15	25	100	75	50	75	50
MEAN	58	64	63	68	70	61
SD	19	21	22	21	16	17
SEM	5	5	6	6	4	4

Table I21: Raw data for SPS_{passing} index throughout the CHO trial

Player	SPS Passing index					
	CHO					
	15	30	45	60	75	90
1	57	45	56	47	52	43
2	31	63	51	14	48	54
3	42	57	45	43	53	40
4	22	35	49	23	20	53
5	42	41	54	28	44	58
6	44	45	34	0	16	34
7	50	65	36	39	55	74
8	62	59	25	31	58	24
9	34	71	37	20	45	81
10	28	39	31	31	27	43
11	23	49	52	38	36	46
12	56	69	97	84	44	77
13	57	27	28	67	42	51
14	70	58	75	55	75	49
15	43	43	99	67	20	59
MEAN	44	51	51	39	42	52
SD	15	13	23	22	16	16
SEM	4	3	6	6	4	4

Table I22: Raw data for SPS_{passing} index throughout the PL trial

Player	SPS Passing index					
	PI					
	15	30	45	60	75	90
1	33	48	26	23	44	32
2	36	36	17	47	85	33
3	29	41	37	55	40	22
4	60	45	38	23	45	53
5	51	46	65	47	32	53
6	61	58	70	74	59	38
7	59	35	63	68	56	47
8	31	16	31	48	52	32
9	37	54	57	78	84	56
10	24	72	34	58	45	69
11	56	25	21	21	30	43
12	33	88	66	81	57	50
13	53	45	55	54	49	75
14	47	35	36	56	52	42
15	22	83	65	46	70	40
MEAN	42	49	45	52	53	46
SD	14	20	18	19	16	14
SEM	4	5	5	5	4	4

Table I23: Raw data for dribbling speed throughout the CHO trial

Player	Dribbling speed (m/s)					
	CHO					
	15	30	45	60	75	90
1	3.4	3.8	2.9	3.1	3.7	3.6
2	3.3	3.5	3.3	3.4	3.5	3.6
3	3.7	3.7	4.0	4.0	3.9	4.0
4	4.2	4.2	3.9	3.9	3.9	4.3
5	3.7	4.1	3.8	3.6	3.8	3.8
6	4.4	4.3	4.3	4.4	3.9	4.6
7	4.1	3.5	4.0	4.0	3.9	3.9
8	4.7	4.7	3.8	4.4	5.1	4.6
9	3.8	4.2	3.7	4.2	4.3	4.2
10	3.5	3.8	3.8	3.4	3.8	3.6
11	3.7	3.6	3.7	3.9	3.9	4.0
12	4.0	4.0	4.0	4.2	3.7	3.7
13	4.6	4.3	4.2	3.9	4.1	4.0
14	3.9	3.9	3.8	3.9	3.7	3.8
15	3.9	3.8	3.9	3.6	3.7	3.8
MEAN	3.9	4.0	3.8	3.9	3.9	4.0
SD	0.4	0.3	0.3	0.4	0.4	0.3
SEM	0.1	0.1	0.1	0.1	0.1	0.1

Table I24: Raw data for dribbling speed throughout the PL trial

Player	Dribbling speed (m/s)					
	PI					
	15	30	45	60	75	90
1	3.0	3.3	3.5	3.2	3.4	3.9
2	3.2	3.5	3.5	3.5	3.6	3.4
3	3.9	3.5	4.0	3.7	4.0	4.3
4	3.9	4.4	4.3	4.5	4.1	4.0
5	3.9	3.8	3.7	3.8	3.6	3.8
6	4.4	4.4	4.5	4.4	4.5	3.7
7	3.7	3.6	3.5	3.6	4.0	3.5
8	4.1	4.4	4.7	4.4	4.4	4.5
9	3.8	4.0	4.7	4.2	4.1	4.2
10	3.8	3.7	3.6	3.7	3.8	3.6
11	3.9	4.2	4.2	3.5	4.1	4.3
12	3.6	4.4	4.0	4.4	4.2	4.3
13	3.9	4.4	4.2	3.9	3.9	4.0
14	3.9	3.6	3.6	3.9	3.8	3.6
15	3.5	3.6	3.9	3.6	3.7	3.6
MEAN	3.8	3.9	4.0	3.9	3.9	3.9
SD	0.3	0.4	0.4	0.4	0.3	0.3
SEM	0.1	0.1	0.1	0.1	0.1	0.1

Table I25: Raw data for dribbling precision throughout the CHO trial

Player	Dribbling precision (cm)					
	CHO					
	15	30	45	60	75	90
1	53	50	58	63	48	50
2	48	55	59	60	53	51
3	45	47	47	44	42	52
4	61	57	60	51	51	54
5	45	39	36	45	41	45
6	57	62	58	56	53	59
7	55	39	48	42	58	45
8	60	66	53	58	49	47
9	50	50	47	50	51	45
10	48	44	46	44	48	46
11	60	47	47	49	50	49
12	41	44	47	46	46	42
13	50	44	43	49	42	50
14	49	44	62	52	51	51
15	60	68	70	61	63	58
MEAN	52	51	52	51	50	49
SD	6	9	9	7	6	5
SEM	2	2	2	2	2	1

Table I26: Raw data for dribbling precision throughout the PL trial

Player	Dribbling precision (cm)					
	PI					
	15	30	45	60	75	90
1	64	63	68	60	56	54
2	59	49	56	53	57	60
3	52	54	47	43	49	44
4	62	57	63	61	56	60
5	46	50	44	49	44	44
6	57	51	55	55	47	48
7	48	43	42	39	46	40
8	64	63	54	65	59	58
9	49	54	45	42	47	42
10	48	52	54	54	53	50
11	47	45	44	49	42	46
12	45	47	42	43	40	43
13	49	43	50	50	45	56
14	51	52	51	48	47	46
15	52	53	58	51	58	52
MEAN	53	52	52	51	50	49
SD	7	6	8	7	6	7
SEM	2	2	2	2	2	2

Table I27: Raw data for dribbling success throughout the CHO trial

Player	Dribbling success (%)					
	CHO					
	15	30	45	60	75	90
1	96	100	93	100	100	100
2	96	100	100	100	87	80
3	100	93	93	100	100	93
4	100	100	80	90	100	87
5	100	93	100	90	100	100
6	95	100	73	96	73	100
7	90	100	100	100	93	100
8	95	93	73	100	93	87
9	95	80	100	96	87	100
10	96	93	93	85	100	93
11	80	100	93	100	93	93
12	100	100	100	90	80	100
13	95	93	73	96	100	100
14	100	100	100	100	100	100
15	100	93	100	90	100	100
MEAN	96	96	92	96	94	96
SD	5	6	11	5	9	7
SEM	1	1	3	1	2	2

Table I28: Raw data for dribbling success throughout the PL trial

Player	Dribbling success (%)					
	PI					
	15	30	45	60	75	90
1	100	93	100	90	100	100
2	100	93	100	92	100	100
3	90	93	100	100	100	93
4	100	93	100	90	100	100
5	100	93	93	100	93	100
6	95	100	93	100	100	80
7	92	93	100	90	87	87
8	100	93	100	90	100	100
9	95	87	93	80	100	80
10	80	73	80	92	87	87
11	85	87	100	96	100	87
12	100	93	100	90	100	100
13	100	93	100	90	100	100
14	95	93	100	96	100	87
15	88	100	100	90	93	87
MEAN	95	92	97	92	97	92
SD	6	6	6	5	5	8
SEM	2	2	1	1	1	2

Table I29: Raw data for SPS_{dribbling} index throughout the CHO trial

Player	SPS Dribbling index					
	CHO					
	15	30	45	60	75	90
1	22	25	18	20	24	24
2	21	23	21	22	20	19
3	24	23	24	27	26	24
4	28	27	21	23	25	24
5	24	25	25	22	25	25
6	27	28	21	28	19	30
7	24	23	26	26	24	26
8	29	29	18	29	31	26
9	24	22	24	26	25	27
10	22	24	24	19	25	22
11	19	24	23	26	24	24
12	27	27	26	25	19	24
13	29	26	20	24	27	27
14	25	25	25	25	24	25
15	25	23	26	21	24	25
MEAN	25	25	23	24	24	25
SD	3	2	3	3	3	2
SEM	1	1	1	1	1	1

Table I30: Raw data for SPS_{dribbling} index throughout the PL trial

Player	SPS Dribbling index					
	PI					
	15	30	45	60	75	90
1	20	20	23	19	22	26
2	21	21	23	21	23	22
3	23	22	26	24	26	26
4	26	27	28	26	27	26
5	26	23	23	25	22	25
6	27	29	28	29	29	19
7	22	22	23	21	23	20
8	27	27	31	26	29	30
9	24	23	29	22	27	22
10	20	18	19	23	21	21
11	22	24	27	22	27	24
12	24	27	26	26	28	28
13	25	27	28	23	26	26
14	24	22	23	25	25	21
15	20	24	25	21	22	21
MEAN	23	24	26	24	25	24
SD	3	3	3	3	3	3
SEM	1	1	1	1	1	1

Appendix I5: Raw Data – Study 4 – Physiological variables

Table I31: Average HR variables throughout the CHO and PL trials

Player	HR (bpm)			
	CHO		PI	
	Mean	Peak	Mean	Peak
1	142	184	149	182
2	139	189	145	186
3	159	195	146	193
4	146	194	139	200
5	144	186	149	196
6	146	190	146	189
7	138	184	139	179
8	148	192	150	193
9	155	191	159	203
10	147	186	136	179
11	141	187	148	188
12	140	175	144	183
13	144	180	147	186
14	150	185	152	190
15	138	190	140	173
MEAN	145	187	146	188
SD	6	5	6	8
SEM	2	1	2	2

Table I32: Blood lactate concentrations (mmol/L) throughout the CHO trial

Player	Blood lactate (mmol/l)								
	CHO								
	Rest	Pre	15	30	45	Half-time	60	75	90
1	0.7	2.0	7.0	8.4	7.4	3.3	5.1	4.4	5.7
2	0.5	1.0	6.3	6.9	5.5	1.7	4.6	4.4	2.8
3	1.7	2.3	11.1	10.2	10.0	4.0	6.5	6.4	7.0
4	1.2	1.9	6.1	4.0	3.9	3.0	5.5	3.7	6.3
5	2.0	1.5	8.4	7.7	8.0	2.0	5.7	5.8	5.4
6	0.6	1.4	7.0	5.3	6.2	3.3	4.5	5.5	6.3
7	0.9	1.1	4.8	4.8	4.0	1.2	3.7	3.9	4.1
8	1.1	1.3	7.1	6.2	6.0	2.5	4.8	4.5	5.5
9	0.7	1.2	7.0	15.0	14.7	5.9	11.9	12.9	11.9
10	2.3	1.0	6.1	3.8	3.8	0.9	3.6	3.2	4.3
11	1.0	1.3	6.1	5.0	4.2	2.8	3.9	3.7	4.1
12	1.1	1.8	7.0	6.4	2.2	2.8	2.9	4.5	3.8
13	0.8	1.5	4.8	5.0	3.8	1.8	5.8	4.3	4.9
14	1.6	1.5	5.3	5.0	5.5	2.8	4.7	5.2	5.6
15	1.5	2.1	11.2	12.2	10.4	5.0	8.6	7.9	9.4
MEAN	1.2	1.5	7.0	7.1	6.4	2.9	5.5	5.4	5.8
SD	0.5	0.4	1.9	3.2	3.3	1.3	2.3	2.4	2.3
SEM	0.1	0.1	0.5	0.8	0.8	0.3	0.6	0.6	0.6

Table I33: Blood lactate concentrations (mmol/L) throughout the PL trial

Player	Blood lactate (mmol/l)								
	Pl								
	Rest	Pre	15	30	45	Half-time	60	75	90
1	1.1	1.4	10.6	8.5	7.4	2.6	6.9	7.1	6.6
2	0.6	1.7	5.6	5.3	4.4	1.0	2.9	4.1	3.3
3	1.0	1.4	6.7	6.7	6.1	1.9	5.7	4.5	6.6
4	0.7	0.7	8.1	2.7	1.9	1.5	2.0	2.2	1.4
5	0.7	1.8	8.1	6.9	11.9	4.0	9.4	7.7	9.6
6	0.7	1.0	5.4	4.9	5.3	2.2	3.6	3.9	4.7
7	1.3	1.5	6.0	4.2	4.0	2.9	3.9	3.8	5.3
8	1.1	2.3	9.3	7.7	7.1	2.2	4.9	5.2	6.6
9	0.9	0.9	15.0	15.0	15.0	7.1	14.1	13.2	14.2
10	1.2	1.0	8.6	7.9	4.7	1.8	3.7	3.6	4.0
11	1.8	2.0	7.2	6.4	6.4	2.4	4.9	5.0	5.8
12	0.9	1.9	5.2	3.7	3.4	1.3	3.8	2.5	2.4
13	0.9	1.7	6.9	7.6	7.0	2.2	7.3	5.9	6.8
14	1.2	1.3	7.2	5.9	5.6	1.7	4.2	3.5	5.9
15	0.8	0.9	11.5	10.0	9.7	4.3	7.5	8.2	7.7
MEAN	1.0	1.4	8.1	6.9	6.7	2.6	5.7	5.4	6.1
SD	0.3	0.5	2.7	3.0	3.4	1.5	3.1	2.8	3.1
SEM	0.1	0.1	0.7	0.8	0.9	0.4	0.8	0.7	0.8

Table I34: Blood glucose concentrations (mmol/L) throughout the CHO trial

Player	Blood glucose (mmol/l)								
	CHO								
	Rest	Pre	15	30	45	Half-time	60	75	90
1	5.2	5.9	5.7	6.2	5.3	5.8	4.2	4.5	5.2
2	5.0	4.9	3.9	4.7	4.4	4.7	3.4	4.8	5.2
3	5.4	6.2	7.5	7.2	7.6	7.6	3.9	5.2	5.8
4	4.8	6.5	5.4	5.7	6.0	6.0	4.2	5.4	5.4
5	6.5	6.7	5.4	6.4	5.9	5.8	5.5	5.7	4.7
6	5.6	6.2	6.9	6.5	6.6	6.7	3.6	4.6	5.3
7	4.9	5.4	4.9	5.1	5.1	4.7	4.7	4.7	4.8
8	4.9	5.5	4.7	5.8	6.3	5.4	4.0	5.5	5.2
9	5.2	5.4	5.7	6.3	7.5	6.0	4.5	4.4	4.8
10	4.9	5.7	5.1	5.2	4.9	5.1	4.8	4.7	5.2
11	5.2	5.5	5.7	6.0	5.5	6.2	4.9	5.9	5.4
12	5.7	6.1	5.7	6.4	4.9	6.3	3.3	4.8	5.5
13	4.9	6.3	6.1	6.7	6.0	6.0	3.8	4.6	5.9
14	5.5	6.5	5.9	6.7	7.7	8.3	3.9	5.7	5.8
15	5.3	5.4	6.6	5.8	6.2	7.0	4.8	5.1	5.5
MEAN	5.3	5.9	5.7	6.0	6.0	6.1	4.2	5.0	5.3
SD	0.4	0.5	0.9	0.7	1.0	1.0	0.6	0.5	0.4
SEM	0.1	0.1	0.2	0.2	0.3	0.3	0.2	0.1	0.1

Table I35: Blood glucose concentrations (mmol/L) throughout the PL trial

Player	Blood glucose (mmol/l)								
	PI								
	Rest	Pre	15	30	45	Half-time	60	75	90
1	3.7	5.4	6.9	6.4	5.7	4.8	5.1	5.6	4.8
2	5.1	4.2	5.1	4.7	4.3	4.3	3.3	3.6	3.8
3	4.8	5.5	6.7	6.0	5.3	4.6	5.6	5.0	5.3
4	5.5	5.9	6.0	4.8	4.2	4.3	3.5	3.3	3.3
5	5.3	5.5	6.0	5.7	5.2	5.3	4.2	4.4	4.0
6	5.9	5.7	6.0	5.9	5.7	5.5	4.9	5.4	5.7
7	4.8	5.8	5.3	6.2	5.8	6.2	4.8	5.2	5.2
8	4.7	4.8	5.9	5.8	6.0	5.4	4.8	5.1	5.7
9	5.2	6.2	6.6	6.9	7.4	6.0	4.2	4.5	4.7
10	5.8	4.7	5.2	4.8	4.8	4.8	4.6	4.8	4.7
11	5.7	5.4	6.8	6.7	6.3	5.7	5.8	6.2	6.3
12	5.1	4.6	5.5	4.8	5.3	4.5	4.8	5.0	5.3
13	5.3	4.9	6.0	6.2	5.7	4.9	5.2	5.2	5.0
14	5.4	6.4	6.0	5.5	5.2	5.2	4.8	4.7	5.2
15	5.3	5.1	5.5	4.7	4.1	4.4	4.1	3.8	2.8
MEAN	5.2	5.3	6.0	5.7	5.4	5.1	4.6	4.8	4.8
SD	0.5	0.6	0.6	0.8	0.9	0.6	0.7	0.8	1.0
SEM	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

Table I36: Blood pH throughout the CHO trial

Player	Blood pH								
	CHO								
	Rest	Pre	15	30	45	Half-time	60	75	90
1	7.45	7.45	7.35	7.36	7.39	7.43	7.39	7.39	7.39
2	7.44	7.42	7.39	7.39	7.39	7.42	7.44	7.41	7.42
3	7.38	7.41	7.28	7.29	7.31	7.39	7.35	7.38	7.34
4	7.36	7.39	7.42	7.38	7.37	7.37	7.38	7.36	7.37
5	7.43	7.42	7.32	7.35	7.34	7.40	7.38	7.36	7.38
6	7.40	7.43	7.38	7.41	7.41	7.43	7.41	7.45	7.43
7	7.43	7.42	7.40	7.41	7.43	7.39	7.42	7.41	7.41
8	7.42	7.43	7.36	7.37	7.38	7.40	7.38	7.39	7.39
9	7.43	7.39	7.35	7.20	7.25	7.38	7.29	7.29	7.31
10	7.39	7.42	7.37	7.41	7.41	7.42	7.44	7.42	7.43
11	7.37	7.39	7.35	7.35	7.37	7.43	7.37	7.38	7.40
12	7.40	7.41	7.35	7.32	7.39	7.40	7.35	7.36	7.38
13	7.42	7.40	7.36	7.39	7.39	7.43	7.39	7.39	7.38
14	7.41	7.41	7.41	7.41	7.41	7.43	7.43	7.41	7.39
15	7.40	7.42	7.21	7.27	7.26	7.37	7.32	7.33	7.31
MEAN	7.41	7.41	7.35	7.35	7.37	7.41	7.38	7.38	7.38
SD	0.03	0.02	0.05	0.06	0.05	0.02	0.04	0.04	0.04
SEM	0.01	0.00	0.01	0.02	0.01	0.01	0.01	0.01	0.01

Table I37: Blood pH throughout the PL trial

Player	Blood pH								
	Pl								
	Rest	Pre	15	30	45	Half-time	60	75	90
1	7.45	7.44	7.28	7.33	7.38	7.42	7.33	7.35	7.4
2	7.44	7.42	7.38	7.4	7.41	7.43	7.44	7.43	7.42
3	7.43	7.47	7.33	7.39	7.38	7.41	7.35	7.38	7.39
4	7.4	7.59	7.34	7.37	7.4	7.36	7.38	7.37	7.37
5	7.43	7.42	7.34	7.36	7.3	7.4	7.34	7.35	7.32
6	7.4	7.42	7.4	7.41	7.45	7.43	7.43	7.42	7.43
7	7.44	7.44	7.39	7.39	7.39	7.42	7.41	7.43	7.42
8	7.41	7.4	7.31	7.34	7.35	7.41	7.36	7.36	7.37
9	7.41	7.42	7.2	7.21	7.25	7.37	7.29	7.29	7.28
10	7.41	7.4	7.35	7.39	7.4	7.42	7.41	7.42	7.47
11	7.38	7.39	7.34	7.36	7.38	7.42	7.37	7.39	7.39
12	7.37	7.41	7.35	7.36	7.38	7.42	7.41	7.4	7.41
13	7.42	7.42	7.34	7.34	7.36	7.4	7.34	7.36	7.35
14	7.41	7.42	7.38	7.41	7.44	7.43	7.42	7.42	7.42
15	7.42	7.44	7.31	7.34	7.33	7.41	7.36	7.37	7.36
MEAN	7.41	7.43	7.34	7.36	7.37	7.41	7.38	7.38	7.39
SD	0.02	0.05	0.05	0.05	0.05	0.02	0.04	0.04	0.05
SEM	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Table I38: Blood haematocrit throughout the CHO trial

Player	Hct (%)								
	CHO								
	Rest	Pre	15	30	45	Half-time	60	75	90
1	49	45	48	44	44	41	47	46	45
2	43	39	44	41	45	42	46	43	45
3	53	51	51	53	49	49	51	53	51
4	47	44	42	40	42	41	42	41	43
5	41	44	52	47	45	44	44	50	49
6	44	42	50	45	44	43	44	46	49
7	42	46	48	47	50	48	48	47	49
8	47	47	47	48	46	47	51	52	49
9	41	43	48	46	45	44	45	45	46
10	46	45	49	49	48	47	48	53	52
11	45	46	46	47	48	43	47	44	47
12	39	39	48	45	47	39	48	42	45
13	44	48	47	47	50	45	44	48	44
14	55	49	50	50	51	43	49	50	52
15	46	47	47	47	46	45	45	43	45
MEAN	45	45	48	46	47	44	47	47	47
SD	4	3	3	3	3	3	3	4	3
SEM	1	1	1	1	1	1	1	1	1

Table I39: Blood haematocrit throughout the PL trial

Player	Hct (%)								
	PI								
	Rest	Pre	15	30	45	Half-time	60	75	90
1	50	45	52	47	48	45	47	46	47
2	40	41	43	44	45	45	46	48	44
3	52	51	47	47	45	43	45	46	48
4	41	41	48	45	49	42	47	47	47
5	45	51	48	47	46	45	42	44	41
6	45	45	46	47	46	45	48	44	46
7	51	45	47	49	50	50	47	47	49
8	51	48	49	51	53	47	52	49	49
9	43	39	50	51	49	42	45	46	45
10	42	47	44	43	44	42	45	41	54
11	48	46	51	47	51	47	47	45	48
12	41	41	46	46	42	46	46	42	45
13	46	47	48	47	49	47	47	46	46
14	50	47	51	50	54	45	51	49	48
15	42	46	47	43	46	43	46	49	48
MEAN	46	45	48	47	48	45	47	46	47
SD	4	4	3	3	3	2	2	2	3
SEM	1	1	1	1	1	1	1	1	1

Table I40: Blood haemoglobin throughout the CHO trial

Player	Hb								
	CHO								
	Rest	Pre	15	30	45	Half-time	60	75	90
1	121	154	133	133	133	142	142	124	157
2	135	121	149	137	141	143	148	152	122
3	171	157	166	154	164	156	192	163	166
4	138	142	133	137	142	143	136	147	146
5	141	141	144	152	146	146	151	155	152
6	135	135	155	152	145	144	155	154	157
7	134	152	151	155	153	148	150	148	147
8	134	144	150	152	160	154	143	152	155
9	125	136	145	133	142	146	141	135	138
10	144	156	167	166	161	161	160	166	162
11	138	134	132	126	140	136	128	136	143
12	125	144	156	151	152	151	150	149	148
13	149	141	151	141	151	136	152	139	152
14	158	147	159	152	160	157	155	167	156
15	130	133	161	143	151	151	152	147	148
MEAN	139	142	150	146	149	148	150	149	150
SD	13	10	11	11	9	7	14	12	11
SEM	3	3	3	3	2	2	4	3	3

Table I41: Blood haemoglobin throughout the PL trial

Player	Hb								
	PI								
	Rest	Pre	15	30	45	Half-time	60	75	90
1	124	131	141	138	140	137	139	138	129
2	138	129	148	149	151	144	145	146	150
3	148	150	149	155	152	149	144	152	143
4	153	136	167	161	135	135	164	148	147
5	135	149	143	137	155	151	149	139	149
6	138	144	140	136	137	139	147	139	147
7	158	147	151	157	148	139	143	157	156
8	144	152	160	160	157	135	155	164	159
9	138	136	144	127	148	136	152	144	149
10	150	139	150	156	150	148	152	148	134
11	142	130	122	144	140	141	127	141	145
12	144	134	152	160	153	146	154	154	153
13	138	138	150	150	152	144	150	148	135
14	160	163	158	177	173	161	166	167	157
15	133	137	134	132	142	136	143	147	140
MEAN	143	141	147	149	149	143	149	149	146
SD	10	10	11	13	10	7	10	9	9
SEM	3	2	3	3	2	2	2	2	2

Table I42: Actual blood bicarbonate (HCO³⁻) throughout the CHO trial

Player	Actual bicarbonate							
	CHO							
	Pre-ex	15	30	45	Half time	60	75	90
1	27.63	20.37	19.92	22.25	25.89	23.61	24.06	21.79
2	28.7	21.79	21.79	23.61	27.24	23.94	24.25	25.3
3	28.05	19.38	19.84	20.77	25.43	23.6	24.4	23.07
4	25.43	17.51	21.3	21.25	22.98	22.41	21.61	20.81
5	27.73	19.71	21.95	22.66	24.62	23.07	21.61	21.74
6	26.39	21.3	22.35	22.35	25.39	23.3	22.94	21.91
7	27.24	22.77	23.3	23.9	25.43	23.84	24.25	22.82
8	26.39	19.92	21.25	21.3	23.7	21.3	21.34	22.25
9	27.24	20.37	13.19	13.49	22.63	16.95	15.87	16.62
10	27.73	22.98	24.25	24.72	27.73	24.45	25.3	23.9
11	27.24	19.46	21.12	22.11	25.39	22.11	23.52	22.3
12	26.15	20.37	21.25	19.52	22.77	22.78	22.46	21.74
13	27.41	22.03	23.61	23.61	25.89	23.61	23.16	22.63
14	29	23.3	24.25	23.3	26.39	23.9	23.3	22.25
15	26.76	16.5	16.53	17.5	22.11	20.1	20.17	19.26
MEAN	27.27	20.52	21.06	21.49	24.91	22.60	22.55	21.89
SD	0.95	1.93	2.93	2.88	1.72	1.93	2.31	1.98
SEM	0.25	0.50	0.76	0.74	0.44	0.50	0.60	0.51

Table I43: Actual blood bicarbonate (HCO³⁻) throughout the PL trial

Player	Actual bicarbonate							
	PL							
	Pre-ex	15	30	45	Half time	60	75	90
1	28.02	17.97	18.59	21.3	25.3	23.33	21.12	21.84
2	28.7	24.4	24.62	26.15	27.88	25.98	25.39	25.3
3	27.84	21.75	23.16	23.52	26.15	23.19	22.63	23.16
4	41.02	20.4	23.85	22.77	23.73	23.07	22.55	24.28
5	26.27	20.4	21.06	18.08	24.62	20.64	21.12	18.94
6	26.76	21.84	22.82	22.42	24.39	23.4	23.35	22.4
7	27	21.79	23.16	22.25	25.79	24.25	24.39	23.35
8	26.02	18.13	19.02	19.88	24.72	21.61	22.46	20.38
9	28.7	14.07	12.9	13.49	22.55	16.95	16.23	15.51
10	24.62	19.88	21.34	23.7	25.79	24.25	23.84	21.84
11	28.6	20.64	21.61	21.3	26.76	22.98	23.16	21.79
12	24.72	21.12	22.03	23.07	23.84	23.3	23.7	24.25
13	27.73	21.45	21.04	22.03	25.55	21.45	21.61	21.53
14	27.73	22.63	24.25	23.94	27.38	25.79	25.3	23.84
15	27	18.51	19.42	18.98	22.35	20.34	19.51	17.37
MEAN	28.05	20.33	21.26	21.53	25.12	22.70	22.42	21.72
SD	3.81	2.44	2.96	3.01	1.61	2.27	2.34	2.71
SEM	0.98	0.63	0.76	0.78	0.42	0.59	0.61	0.70

Table I44: Standard blood bicarbonate (HCO³⁻) throughout the CHO trial

Player	Standard bicarbonate							
	PL							
	Pre-ex	15	30	45	Half time	60	75	90
1	25.91	22.34	21.91	22.95	24.5	24.91	23.18	22.58
2	26.74	24.63	24.46	25.28	26.06	24.6	24.48	24.58
3	25.4	23.85	23.72	24.17	25.28	24.45	23.58	23.74
4	31.62	22.8	24.53	23.4	24.52	23.93	23.8	24.85
5	25.05	22.8	22.91	22.06	24.47	23.05	23.17	22.23
6	25.46	22.73	23.12	22.2	23.81	23.17	23.33	22.68
7	25.29	22.83	23.85	23.14	24.74	24.01	23.91	23.32
8	25.31	21.88	21.92	22.35	24.36	23.32	23.8	22.42
9	26.78	21.19	20.33	20.14	23.61	21.47	21.06	20.8
10	24.46	22.3	22.47	23.87	24.93	24.04	23.68	21.58
11	27.05	22.91	23.21	22.73	25.43	23.95	23.67	22.82
12	24.33	23.13	23.61	23.86	23.68	23.4	23.81	23.98
13	26.05	23.48	23.26	23.57	25.07	23.51	23.24	23.39
14	26.09	23.51	24.01	23.3	25.75	24.86	24.64	23.61
15	25.35	22.05	22.15	22.02	22.94	22.36	21.64	20.44
MEAN	26.06	22.83	23.03	23.00	24.61	23.67	23.40	22.87
SD	1.73	0.84	1.12	1.19	0.86	0.93	0.94	1.27
SEM	0.45	0.22	0.29	0.31	0.22	0.24	0.24	0.33

Table I45: Standard blood bicarbonate (HCO³⁻) throughout the PL trial

Player	Standard bicarbonate							
	CHO							
	Pre-ex	15	30	45	Half time	60	75	90
1	25.47	22.65	22.19	23.17	24.72	23.97	24.29	22.85
2	26.67	22.87	22.87	24.02	25.8	23.43	24.07	24.64
3	26.44	23.23	23.38	23.64	25.26	24.71	24.75	24.52
4	25.16	19.56	22.72	22.88	24.01	23.41	23.25	22.58
5	26.18	22.83	23.63	24.27	24.49	23.82	23.26	23.01
6	25.06	22.76	22.97	22.82	24.52	23.41	22.56	22.25
7	25.8	23.35	23.48	23.53	25.18	23.67	24.1	23.2
8	25.15	22.21	22.93	22.74	24.15	22.76	22.53	23.15
9	26.18	22.65	20.66	20.1	23.54	21.48	20.8	20.9
10	26.06	23.91	24.07	24.3	26.12	23.59	24.52	23.54
11	26.25	21.97	23.2	23.41	24.44	23.37	24.05	22.99
12	25.23	22.65	23.66	21.38	23.35	24.19	23.73	22.84
13	26.23	23.62	24.04	24.22	24.84	24.05	23.74	23.62
14	26.99	23.42	24.07	23.51	25.14	23.51	23.48	23.17
15	25.52	22.56	21.54	22.31	23.49	22.92	22.75	22.59
MEAN	25.89	22.68	23.03	23.09	24.60	23.49	23.46	23.06
SD	0.60	1.01	0.96	1.15	0.82	0.74	1.00	0.89
SEM	0.16	0.26	0.25	0.30	0.21	0.19	0.26	0.23

Table I46: Base excess throughout the CHO trial

Player	Base excess							
	CHO							
	Pre-ex	15	30	45	Half time	60	75	90
1	1.77	-1.77	-2.39	-1.2	0.82	-0.08	0.3	-1.58
2	3.4	-1.58	-1.58	-0.08	2.19	-1.03	-0.04	0.58
3	3.1	-0.87	-0.74	-0.46	1.42	0.9	0.82	0.7
4	1.42	-5.85	-1.74	-1.54	-0.11	-0.83	-0.99	-1.9
5	2.59	-1.58	-0.47	0.37	0.52	-0.28	-0.99	-1.38
6	1.24	-1.74	-1.61	-1.61	0.41	-0.83	-2.11	-2.47
7	2.19	-1.02	-0.83	-0.82	1.42	-0.62	-0.04	-1.22
8	1.24	-2.39	-1.54	-1.74	-0.25	-1.74	-1.95	-1.2
9	2.93	-1.77	-4.02	-5.01	-0.64	-3.12	-4.02	-3.89
10	2.59	-0.11	-0.04	0.35	2.59	-0.61	0.58	-0.82
11	2.93	-2.52	-1.15	-0.82	0.41	-0.82	0.09	-1.4
12	1.53	-1.77	-0.3	-3.45	-1.02	0.22	-0.29	-1.38
13	2.82	-0.64	-0.08	-0.08	0.82	-0.08	-0.45	-0.64
14	3.89	-0.83	-0.04	-0.83	1.24	-0.82	-0.83	-1.2
15	1.79	-1.53	-2.98	-1.93	-0.82	-1.26	-1.45	-1.71
MEAN	2.36	-1.73	-1.30	-1.26	0.60	-0.73	-0.76	-1.30
SD	0.83	1.31	1.16	1.44	1.06	0.92	1.25	1.10
SEM	0.22	0.34	0.30	0.37	0.27	0.24	0.32	0.28

Table I47: Base excess throughout the PL trial

Player	Base excess							
	PL							
	Pre-ex	15	30	45	Half time	60	75	90
1	2.34	-2.03	-2.76	-1.74	0.58	1.17	-1.15	-1.79
2	3.4	0.82	0.52	1.53	2.47	0.66	0.41	0.58
3	1.45	-0.14	-0.45	0.09	1.53	0.56	-0.64	-0.45
4	9.4	-1.51	0.61	-1.02	0.76	-0.28	-0.46	0.97
5	1.39	-1.51	-1.45	-2.43	0.52	-1.31	-1.15	-2.22
6	1.79	-1.79	-1.22	-2.54	-0.41	-1.23	-1.03	-2.06
7	1.5	-1.58	-0.45	-1.2	0.98	-0.04	-0.41	-1.03
8	1.67	-2.64	-2.64	-2.18	0.35	-0.99	-0.29	-2.26
9	3.4	-3.29	-4.51	-5.01	-0.46	-3.12	-3.72	-4.07
10	0.52	-2.18	-1.95	-0.25	0.98	-0.04	-0.62	-3.51
11	4.05	-1.31	-0.99	-1.74	1.79	-0.11	-0.45	-1.58
12	0.35	-1.15	-0.64	-0.28	-0.62	-0.83	-0.25	-0.04
13	2.59	-0.64	-0.97	-0.64	1.28	-0.64	-0.99	-0.81
14	2.59	-0.64	-0.04	-1.03	2.06	0.98	0.58	-0.62
15	1.5	-2.33	-2.31	-2.43	-1.61	-2.04	-2.97	-4.49
MEAN	2.53	-1.46	-1.28	-1.39	0.68	-0.48	-0.88	-1.56
SD	2.17	1.03	1.37	1.50	1.11	1.16	1.13	1.61
SEM	0.56	0.27	0.35	0.39	0.29	0.30	0.29	0.41

Table I48: Plasma volume changes throughout the CHO trial

Player	Plasma volume change								
	CHO								
	Rest	Pre	15	30	45	Half-time	60	75	90
1		-15.3	-8.1	-0.1	-0.1	-1.4	-11.4	3.3	-16.9
2		19.4	-11.0	2.0	-7.6	-3.9	-13.6	-11.2	6.8
3		13.6	7.4	11.0	13.1	18.9	-7.1	4.9	7.4
4		2.7	13.5	14.0	6.4	7.4	11.0	4.5	1.7
5		-5.1	-20.3	-16.7	-10.0	-8.3	-11.4	-22.9	-19.8
6		3.6	-22.2	-12.8	-6.9	-4.6	-12.9	-15.5	-21.7
7		-17.9	-20.4	-21.0	-24.5	-18.8	-19.9	-17.3	-19.8
8		-6.9	-10.7	-13.5	-14.7	-13.0	-13.4	-20.2	-16.8
9		-11.2	-8.1	-14.0	-17.9	-18.7	-17.4	-13.7	-17.1
10		-6.0	-18.6	-18.1	-13.9	-12.2	-13.3	-24.5	-21.0
11		1.1	2.6	5.5	-6.8	5.2	3.9	3.3	-7.0
12		-13.2	-8.1	-25.4	-28.5	-17.2	-29.0	-20.2	-23.8
13		-1.9	-6.6	0.0	-11.9	7.6	-2.0	-0.5	-2.0
14		21.8	10.4	15.5	7.5	27.5	15.5	5.1	8.0
15		-4.1	-20.7	-10.8	-13.9	-12.3	-12.9	-6.7	-10.5
MEAN	#####	-1.3	-8.0	-5.6	-8.6	-2.9	-8.9	-8.8	-10.2
SD	#####	12.0	11.8	13.3	11.6	13.9	11.7	11.3	11.7
SEM	#####	3.1	3.1	3.4	3.0	3.6	3.0	2.9	3.0

Table I49: Plasma volume changes throughout the PL trial

Player	Plasma volume change								
	PI								
	Rest	Pre	15	30	45	Half-time	60	75	90
1		4.1	-15.6	-5.9	-7.1	2.5	-4.7	-3.8	-4.5
2		5.2	-11.4	-13.6	-16.2	-12.2	-14.3	-18.1	-14.1
3		0.7	9.7	5.4	11.6	18.0	17.8	9.5	12.1
4		12.5	-4.5	-11.4	-2.0	11.4	-16.2	-7.1	-6.5
5		-19.3	-4.5	-5.9	-14.5	-10.6	-4.5	-1.1	-2.8
6		-4.2	-3.2	-2.2	-1.1	-0.7	-11.2	1.1	-7.8
7		20.6	13.2	4.7	8.9	16.0	19.5	8.9	5.4
8		0.5	-6.3	-10.0	-12.0	15.4	-9.0	-8.6	-5.7
9		8.6	-15.9	-6.6	-16.6	3.3	-12.4	-9.2	-10.6
10		-1.4	-3.4	-5.5	-3.4	1.4	-6.4	3.1	-11.2
11		13.4	9.7	0.5	-4.4	2.6	14.0	6.5	-2.1
12		7.5	-13.3	-17.6	-7.5	-9.7	-14.4	-8.1	-12.3
13		-1.9	-11.4	-9.7	-14.3	-5.9	-9.7	-6.8	2.2
14		4.0	-0.8	-9.6	-14.9	9.3	-5.5	-2.3	6.0
15		-9.6	-9.3	-1.0	-12.8	-3.9	-13.4	-20.4	-14.8
MEAN	#####	2.7	-4.5	-5.9	-7.1	2.4	-4.7	-3.8	-4.4
SD	#####	9.7	9.2	6.5	8.8	9.9	11.9	8.9	8.0
SEM	#####	2.5	2.4	1.7	2.3	2.6	3.1	2.3	2.1

Table I50: Plasma osmolality throughout the CHO and PL trials

Player	Plasma osmolality (Osmol/kg)			
	CHO		PI	
	Pre-ex	Post-ex	Pre-ex	Post-ex
1	0.298	0.315	0.308	0.276
2	0.292	0.349	0.277	0.282
3	0.263	0.261	0.292	0.291
4	0.291	0.305	0.286	0.287
5	0.297	0.316	0.302	0.318
6	0.284	0.284	0.298	0.304
7	0.269	0.283	0.283	0.301
8	0.281	0.316	0.275	0.283
9	0.258	0.277	0.282	0.303
10	0.290	0.291	0.291	0.313
11	0.291	0.291	0.287	0.272
12	0.297	0.302	0.390	0.282
13	0.284	0.293	0.251	0.269
14	0.289	0.300	0.245	0.257
15	0.293	0.316	0.265	0.272
MEAN	0.285	0.300	0.289	0.287
SD	0.012	0.021	0.033	0.017
SEM	0.003	0.005	0.009	0.005

Table I51: Raw data for mass change calculations throughout the CHO trial

Player	Body mass losses				
	CHO				
	Mass Pre (kg)	Mass Post (kg)	Urine (L)	Fluid In (L)	Net mass loss (kg)
1	72.0	70.2	0.0	2012.0	3.8
2	72.4	71.8	565.0	2020.4	2.1
3	78.0	77.1	0.0	2138.0	3.0
4	62.8	61.8	180.0	1818.8	2.6
5	68.5	67.6	0.0	1938.5	2.8
6	72.4	72.6	0.0	2020.4	1.8
7	66.8	66.2	50.0	1902.8	2.5
8	68.6	68.0	0.0	1940.6	2.5
9	65.7	65.4	0.0	1879.7	2.2
10	78.7	77.6	350.0	2152.7	2.9
11	66.0	66.2	66.0	1886.0	1.6
12	60.2	59.9	0.0	1764.2	2.1
13	55.8	55.2	430.0	1671.8	1.8
14	73.2	72.6	810.0	2037.2	1.8
15	93.8	93.1	380.0	2469.8	2.8
MEAN	70.3	69.7	188.7	1976.9	2.4
SD	9.0	8.9	258.0	188.6	0.6
SEM	2.3	2.3	66.6	48.7	0.2

Table I52: Raw data for mass change calculations throughout the PL trial

Player	Body mass losses				
	PI				
	Mass Pre (kg)	Mass Post (kg)	Urine (L)	Fluid In (L)	Net mass loss (kg)
1	70.4	70.3	0.0	1978.4	2.1
2	71.0	70.8	550.0	1991.0	1.6
3	78.0	77.1	0.0	2138.0	3.0
4	62.2	62.0	0.0	1806.2	2.0
5	67.9	67.6	0.0	1925.9	2.2
6	71.5	71.6	0.0	2001.5	1.9
7	66.7	66.2	0.0	1900.7	2.4
8	68.4	67.5	0.0	1936.4	2.8
9	66.3	66.1	0.0	1892.3	2.1
10	77.8	77.2	0.0	2133.8	2.7
11	66.0	66.5	0.0	1886.0	1.4
12	59.5	59.4	0.0	1749.5	1.8
13	55.2	54.8	420.0	1659.2	1.6
14	72.4	72.4	570.0	2020.4	1.5
15	91.5	91.3	0.0	2421.5	2.6
MEAN	69.7	69.4	102.7	1962.7	2.1
SD	8.6	8.5	214.8	180.3	0.5
SEM	2.2	2.2	55.5	46.6	0.1

Table I53: RPE values throughout the CHO trial

Player	RPE (units)								
	CHO								
	Rest	15	30	45	Half-time	60	75	90	
1	6	14	18	19	6	17	18	18	
2	6	13	15	16	6	15	16	18	
3	6	13	17	18	6	16	18	17	
4	6	13	15	15	6	14	17	19	
5	6	12	13	13	6	12	13	13	
6	6	13	14	15	6	14	16	17	
7	6	10	13	14	6	12	15	16	
8	6	10	12	11	6	10	12	12	
9	6	16	18	20	6	17	19	20	
10	6	10	12	12	6	11	12	13	
11	6	10	11	11	6	10	10	11	
12	6	12	13	14	6	14	16	17	
13	6	11	13	14	6	14	15	15	
14	6	13	15	16	6	15	17	18	
15	6	14	16	16	6	15	16	17	
MEAN	6	12	14	15	6	14	15	16	
SD	0	2	2	3	0	2	3	3	
SEM	0	0	1	1	0	1	1	1	

Table I54: RPE values throughout the PL trial

Player	RPE (units)								
	PI								
	Rest	15	30	45	Half-time	60	75	90	
1	6	15	17	16	6	16	18	19	
2	6	12	13	14	6	14	15	15	
3	6	13	15	16	6	15	18	18	
4	6	10	14	15	6	14	18	15	
5	6	15	18	18	6	17	18	18	
6	6	13	16	16	6	14	16	17	
7	6	10	11	13	6	11	13	13	
8	6	13	13	13	6	12	12	12	
9	6	15	17	19	6	17	19	20	
10	6	11	13	14	6	11	13	14	
11	6	8	8	9	6	9	9	10	
12	6	12	14	15	6	14	15	16	
13	6	12	13	15	6	13	14	16	
14	6	12	13	14	6	13	15	16	
15	6	16	18	19	6	18	19	20	
MEAN	6	12	14	15	6	14	15	16	
SD	0	2	3	3	0	2	3	3	
SEM	0	1	1	1	0	1	1	1	

Table I55: Mean 15 m sprint velocities throughout the CHO trial

Player	15 m sprint velocity (m/s)					
	CHO					
	15	30	45	60	75	90
1	6.32	6.12	6.12	6.12	6.03	6.14
2	5.72	5.73	5.77	5.75	5.79	5.74
3	6.44	6.40	6.35	6.34	6.45	6.46
4	5.90	5.79	5.72	5.76	5.73	5.77
5	5.99	5.81	5.78	5.79	5.82	5.70
6	5.51	5.81	5.80	5.77	5.84	5.91
7	6.26	6.11	5.99	5.85	5.88	6.10
8	6.01	5.97	5.94	5.89	5.98	5.89
9	6.17	6.08	5.96	5.94	6.05	5.88
10	5.80	5.67	5.73	5.60	5.65	5.57
11	6.01	5.71	5.44	5.51	5.32	5.63
12	5.83	5.70	5.73	5.75	5.78	5.81
13	6.13	6.01	6.04	6.02	6.06	6.10
14	6.19	6.07	6.09	6.07	6.06	6.05
15	5.81	5.78	5.77	5.77	5.63	5.67
MEAN	6.01	5.92	5.88	5.86	5.87	5.89
SD	0.25	0.21	0.22	0.21	0.26	0.24
SEM	0.06	0.05	0.06	0.05	0.07	0.06

Table I56: Mean 15 m sprint velocities throughout the PL trial

Player	15 m sprint velocity (m/s)					
	PI					
	15	30	45	60	75	90
1	6.38	5.98	6.17	6.12	6.15	6.11
2	5.71	5.70	5.53	5.51	5.63	5.39
3	6.43	6.18	6.37	6.29	6.24	6.48
4	5.90	5.85	5.75	5.69	5.55	5.35
5	6.00	5.90	5.67	5.83	5.70	5.86
6	5.91	5.90	5.94	5.94	5.95	5.91
7	6.08	5.85	5.79	5.92	5.82	5.92
8	5.99	5.97	5.96	5.80	5.91	5.94
9	6.24	6.17	6.07	6.08	6.11	6.03
10	5.86	5.75	5.61	5.57	5.64	5.67
11	5.92	5.85	5.80	5.70	5.91	6.02
12	5.96	5.85	5.68	5.79	5.77	5.70
13	6.17	6.16	6.19	6.13	6.17	6.18
14	6.36	6.28	6.25	6.09	6.10	6.10
15	5.93	5.42	5.36	5.55	5.46	5.31
MEAN	6.06	5.92	5.88	5.87	5.87	5.86
SD	0.21	0.22	0.29	0.24	0.25	0.33
SEM	0.06	0.06	0.08	0.06	0.06	0.08

Appendix J1: Raw Data – Study 5 – Participant anthropometrics

Table J1: Raw data of player anthropometrics involved in study 5

Player	CHO			PI		
	Mass (kg)	Height (m)	Age (years)	Mass (kg)	Height (m)	Age (years)
1	60.5	1.77	16	59.8	1.78	16
2	61.3	1.72	16	61.5	1.72	16
3	62.4	1.78	15	62	1.79	15
4	64.2	1.62	15	64.2	1.62	15
5	61.6	1.82	16	59.5	1.73	16
6	55.2	1.61	15	56.9	1.60	15
7	70.8	1.81	16	70.5	1.81	16
8	73.6	1.73	16	73	1.75	16
9	67.9	1.70	15	68.5	1.70	15
10	73.1	1.83	16	74.4	1.82	16
MEAN	65.1	1.74	16	65.0	1.73	16
SD	6.1	0.08	1	6.1	0.07	1
SEM	1.9	0.02	1	1.9	0.02	1

Table J2: Raw data of estimated aerobic capacity values from multistage fitness test

Player	Estimated Aerobic Capacity (ml/kg/min)
1	60.6
2	57.8
3	57.5
4	61.2
5	61.3
6	57.5
7	57.5
8	55.8
9	57.5
10	57.1
MEAN	58.4
SD	1.9
SEM	0.6

Appendix J2: Raw Data – Study 5 – Pre-trial diet and urine analyses

Table J3: Pre-trial dietary and osmolality data for CHO

Player	CHO					
	Energy contribution			Total Calories	MJ/d	Urine osmolality (mOsmol/kg)
	% Fat	% CHO	% Protein			
1	42	37	20	2384	10.0	164
2	30	55	15	2310	9.7	840
3	40	46	13	3118	13.0	77
4	24	53	22	2648	11.1	134
5	36	46	17	3365	14.1	373
6	43	42	16	3847	16.1	1047
7	19	72	9	2765	11.6	982
8	38	49	14	2906	12.2	1080
9	30	58	12	2345	9.8	143
10	27	55	19	2803	11.7	907
MEAN	32.80	51.31	15.76	2848.93	11.92	575
STDEV	8.09	9.65	4.02	488.52	2.04	430
SEM	2.56	3.05	1.27	154.48	0.65	136

Table J4: Pre-trial dietary and osmolality data for PL

Player	PI					
	Energy contribution			Total Calories	MJ/d	Urine osmolality (mOsmol/kg)
	% Fat	% CHO	% Protein			
1	31	54	15	2565	10.7	117
2	38	51	11	1836	7.7	111
3	27	52	20	2384	10.0	920
4	29	50	21	2546	10.7	79
5	40	44	16	4782	20.0	360
6	33	56	10	3124	13.1	103
7	21	58	21	1808	7.6	581
8	27	56	17	2556	10.7	1192
9	28	60	12	2930	12.3	111
10	24	58	18	2189	9.2	646
MEAN	29.74	53.94	16.16	2672.08	11.18	422
STDEV	6.03	4.65	4.13	851.47	3.56	398
SEM	1.91	1.47	1.31	269.26	1.13	126

Table J5: Average pre-trial dietary data for both CHO and PL trials

	Average of two trials				
	Energy contribution			Total calories	Mj/d
	% Fat	% CHO	% Protein		
MEAN	31	53	16	2761	11.5
STDEV	7	7	4	682	2.9
SEM	2	2	1	152	0.6

Appendix J3: Raw Data – Study 5 – Pre-trial environmental conditions

Table J6: Pre-trial environmental conditions for CHO and PL trials

Player	CHO			PI		
	Temp (°c)	Humidity (%)	Pressure (mmHg)	Temp (°c)	Humidity (%)	Pressure (mmHg)
1	6	77	763	5	51	758
2	5	51	758	6	77	763
3	6	77	763	5	51	758
4	6	77	763	5	51	758
5	6	77	763	5	51	758
6	5	51	758	6	77	763
7	5	51	758	6	77	763
8	6	77	763	5	51	758
9	5	51	758	6	77	763
10	5	51	758	6	77	763
MEAN	5.5	64.0	760.5	5.5	64.0	760.5
SD	0.5	13.7	2.6	0.5	13.7	2.6
SEM	0.2	4.3	0.8	0.2	4.3	0.8

Appendix J4: Raw Data – Study 5 – Physiological data

Table J7: Average HR variables throughout the CHO and PL trials

Player	HR (bpm)			
	CHO		PI	
	Mean	Peak	Mean	Peak
1	164	200	171	204
2	173	207	157	192
3	156	204	157	192
4	143	184	157	192
5	160	191	157	192
6	152	200	148	191
7	149	181	143	177
8	159	198	162	199
9	159	198	156	194
10	168	198	163	192
MEAN	158	196	157	193
SD	9	8	8	7
SEM	3	3	2	2

Table J8: Blood lactate concentrations (mmol/L) throughout the CHO trial

Player	Blood lactate (mmol/l)							
	CHO							
	Rest	15	30	45	Half-time	60	75	90
1	1.6	6.3	2.7	1.3	2.0	2.6	1.7	1.8
2	2.1	5.0	6.3	5.4	3.9	3.3	4.6	4.1
3	1.3	8.3	7.7	9.2	4.6	5.1	3.9	6.8
4	1.1	1.4	4.2	5.1	2.3	2.9	3.6	4.8
5	2.4	7.2	8.4	8.2	5.4	5.4	4.8	4.3
6	1.0	3.8	3.0	5.1	2.4	8.1	5.2	3.3
7	1.2	7.9	8.0	6.1	6.2	7.4	5.7	6.6
8	1.2	7.3	11.6	6.1	6.1	2.8	13.1	10.1
9	1.4	8.2	6.3	6.3	6.2	6.1	6.9	3.3
10	1.1	6.7	6.6	5.2	4.3	3.6	4.0	4.3
MEAN	1.4	6.2	6.5	5.8	4.3	4.7	5.4	4.9
SD	0.5	2.2	2.7	2.1	1.7	2.0	3.1	2.3
SEM	0.1	0.7	0.9	0.7	0.5	0.6	1.0	0.7

Table J9: Blood lactate concentrations (mmol/L) throughout the PL trial

Player	Blood lactate (mmol/l)							
	PI							
	Rest	15	30	45	Half-time	60	75	90
1	0.9	4.2	3.8	4.4	4.0	2.9	6.0	1.7
2	1.3	1.2	3.0	4.3	8.1	3.2	1.9	1.9
3	1.2	6.4	6.9	8.0	4.4	4.7	2.6	8.9
4	2.7	2.4	4.1	3.8	2.6	6.1	2.6	2.1
5	1.4	7.3	8.1	7.7	7.4	7.3	7.2	6.7
6	1.3	2.6	3.4	7.9	3.3	3.2	2.9	6.9
7	1.6	7.6	5.7	4.8	4.4	4.1	2.1	7.4
8	1.2	7.9	3.8	6.1	1.4	6.8	8.7	5.0
9	1.4	5.8	5.0	4.3	2.8	2.0	4.0	2.6
10	1.9	3.2	3.4	2.9	5.7	3.6	7.3	7.4
MEAN	1.5	4.9	4.7	5.4	4.4	4.4	4.5	5.1
SD	0.5	2.4	1.7	1.9	2.1	1.8	2.5	2.7
SEM	0.2	0.8	0.5	0.6	0.7	0.6	0.8	0.9

Table J10: Blood glucose concentrations (mmol/L) throughout the CHO trial

Player	Blood glucose (mmol/l)							
	CHO							
	Rest	15	30	45	Half-time	60	75	90
1	4.7	2.9	5.4	6.1	3.2	2.9	2.9	4.2
2	5.6	4.8	8.9	5.3	4.3	2.9	4.1	5.4
3	4.1	5.2	5.3	6.9	5.9	3.9	4.2	3.8
4	4.8	4.5	4.4	5.8	3.7	4.3	4.9	5.1
5	5.1	7.1	9.3	9.7	6.3	4.7	4.2	3.8
6	4.4	6.0	6.1	8.4	4.7	3.7	5.3	5.4
7	6.9	6.1	9.9	7.1	5.0	5.1	4.6	6.4
8	5.3	7.7	6.1	6.1	4.1	4.9	7.0	7.4
9	6.9	5.6	5.8	6.9	4.9	2.8	4.3	4.7
10	6.8	5.4	6.0	6.2	3.9	4.2	4.5	5.7
MEAN	5.5	5.5	6.7	6.9	4.6	3.9	4.6	5.2
SD	1.1	1.3	1.9	1.3	1.0	0.9	1.0	1.1
SEM	0.3	0.4	0.6	0.4	0.3	0.3	0.3	0.4

Table J11: Blood glucose concentrations (mmol/L) throughout the PL trial

Player	Blood glucose (mmol/l)							
	PI							
	Rest	15	30	45	Half-time	60	75	90
1	4.9	4.2	5.2	4.1	2.3	2.5	2.9	2.7
2	4.3	4.7	6.9	5.2	4.4	3.3	4.9	4.8
3	4.9	7.2	6.1	5.5	3.4	3.3	2.9	4.1
4	6.2	7.7	7.5	4.4	3.4	4.2	4.7	4.2
5	4.8	10.6	12.7	9.1	7.5	6.7	4.4	6.6
6	3.9	4.1	5.3	4.4	2.6	3.2	4.3	2.7
7	7.1	5.8	4.4	4.4	4.0	4.5	3.6	3.4
8	8.7	9.3	7.2	8.5	5.4	4.3	3.9	3.4
9	4.6	4.3	3.9	3.9	3.1	2.4	3.1	5.1
10	5.1	4.9	6.2	4.4	3.2	3.4	5.3	4.2
MEAN	5.5	6.3	6.5	5.4	3.9	3.8	4.0	4.1
SD	1.5	2.3	2.5	1.9	1.5	1.2	0.9	1.2
SEM	0.5	0.7	0.8	0.6	0.5	0.4	0.3	0.4

Table J12: Raw data for mass change calculations throughout the CHO trial

Player	Mass losses				
	CHO				
	Mass Pre (kg)	Mass Post (kg)	Urine (L)	Fluid In (L)	Net mass loss (kg)
1	60.5	60.3	510.0	1270.5	760.7
2	61.3	61.7	0.0	1287.3	1286.9
3	62.4	63.0	300.0	1310.4	1009.8
4	64.2	64.2	290.0	1348.2	1058.2
5	61.6	61.7	410.0	1293.6	883.5
6	55.2	55.4	0.0	1159.2	1159.0
7	70.8	71.2	0.0	1486.8	1486.4
8	73.6	74.2	0.0	1545.6	1545.0
9	67.9	67.7	0.0	1425.9	1426.1
10	73.1	73.2	0.0	1535.1	1535.0
MEAN	65.1	65.3	151.0	1366.26	1215.1
SD	6.1	6.1	203.9	127.26	283.0
SEM	1.9	1.9	64.5	40.24	89.5

Table J13: Raw data for mass change calculations throughout the PL trial

Player	Mass losses				
	PI				
	Mass Pre (kg)	Mass Post (kg)	Urine (L)	Fluid In (L)	Net mass loss (kg)
1	59.8	60.5	0.0	1255.8	1255.1
2	61.5	61.3	380.0	1291.5	911.7
3	62.0	62.6	0.0	1302.0	1301.4
4	64.2	64.1	0.0	1348.2	1348.3
5	59.5	59.8	0.0	1249.5	1249.2
6	56.9	55.8	840.0	1194.9	356.0
7	70.5	71.7	300.0	1480.5	1179.3
8	73.0	73.0	0.0	1533.0	1533.0
9	68.5	67.8	1050.0	1438.5	389.2
10	74.4	74.0	490.0	1562.4	1072.8
MEAN	65.0	65.1	306.0	1365.63	1059.6
SD	6.1	6.2	386.8	129.01	397.3
SEM	1.9	2.0	122.3	40.80	125.7