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THE INFLUENCE OF CARBOHYDRATE-ELECTROLYTE INGESTION ON METABOLISM AND SOCCER SKILL PERFORMANCE DURING AND FOLLOWING PROLONGED INTERMITTENT EXERCISE

by

Ajmol Ali

A Doctoral Thesis

Submitted in partial fulfilment of the requirements for the award of Doctor of Philosophy for Loughborough University

September 2002

© by Ajmol Ali 2002
This thesis is dedicated to my parents, Aftab Ali and Sitarun Nessa, who, in their own way, made it all possible.
“Some people believe football is a matter of life and death. I'm very disappointed with that attitude. I can assure you it is much, much more important than that.”

Bill Shankly
PUBLICATIONS AND CONFERENCE PROCEEDINGS

Publications:


Conference proceedings:


ACKNOWLEDGEMENTS

I would like to thank a number of people for their help in producing this Doctoral thesis. First and foremost, I would like to extend my gratitude to Professor Clyde Williams for not only agreeing to be my supervisor but for all his help and support during these past 3 years. I would also like to thank him for helping me through my period of moratorium and guidance with future career prospects.

I want to thank Professor Fred Yeadon for taking up the role of Director of Research at very late notice. Furthermore, I would like to highlight the invaluable support of Dr Ceri Nicholas in helping to shape the direction of my studies and for her assistance during the experiments themselves. I would also like to express my gratitude to Dr John Leiper for flying down from Aberdeen University to help with the gastric emptying study. Moreover, I am extremely grateful for the assistance given by Mike Holliday and Dr Greg Atkinson with the various statistical procedures used during these investigations.

I am indebted for the financial support given by GlaxoSmithKline and would especially like to thank Professor David Parker, Maarten van den Braak and Jacqui Shaw for their input and constructive criticism during these past few years.

A number of other people within the School of Sports and Exercise Science also deserve a mention. My thanks go to Judy Brewin for her administrative abilities and continued encouragement, Lisa Pierce for carrying out the analysis on the dietary records, Maria Nute for help with blood collection and analysis and Spencer Newport and Gabriella Scanlon for assistance with general laboratory procedures and practices. In addition, I would like to thank David Bentley for repairing equipment and apparatus that came into contact with stray footballs and for help with the construction of the goalkeeper.

I would like to thank my fellow PhD students from the Human Muscle Metabolism Research Group – David Bailey, Andrew Foskett, Nicholas Gant, Susan Backhouse
and Ching-Ling Wu – for their humour, encouragement and assistance throughout the course of this Doctoral thesis. A special mention also goes to John Brooks, Sophie Davison, John Eldred, Matthew Hirst, Christopher Oram, Christopher Bate and Daniel Harris; undergraduate students who spent many long, exhausting and unsociable hours in the laboratory collecting data.

Finally, I would like to express my gratitude to the many subjects, namely players from the Loughborough Students Athletic Football Club, for agreeing to participate in these very time-consuming and gruelling experiments.
Although soccer is one of the more researched intermittent team sports, there is a surprisingly modest amount of information available on the effects of fatigue on skill performance. The main reasons for this are due to the problems of overcoming the barriers of controlling the many variables in the field and a lack of reliable and valid skill tests. The Loughborough Intermittent Shuttle running Test (LIST) is a recently developed exercise protocol which closely simulates the demands of multiple-sprint sports such as soccer in a controlled environment. Furthermore, the Loughborough Soccer Passing Test (LSPT) and Loughborough Soccer Shooting Test (LSST) were developed (and modified further as part of this thesis, Chapters 5 and 6) and found to be reliable and valid indicators of soccer skill. Therefore, one of the main aims of this thesis was to investigate the influence of 90 min of the LIST on soccer skill performance.

Early researchers (e.g. Karlsson, 1969 and Saltin, 1973) reported the benefits of maintaining a high muscle glycogen content on soccer performance and more recent investigators looked at the effect of providing carbohydrate (CHO) during exercise on work rate and soccer skill. However, many of these experiments were completed in the field setting and used poor tests of skill. Therefore, the primary aim of these series of experiments was to determine the influence of ingesting a carbohydrate-electrolyte (CHO-E) solution during the LIST on soccer skill performance.

There was an 8% deterioration in LSPT performance following 90 min of intermittent high-intensity running, even with fluid ingestion (p<0.05). Furthermore, the ingestion of a CHO-E solution during exercise showed tendencies for better maintenance of skill performance towards the end of exercise. Moreover, CHO-E supplementation better maintained sprint performance and a higher relative exercise intensity during exercise (p<0.05). This is crucial in soccer performance, as players who are unable to sprint to get to the ball will be unable to perform the necessary skill.

From the results of Chapters 5 and 6 it was found that the modified passing (LSPT) and goal-shooting (LSST) tests were valid and reliable tests of soccer skill. Moreover,
they were found to be more repeatable when higher calibre players performed the tests.

To investigate whether there was a gradual or sudden decrease in skill performance subjects performed the LSPT before and after every 15-min block of the LIST (Chapter 7). Although no significant differences were observed in LSPT performance, there appeared to be an 'inverted-U' pattern of performance. Nevertheless, with CHO-E ingestion subjects tended to better maintain sprint performance and reported lower perceptions of effort during the latter stages of the LIST ($p<0.05$).

From the results of Chapter 8, it was found that the gastric emptying potential of the CHO-E solution was the same as the placebo control during the LIST ($p>0.05$).

The main purpose of Chapter 9 was to assess whether an increased supply of CHO would highlight any differences between the control and experimental conditions. Although LSPT performance deteriorated by 8% from baseline to post-LIST, there were no added benefits of increasing the amount of CHO intake. As in previous studies there was a ‘speed-accuracy trade-off’ in LSST performance i.e. subjects increased the time taken to complete each shot sequence and reduced the shot speed to maintain shooting accuracy post-LIST. There was a trend for CHO-E ingestion to maintain a better shot speed and time taken for each sequence. The ingestion of CHO-E also reduced the perception of effort ($p<0.05$) and led to more positive feelings of affective valence during the last 30 min of the LIST.

Therefore, based on these findings, it was concluded that the ingestion of CHO-E solutions over water alone should be encouraged to soccer players because of the tendency to better maintain soccer skill and the associated physiological, biochemical and psychological benefits during such exercise.

Keywords: carbohydrate, fatigue, fluid, intermittent running, soccer, skill, sprint
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CHAPTER 1

INTRODUCTION

The ever-increasing amount of information on the benefits of appropriate nourishment and hydration to improve athletic performance has brought applied sports nutrition into the public domain. This has led to the development of numerous pre-exercise, during exercise and post-exercise nutritional diets and strategies. Indeed, the market for sports drinks and associated products has grown considerably over recent years and is now a multi-billion dollar business throughout the globe. This is because fluid consumption throughout prolonged exercise can decrease the effect of dehydration and attenuate its associated effect on thermal and cardiovascular function and exercise performance (Candas et al., 1986; Hamilton et al., 1991; Montain and Coyle, 1992). Furthermore, the ingestion of carbohydrate-electrolyte (CHO-E) solutions immediately before and frequently during exercise has been shown to delay fatigue and so increase endurance capacity (Coyle et al., 1983; Hargreaves et al., 1984; Yaspelkis et al., 1993) and improve exercise performance (Mitchell et al., 1988; Murray et al., 1987; Tsintzas et al., 1993).

It is paradoxical that most research within applied sports nutrition is based predominantly around prolonged, continuous exercise when there is considerably greater participation within multiple-sprint sports such as soccer (Williams, 1990). Performance benefits and improvements in endurance capacity from CHO supplementation have been reported in continuous cycling (e.g. Coyle et al., 1983; 1986), intermittent cycling (e.g. Hargreaves et al., 1984; Murray et al., 1987; Yaspelkis et al., 1993) and prolonged continuous submaximal running (e.g. Tsintzas et al., 1996) with fewer studies employing intermittent running protocols (e.g. Nicholas et al., 1995). The game of soccer is the world's most popular team sport with around 240 million regular players around the globe (FIFA, 2001). Thus, due to its popularity, as well as the amount of financial interest in the game, it is one of the most extensively researched intermittent team sports (Shi and Gisolfi, 1998). Nevertheless, this is largely based on gathering match analysis data (e.g. Reilly and Thomas, 1976) and the physiological demands on players during training and match
play (e.g. Bangsbo, 1994a), with a dearth of evidence relating to skill performance. Again, this seems remarkable, as the skill elements of the game are the key to success and winning performances.

During a soccer game players exercise at an intensity equivalent to 70-80% $\text{VO}_2\text{max}$ (Bangsbo, 1994a). There is a heavy demand on glycogen stores when individuals work for prolonged periods at these high intensities (Romijn et al., 1993) and, due to the relatively small supply of this substrate in the body, it may be suggested as a limiting factor in soccer performance. Indeed, the amount of work performed by players, expressed as distance covered, decreased in the second half and this was related to low muscle glycogen concentrations (Karlsson, 1969). Furthermore, Saltin (1973) reported that players who commenced a match with low glycogen stores ran significantly less and sprinted less than players who began the game with normal amounts of muscle glycogen during an exhibition match. Therefore, it would appear that if there was a way in maintaining glycogen availability towards the end of a game then fatigue may be delayed and performance maintained.

Leatt and Jacobs (1989) investigated the possibility that a glucose polymer solution given before, and at halftime of a game, would reduce muscle glycogen utilisation; therefore, they biopsied players before and after a competitive exhibition match (8-a-side). They reported a 31% greater glycogen utilisation in the placebo trial but the significance of this to the game situation was unclear as no performance measures were taken. An earlier investigation did report that the administration of glucose before a game improved soccer performance i.e. players in teams ingesting CHO scored more goals and conceded fewer goals (Muckle 1973), but the design of this study was seriously flawed. Moreover, as these studies were conducted in the field setting, other factors that may have influenced performance were not controlled for and so may have had an independent effect on soccer skill.

Therefore, due to the difficulty in replicating game situations in a reliable and valid way intermittent sports have not been studied extensively. This is due to the practice of manipulating the specific variables in the sport itself (in the field) is laden with error. This is not so much of a problem for running or cycling based studies where
controlled experiments, on treadmills and cycle ergometers in the laboratory context, may prevail. Indeed, Quanz (1999) investigated the effectiveness of CHO ingestion during 90 min of simulated soccer match play on a subsequent run to exhaustion. The main finding was that there was a 30% longer run time to exhaustion in the CHO trial. However, as the experiment was completed using a treadmill protocol the application to a free running game of soccer, where players continuously turn, accelerate and decelerate, can be questioned. Furthermore, the blood lactate concentrations were only about 3 mmol.L\(^{-1}\) throughout exercise, suggesting that the protocol may not have replicated the high-intensity nature of soccer.

Recognising the limitations of field studies and treadmill based investigations, a protocol has been developed, within the last few years, which has been shown to elicit similar physiological responses to intermittent activities such as soccer (Loughborough Intermittent Shuttle running Test or LIST; Nicholas et al., 1995; 2000). Using this test, it has been found that ingestion of a CHO-E solution during exercise increased the run time to fatigue by 33% (Nicholas et al., 1995) and 52% (Davis et al., 1999). Furthermore, a subsequent study gave support for earlier field studies (e.g. Saltin, 1973; Leatt and Jacobs, 1989) that muscle glycogen availability may be the critical factor in improving/maintaining performance during intermittent exercise (Nicholas et al., 1999).

The reasons behind the scarcity of research into soccer skill are probably associated with a lack of valid and reliable skill tests. There have been some attempts by previous investigators at producing soccer 'skill' tests (Northcott et al., 1998; Reilly, 1983; Zelenka et al., 1967). However, due to the use of static passing and shooting drills they may be assessing 'technique' rather than 'skill' per se. They also either give no indication of any reliability and validity testing (Northcott et al., 1998; Zelenka et al., 1967) or inappropriately use Pearson's \(r\) as a method for assessing repeatability (Reilly and Holmes, 1983). Recognising the limitations of previous endeavours to produce soccer skill tests we have developed soccer passing and shooting tests for research use (McGregor et al., 1999a; Reddin, 1999). McGregor and colleagues (1999a) developed the Loughborough Soccer Passing Test (LSPT) and subsequently validated the skill test using 67 soccer players, who were of at least university standard. Reddin (1999) later developed the Loughborough Soccer
Shooting Test (LSST) and validated the test using professional, university, schoolboy and recreational players.

McGregor et al. (1999b), using the LIST protocol, investigated the influence of fluid ingestion on soccer skill performance. They found that in the absence of fluid ingestion during the 90-min exercise there was a 5% deterioration in soccer-dribbling performance. However, when fluid was provided, skill performance was maintained post-exercise. Therefore, it was speculated that dehydration might have been the mechanism for fatigue. However, even after complete rehydration of fluid lost during the LIST, skill performance did not return to pre-exercise levels (McGregor, 1999). Thus, the authors concluded that it might be muscle glycogen availability, rather than dehydration per se, that was responsible for the decrement in skill performance. Nevertheless, whilst comparing the influence of ingesting no fluid, flavoured placebo and 6.4% carbohydrate-electrolyte solution during the LIST on skill performance, they found no difference between the two fluid trials with a decrement in the 'no fluid' trial only. However, it was considered that muscle glycogen may not have reached critically low concentrations for an effect on performance to be observed.

Thus, the overall aim of these series of experiments presented in this thesis was to examine the influence of ingesting a CHO-E solution on soccer skill performance following prolonged, high-intensity shuttle running, whilst in a state of low muscle glycogen concentration.

1.1 Overview of thesis

This thesis is presented in 10 chapters, each with specific aims. Chapter 2 is a review of the literature detailing the specific demands of soccer in relation to energy expenditure and substrate utilisation, possible fatiguing agents during soccer and the efficacy of fluid and CHO-E replacement for soccer skill retention.

Chapter 3 describes the general methods used in the studies reported in this thesis.
Chapter 4 describes the study that investigated whether low muscle glycogen concentration influenced skill performance and the influence of ingesting a CHO-E solution on skill performance following 90 min of intermittent exercise.

Chapters 5 and 6 describe how the passing (LSPT) and goal-shooting (LSST) tests were modified to improve their sensitivity and ecological validity.

Chapter 7 describes a study that repeated the study described in Chapter 4 but using more skilled players and the modified skill tests described in Chapters 5 and 6. However, the primary aim was to monitor skill performance during the 90-min exercise protocol to determine whether there was a gradual or sudden decrement in performance.

Chapter 8 describes a study that was designed to assess the gastric emptying of fluid during prolonged high-intensity shuttle running. Additionally, to establish whether there were any differences in the gastric emptying rate between a 6.4% CHO-E beverage and an artificially flavoured water placebo solution.

Chapter 9 describes a similar study to that reported in Chapter 7 but subjects were provided with an increased fluid and CHO supply. Moreover, to investigate the ‘feel-good’ factor of CHO ingestion further, psychological scales of affect were also administered along with the traditional ratings of perceived exertion (RPE) scale.

Chapter 10 is a summary of the results of the studies reported in this thesis – discussed in relation to the wider research literature on this topic.
The present review will aim to highlight the specific demands in relation to energy expenditure and substrate utilisation, moving on to a discussion of possible causes of fatigue during soccer and the efficacy of fluid and carbohydrate replacement for soccer players. In addition to factors influencing physiological work rate, the implications for the performance of soccer skill will also be considered.

2.1 Match analysis

A number of techniques have been used to perform match analysis and so determine the demands of soccer. The detailed description of these techniques is beyond the scope of this review and so the interested reader may be referred to Hughes (1996) for an appraisal on the topic of notational techniques. Moreover, specific information pertaining to work rate profiles, movement patterns, positional differences and so on can be found elsewhere (e.g. Reilly and Thomas, 1976; Withers et al., 1982).

2.2 Energy metabolism during soccer

When discussing the aetiology of fatigue in soccer, due to the diverse activities involved, there is a variety of metabolic factors which need to be considered. These fall under the broad headings of aerobic and anaerobic sources of energy production.

2.2.1 Aerobic energy production

A number of attempts have been made to determine the contribution of the aerobic system during soccer via measurement of \( \text{VO}_2 \) during various game situations (Durnin and Passmore, 1967; Kawakami et al., 1992; Ogushi et al., 1993; Miyagi et al., 1998). As
these were practice games, they may not give a true representation of aerobic energy production during actual matchplay. More recently, the development of the Loughborough Intermittent Shuttle running Test (LIST) has enabled the investigation of metabolism during simulated soccer games. In conjunction with one of the latest portable ambulatory systems (KB1-C, AeroSport Inc.), it was found that the average intensity during the LIST, at the pre-determined speeds, was between 75 and 80% \( \dot{\text{VO}}_2 \) max (Ali, 1998).

Heart rate (HR) data have been used to estimate the aerobic energy production during soccer (Reilly and Thomas, 1979; Ekblom, 1986; Bangsbo, 1994b). This method is much simpler, less expensive and less cumbersome for players. Reilly and Thomas (1979) estimated the aerobic contribution to be 75% of \( \dot{\text{VO}}_2 \) max using HR data. However, the problem with this method is that it relies on the assumption that HR and \( \dot{\text{VO}}_2 \) follow a linear relationship up to and including maximal effort. According to Davies (1968), the major limitation is the asymptotic nature of the HR-\( \dot{\text{VO}}_2 \) curve near maximal work rate, thus a linear extrapolation will tend to underestimate \( \dot{\text{VO}}_2 \) max. Consequently, relative work rates based on this figure will tend to be overestimated. Furthermore, Bangsbo (1994b) suggested that HR may be influenced by static muscle contraction, heat and emotional stress and thus sometimes can overestimate the \( \dot{\text{VO}}_2 \) of players.

Rectal temperatures have also been used as an indicator of the average energy yield during soccer performance. In a study of players in the Swedish national league, it was found that players from the top division had higher average rectal temperatures during match play compared to their colleagues in the lower divisions, thus indicating greater physiological demand in more elite game play (Ekblom, 1986). From such information, and the known relationship between rectal temperature and relative oxygen uptake (Astrand, 1960; Saltin and Hermansen, 1966), Ekblom (1986) suggested that players were performing at about 80% of their \( \dot{\text{VO}}_2 \) max during national top level soccer, a figure since criticised for being slightly exaggerated (Bangsbo, 1994a).
Bangsbo (1994a) suggested that from the general findings within the literature it appears that the mean relative work rate in soccer is around 70% \( \dot{VO}_2 \text{max} \), corresponding to an energy production of 1360 kcal for a player weighing 75 kg with a \( \dot{VO}_2 \text{max} \) of 60 ml.kg\(^{-1}\) min\(^{-1}\).

### 2.2.2 Anaerobic energy production

Although it has been suggested that only 12% of energy production in soccer match play is of an anaerobic origin (Mayhew and Wenger, 1985), this 12% incorporates arguably some of the most important actions, specifically heading, jumping, tackling, sprinting and shooting (Bangsbo, 1994a). There appears to be some debate as to which of the anaerobic systems dominate during soccer, with some favouring the ATP-PCr system due to the shortness of the high intensity periods of the game (Tumilty, 1993). Elite players perform 19 sprints of ~2-s duration per match (Bangsbo et al., 1991) and stores of ATP and PCr are required for this. The stores of PCr are virtually depleted during exhaustive sprints, resynthesis of which begins immediately, drawing upon a combination of glycolysis and oxidative metabolism (Shephard, 1992). Without sufficient resynthesis of PCr between sprints the player will become fatigued (see below).

Glycolysis is also involved in the resynthesis of ATP during soccer. As glycolysis leads to lactate formation, this has commonly been used, via extrapolation, as an indicator of the amount of glycolysis that has occurred. For example, blood samples have been taken at half-time and immediately after the games (Ekblom, 1986; Rhode and Espersen, 1988) and during games (Gerisch et al., 1988; Smith et al., 1993). Bangsbo et al. (1991) found values of 4.8 and 3.7 mmol.l\(^{-1}\) at the end of the first and second halves, respectively, in Danish first and second division players, thus indicating that more glycolysis occurred in the first as opposed to the second half. Similar findings were reported in high-intensity intermittent cycling exercise (Gaitanos et al., 1993). The authors found a relation between lower work rate over 10 successive sprints and the degree of anaerobic glycolysis, with the lowest work rate and amount of glycolysis in the 10th sprint.
As the quantity of blood lactate produced during soccer (~4-5 mmol.l⁻¹; Bangsbo et al., 1991) is much less than that of high-intensity exercise (e.g. ~15 mmol.l⁻¹ following maximal sprints; Nevill et al., 1993), it may be concluded that glycolysis has a minor role in soccer performance. This notion has been modified of late as authors such as Bangsbo (1994a) and Tumilty (1993) have questioned the use of blood lactate as an indicator of lactate production and thus glycolysis. Bangsbo (1994b) contended that as the concentration of blood lactate is dependent on the release of lactate from the muscle and the removal of lactate from the blood, this can therefore underestimate lactate production. Blood lactate is also prone to considerable variation, depending on the exact time of measurement; this may help to explain the disparity in reported values – from ~4 mmol.l⁻¹ (Bangsbo et al., 1991) up to 13 mmol.l⁻¹ reported by Ekblom (1986). Moreover, the rate of lactate production may be high, but the duration of activity too short to result in large blood lactate values (Bangsbo, 1994b).

In summary, even though it is difficult to determine accurately the exact quantity of lactate produced, and thus gauge the amount of anaerobic glycolysis, this system does still appear to be influential during soccer (Bangsbo, 1994b).

2.2.3 Substrate utilisation

The primary determinants of substrate utilisation are the intensity and duration of exercise, but other factors include training status, environmental conditions and standard of play (Coggan and Coyle, 1991). Soccer is a prolonged activity and played at an intensity of 70-80% VO₂ max, with an RER of 0.88; this corresponds to 60 and 40% of CHO (both glycogen and glucose) and fats, respectively – thus highlighting the importance of carbohydrates in soccer (Bangsbo, 1994b). Protein metabolism plays a minor role, providing less than 10% of energy for muscular contraction (Wagenmakers et al., 1989).
The huge importance of glycogen was demonstrated by Saltin (1973), who found that the glycogen content of the quadriceps was 96, 32 and 9 mmol.kg⁻¹ before, at half-time and after a game, respectively. Saltin (1973) also showed that players with low glycogen did less high-intensity running (see below). Furthermore, Nordheim and Vollestad (1990) propose that actual glycogen degradation could be more than what has been reported due to glycogen resynthesis during the low intensity or rest periods of the game.

Blood borne glucose has been shown to increase when sufficient liver glycogen stores and glycogen precursors are available (Reynolds and Ekblom, 1985; op. cit. Ekblom, 1986). Indeed, blood glucose levels for Canadian national soccer players were found to increase from a pre-game level of 4.96 to 5.67 mmol.l⁻¹ at half time, and then fall to 4.74 mmol.l⁻¹ at the end of the match (Leatt, 1986; op. cit. Shephard, 1992). These results suggest that glycogen was available in the first half of the game but a deficiency arose in the second half, thus supporting the findings of other studies (Bangsbo et al., 1991; Saltin, 1973).

Blood borne free fatty acid (FFA) concentrations become increasingly important as the CHO stores become depleted. The increase in blood borne FFA has been reported in soccer games and this is especially so in the second half (Bangsbo, 1994b), again possibly indicating that as the glycogen stores are decreasing then that is becoming the substrate of choice. There is only a minor increase in glycerol during soccer exercise, thus suggesting a high uptake in various tissues of glycerol (most probably by the liver; Bangsbo, 1994b). Therefore, glycerol may be a significant gluconeogenic precursor during soccer (Bangsbo, 1994b). The uptake of FFA and the amount oxidised during a match cannot be determined from blood FFA and glycerol concentrations (Bangsbo, 1994b) and therefore, it would seem that the appearance of these substrates in the blood only provides an indication of their availability.
2.3 Fatigue and soccer

Motion analysis shows that the distance covered in the second half of a soccer game is less than the first half (Van Gool et al., 1988; Bangsbo et al., 1991). This fall in work rate indicates a manifestation of fatigue. What is more, the fact that more goals are scored towards the end of the game, can possibly be linked to this fall in work rate – which may subsequently allow more space for the attacking players – or may be due to lapses in concentration or mental fatigue (Reilly, 1996).

Fatigue has been defined as, “a failure to maintain the required or expected force” (Edwards, 1981) and more recently as, “a decreased force generating capacity” (Vollestad and Sejersted, 1988). However, fatigue is a very complex phenomenon because it has many contributory factors, especially so during intermittent exercise such as in soccer, i.e. prolonged, endurance exercise punctuated with bursts of high-intensity exercise. Therefore, the deterioration in performance observed towards the end of a game will be a result of the fatigue processes that occur during both short-intense and enduring exercise. Consequently, fatigue in soccer will be discussed not only with reference to prolonged, endurance exercise but also to short, high-intensity exercise, as is the nature of soccer.

2.3.1 Depletion of energy substrates

A classical theory of fatigue is that at a certain point of the exercise ATP consumption cannot be met by an equal rate of ATP formation, thus resulting in energetic deficiency and impaired force generation (Bigland-Ritchie, 1987; Sahlin, 1992). The substrates used by the various energy releasing pathways take the form of PCr, glycogen and glucose, and various types of fats.

Following prolonged exercise, or even exercise of a short duration, stores of ATP may be expected to decline to minute levels. However, during exercise to fatigue the maximal decrease in muscle ATP content is about 10-40%, and this has caused some to question
the theory that fatigue is caused by energetic deficiencies (Sahlin, 1992). It has been suggested that it may not be a reduction in ATP per se, thus not an energy supply problem, but the products of ATP hydrolysis that play a role in fatigue. Sahlin et al. (1998) indicated that a small decline in ATP concentration will subsequently cause a major relative increase in ADP and inorganic phosphate (Pi), which have been shown not only to impair power output during concentric contractions (Allen et al., 1992; Westerblad et al., 1991) but also to reduce the free energy released during ATP hydrolysis.

The argument for energetic deficiencies contributing towards fatigue relates to other products of ATP hydrolysis. Increases in the degradation products of ATP can be detected in blood (hypoxanthines – which are further degradation products of inosine monophosphate (IMP) – and ammonia (NH₃)) or muscle (IMP and NH₃) and may be used as markers of energy deficiency (Sahlin et al., 1998). Inosine monophosphate has been found to be correlated to increases in muscle lactate and to a decrease in PCr content (Sahlin et al., 1989); increases in IMP and blood hypoxanthines have also been correlated to muscle fatigue (Hellsten-Westig et al., 1991). In addition, using the needle biopsy technique, Sahlin and Broberg (1990) discovered that at high-intensity exercise both IMP and NH₃ accumulate in the working muscle with a concomitant decrease in total adenine nucleotides (ATP + ADP + AMP). All these correlations between increases in markers of energy deficiency and fatigue-related factors indicate that there is an argument for fatigue being due to energy deficiencies. An important point to note here is that a correlation does not prove a causal relationship.

2.3.1.1 Phosphocreatine (PCr)

The importance of the PCr system during soccer has already been stressed. Thus, a deterioration in this system's capabilities may offer a reason, at least partly, to the decrement in work rate as observed in soccer (Van Gool et al., 1988; Bangsbo et al., 1991).
The concentrations of PCr decrease during prolonged exercise but at fatigue PCr is higher (33% of initial value) than after high intensity exercise (11% of initial value) (Sahlin et al., 1998), thus one may suggest that deficiencies of this substrate are not the cause of fatigue after prolonged exercise. However, many authors suggest that a decrease in performance (fatigue) may not necessarily be due to energy deficiencies but due to an inefficient restoration of PCr (Balsom et al., 1992; Jones et al., 1985; Simonson, 1971). Balsom et al. (1992) studied the effect of recovery time on performance of 40-m sprints with recovery intervals of 30 (R30), 60 (R60) or 120 s (R120). They discovered that running speed in the R120 trial was maintained for all 15 sprints whereas performance decreased with successive sprints in the other two trials (R30 and R60). In addition, running speed over the last 10 m of each sprint decreased in all three trials but acceleration from 0-15 m was only affected with the shortest 30-s rest period. It was suggested that the observed decrease in performance was due to insufficient restoration of PCr and although not measured, a decline in muscle pH in the short rest periods (Balsom et al., 1992).

This hypothesis is also supported by evidence that PCr recovery follows the same time course as peak power output (PPO) recovery (Sahlin and Ren, 1989; Bogdanis et al., 1995) and that oral creatine supplementation increases PCr concentration with a simultaneous increase in PPO with no further increase in muscle lactate (Greenhaff et al., 1994). Furthermore, PCr concentrations, shown by nuclear magnetic resonance (NMR), recovered to near maximal levels during 2 min of rest between maximal bouts of exercise (Bangsbo, 1994b). Trump et al. (1994) also discovered that occlusion of the circulation to the working leg during the 4-min recovery between repeated bouts of maximal isokinetic cycling prevented PCr resynthesis and reduced total work in the subsequent sprint by ~15% in the occluded compared to the non-occluded leg. However, Bogdanis et al. (1995) found that PPO recovery occurred as the muscle became increasingly more acidic, thus contradicting the earlier suggestion by Balsom and co-workers (1992).
It would seem therefore, that the fatiguing effect of high-intensity bouts of exercise on subsequent performance will be dependent upon the rest periods involved during play. However, match analysis data show that high speed running occurs every 70 s and sprints only occur every 4-5 min during match-play (Bangsbo et al., 1991). As sprint running performance was unaffected by recovery durations of 2 min (Balsom et al., 1992), one may suggest that PCr availability alone is not a key factor for fatigue as ample time is available for the resynthesis of PCr between sprints.

The protocols of the above studies involved high-intensity exercise with no 'background' activities during the recovery periods. Although sprints may occur infrequently in soccer, the players are not in a state of complete rest between bouts of high-intensity exercise, but rather, complete running, jogging and walking activities. Thus, it may be argued that inefficient restoration of PCr may occur. Moreover, aerobic metabolism is required to resynthesise PCr stores, and as this system is also required for the periods of background running and jogging, then it may be unable to do both tasks efficiently, and hence contribute to fatigue.

2.3.1.2 Muscle glycogen

The use of glycogen as an energy substrate by skeletal muscle is directly related to the duration and intensity of exercise (Saltin and Karlsson, 1971). As soccer is played at intensities of 70-80% \( \text{VO}_2\text{max} \) it has been found that muscle glycogen and blood glucose are the predominant substrates used for metabolism during such prolonged, strenuous exercise (Saltin, 1973; Coggan and Coyle, 1987; Romijn et al., 1993).

There is a finite store of carbohydrate in the body which is sufficiently small to be threatened during a soccer match (Shephard, 1992), whereas for all intents and purposes fat stores are unlimited. For example, a player with 28 kg of skeletal muscle will have a total intramuscular store of \(~1600\ \text{kcal of carbohydrate, with an additional 90-100 g of glycogen (360-400 kcal of energy) stored in the liver (Shephard, 1992). In comparison,
The amount of energy stored as fat can amount to 50,000-100,000 kcal in lean men and women (Shephard, 1992).

The traditional way of determining muscle glycogen is via the analysis of samples obtained using the muscle biopsy technique (e.g. Bergstrom et al., 1967; Saltin, 1973; Smaros, 1980). More recently, using magnetic resonance spectroscopy (MRS), Rico-Sanz et al. (1999a) found slightly higher glycogen content (144 mmol.kg\(^{-1}\) ww) than other Swedish or Finnish studies of between 58-96 mmol.kg\(^{-1}\) ww (Ekblom, 1986; Saltin, 1973; Smaros, 1980). The most obvious advantage of this newer method for determining muscle glycogen content is that it is non-invasive and there is no wounding and subsequent healing of the muscle, and so subjects can exercise to full potential and perform the exercise again. A methodological disadvantage is that the technique cannot differentiate metabolite content between single fibres. In addition, there may be problems with the timing of the machines or differences in machines between laboratories i.e. different calibration procedures and so on. However, MRS has been deemed to be a successful method to determine glycogen and other phosphate content in soccer players (Rico-Sanz et al., 1999a; 1999b).

Various researchers have reported different degrees of muscle glycogen depletion during matches, ranging from 20-90% of pre-match concentrations (Agnevic, 1970; Saltin, 1973; Smaros, 1980; Rico-Sanz et al., 1999b). This could be due to the level of competition i.e. higher the competition level, the greater the decrement, differences in pre-exercise concentrations, where the sample was taken (vastus lateralis or gastrocnemius), or the method employed (biopsy or MRS). The important point is that fatigue may be due to a severe reduction of glycogen whereby the body cannot carry on at a given work rate due to a lack of substrate.
2.3.1.3 Evidence for glycogen deficiencies causing fatigue

A number of findings support the hypothesis that deficiency in energy supply is a significant factor in causing fatigue during prolonged exercise. When exercising at intensities of 60-85% \( \dot{VO}_2 \text{max} \), fatigue has been found to occur concurrently with the depletion of muscle glycogen (Essen, 1978; Sherman, 1995; Sahlin et al., 1998). For example, Rico-Sanz and co-workers (1999b) found a 36% degradation of muscle glycogen following 42 min of intermittent running to exhaustion and a high correlation between glycogen utilised and the time to exhaustion.

More specifically to soccer exercise, the occurrence of fatigue has also been closely related to pre-exercise muscle glycogen content (Karlsson, 1969; Saltin, 1973). Saltin (1973) showed that 25% less distance was covered by players with low glycogen content in a competitive game with the most notable difference distance covered at high intensity. Those players with low glycogen concentrations walked 59% of the distance and covered 15% at maximal speed, whereas players with high muscle glycogen content covered 27% walking and 27% sprinting. Furthermore, as well as observing a rapid decrease in muscle glycogen during a soccer game, Karlsson (1969) found that players with the lowest glycogen content at half time had a slower average speed and covered less ground in the second half. Thus, the finding of low muscle glycogen concentrations at the end of a soccer match (Saltin, 1973) and a more pronounced use of glycogen in the first compared with the second half (Karlsson, 1969), indicates that the level of muscle glycogen prior to a match may influence performance towards the end of a game. However, these studies were based on measurements in the field and so can be criticised for lacking experimental control.

Bangsbo et al. (1992) and Nicholas et al. (1999) conducted investigations on the effects of elevating pre-exercise glycogen levels, via a high-CHO diet preceding the exercise trials, on exercise capacity. These investigations were completed under more controlled conditions, using intermittent exercise protocols designed to simulate the demands placed
on players during actual match play. Both studies discovered that exercise time to exhaustion was increased following carbohydrate supplementation. In addition, supplementation with CHO during exercise itself has been shown to delay the onset of fatigue (Spencer et al., 1991, Coyle 1992) and lead to a reduced IMP formation (Spencer et al., 1991).

2.3.1.4 Mechanisms for low glycogen content causing fatigue

The exact mechanism causing fatigue when glycogen is severely reduced is yet to be clarified, but is likely to be due to other interacting factors associated with the metabolic processes involved in muscle contraction (Sherman, 1995). It has been shown that prolonged exercise to fatigue, leading to low intramuscular levels of glycogen, has led to an enhanced breakdown of muscle adenine nucleotides (ATP + ADP + AMP) to IMP and NH₃ (Broberg and Sahlin, 1989). Thus, fatigue may be a consequence of ATP resynthesis failure, due to a relative pyruvate deficiency, which results in reduced substrate availability for anaplerotic reactions that supply the tricarboxylic acid (TCA) cycle (Costill and Hargreaves, 1992). The result is an impairment of the contractile process. More specifically to soccer, Bangsbo (1994b) suggested that the low glycogen content may lead to insufficient tension generation during the high-intensity periods of the game. Fast twitch (FT) fibres may progressively become more involved in development of force as the slow twitch (ST) fibres fatigue and may not be able to recover completely during periods of rest, leading to a gradual exhaustion in these fibres. Combined with the reduced capacity of ST fibres, the fatigue of some FT fibres could result in impaired performance towards the end of a match (Bangsbo, 1994b).

2.3.2 Excitation-contraction coupling (ECC) and fatigue

Force production in muscle is the end result of a long chain of events (excitation-contraction coupling or ECC) and it follows that a defect in any of the links in the chain might contribute to fatigue (see Allen et al., 1992 or Westerblad et al., 1991 for detailed
reviews). Due to its complexity, Edwards (1983) has offered a 'chain of command' for muscular contraction and the potential mechanisms underlying fatigue (Figure 2.1). The possible fatiguing mechanisms will be discussed in relation to the game of soccer.

2.3.2.1 Acidity

Blood lactate concentrations of over 10 mmol.l⁻¹ have been observed in soccer players (Apor, 1970; Ekblom, 1986), thus muscle lactate values may be expected to be even higher. Furthermore, muscle pH has been shown to fall from a resting value of 7.1 to 6.5/6.6 during exhaustive intense exercise and changes of this magnitude are known to adversely affect energy production and muscle contraction (Ekblom, 1986).

In relation to ECC, acidosis may reduce the sensitivity of the contractile proteins to calcium (Ca²⁺). At the molecular level the simplest way in which such a reduced sensitivity could occur would be if there was direct competition between Ca²⁺ and another ion for the Ca²⁺ binding site on troponin; such an ion is H⁺. As H⁺ concentration increases (and pH decreases) with prolonged and high intensity exercise, then the sensitivity of Ca²⁺ will be reduced, thus culminating in a reduced tension development. Even though this idea is supported by a vast majority of experimental findings (see Sahlin, 1992 for review), these experiments were performed under well controlled laboratory conditions using single muscle or small muscle groups or even in vitro studies with skinned fibres – a situation where the intracellular chemical composition can be altered (Allen et al., 1992). Thus, the direct extrapolation of these results to the complexities of exercising humans in dynamic activities may not be applicable.

In addition, muscle pH is rarely below 6.8 during match play, as bouts of maximal activities in soccer are short and recovery periods are relatively long. As a consequence, Bangsbo (1994a) contended that lactate accumulation, and subsequent lowering of pH, may not be the cause of fatigue in soccer. Furthermore, PCr restoration has been found to mirror force recovery, and this occurred as pH was still low (Bogdanis et al., 1995; Sahlin
and Ren, 1989). Therefore, there may be no direct effect of acidity on the contractile machinery, at least not during high-intensity exercise.

Figure 2.1 Chain of command for muscular contraction and the possible mechanisms underlying fatigue (after Edwards, 1983).
Even still, acidosis may be a factor in fatigue but through indirect mechanism(s), where the acidotic impairment of ADP rephosphorylation may be a contributing factor. The decrease in pH will potentiate the ATP inhibition of phosphofructokinase (PFK), the main regulatory step of glycolysis and ATP production, and thus reduce glycolysis (Sahlin, 1992; Wilmore and Costill, 1999). Acidotic inhibition of glycolysis will prevent excessive decreases in pH which otherwise could be lethal to the cell and may be a contributing factor in fatigue (Sahlin, 1992); hence the notion that fatigue is a ‘safety mechanism’ (Edwards, 1981). The observed relationships between muscle lactate and IMP and between blood lactate and plasma NH₃ support this contention (see Sahlin and Broberg, 1990 for review).

2.3.2.2 Ionic imbalances

An impairment of metabolic processes has been widely implicated as causing muscular fatigue. However, it is evident that disturbances in electrolyte regulation in muscle fluids are closely linked to the processes of muscular fatigue (McKenna, 1992). From the early work of Hodgkin and Huxley (1952; op. cit. McKenna, 1992) it was discovered that the action potential is based on a sodium (Na⁺) influx followed by a potassium (K⁺) efflux, with each action potential causing a very small rise in Na⁺ and a fall in K⁺ in the intracellular space, with opposite effects in the extracellular space. The sodium-potassium (Na⁺-K⁺) pump opposes the K⁺ and Na⁺ fluxes across the cell membrane and is therefore crucial in the maintenance of ionic concentration gradients, so that future action potentials can be initiated.

It is well known that venous plasma K⁺ concentration rises during muscular contraction and that this K⁺ originates principally from the contracting muscle (Lindinger and Sjogaard, 1991). Along with the K⁺ efflux from the exercising muscle there is a decline in the muscle K⁺ content as shown in both prolonged and intense exercise (see McKenna, 1992 for review). There is also an increase in intracellular water during exercise (Bergstrom et al., 1971) and thus, the combined cellular K⁺ efflux and water influx, will
lead to a decrease in intracellular K+ concentration of 6-20% (McKenna, 1992). This large increase in ionic imbalance during intense exercise indicates that the ion fluxes exceed the capacity of the Na+-K+ pump to maintain an ionic balance, thus reducing muscle membrane potential, which may subsequently result in a direct decrease in the muscle contractile performance (McKenna, 1992; Figure 2.1).

The majority of investigations into ionic imbalances and fatigue have involved the use of high-intensity cycling exercise (see McKenna, 1992 for review), with limited information regarding activities similar to soccer. Therefore, there is a need to carry out more research in this area.

2.3.3 Central factors

The discomfort and pain associated with prolonged exercise will subsequently lead to factors relating to central nervous system (CNS) function to increase in importance (Sahlin, 1992; Sahlin et al., 1998). The notion of central fatigue has been defined as a, "negative influence that exists despite an individual's full motivation" (Davis and Bailey, 1997). Other definitions may include such terms as, 'psychological factors, perception and central drive'; the main point is that the impairment leading to fatigue occurs within the CNS (Sahlin, 1992).

One of the proposed mechanisms for the central fatigue theory involves the neurotransmitter 5-hydroxytryptamine (5-HT) or serotonin. Circumstantial evidence suggests that an increase in brain 5-HT may hasten the onset of fatigue (Newsholme et al., 1987; op. cit. Davis, 1995). Serotonin has been found to be involved in feelings of tiredness or lethargy and also in the perception of pain (Wilson and Maughan, 1992). The level of free-tryptophan, an amino acid that increases with endurance exercise (Wilson and Maughan, 1992), has been implicated in synthesising 5-HT in the brain. Indeed, Chaoulaff (1989) showed that tryptophan concentration elevated 5-HT concentration in the brain of rats – but the applicability to exercising humans may be questioned. There are
some field studies which suggest that supplementation with branched chained amino acids (BCAA) during exercise reduces the levels of free-tryptophan in humans (Blomstrand et al., 1991). Blomstrand and colleagues (1991) investigated the influence of BCAA supplementation during a 30-km cross-country race or a marathon (42.2 km) and the effects on mental and physical performances were measured. Mental performance, as determined by the Stroop colour and word test, was improved following the 30-km race with BCAA supplementation as opposed to a placebo control. Furthermore, physical performance, as determined by time to complete a marathon, was improved only in the 'slower' runners (i.e. completion time of 3.05-3.5 h) and not the 'faster' runners (i.e. completion time of <3.05 h), with BCAA supplementation. However, such field studies have since been criticised for not controlling subjects' food and water intake, not dividing them up into specific experimental and control groups and not controlling for experimenter or subject bias (Davis and Bailey, 1997). Indeed, more controlled laboratory studies show no benefits of BCAA supplementation (Varnier et al., 1994). A more detailed discussion on serotonin and the central fatigue hypothesis is beyond the scope of this review and the interested reader is referred to Davis (1995) and Davis and Bailey (1997).

Increases in plasma NH₃ occur during both short-term high-intensity exercise and prolonged exercise (Sahlin and Broberg, 1990). Since NH₃ is a potential neurotoxin it has been suggested that the increased plasma level could impair the function of the CNS (Mutch and Banister, 1983; see Davis and Bailey, 1997 for review).

Dehydration has also been implicated in having a negative influence on mental function (see below). Furthermore, central fatigue may at least under some conditions be related to metabolic disturbances induced by the exercise (Sahlin, 1992). After long-term exercise blood glucose decreases, due to liver glycogen depletion and, due to a reduction in the supply of energy substrate to the nervous system, may result in impaired mental functioning during soccer (Reilly and Lewis, 1985).
2.4 Fluid replacement

2.4.1 Temperature regulation

At rest the rate of heat production is low, but at high work rates, metabolic heat production can exceed 80 kJ.min\(^{-1}\) (20 kcal.min\(^{-1}\), Maughan and Noakes, 1991). As a result of the increased rate of metabolic heat production during exercise, the body’s core temperature (CNS, thorax, and abdominal cavity) is significantly elevated due to the convective flow of blood to the core (Gisolfi and Duchman, 1992). This is true over a wide range of workloads and ambient temperatures (Saltin and Costill, 1988). Table 2.1 shows that post-match rectal temperatures in excess of 39°C are common, with some studies reporting individual values of over 40°C (Ekblom, 1986).

In response to this rise in core temperature, heat receptors located in the anterior hypothalamus are stimulated and cutaneous blood flow is increased to transport heat from the core to the skin and sweating is initiated (Gisolfi and Duchman, 1992). The evaporation of sweat removes heat from the body and plays a major role in preventing excessive rise in body temperature during exercise (Shi and Gisolfi, 1998).

The secretion of sweat also represents the loss of vital body fluids, namely water. Water is essential for life, and the depletion of body water will not only affect exercise performance but also the health and safety of the soccer player. Water provides the medium for biochemical reactions within cell tissues and is essential for maintaining an adequate blood volume and therefore the “integrity of the cardiovascular system” (Sawka and Pandolf, 1990).
2.4.2 Fluid loss during soccer

There is a limited amount of information regarding fluid, and thus body weight, loss for soccer players. Even so, as Shi and Gisolfi (1998) pointed out, of the intermittent exercises studied in terms of fluid replacement, soccer has been the most extensively investigated. Table 2.1 also shows the body weight losses of soccer players during training and competition. There are practical problems in collecting this information for elite players because managers are reluctant to let their protégés be hindered with this type of measurements when they want them to concentrate on the game (Maughan and Leiper, 1994).

Table 2.1 Summary of studies investigating fluid balance and thermoregulation during competitive soccer matches. The sweat loss shown is actual reduction in body weight after correction for fluid intake, in absolute (litres) and relative (% body weight) form. (Maughan and Leiper, 1994)

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<th>Ambient temperature (°C)</th>
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<th>Sweat loss litres (%)</th>
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<td>7</td>
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<td>33</td>
<td>40</td>
<td>8</td>
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<td>3.08</td>
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<td>26</td>
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<td>8</td>
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<td>13</td>
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<td>27</td>
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<td>38</td>
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<td>12-15</td>
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<td>23</td>
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<td>19</td>
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<td>1.31</td>
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Intermittent exercise is more demanding on the body than continuous exercise of the same average intensity (Nevill et al., 1995). This is because intermittent exercise increases body temperature more (0.3°C) than continuous exercise at a given \( \text{VO}_2 \) and due to blood lactate concentrations being further elevated, above that of continuous exercise (Bangsbo, 1994a). Concomitantly, sweat loss during intermittent exercise can exceed sweat loss during continuous exercise (Shi and Gisolfi, 1998). For instance, sweat losses during soccer (see Table 2.2) are comparable with sweat loss during marathons (0.96-1.27 l.h\(^{-1}\)) (see Sawka and Pandolf, 1990 for review). This highlights the problem facing not only soccer players but multiple-sprint games players in general.

Most of the observations on fluid loss during soccer match play have been made under temperate conditions (e.g. \(-21^\circ\text{C}\); Saltin, 1964). In a study carried out under varying temperatures (range: 13.2°C - 33°C), Mustafa and Mahmoud (1979) reported evaporative water losses of 5 l during soccer. Such losses would not only impair both physical and cognitive performance (Maughan and Leiper, 1994) but would seriously jeopardise the health of the player.

2.4.3 Dehydration and associated problems

Although one may associate dehydration with hot and humid climates, even in cold conditions considerable amounts of sweat can be lost in an attempt to dissipate heat, thus resulting in a degree of dehydration (Maughan, 1991). This is highlighted by the investigative work of Davies and co-workers (1995), who followed an English Premier League team for 4 weeks, under English winter conditions (mean temperature of 6.9°C, relative humidity of 80.8%), and found that the corrected weight loss was 2.9%. Due to dehydration, skin blood flow is likely to be compromised, reducing heat loss and causing increases in core temperature (Nadel et al., 1979). Moreover, as sweat is hypotonic, then intracellular water tends to become hypertonic, thus also contributing to intracellular dehydration (Saltin and Costill, 1988).
2.4.3.1 Performance

Performance in soccer is difficult to quantify (Maughan and Leiper, 1994), but studies of running and cycling have shown that both sprint and endurance exercise performance are adversely affected by hypohydration (Armstrong et al., 1985; Nielsen et al., 1982). Therefore, players in multiple-sprint sports such as soccer are likely to be adversely affected by dehydration. Even a mild degree of dehydration will impair skilled performance and affect strength, stamina and speed (MacLaren, 1996). Saltin and Costill (1988) suggested that a 2% loss of body weight will impair endurance performance by -10% and, should it reach as much as 5%, then performance losses of -30% can be expected.

It may not be dehydration or hypohydration per se that causes the decrement in performance. A series of well controlled experiments were performed to determine in more detail the relative role of water losses, ion losses, elevated core temperature and reduction in availability of substrates on performance capacity (Nielsen et al., 1981). On separate days approximately a week apart, subjects were either: i) given diuretics (pure water losses); ii) put in a sauna (water and ion losses); iii) submerged in hot water (elevated body temperature) or, iv) asked to perform 2 hours of intense cycling exercise (water and ion losses, elevated body temperatures, and reduction in the availability of substrates) and then to perform an exercise capacity test. Elevation of core temperature caused similar decrements in performance, as did loss of water, with slightly further diminution caused by water and ion losses. However, the largest reduction in performance capacity was caused by the 2-h intense cycling exercise. Thus, all the treatment conditions played a role in reducing exercise capacity. Therefore, this study highlighted the need not only to minimise water and ion losses, but also to reduce the increase in core temperature and to allow the ample availability of substrates, if optimal exercise performance is desired at the end of prolonged exercise.
2.4.3.2 Mental performance

Mental performance has also been shown to be adversely affected by body water deficits. Gopinathan et al. (1988; op cit. Maughan and Leiper, 1994) found that performance in a variety of cognitive tests was adversely affected when the level of dehydration (induced by exercise in the heat) reached 2% of initial body weight. It is also generally accepted that cognitive performance, which is an important aspect of games such as soccer, is also impaired when dehydration and hyperthermia are present (Maughan and Leiper, 1994). In studies of prolonged high-intensity intermittent exercise, water ingestion was found to increase endurance time (Reynolds et al., 1985; op cit. Ekblom, 1986) and to improve the ability to perform mental functions such as thought processing and accuracy tasks (Reynolds and Ekblom, 1985; op cit. Ekblom, 1986). More research is required to verify these claims.

2.4.3.3 Muscle strength

Hypohydration has been shown not to have a consistent effect on muscular strength but muscular endurance is often reduced by hypohydration (see Sawka and Pandolf, 1990 for review). There has been little or no research on muscle strength of intermittent games players, with or without fluid ingestion.

2.4.4 Electrolyte losses

The exact concentration of electrolyte loss in sweat is difficult to determine due in part to the difficulties of sampling sweat and ascertaining that the samples are representative of whole-body losses (Saltin and Costill, 1988). There has been little investigative work in this area for soccer players but, athletes exercising in the heat for 2 h lost 4 litres of fluid (5.8% body mass), thus lowering their sodium and chloride content by approximately 5-7% and 1.2% of other ions (including potassium; Costill et al., 1976). Extrapolation of these data, as soccer players have been shown to have similar weight losses (Table 2.1)
would suggest that similar ion losses can be expected in these athletes. As the body loses more water than electrolytes during heavy sweating, the concentration of these minerals increases in the body fluids. Therefore, this illustrates the fact that for the body to regain normal balance during periods of heavy sweating, the need to replace water is greater than the need to replace electrolytes (Saltin and Costill, 1988).

2.4.5 Fluid replacement and soccer performance

Montain and Coyle (1992) designed an experiment to show the physiological advantages that accompany adequate fluid intake. Participants exercised in the heat for 2 hours under four different conditions: i) no fluid; ii) 20% of sweat loss replaced; iii) 50% of sweat loss replaced and iv) 80% of sweat rate replaced. They discovered that the greater the fluid replacement the better the physiological function in terms of heart rate, stroke volume, cardiac output and core temperature. However, they did not include any exercise tests to determine the effects of fluid replacement on performance.

As soccer results in a significant fluid loss, it is rational to conclude that the best way of replenishing this deficit would be to ingest water. Most studies examining the influence of fluid replacement on exercise have concentrated on the enhancement of exercise time to exhaustion and not exercise performance per se (see Murray, 1987 and Maughan, 1991 for reviews), thus making it difficult to establish the impact of fluid replacement on soccer performance. Furthermore, when researchers have investigated the effects of fluid replacement on performance, they have been as a secondary effect to the replacement of glucose (Nadel et al., 1990). Below et al. (1995) did find separate and additive effects of water and CHO replacement on performance, but their performance test involved cycling and not prolonged, intermittent, running exercise.

Fallowfield and colleagues (1995) conducted an investigation that specifically looked at performance during soccer. Their aim was to determine the influence of water ingestion on repeated sprint performance during simulated soccer type activity on a motorised
treadmill. Subjects were administered 8 ml.kg⁻¹ body mass (BM) of water pre-exercise and during the half-time (15-min) break, with 2 ml.kg⁻¹ BM given every 15 min of exercise, in the experimental trial; no water was given in the control trial. Body mass was maintained in the water trial but decreased by 2.3% in the ‘no fluid’ trial. This was associated with greater total distance covered in the 6-s sprint phases in the second half of test. However, no differences were found in maximum sprint speed, blood lactate concentration, blood glucose and heart rate between the two trials. Therefore, the authors concluded that water ingestion maintained body mass and improved sprinting capacity in the second half of a simulated soccer match but did not affect maximum sprint performance.

2.5 Carbohydrate (CHO) ingestion during exercise

Much interest has been devoted to carbohydrate feedings before exercise to enhance the availability of glycogen in muscle and liver, and glucose in blood. Furthermore, there is a wealth of data on the type, timing and amount of CHO ingestion during the post-exercise recovery period to restore muscle glycogen reserves and so recover exercise capacity. These areas are beyond the scope of the present review, which will focus on the metabolic effects of CHO ingestion during exercise and how this relates to exercise performance. The interested reader is referred to Hargreaves (1999) and Sherman (1991) for extended reviews on CHO ingestion before and after exercise.

2.5.1 Metabolic responses to CHO ingestion during exercise

Investigations on the utilisation of exogenous CHO during exercise rely mainly on the analysis of labelled carbon after ingesting different forms of CHO (Aragon-Vargas, 2001). Different methodologies cause some difficulties in the estimations but there is a basic agreement that ingested CHO may provide between 10 and 30% of total CHO oxidation (Hawley et al., 1992). Moreover, the metabolic effects of CHO ingestion vary with exercise type, intensity and duration and these will be discussed in turn.
2.5.1.1 Submaximal cycling exercise

A key positive effect of CHO ingestion during cycling exercise is often manifested late during exercise of 2 h or more. When muscle glycogen stores are high, blood glucose provides only about 25% of CHO as fuel, but late in exercise, when glycogen concentrations are low, blood glucose oxidation accounts for most of the CHO oxidation (Coggan and Coyle, 1991). Blood glucose concentration decreases with prolonged cycling exercise and can lead to a decrement in performance (Coyle et al., 1986). This decrease in blood glucose may be prevented by exogenous CHO supply. Indeed, based on their cycling studies, Coyle and colleagues (1986) proposed that ingestion of CHO maintains blood glucose availability and prevents this decrease in CHO oxidation, even when muscle glycogen is almost depleted, enabling exercise to be continued for longer.

Other cycling studies also demonstrated the metabolic effects of ingesting different concentrations of CHO during exercise. A well controlled study by Mitchell et al. (1989) involved subjects performing 5 x 105-min rides (4 x continuous bouts at 70% \( \dot{V}O_2 \) max and 1 x intermittent exercise bout at an average intensity of 70% \( \dot{V}O_2 \) max) followed by a 15-min performance ride. Subjects were provided with 150 ml of fluid, containing 0, 6, 12 and 18% CHO, every 15 min of the continuous exercise (the results of the intermittent trial will be discussed later). During the submaximal rides subjects oxidised \( \sim 2.5 \) g CHO.min\(^{-1}\) and, based on various assumptions, it was calculated that 1.4 g CHO.min\(^{-1}\) of this was provided by glycogenolysis. In the 12% CHO trial a large portion of the remaining 1.1 g CHO.min\(^{-1}\) could have been provided by the ingested CHO. Indeed, the authors calculated that \( \sim 1.05 \) g CHO.min\(^{-1}\) was available in this way. In the placebo trial (0% CHO) no exogenous CHO was supplied, therefore the CHO must have come from extramuscular sources, notably the liver. This would have been especially the case towards the end of the 105-min ride as the rate of muscle glycogenolysis diminishes with lowered stores and hepatic release tends to increase (Bergstrom and Hultman, 1967). The results of the study also supported previous work which showed that when blood glucose
concentrations are maintained (i.e. in the 12% CHO trial), the rate of glucose uptake in well trained endurance athletes can be quite high (Coyle et al., 1986; Coggan and Coyle, 1987).

Furthermore, the majority of submaximal cycling studies have reported no change in muscle glycogen utilisation rates (glycogen sparing) whether CHO was ingested or not (Coyle et al., 1986; Coggan and Coyle, 1987; Hargreaves and Briggs, 1988; Mitchell et al., 1989). However, other studies did find a sparing effect of muscle glycogen with CHO ingestion (Bergstrom and Hultman, 1967; Yaspelkis and Ivy, 1991) and procedural differences have been proposed as a possible reason for this (Mitchell et al., 1989).

Due to the modest increase in blood glucose, the absence of an increase in plasma insulin concentration and the delayed CHO oxidation rate in the study by Coyle et al. (1986), it is possible that the ingested CHO was not available to the working muscles until the second hour after exercise (Tsintzas and Williams, 1998). This delay, coupled with no extra muscle glycogen use during 3 and 4 h of exercise, suggests that sparing of muscle glycogen could have occurred with CHO ingestion during this period (Tsintzas and Williams, 1998). Indeed, Coyle et al. (1986) did report a lower glycogen utilisation in type II fibres with CHO ingestion and they suggested that selective depletion may have taken place. Furthermore, even when hyperglycaemia was induced by glucose infusion, plasma insulin was unaffected in the first hour of exercise (peaked at 80 min) with no difference in glycogen utilisation compared to the control (Coyle et al., 1991). However, in the study by Yaspelkis and Ivy (1991) plasma insulin concentrations did increase with CHO ingestion and this led to a concomitant decrease in glycogen utilisation. Therefore, Tsintzas and Williams (1998) suggested that both mild and modest hyperglycaemia cannot induce any changes in muscle glycogen utilisation during submaximal cycling at 70% $\dot{V}O_2$ max if hyperinsulinaemia does not occur first (at least during the first hour of exercise).
2.5.1.2 Submaximal running exercise

Unlike the majority of cycling studies, fatigue following prolonged running exercise is not typically associated with a large fall in blood glucose levels and decreased rates of CHO oxidation (Tsintzas et al., 1993; 1996; Williams et al., 1990). In most running studies blood glucose concentrations do not decline but rather are maintained or increased during exercise compared with control conditions (Madsen et al., 1990; Millard-Stafford et al., 1992; Tsintzas et al., 1993). In addition, when CHO is ingested during submaximal running exercise, CHO oxidation rates are either similar (Williams et al., 1990; Millard-Stafford et al., 1992; Tsintzas et al., 1995) or higher (Sasaki et al., 1987; Wilber and Moffat, 1992) than the control treatment. Although many studies did report an improvement in endurance performance with CHO ingestion, they did not investigate the underlying mechanism for this improvement.

Tsintzas and co-workers (1995) specifically investigated the influence of CHO ingestion on glycogen utilisation during 60 min of treadmill running. Subjects were administered 50 g of CHO (in a 5.5% solution) and this resulted in a 28% sparing of muscle glycogen in the vastus lateralis muscle. An increase in blood glucose concentration and a significant increase in serum insulin concentrations accompanied the glycogen sparing. Moreover, there was a greater sparing (42%) in type I fibres (with no change in type II fibre type) and this was significantly correlated to the increase in serum insulin concentrations in the first 20 min of exercise. Furthermore, as CHO oxidation rate was unaffected by CHO supplementation, the authors suggested that the decreased glycogen utilisation would be reflected by a greater oxidation of blood glucose in the type I fibres in the working muscles (and hence a sparing of muscle glycogen concentrations). The results of this study also highlights that it is a reduced glycogenolysis in the active (type I) fibres rather than an increased glycogen synthesis in the inactive (type II) fibres that leads to the sparing effect.
Therefore, it is possible that there is a difference in the relative importance of blood glucose versus muscle glycogen use as CHO fuel sources during running and cycling and that this can explain the differences in glycogen use with CHO ingestion (Hargreaves, 1999). Differences in active muscle mass, recruitment patterns, and/or contraction dynamics between running and cycling may also play a role (Hargreaves, 1999).

2.5.1.3 Intermittent exercise

Only in recent years has intermittent exercise become the focus of study when investigating metabolism in relation to CHO ingested during exercise. The procedure devised by Mitchell and colleagues (1989) allowed comparison of metabolic responses to a 12% CHO solution during 2 h of continuous and intermittent exercise at an average intensity equivalent to 70% of \( \dot{V}O_2 \) max. There was no disparity in blood glucose and insulin concentrations between the trials, nor were there differences in CHO oxidation and glycogen utilisation rates. Therefore, the authors concluded that CHO supplementation during intermittent exercise does not seem to provide a performance benefit compared to continuous exercise nor does it alter muscle glycogen use. However, their protocol involved 7 x 15 min of exercise at 70% \( \dot{V}O_2 \) max interspersed with 3-min rest intervals, so can be criticised for resembling a continuous rather than an intermittent protocol per se.

Yaspelkis et al. (1993), using cycling exercise that varied between low (45% \( \dot{V}O_2 \) max) and moderate (75% \( \dot{V}O_2 \) max) intensities, found that the provision of glucose at a rate of \( \approx 75 \text{ g.hour}^{-1} \) resulted in marked increases in plasma glucose and insulin concentrations. These changes were accompanied by a 30% reduction in glycogen utilisation. The authors concluded that for reduced glycogen utilisation to occur there must be sufficient hyperglycaemia and hyperinsulinaemia during the exercise. Furthermore, they found that glycogen sparing occurred only in type I and not type II fibres. As this study utilised cycling to investigate metabolism during intermittent exercise, it may not be readily applicable to intermittent running type exercise such as soccer.
To determine whether a glucose polymer solution given before and at half-time of a game would reduce muscle glycogen utilisation, Leatt and Jacobs (1989) biopsied 10 soccer players before and after a competitive exhibition match (8-a-side). Five players from each side were biopsied and comprised of 2 defenders, 2 midfielders and 1 striker per side to counteract positional differences. The drinks, either a 6.6% CHO solution or flavoured placebo, were administered at an equivalent of 5 ml.kg\(^{-1}\) BM before and at halftime of the game. The main finding was that there was a 31% greater utilisation of muscle glycogen in the placebo trial. Low muscle glycogen concentration was associated with impaired rate of energy transduction via aerobic and anaerobic glycogenolysis (see Leatt and Jacobs, 1989, for review). The lack of adequate experimental control was a limitation of this field study.

Therefore, more controlled laboratory studies have been conducted to investigate the fate of ingested CHO during intermittent soccer type exercise (McGregor, 1999; Nicholas et al., 1999). Six trained games players were provided with 50 g.hour\(^{-1}\) of CHO during 90 min of the LIST and this resulted in a higher insulin response and a slightly higher (but not statistically significant) blood glucose response (Nicholas et al., 1999). Moreover, mixed muscle glycogen utilisation was reduced by 22%. Using a biochemical method of determining glycogen use in different muscle types (Tsintzas et al., 1995; 1996), it was found that glycogen utilisation was reduced in both type I and type II fibres when CHO was ingested during this type of intermittent exercise (Nicholas et al., 1999). Furthermore, the analysis showed that in the placebo trial there was a significantly greater glycogen utilisation in type II than type I fibres. It may be that CHO ingestion allows glycogen resynthesis to occur during the low-intensity exercise periods and rest intervals during the LIST – at least in type II fibres (Tsintzas and Williams, 1998). However, in type I fibres the sparing of glycogen was probably due to the reduced utilisation during the low and moderate intensity exercise bouts. Furthermore, another study using a similar exercise protocol, reported that despite changes in metabolite and hormonal concentrations, there was no difference in CHO and fat oxidation between the CHO and placebo trials (McGregor, 1999). Therefore, the contribution of CHO to energy
metabolism may have been derived from different sources, e.g. a decreased muscle glycogenolysis may be compensated by an increase in the uptake and oxidation of blood glucose following CHO ingestion (and thus maintaining a similar CHO oxidation rate to the control trial).

In summary, although the research literature is equivocal, it appears that CHO ingestion during soccer type exercise may reduce muscle glycogenolysis and so spare muscle glycogen during the latter stages. It seems that the CHO ingested must increase blood glucose and insulin concentrations to have this sparing effect. Furthermore, the ingested CHO enables oxidation of the exogenous supply and so spares glycogen in type I fibres. On the other hand, CHO ingestion may have the effect of inducing glycogen resynthesis during the low intensity and recovery periods of the intermittent exercise in type II muscle fibres. However, no clear evidence exists to support this speculation.

2.5.2 CHO ingestion and exercise performance

From the above discussion it can be seen that depending on different types, intensities and modes of exercise there are different metabolic effects of CHO ingestion during exercise. Therefore, CHO ingestion and exercise performance will be discussed in relation to different types and intensities of exercise.

2.5.2.1 Prolonged submaximal exercise performance

There is compelling evidence which supports the notion that CHO ingestion during exercise improves the performance of prolonged, moderate intensity exercise (Coggan and Coyle, 1991; Hargreaves, 1999; Aragon-Vargas, 2001). Coyle et al. (1986) gave 7 well trained cyclists 130 g of glucose polymer in a 50% solution 20min into exercise and 27 g in a 10% solution every 20min thereafter. The subjects cycled at an average intensity of 71% \( \text{VO}_2 \text{max} \) and it was found that CHO supplementation delayed the onset of fatigue by 1 hour. Tsintzas and colleagues (1995) gave 11 recreational runners a 5.5%
CHO solution and they reported a 14% improvement in treadmill run to exhaustion at 70% \( VO_2 \) max. Using a similar protocol a later study reported a 27% improvement in run time to exhaustion as well (Tsintzas et al., 1996). However, there are some studies which failed to find an improvement in performance with CHO ingestion during exercise (Felig et al., 1982; Flynn et al., 1987; Ivy et al., 1979). This could have been due to the method used in determining performance and/or amount of CHO provided, as most studies showing positive effects generally involved administration of large amounts of substrate.

As mentioned previously, the underlying mechanism seems to differ between the mode of exercise. It appears that in submaximal cycling studies, CHO ingestion during exercise maintains blood glucose late in exercise, thus maintaining CHO oxidation rates, and so increasing time to fatigue (Coyle et al., 1986; Coggan and Coyle, 1991). During submaximal treadmill running, CHO ingestion has the effect of sparing muscle glycogen and so it is available later in exercise and thereby delays fatigue and improves exercise capacity (e.g. Tsintzas et al., 1996). Whatever the mechanism, the consensus view is that CHO ingestion during submaximal exercise improves performance.

2.5.2.2 Short duration, high intensity/sprint exercise performance

Traditionally, CHO ingestion was recommended for prolonged, submaximal exercise where substrate availability was thought to affect performance. Indeed, as early as 1996, the American College of Sports Medicine position stand stated that for exercise lasting <1 h there was little evidence for physiological or performance benefits between CHO containing beverages and plain water. More recently, some studies have put forward the beneficial impact of consuming CHO for exercise lasting less than 1 hour.

Ball et al. (1995) investigated whether CHO ingestion during high-intensity cycling exercise would affect sprint capacity at the end of the exercise. Eight male competitive cyclists completed 50 min of cycling at 80% \( VO_2 \) max followed by a Wingate test. Subjects were provided with 2 ml.kg\(^{-1}\) BM of either a CHO-E or placebo solution after
every 10 min of exercise. Peak power, mean power and minimum power were all higher in the final sprint after CHO ingestion. Furthermore, Sugiura and Kobayashi (1996) showed that regardless of whether the athletes performed high-intensity cycling exercise in a continuous or intermittent fashion, the subsequent Wingate test showed a higher mean and peak power output and a lower fatigue index in the CHO trial. Therefore, it would appear that athletes are able to benefit from consuming a CHO-E solution during high-intensity, moderate duration competition.

2.5.2.3 Intermittent exercise performance

One of the early studies looking at the influence of CHO ingestion on intermittent exercise performance was conducted by Hargreaves and co-workers (1984). Ten male subjects cycled for 20 min at 50% VO\textsubscript{2} max, followed by 10 min of intense intermittent exercise (4 x 30 s of cycling at 100% VO\textsubscript{2} max interspersed with 2-min rest). This sequence was repeated every 30 min for 4 hours and the final sprint bout was a timed ride to exhaustion. Subjects were provided with 43 g of solid CHO with 400 ml water at 0 min and after every 60 min in the experimental trial and 400 ml of an artificially sweetened drink in the placebo trial. The main finding was that during the sprint to exhaustion, subjects performed 45% longer in the CHO trial. It was suggested that due to the muscle glycogen concentrations being significantly lower after the placebo trial, the exogenous CHO supply spared muscle glycogen utilisation during the exercise.

Similar findings have been observed when intermittent running protocols are employed. Nicholas and colleagues (1995) investigated the impact of consuming CHO during the LIST on sprint performance and endurance capacity. Nine recreationally active subjects performed 75 min of the LIST and then ran to exhaustion (alternating cruise and jog). The subjects were provided with an equivalent of 5 ml.kg\textsuperscript{-1}BM of a 6.9% CHO drink or placebo solution before exercise and 2 ml.kg\textsuperscript{-1}BM every 15 min of exercise. The principal finding was that CHO supplementation improved run time to fatigue by 33% relative to the flavoured water drink. The authors also suggested that fatigue was more likely to be
due to lower utilisation of glycogen during the earlier part of exercise, thus sparing glycogen for the latter run to exhaustion. Support for these results were provided by Davis et al. (1999), who showed a 52% longer run to exhaustion when subjects consumed a CHO-E solution during a similar exercise model.

Not all studies employing an intermittent protocol have found an improvement in performance with CHO ingestion during exercise. Nassis et al. (1998) utilised a prolonged, high-intensity intermittent exercise protocol on a treadmill to investigate the influence of drinking a CHO-E solution on endurance capacity. Nine club level runners performed an intermittent exercise protocol originally described by Bangsbo et al. (1992) which involved repeated 15-s bouts of fast running followed by 10 s of slow running. They were provided with a commercially available 6.9% CHO-E or a flavoured placebo solution at the start (3 ml.kg⁻¹) and after every 20 min (2 ml.kg⁻¹) of exercise. The CHO ingestion did not show any performance benefits (113 vs. 110 min, placebo vs. CHO, ns.). The lack of a difference in performance was attributed to a modest CHO delivery rate of 30 g.h⁻¹ and/or the high-intensity nature of the exercise. This is unlikely as other studies employing the same or higher exercise intensities did not show an interference with gastric emptying and delivery of glucose to the blood (Aragon-Vargas, 2001).

More specifically to soccer, Quanz (1999) examined the effectiveness of CHO ingestion during 90 min of simulated soccer match play on a treadmill on a subsequent run to exhaustion. The running protocol involved 918 speed changes on a treadmill between 4 and 25 km.h⁻¹ (1.4-7 m.s⁻¹). The total run distance was ~11 km over the 90 min and there was a short half time break and 4 additional short breaks for blood sampling and drinking time. Subjects consumed an initial 200-ml bolus followed by serial feedings of 160 ml of fluid after every 15 min of exercise, of either a 10% CHO or placebo solution. After the running protocol a maximal performance capacity test was completed consisting of 15 s of aerobic (12 km.h⁻¹) and 10 s anaerobic (19 km.h⁻¹) running until exhaustion. The main finding was a 30% better performance time in the CHO trial with all subjects performing better when fed CHO. The author suggested that in the high intensity phases of the
simulated soccer exercise the described glycogen depletion in type II fibres took place and supplementation with CHO resulted in restoring glycogen stores in these fibres. Therefore, performance was better in CHO trial as these fibres were able to tolerate a more prolonged workload. As no muscle biopsies were performed during the exercise these suggestions remain speculative.

In summary, most investigations, whether running or cycling based studies, examining CHO ingestion during prolonged, high-intensity intermittent exercise, have shown an improvement in performance. The proposed mechanism for the improvement seems to be high rates of CHO oxidation and/or glycogen sparing.

2.5.3 Practical issues concerning ingested CHO

2.5.3.1 Type of CHO

In 1996, the American College of Sports Medicine stated that the inclusion of glucose, sucrose and other complex carbohydrates in fluid replacement solutions have equal effectiveness in increasing CHO oxidation, delaying fatigue and improving performance (ACSM, 1996). Indeed, there appear to be relatively few, if any differences on metabolism and performance when exercising subjects are fed with glucose, sucrose or glucose polymers (maltodextrins) (Massicotte et al., 1989; Hawley et al., 1992; Wagenmakers et al., 1993). Suguira and Kobayashi (1996) examined the effects of glucose, fructose and a flavoured water placebo, ingested during the halftime break of a 90-min exercise bout (either continuous or intermittent cycling). They found that fructose and glucose were better for sprint performance than water in the continuous trials, but glucose was better than the other two in the intermittent trials. The decrease in blood glucose in the fructose trials was speculated to be due to glucose uptake by muscles, delay in intestinal fructose uptake, and/or delay in fructose conversion into glucose (Suguira and Kobayashi, 1996). Therefore, the results of this study suggest that fructose was not the optimal CHO source during intermittent exercise.

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There are similar oxidation rates for sucrose, glucose and maltodextrins, as long as they provide sufficient amounts of CHO to be delivered to the working muscles (Hawley et al., 1992). Fructose is not as readily oxidised and results in lower CHO oxidation rates (Massicotte et al, 1989), due to its slower rate of absorption, which may cause gastrointestinal distress and impaired performance (Murray et al., 1989a; Suguiira and Kobayashi, 1996). The combination of 50 g glucose and 50 g fructose provided in the same solution was better than 100 g glucose in enhancing CHO oxidation rates (Adopo et al., 1994). Therefore, the formulation found in many sports drinks is one where several carbohydrates are combined to improve CHO oxidation (Aragon-Vargas, 2001).

2.5.3.2 Timing of ingestion

Providing glucose at a rate of over 1 g.min\(^{-1}\) towards the end of prolonged exercise can be achieved by either ingesting CHO throughout exercise or by delaying CHO ingestion until late in exercise (Coggan and Coyle, 1989). If subjects delay CHO ingestion until too late in exercise (i.e. less than 30 min before fatigue), the rate at which the ingested CHO enters the blood as glucose may not be fast enough to maintain euglycemia and performance may deteriorate. Furthermore, if subjects wait until 30 min before fatigue to ingest CHO (assuming they can predict this) then the energy content will have to be very concentrated for adequate delivery to the blood. This may cause problems with gastric emptying due to the high energy content. Therefore, the preferred option would be to consume CHO containing beverage throughout the duration of exercise so that blood glucose concentration and CHO oxidation can be maintained late in exercise (Hargreaves, 1999; Aragon-Vargas, 2001).
2.5.3.3 Amount of CHO

Most studies which have reported that CHO ingestion throughout exercise can improve submaximal cycling (Coggan and Coyle, 1989; 1991; Murray et al., 1989b; 1991), submaximal running (Tsintzas et al., 1995; 1996), intermittent cycling (Hargreaves et al., 1984) and intermittent running (Nicholas et al., 1995) performance have given subjects 30-60 g of CHO per hour. Some studies have not shown an improvement in performance with low rates of CHO ingestion (e.g. 30 g.h⁻¹, Nassis et al., 1998), whereas Maughan (1991) suggested that many studies that do show an improvement in performance with CHO ingestion provide relatively large amounts of CHO. There is no clear dose-response relationship between the amount of CHO ingestion during exercise and improvements in performance (Hargreaves, 1999).

Mitchell and co-workers (1989) aimed to determine the effect of a wide range of CHO doses on CHO metabolism and exercise performance. The results of the 6% CHO solution suggested that a dose of 37 g.h⁻¹ CHO was not enough to elicit improvements in performance. Other studies have shown a performance benefit from ~6% CHO drinks and so the authors stated that a dose of 37 g.h⁻¹ may be a minimum requirement as it provides inconsistent results. Furthermore, if performance was dose-dependant then the best performance would have been expected in the 18%CHO trial. However, no added benefit of the 18% over the 12% solution was found. Mitchell et al. (1989) therefore stressed that an increase in dose from 74 to 111 g.h⁻¹ CHO did not impair performance compared to placebo but did not elicit an improvement. It may be that a delivery rate of 111 g.h⁻¹ CHO may have reduced gastric emptying due to the higher caloric density of the solution (see below) and hence no additional benefit. This finding is corroborated by the work of Wagenmakers and associates (1993), who also found that when CHO is ingested at a rate higher than about 60 g.h⁻¹, exogenous glucose oxidation rates do not appreciably increase. In other words, ingested CHO is oxidised at approximately 1 g.min⁻¹ during exercise (Bosch et al., 1994; McConnell et al., 1994).
More specifically to soccer, Ingle et al. (1999) investigated the effect of consuming 0, 2 and 8% CHO solutions during the LIST on a subsequent run to exhaustion (similar protocol to Nicholas et al., 1995). The reported that the higher CHO containing solution was better than the placebo (0%) and weak (2%) CHO drinks. Therefore, it appears that there is an optimal rate at which CHO should be provided to provide the most favourable effects on metabolism and performance. However, this can differ with mode of exercise and individual variations.

2.5.3.4 Solid vs. liquid CHO ingestion

An interesting departure on the type of CHO ingested during exercise is whether the substrate should be in liquid or solid form. Walton and Rhodes (1997) were specifically interested in determining whether there was a difference between consuming liquid or solid CHO on intermittent running to exhaustion. Ten female soccer players were provided with a flavoured water placebo, a 12.5% CHO drink (50 g) or 50 g solid CHO (in an energy bar) 5 min prior to the intermittent running. The authors reported a 50% improvement in performance with CHO ingestion, relative to the water placebo, regardless of whether it was in solid or liquid form.

The results of the above study are in agreement with others in the literature i.e. when solid CHO is supplemented with water ingestion, there are similar metabolic and performance responses to liquid CHO (Hargreaves et al., 1984; Fielding et al., 1985; Lugo et al., 1993; Mason et al., 1993; Yaspelkis et al., 1993). Therefore, liquid and solid forms of CHO seem equally effective ways to supply glucose during exercise and improve performance, but the CHO drinks fulfil a double purpose because they replace the loss of fluids from sweat.
2.6 Gastric emptying

A discussion on the methodologies used to determine gastric emptying during rest and exercise is beyond the scope of this review – see Costill (1990) and Leiper (2001) for detailed descriptions. This review will concentrate on disparate factors that play a part in determining gastric emptying rates.

2.6.1 Volume of fluid

A number of studies suggest that the rate at which carbohydrate-electrolyte drinks are emptied from the stomach is influenced primarily by the volume of fluid ingested and the carbohydrate content of the beverage (Costill and Saltin, 1974; Mitchell and Voss, 1991; Noakes et al., 1991; Coyle and Montain, 1992; Vist and Maughan, 1994). One of the early studies investigating the influence of volume on gastric emptying was performed by Costill and Saltin (1974). They measured the gastric volume 15min after ingesting 200, 400, 600, 800 and 1000 ml of a 2.5% glucose solution. Costill and Saltin (1974) found that emptying was greater after 600ml of fluid was ingested than 400ml which in turn was greater than 200ml. There was no difference between 600 and 800 ml, with a tendency for less to be emptied after subjects consumed 1000 ml. Therefore, it would seem that there is an upper limit to of gastric volume, above which emptying rates may plateau or even slow (Noakes et al., 1991). The mechanism for this phenomenon seems to be that increasing the volume of the gastric contents stimulates the activity of the stretch receptors in the gastric mucosa, which in turn increases the intragastric pressure and promotes faster emptying (Noakes et al., 1991). If there is too much volume in the stomach, then inhibition of emptying can occur so that the absorptive capacity of the small intestine is not overwhelmed – a situation which can lead to gastrointestinal distress and diarrhoea (Leiper, 2001).

Further research has shown that repeated ingestion of fluid will maintain a high gastric volume and result in faster rates of emptying than if a single bolus was consumed (Rehrer...
et al., 1989; Mitchell and Voss, 1991; Noakes et al., 1991). This has the effect of maintaining a high volume in the stomach so that rates of emptying can be equivalent to the initial phase of emptying. Indeed, it is the total volume in the stomach that is important and this includes the volume of the drink ingested plus the volume of gastric secretions and swallowed saliva (Leiper, 2001). Still, there is a high variability among individuals in the rates of emptying and care must be taken when ingesting fluid as too much may cause gastrointestinal distress and can actually reduce emptying (Costill and Saltin, 1974).

2.6.2 Energy content of fluid

Plain water empties rapidly from the stomach, while increasing the energy content of ingested solutions slows the rate of emptying (Leiper, 2001), but the exact nature of this phenomenon is somewhat confusing (Coombes and Hamilton, 2000). Some studies have shown an inverse relationship between glucose concentration and gastric emptying rate (e.g. Hunt et al., 1985). Maughan (1997) suggested that solutions containing less than 2.5% CHO empty at similar rates as water, but solutions over 6% slow emptying. Noakes et al. (1991) and Coyle and Montain (1992) proposed that solutions containing less than 8% CHO appear to have little effect on gastric emptying rate. Coombes and Hamilton (2000) went even further by stating that there are some studies that have shown no difference in gastric emptying rate between water and CHO solutions of up to 10%, but this is probably due to the disparity in study designs.

What does appear to be accepted is that there is a trade-off between CHO delivery and water delivery in relation to CHO ingestion during exercise: CHO delivery is increased with greater concentrations of CHO in the solution, but at the same time fluid delivery is compromised (Coyle and Montain, 1992). Therefore, the majority of sports drink formulations have a CHO content of between 6-8% as this would seem to be most beneficial in maintaining an adequate CHO delivery rate without compromising fluid delivery.
2.6.3 Type of CHO

As with the exact CHO content for optimal gastric emptying, there are equivocal data on the most favourable type of CHO within a beverage. Some suggest that the CHO type may have little or no effect on emptying (Shi and Gisolfi, 1998). There is some argument as to the exact effects of glucose, glucose polymers (maltodextrins) and fructose. It has been reported that the addition of 2-3% fructose in a formulation appears to improve gastric emptying rate, compared to glucose alone (Neufer et al., 1986). As mentioned previously, Adopo and co-workers (1994) found that adding fructose to a glucose solution increased CHO oxidation by 21% compared to an isoenergetic glucose solution. Furthermore, Jeukendrup (1999) claimed that fructose will improve palatability, can reduce the insulin response to ingested CHO by 20-30% and so reduce lipolysis to a lesser extent, and can also reduce ‘rebound hypoglycaemia’ (cf. Costill et al., 1977). However, fructose has been shown to cause gastrointestinal distress if there is too much in the drink (Murray et al., 1989a), especially during intermittent exercise (Suguira and Kobayashi, 1996). The same can be also said for galactose and amylose and they are also less well oxidised by the body on their own (Jeukendrup, 1999).

Foster and colleagues (1980) showed that at the same CHO concentrations, glucose polymer solutions have much lower osmolality than formulations containing glucose alone. Therefore, if the drink was made up of maltodextrins, then a higher CHO content could be used, as the drink would still be either isotonic or hypotonic to plasma. The gastric emptying rate was also higher (~17 ml.min⁻¹) in the polymer drink than glucose alone (~10 ml.min⁻¹). This is compared to water which has a rate of ~15-25 ml.min⁻¹ at rest (Costill and Saltin, 1974; Coyle et al., 1978). At CHO concentrations comparable to that of sports drinks the glucose polymer was able to deliver simultaneously 69% more fluid and 33% more CHO than the glucose solution (Foster et al., 1980).
Therefore, to increase gastric emptying and other associated factors (e.g. palatability, CHO oxidation etc) multiple types of CHO may be preferable when deciding on a sports drink formulation (Jeukendrup, 1999).

2.6.4 Beverage temperature

In their seminal study, Costill and Saltin (1974) reported that gastric emptying was slightly faster for cold drinks (5°C) relative to hot drinks (35°C). Moreover, Sun et al. (1988) showed that cold (4°C) or hot (50°C) drinks empty slower in the first 10 min than drinks ingested at body temperature. However, there was a greater blood concentration of the tracer used to estimate gastric emptying 5 min after ingesting the hot solution (Lambert and Maughan, 1992), thus suggesting that the intragastric temperature rapidly returned to normal body temperature. Therefore, the temperature of the ingested solution has little effect on the overall gastric emptying rate (Leiper (2001). The temperature may affect the palatability of the drink and may influence the volume that is voluntarily consumed (Leiper, 2001).

2.6.5 Osmolality

Foster and colleagues (1980) reported that osmolality may be a factor in determining gastric emptying as glucose polymer solutions delivered greater CHO and fluid to the small intestine. Most investigators have found little or no difference in the rates of emptying of isoenergetic solutions of glucose monomers compared with maltodextrins, despite the often large differences in osmolality (Rehrer et al., 1993; Brouns et al., 1995; Vist and Maughan, 1995; Maughan, 1997). Indeed, Rehrer et al. (1993) showed that the addition of sodium chloride and potassium chloride with a combined osmolality of up to 336 mosmol.kg\(^{-1}\) to a 15% maltodextrin solution with an initial osmolality of 114 mosmol.kg\(^{-1}\) did not significantly affect gastric emptying compared with the maltodextrin solution without electrolytes.
The fact that osmolality has been considered a factor is because of the misconception that the fluid must become isotonic prior to passage from the stomach (Coombes and Hamilton, 2000). Murray (1987) showed that the osmolality of the fluid leaving the stomach was nearly the same as when it was ingested. Therefore, the osmolality of fluids seems to be of secondary importance to volume and CHO content in relation to gastric emptying (Brouns et al., 1995).

2.6.6 Exercise type, intensity and duration

Previous studies suggest that if the average exercise intensity is below 70-75% \( \dot{V}O_2 \text{max} \) then gastric emptying is similar to rest (Brouns et al., 1993; Shi and Gisolfi, 1998). Furthermore, at very high intensities of exercise (>80% \( \dot{V}O_2 \text{max} \)), the duration may be too short for any benefit to be derived from the ingested sports drink (Maughan, 1991; Shi and Gisolfi, 1998). Some studies do show performance benefits of ingesting CHO during high-intensity exercise lasting less than 1 hour (Ball et al., 1995), and therefore sufficient fluid must have emptied from the stomach. In terms of prolonged exercise duration, the majority of studies show that during moderate exercise of up to 3 h, gastric emptying can be maintained at high rates if sufficiently 'topped-up' at regular intervals (Maughan, 1991).

Subjective responses suggest that elite runners are unlikely to ingest fluid prior to exercise because they have experienced gastrointestinal and other distress (e.g. stomach cramps) during exercise. Indeed, Brouns et al. (1987) did report a higher incidence of gastrointestinal distress with fluid consumption in runners compared to cyclists. Elite cyclists are therefore more likely to ingest larger quantities of fluid before and during exercise. Therefore, it may be posited that the mode of exercise may be affecting gastric emptying rates and that running may slow emptying thus causing distress in some athletes. However, controlled studies do not support this notion.
Costill (1990) provided data from an experiment which investigated the influence of exercise mode on gastric emptying rates. Subjects were given 150 ml of a 6% solution every 15 min during the 2-h trials (rest, cycling or running). A faster rate of emptying was consistently observed during the submaximal running than cycling (both at an intensity equivalent to 70% VO₂ max). Moreover, the gastric emptying rate was not different between cycling and rest. The mechanism responsible for the faster rate of emptying in moderate intensity running has yet to be clearly defined. However, Costill (1990) suggested that the motion of the body whilst running causes a shifting of the stomach’s contents toward the antrum (distal end of stomach), thereby facilitating the delivery of the fluid to the duodenum. Other studies have shown no significant differences between cycling and running in terms of gastric emptying rates (Houmard et al., 1991; Rehrer et al., 1990). Furthermore, other investigations have shown no difference between treadmill running at relatively moderate levels and rest, but this could be due to differences in study design and composition of beverages rather than the exercise per se (Maughan, 1991).

Differences in metabolism and performance have been observed on numerous occasions between continuous and intermittent exercise and it has been proposed that this could relate to the high-intensity periods of the latter reducing gastric emptying. A well controlled study by Leiper and associates (2001a) specifically investigated the influence of CHO ingestion on gastric emptying during high-intensity intermittent exercise. Eight recreationally active subjects performed 4 trials, each lasting 60 min: i) rest, ii) 66% VO₂ max continuous exercise, iii) 66% VO₂ max (average) intermittent exercise and iv) 75% VO₂ max (average) intermittent exercise. The subjects were administered 600 ml of a 6% CHO solution prior to exercise. The total volume remaining in the stomach after the 60 min was similar during the rest and continuous exercise trials; volume was significantly higher in the intermittent trials. In addition, the energy delivery to the duodenum was similar in rest and the continuous exercise, and this was greater than the intermittent trials. Although previous studies had suggested that average exercise intensities of <70% VO₂ max would not alter gastric emptying significantly from rest (Brouns et al., 1993; Shi and Gisolfi, 1998), the results of this study demonstrated that
intermittent exercise at the same average intensity of continuous exercise reduced emptying. Furthermore, ingestion of fluids has been shown to help intermittent cycling performance (e.g. Hargreaves et al., 1984; Yaspelkis et al., 1993) and therefore, even if slowed, the amount emptied must be enough to cause some benefit. As this study involved a cycling protocol it may not be readily applicable to soccer type running exercise.

2.6.7 Gastric emptying during soccer

Due to the difficulties in measurement there is very little information relating to gastric emptying during soccer and there appears to be only one study that has investigated the area (Leiper et al., 2001b). Seven subjects performed low intensity walking exercise for 40 min (control) or played 30 min of a 5-a-side soccer game (2 x 15 min separated by 10-min break). Prior to the trials, and in the 10-min break, subjects given 500ml of a 6% CHO-E drink. The main finding was that 5-a-side soccer, played at an intensity of 55-60% \( \text{VO}_2\text{max} \) (determined via extrapolation of heart rate data), was sufficient to cause a decrease in gastric emptying. Overall, 17% of the CHO drink was emptied in the soccer trial, which was markedly lower than the 49% observed in the low intensity walking trial. Therefore, of the 60-g CHO ingested during each trial, 14 g was emptied in the duodenum in the soccer trial and nearly 30 g emptied in the rest trial. Carbohydrate-electrolyte drinks do seem to bestow benefits during intermittent running (Nicholas et al., 1995; Northcott et al., 1999; Ostojic and Mazic, 2002) and so sufficient CHO and water must empty into the duodenum. However, the study can be criticised for involving non-soccer players and inducing only a moderate intensity of exercise (<60% \( \text{VO}_2\text{max} \)) which may not be representative of most soccer play.

2.6.8 Summary of factors affecting gastric emptying

It appears that the volume in the stomach is one of, if not the principal, regulators of gastric emptying. Moreover, topping up the volume in the stomach with serial feedings
also maintains high rates of emptying. Although earlier studies suggested that the osmolality of the drink reduced the rate of emptying, more recent studies have not shown this to be such a crucial factor. Indeed, fluids having similar amounts of CHO but differing osmolality have been shown to empty at similar rates, therefore, supporting the concept that energy content is a greater regulator of emptying than osmolality. In addition, there does not seem to be a difference in emptying between the different types of CHO apart from fructose, which has been shown also to induce gastrointestinal distress.

The exact effect of exercise type, intensity and duration remains equivocal. Gastric emptying seems to improve with moderate exercise but then possibly decreases during very high intensity exercise. Also, due to the motion generated in the stomach from the muscles used, gastric emptying may be improved in running compared to cycling. Furthermore, at the same average intensity, intermittent exercise has been shown to reduce emptying compared to continuous exercise.

From a practical point of view, it should be noted that there are wide individual variations in the response to each of the variables known to affect gastric emptying. Whereas some subjects may empty 80-90% of an ingested solution in 15-20 min, others may empty less than 10% of the test drink (Costill, 1990).

2.7 Intestinal absorption

There are a number of techniques used to determine intestinal absorption and the interested reader is referred to Gisolfi et al. (1990) and Leiper (2001) for reviews on the topic. The following section will focus on some of the factors that may affect intestinal absorption at rest and during exercise.

2.7.1 Energy content of fluid
Gisolfi et al. (1992) compared the effects of 2, 4, 6 and 8% solutions, made up of glucose, sucrose, maltodextrins or corn syrup, on intestinal absorption. The authors found that water absorption was independent of carbohydrate type in solutions containing up to 6% of CHO with the same osmolality and caloric concentration. Increasing CHO concentration up to 8% significantly reduced water absorption from isocaloric solutions of glucose and corn syrup solids, but not from 8% solutions of sucrose or maltodextrins. However, Davis and colleagues (1990) using a tracer method, found that the availability of ingested fluids is not impaired if the CHO content is in the form of a glucose-fructose mixture and does not exceed 10%. The disparity of these data is probably due to methodological differences.

2.7.2 Type of CHO

There is conflicting evidence on the type of CHO that is optimal for intestinal absorption of CHO and water and the differences could be due to the different techniques used to determine absorption. Leiper et al. (1996), using a jejunal perfusion method, suggested that total CHO uptake from sucrose or monosaccharide mixtures tends to be similar to that from equimolar amounts of glucose monomer. They also reported that water absorption from sucrose solutions was slower than equimolar amounts of glucose. Shi et al. (1995) showed that water was absorbed more quickly in sucrose than glucose solutions. Shi and co-workers (1995) compared the intestinal absorption of two solutions: glucose/fructose and glucose/sucrose mixtures. The glucose/sucrose mixture tended to promote the greatest water and sodium absorption but only a moderate amount of CHO. The glucose/fructose formulation induced the highest CHO absorption and moderate fluid water absorption but lowest sodium absorption. Overall, the investigators concluded that solutions containing two transportable substrates enhanced solute and water flux more than solutions with only one substrate – probably due to stimulation of more transport mechanisms – despite the fact that combining substrates increases osmolality (Shi et al., 1995). Even though a combination of carbohydrates may be preferential, the ingestion of large amounts of fructose should be avoided as the human intestine has a relatively
limited capacity to absorb it and gastrointestinal distress and diarrhoea may result (Leiper, 2001).

2.7.3 Effect of exercise

There have been relatively few studies of the effect of exercise on intestinal absorption and is largely due to the practical difficulties associated with perfusing the small intestine in individuals who are exercising (Leiper, 2001). Some studies have reported that exercise reduces the rate of intestinal absorption of fluid. Barclay and Turnberg (1988; *op cit.* Gisolfi *et al.*, 1990) found that low intensity cycle exercise resulted in a reduction of water and electrolyte absorption. Spranger *et al.* (1989; *op cit.* Gisolfi *et al.*, 1990) failed to find any influence of exercise on intestinal absorption. Furthermore, no difference in absorption rates were observed between rest and cycle exercise at 30%, 50% and 70% \( \dot{V}O_2 \) max from either water or a CHO-E drink (Gisolfi *et al.*, 1991). Disparities in the results between studies have been attributed to differences in mode of exercise, ambient temperature, method employed to measure absorption, segment of the intestine studied or formulation of the test drink (Gisolfi *et al.*, 1990). It is highly probable that intermittent, high intensity exercise will reduce absorption at least to the same extent that it affects gastric emptying (Leiper, 2001). No such work has of yet been carried out due to the difficulties in employing the various methods during high-intensity exercise. Therefore, whether intestinal absorption of CHO and water is greatly influenced by intermittent, soccer-type activity is yet to be established.

2.8 Soccer skill

2.8.1 Soccer skill tests

Investigations into soccer generally relate to determining work rate profiles such as distance covered and differences in positional play (Reilly and Thomas, 1976; Withers *et al.*, 1982; Ekblom, 1986). There are few reliable studies which have specifically studied soccer performance *per se*, and studies that have done so have concentrated on
physiological parameters, such as sprint performance (e.g. Fallowfield et al., 1995). The execution of skill is deemed one of, if not the most, important aspect of soccer play. Bate (1996) suggested that all sports, to varying extents, involve the application of cognitive, perceptual or motor skill. As it is performed under a rapidly changing environment, Bate (1996) claimed that soccer involves all three skill types.

Due to the difficulties in replicating the complex nature of soccer skill in a way that can be controlled within a laboratory context, there has been a lack of experimental research carried out in this area. One investigation attempted to counteract this problem by not employing a skill test as such but examined aspects of soccer skill within a game situation (Zeederberg et al., 1996). Due to the variables that could not be controlled, the results of this method can be questioned.

There are some tests that are popular with coaching organisations such as the Coca-Cola Soccer Star skill tests (Russell, 1991). This battery of tests is based on various coaching drills and involves such aspects of soccer play as dribbling, turning, passing and shooting. As no investigations have been carried out to determine the reliability and validity of these tests then they are not applicable for research use.

Reilly and Holmes (1983) did obtain data on the validity and reliability of a battery of soccer skills tests in young players using relatively simple tests. These consisted of a wall-volley, shooting, slalom dribble and a straight dribble test. There was a high repeatability of skill tests from week 1 to week 2 and high validity coefficients ($r = 0.65-0.96$) found. Furthermore, discriminant function analysis showed that midfielders, who would tend to show more skilful play during games, had better scores than defenders in the tests, thus highlighting the validity of the tests. Therefore, Reilly and Holmes (1983) suggested that further work could be done using these tests. However, 12-13 year old male schoolchildren were used in the study and the differences in maturity levels of the subjects (i.e. some would have developed more quickly than others and therefore could run faster and kick the ball harder) may have led to differences in ‘skill’ level rather than
ability per se. In addition, the investigators employed Pearson’s $r$ to assess reliability and, as children from a wide range of abilities were used, this may have led to an exaggeration of $r$ due to the heterogeneous sample (Bland and Altman, 1986; Atkinson and Nevill, 1998).

Zelenka and colleagues (1967) used 12 17-18 year old players to validate an early soccer ‘skill’ test. Players were required to complete two 123-m circuits on half a soccer pitch, with 45-60 s rest between trials. The test consisted of sprinting, changes of direction, jumping and crawling under a 90-cm athletic obstacle, slalom dribbling of the ball and passing the ball (using the left or right foot where indicated) into target areas. The investigators performed no statistics on the data to illustrate whether it was valid and reliable. Furthermore, the applicability to soccer could be questioned due to players having to crawl under netting.

Other investigators have used dribbling, passing or shooting tasks to investigate the influence of heat (Burke et al., 1997), fluid (McGregor et al., 1999b) and CHO on soccer skill performance (Northcott et al., 1999; Ostojic and Mazic, 2002). Dribbling tasks can be criticised for examining sprinting ability rather than skill per se. Furthermore, static passing and shooting drills may be assessing ‘technique’ rather than ‘skill’ per se. This is because the skill aspect is where the player has a learnt ability to select and perform the correct technique as determined by demands of the situation. The essence of this view is that cognitive and perceptual aspects of soccer, as well as the motor component (Bate, 1996), need to be present to make it a ‘skilful’ movement.

More recently, two new tests of soccer skill have been developed. The Loughborough Soccer Passing Test (LSPT) requires players to pass the ball at specified coloured targets as quickly as possible. Players need to display a high competency of a number of soccer techniques, including passing, dribbling and control of the ball, to achieve a good performance time. Furthermore, cognitive and perceptual aspects are also examined, as players have to decide on future actions and use peripheral vision. With the use of 67
soccer players, who were at of least university standard, it was found that the test was a valid and reliable indicator of soccer skill (McGregor et al., 1999a). The Loughborough Soccer Shooting Test (LSST) came into being due to the limitations of previous shooting tests (Reddin, 1999). The basic premise of the test is to shoot 10 times at different target areas of a full sized goal. To make it a test of skill rather than technique, players are required to utilise other aspects of soccer play (e.g. passing, control, decision making), shoot at the goal at ball speeds of >30 mph (48 km.h⁻¹) within the shooting zone and avoiding the stationary, life-size goalkeeper. To improve the ecological validity of the test further, players are imposed with a certain time limit to perform each shot to simulate pressurising defenders within a game situation. The LSST was validated using professional, semi-professional, recreational and schoolboy soccer players (Reddin, 1999).

2.8.2 Effect of exercise on cognitive and motor skill

Psychomotor performance has been defined as, “the speed of gathering and processing information regarding the continuously changing situation, making appropriate decisions, mobilisations of attention and concentration” (Chmura and Jusiak, 1994). With the onset of fatigue during the later stages of a soccer match, the psychomotor performance of players may be affected. This in turn may reduce the technical and tactical performance and the outcome of the match (see Chmura and Jusiak, 1994 for review). Therefore, Chmura and Jusiak (1994) studied the possible link between metabolic acidosis and psychomotor performance by investigating relationships between increased lactate production from exercise and psychomotor performance (PMP). Soccer players from the Polish 1st Division (n = 125) performed an anaerobic shuttle running test (maximal sprinting for 161m, lasting ~37 s) and performed PMP tests pre-, and 1, 2, 3, 4, 5, 6 min post-exercise. The PMP tests was a reaction test – performance was based on the number of correct reactions, the mean time to perform the correct reactions and differences between rest and after exercise as a measure of concentration. Optimal PMP was found to occur pre-exercise. Following exercise, PMP was reduced until 1-2 min into the recovery
period and improved thereafter. Therefore, the authors suggested that the reduced PMP after this type of exercise makes it impossible for players to resume effective matchplay immediately and it takes at least 2 min for this to recover. There are problems with the timing and type of collection for measuring lactate used in this study. Furthermore, this type of simple reaction test is not really typical of soccer match play and so can lack applicability.

It has been found that fatigue has detrimental effects on motor skill in well practised individuals (Wrisberg and Herbert, 1975), thus it may be surmised that soccer skill may decline with continuing participation during a game. Considering it's importance, there is a dearth of information pertaining to soccer skill, especially the influence of fatigue on skill. McMorris and co-workers (1994) carried out experiments to determine the effect of moderate and fatiguing exercise on the performance of passing skill, and discovered that the latter led to a decrement in performance. The authors used cycling as a method of producing fatigue and so the relevance to actual soccer is not strong. Furthermore, they used a simple wall-passing test to assess soccer skill.

2.8.3 Fluid replacement and soccer skill performance

McGregor et al. (1999b) used 9 male university players to investigate the influence of fluid ingestion on soccer skill. In the fluid trial subjects consumed 5 ml.kg⁻¹ of water before, and 2 ml.kg⁻¹ after every 15 min of the LIST, and in the other trial consumed no fluid. Players performed a soccer dribbling test before and after the 90-min exercise. The main finding was that skill performance was reduced by 5% in the absence of water but maintained when fluid was ingested before and during the LIST. The authors suggested that fatigue could have been due to the increased thermal strain (Hamilton et al., 1991; Montain and Coyle, 1992) caused by the higher fluid loss in the 'no fluid' trial. McGregor and colleagues (1999b) also postulated that fatigue could have been due to greater glycogen depletion in the 'no fluid' trial as glycogen sparing has been found to occur with fluid ingestion (Hargreaves et al., 1996).
To investigate further whether it is muscle glycogen depletion or hypohydration that influences reduction in skill performance, McGregor (1999) completed a rehydration study. Eight male soccer players performed the 90-min LIST without fluid and then, during the recovery period, were given either 100 ml of water (SV) or fluid equating to 150% of weight loss during the LIST (LV). Subjects performed a dribbling test and the LSPT before and after the LIST and then 2 h after recovery. The main finding was that in the absence of water, skill performance decreased in both passing and dribbling tests following 90 min of the LIST. Skill failed to return to pre-exercise values following a 2-h recovery period. Furthermore, there was no difference between SV and LV.

McGregor (1999) suggested that hypohydration may be a reason why skill decreases following exercise, with a decrease of 2-8% in bodyweight, but as skill did not return following fluid replenishment, then the mechanism may be more complex. The decrement in skill may have been due to a number of circulatory, thermoregulatory, hormonal or metabolic changes that occur in the body (Hamilton et al., 1991; Montain and Coyle, 1992). However, skill did not return to pre-exercise levels independent of drink volume consumed. Therefore, the mechanism may be one that occurs during the exercise period and cannot be altered through ingestion of a CHO free solution or within the time of the recovery period.

2.8.4 CHO ingestion and soccer skill performance

Most of the relatively few investigations into CHO ingestion and soccer skill performance have studied CHO given immediately before and during soccer matches or soccer type intermittent exercise (Zeederberg et al., 1996; McGregor, 1999; Northcott et al., 1999; Ostojic and Mazic, 2002). Abt and associates (1998) specifically examined whether a high CHO meal given 2 days prior to exercise would improve skill performance relative to a mixed diet. After the 2-day diet subjects performed an exercise protocol on a treadmill, designed to simulate the activity pattern during a soccer game. The main
finding was that a 48-h high CHO diet did not attenuate performance. However, the treadmill protocol may not have reduced muscle glycogen concentrations enough. Furthermore, the intermittent protocol on the treadmill may not have been representative of a soccer game as it did not involve any sprints nor any turning movements and included relatively ‘long’ periods of continuous exercise. In addition, the investigators utilised the Zelenka skills test (Zelenka et al., 1967), which has been found to have limitations as a test of soccer skill (see above).

Zeederberg et al. (1996) investigated the effect of CHO ingestion on soccer players’ success in tackling opponents and in controlling, passing, dribbling, heading and shooting the ball during a match. Two soccer teams, which were evenly matched, from the South African 1st Division, took part. Fifteen minutes before the match, and during the half time break, players from each side either consumed 5 ml.kg\(^{-1}\) of a 6.9% glucose-polymer solution (Energade sports drink) or a flavoured placebo solution. Skill proficiency in tackling opponents and controlling, passing, dribbling, heading and shooting the ball was recorded via two video cameras placed diagonally opposite each other in both halves. The authors reported no effect of a CHO-electrolyte solution consumed before and during a 90-min match on motor skill proficiency of soccer players. They suggested that a possible reason could have been due to no evidence of hypoglycaemia in the placebo trial – in both trials blood glucose concentrations were >5 mmol.l\(^{-1}\). However, CHO was provided to the players at a rate of only ~25 g per hour; a rate which may not have been sufficient to highlight any differences between treatments. Furthermore, the very subjective notion of ‘skill’ (only based on successful/unsuccessful outcomes) within an exhibition or friendly match, may have weakened the findings.

Ostojic and Mazic (2002) also used an exhibition match to investigate the influence of CHO ingestion on soccer skill performance. Subjects performed 4 specific soccer skill tests following the 90min game. Subjects were provided with the test drink (7% CHO-E drink or flavoured placebo) before (5 ml.kg\(^{-1}\) BM) and after every 15min (2 ml.kg\(^{-1}\) BM) of the game. The main finding was a 5% improvement in soccer dribbling performance
following CHO supplementation and it was suggested that this could have been due to
depletion of muscle glycogen stores (Ostojic and Mazic, 2002). However, no baseline
measures of skill were made and so it may have been that the CHO group was better than
the placebo group and the treatment did not make a difference. There were also very low
lactate concentrations reported (<3 mmol.l⁻¹) and this may have been a consequence of
the nature of the match i.e. exhibition rather than league competition. Moreover, the
dribbling test may have assessed technique and sprint speed rather than skill per se.

To counteract the problems of controlling the environment and different abilities of
players in field studies, a number of investigations have been undertaken on CHO
ingestion and skill performance with laboratory based running protocols (McGregor,
1999; Northcott et al., 1999). Northcott and co-workers (1999) gave 10 male college
soccer players an 8% CHO beverage or flavoured placebo equivalent to 8 ml.kg⁻¹ BM 15
min before exercise and at half-time of a 90-min intermittent running protocol. Subjects
performed intermittent exercise (jogging, walking, cruising, backwards running and
sprinting) in a circuit which also included passing and shooting drills. The main finding
was that CHO ingestion prevented the drop in performance seen in the last 15 min of
simulated soccer test when drinking water alone. Furthermore, subjects covered a
significantly greater distance in both halves in the CHO trial. The results of the study can
be questioned due to the ‘skill’ aspects probably evaluating technique rather than skill per
se. Also, there was no mention of any validity or reliability assessment on the skill
aspects of the test. The intermittent protocol itself can also be questioned – how did they
distinguish between a jog and a cruise – when people become fatigued they go for a
uniform pace and so it may have become more of a continuous protocol than first
thought.

McGregor (1999) used the LIST, a protocol found to closely simulate the demands of a
soccer game (Nicholas et al., 1995), to investigate whether CHO supplementation during
exercise would maintain soccer skill better than when ingesting water alone. Nine semi-
professional and university standard players performed the LIST whilst consuming a
6.4% CHO-E solution, a flavoured placebo or no fluid. There was no difference in passing performance between trials and, although dribbling performance deteriorated in the no fluid trial, there was no difference between the fluid trials. McGregor (1999) suggested that the reason why there was no difference between the fluid trials could have been because the LIST alone did not reduce muscle glycogen to such low concentrations as to affect skill performance.

Therefore, the effect of ingesting CHO during exercise on soccer skill has yet to be fully established. Many of the relatively few studies show some benefit of consuming CHO but as of yet no clear mechanism for this has been made clear.

2.9 Summary

Due to the diverse activity patterns of soccer, both aerobic and anaerobic energy systems are utilised. This also indicates that there are a number of ways by which players can become fatigued during soccer, especially towards the end of a game. Although much interest has been devoted to the physiological aspects of fatigue there has been less investigative research into why skill performance may deteriorate. Fluid and carbohydrate ingestion during continuous cycling and running exercise have been shown to delay fatigue and improve exercise performance and endurance capacity. In recent years many investigators have demonstrated the benefits of such supplementation during intermittent exercise as well, so much so that CHO solutions are encouraged to games players to improve endurance performance. With the introduction of more controlled tests of soccer skill there has been a steady increase in the available information on the effects of fluid and CHO supplementation on the maintenance of soccer skill.
CHAPTER 3

GENERAL METHODS

3.1 Introduction

This chapter focuses on the general methods used in the studies described in subsequent chapters of this thesis.

All procedures had prior approval by Loughborough University's Ethical Advisory Committee. Before obtaining written consent the individuals who expressed an interest in the experiments were fully informed about the aims, procedures and the demands that the study would place upon them, coupled with any possible risks and discomforts. To ensure their appropriateness subjects were also required to complete a medical history questionnaire (Appendix A). Subjects were without fail reminded of their right to withdraw from any of the studies whenever they so wished.

3.2 Subject control

Subjects were required to report for each experimental trial following a 10-12 h overnight fast. This was to ensure that each subject completed the test with an empty stomach so that the effects of previous meals were negated. Subjects were asked to refrain from any physical activity the day before testing and to consume diets as similar as possible on the days prior to each test. They were also asked to weigh and record their food and drink consumption on the two days preceding each trial in food record diaries, which were later analysed for total energy intake and relative contributions of different food types (Comp-Eat: version 5; Comp-Eat Nutrition Systems).
3.3 Description of equipment used

3.3.1 Experimental environment

All the experimental trials, along with the preliminary tests, were performed in the Loughborough University Sports Hall on a flat, sprung, non-slippery wooden floor. Two lines were clearly marked with coloured tape to indicate the 20-m distance between which the subjects ran between; a halfway line was also marked between the 20-m lines with coloured tape. Photoelectric light cells were used to time the 15-m sprint during the test.

3.3.2 Measurement of height and weight

Height was determined by a stadiometer (Seca Ltd, Birmingham). The investigator ensured that subjects’ heels were in contact with the heel board and an upright posture was assumed before any measurements, accurate to 0.1 cm, were taken. Subjects’ nude body mass was determined using a beam balance (Avery Ltd, model 3306 ABV, Birmingham) to an accuracy of 0.1 kg.

3.3.3 Heart rate monitoring

Heart rate (HR) was monitored during the main trials by short-range telemetry using either the Polar Vantage NV or Polar Sports Tester watch (Polar Electro Fitness Technology, Finland) and stored in memory mode. Heart rate data were downloaded using the appropriate computer program (Polar HR analysis software, version 5.04).

3.3.4 Ambient temperature, humidity and barometric pressure

Dry and wet bulb temperatures were measured using a whirling hygrometer (Brannan Thermometers Ltd, Cumberland). From these measurements humidity was calculated using conversion tables. Barometric pressure was measured using a wall mounted barometer (Fisher Scientific UK, Loughborough, Leics) prior to the onset of the main trials.
3.3.5 Ratings of perceived exertion (RPE)

Ratings of perceived exertion (RPE; Borg, 1973) were noted during the final walk stage of each block of the LIST.

3.3.6 Collection of expired air

Expired air during the experiments was collected either by the Douglas bag or the modified Douglas bag method. With the traditional Douglas bag method, subjects were presented with a noseclip and mouthpiece 30 s prior to gas collection to ensure evacuation of ‘dead space’ with expiratory air. The mouthpiece was connected to the Douglas bag (Harvard Equipment) via a lightweight, low resistance two-way valve (Jakeman and Davies, 1979), a 1.5 m length of wide-bore (30 mm) lightweight tubing (Fulconia) and a two-way tap (Harvard Equipment).

The percentage oxygen (\(F_{\text{E}O_2}\)) and carbon dioxide (\(F_{\text{E}CO_2}\)) content of expired air were both measured by a single unit, incorporating both a paramagnetic oxygen analyser, operating on the basis of the susceptibility of oxygen to a paramagnetic gas, and an infra-red carbon dioxide analyser (Servomex, model 1440C, Crowborough, Essex). The concentration of the gases was given as a digital readout, accurate to ± 0.01%. The analysers were calibrated against nitrogen (Air Products Ltd, Crewe, Cheshire), a calibration gas (16.0% \(O_2\) and 4.0% \(CO_2\); Air Products Ltd, Crewe, Cheshire) and room air immediately prior to each series of gas analyses.

A Harvard digital dry gas meter (Harvard Apparatus Ltd, Edenbridge, Kent), previously calibrated using a 600-litre Tissot Spirometer (Collins Ltd, USA), was used to determine gas volumes. The temperature of expired air was monitored as each bag was evacuated by a thermistor probe (Edale type 2984, model C).

During the shuttle running exercise (the LIST, see below for full description) expired air was collected using the modified Douglas bag collection technique (Figure 3.1). A 200-litre capacity Douglas bag was attached to a rucksack frame by plastic reinforces for carriage during the protocol, with the total weight of the equipment amounting to 2.4 kg. This method is similar to the one described by de Groot and colleagues (1983),
but in the present study the subject has no control over the opening or closing of the valves for gas collection. One complete cycle of the shuttle running exercise was completed for the subject to acclimatise to running with the Douglas bag before the valve was opened to allow gas collection (i.e. on the next walk phase) for the subsequent cycle.

Figure 3.1 Subject wearing the modified Douglas bag rucksack
3.4 Experimental tests and procedures

3.4.1 Maximal oxygen uptake (\(\dot{V}O_2\) max) test

Maximal oxygen uptake (\(\dot{V}O_2\) max) was estimated by means of the ‘Progressive Multistage Fitness Shuttle Run Test’, developed at Loughborough University by Ramsbottom et al. (1988), based upon an original protocol proposed by Leger and Lambert (1982). Due to the progressive nature of the test, a long warm-up was not required but some running and stretching was allowed before the start of the test. During this time the subjects were reminded that the test was maximal and progressive and that they should continue to run at the required pace for as long as possible. Subjects were verbally encouraged throughout the test.

The protocol of the multistage test requires subjects to complete 20-m shuttles at a progressive pace. The test begins at a low speed of 2.22 m.s\(^{-1}\) and gradually increases by 0.14 m.s\(^{-1}\) every minute. Subjects were required to place one foot on or over a taped line, marking 20 m apart from the other, in time with an audible signal (i.e. a ‘bleep’, from a cassette recorder: Sharp, model WQ-CD55E, Japan). Subjects dropped out from the test or were withdrawn by the investigators when they failed to keep up with three successive bleeps. The level obtained was used to find the subject’s \(\dot{V}O_2\) max from the table of predicted values in the authors manual (Ramsbottom et al., 1988). This value was then used to calculate the 95 and 55% of \(\dot{V}O_2\) max shuttle speeds for use in the main exercise trials.

3.4.2 Glycogen reduction exercise

The exercise protocol was designed to reduce the glycogen content in both type I and type II muscle fibres and was based on a model suggested by Vollestad et al. (1992) (Figure 3.2). Subjects initially performed 30 min of exercise at an intensity close to 70% of their cycling \(\dot{V}O_2\) max, with a pedal rate of \(~70\ rev.min^{-1}\). Following a 2min rest, subjects then performed three 50-s ‘sprints’ at double the resistive load, at a pedal rate of \(>80\ rev.min^{-1}\), with 2-min rest between each bout. After another 2-min rest they were required to cycle for a further 45 min at 70% \(\dot{V}O_2\) max to further...
reduce glycogen in type I fibres. The participants were provided with 2 ml.kg⁻¹ body mass of water before and after every 15 min of exercise to offset severe dehydration.

![Diagrammatic representation of the glycogen reduction protocol](image)

**Figure 3.2** Diagrammatic representation of the glycogen reduction protocol

### 3.4.3 Low carbohydrate meal

Following the glycogen reduction exercise, subjects were provided with a meal low in carbohydrate content so that the replenishment of muscle glycogen content was reduced. This meal was designed to be isocaloric, relative to a normal evening meal, (~14 kcal.kg⁻¹ body mass) but low in CHO (1 g.kg⁻¹ body mass). The relative contribution towards total energy content was 28, 38 and 34% from CHO, protein and fat, respectively. Participants were then told to fast 10-12 hours prior to reporting in the laboratory the following morning. In this way liver glycogen content was also reduced.

### 3.4.4 The Loughborough Intermittent Shuttle running Test (LIST)

The LIST was developed to closely simulate the demands of multi-sprint sports such as soccer (Nicholas et al., 1995, 2000). For the purpose of these experiments the LIST was slightly modified, with the elimination of the run to exhaustion (Part B), and the completion of six ‘blocks’ of running, equating to 90 min (i.e. the same duration as a
football match), from the original protocol. Furthermore, subjects ran at 'cruising' and 'jogging' speeds equivalent to 95 and 55% of their individual VO₂ max values.

Table 3.1 shows the sequence of activities in each cycle of the LIST. Each cycle was completed 10 times with the addition of 3 extra walks and a further sprint within each ~15-min 'block'. The block was repeated 6 times, with a 3-min break between blocks.

As with the multistage test, the subjects’ movements were dictated by an audio signal. However, whereas previously there was only the single sound, for this test there were two distinct ones: a long bleep indicated when subjects should be making contact with the end lines and a shorter, higher-pitched bleep, marking the midway point, thereby helping subjects to maintain the required pace.

Table 3.1 The specific activity pattern of one complete cycle of the LIST

<table>
<thead>
<tr>
<th>Pace</th>
<th>Distance (m)</th>
<th>Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking</td>
<td>3 x 20</td>
<td>1.54 m.s.⁻¹</td>
</tr>
<tr>
<td>Maximum sprint</td>
<td>1 x 15</td>
<td>Maximum speed</td>
</tr>
<tr>
<td>Recovery/walk</td>
<td>~ 3</td>
<td>3 s duration</td>
</tr>
<tr>
<td>Running (cruise)</td>
<td>3 x 20</td>
<td>~ 95% VO₂ max</td>
</tr>
<tr>
<td>Jogging</td>
<td>3 x 20</td>
<td>~ 55% VO₂ max</td>
</tr>
</tbody>
</table>

The programme, on a microcomputer (BBC, model 310), was developed by Dr Henryk Lakomy for the purpose of the LIST. Sprint times were measured in one direction over 15 m by two infrared photoelectric cells (RS Components Ltd, Switzerland), interfaced with the microcomputer.
3.5 The Loughborough Soccer Passing Test (LSPT)

The LSPT was developed as a test to assess the multi-faceted aspects of soccer skill, including dribbling, control and decision-making (Hulse, 1998). Using a mixture of professional and university standard players, it has been found to be a valid and reliable instrument to determine soccer skill (McGregor et al., 1999a). Figure 3.2 is a diagrammatic representation of the LSPT.

3.5.1 Equipment and set up

Figure 3.3 is a diagrammatic representation of the LSPT. Four standard gymnasium benches were placed as shown on each of the four lines marking the 15 m x 11 m grid (to the inside of the benches). Prior to placement, four coloured (green, blue, red and white) 50 cm x 30 cm pieces of card were taped to the middle of each bench. Yellow tape was also used to mark the inner (1.5 m x 4 m) and outer (3 m x 5 m) rectangles. The passing zone was the area between these lines. Different coloured cones were used to distinguish the different zones, with a further cone situated in the middle of the inner rectangular grid.

3.5.2 Instructions and penalties for the LSPT

Subjects started with the ball (Ultimatch, Mitre Sports International, Wilmslow, Cheshire) by the central cone, and the first examiner started timing the test, using a hand held stopwatch (Accusplit, model 725 XP), from the moment the ball was touched forward out of the inner rectangle. The second examiner was involved in calling out the order of passes; calls were made as the subject was playing the previous pass. The same examiner was used in each role so as to eliminate inter-experimenter variability. The order of passes was determined by one of four random trial orders (see Appendix D), with each trial consisting of 8 long (green and blue) and 8 short (white and red) passes. Subjects were informed that passes were only allowed to be executed from within the passing area, between the set of marked lines (see Figure 3.3). They were also told that upon retrieval from the previous pass, the ball had to cross two of the inner marked lines before the next pass could be attempted.
The second examiner stopped the clock when the last pass made contact with the bench.

The role of the second examiner was also to record penalty time points accrued during the trials. Thus, the investigator would have to stand in such a position that all four target areas could be viewed. Penalty time was awarded for the following errors:

- 2 s for missing 50 x 30 cm target area
- 2 s for ball hitting any cone
- 2 s for passing the ball outside of the designated area
- 5 s for missing bench or hitting wrong bench

The penalty time was added to the time taken to complete each trial to make total performance time.
3.6 The Loughborough Soccer Shooting Test (LSST)

The LSST also incorporates a number of facets integral to soccer including shooting ability, reaction time, decision making and running speed (Reddin, 1999).

3.6.1 Layout of test

Figure 3.4 is a diagrammatic representation of the set up of the LSST. The necessary lines were measured and marked on the floor using 5-cm yellow tape. The 6-yard (5.5 m) line was initially marked out as well as the area where the goalkeeper was moved to depending on the experimenter’s call. The ‘shooting zone’ was a square (8.5 m x 8.5 m), with the nearest line 18 yards (16.5 m) from the goal line. Four upright road cones were placed on each corner of the shooting zone. A standard gymnasium bench was placed on the middle of the far side of the zone to act as a rebound board.

3.6.2 Goal

The goal was marked on a piece of polyethylene sheeting (John Bell Rope Ltd, Loughborough) measuring 7 m x 9 m. The single sheet was folded over with the ends stitched together (so as to create a 3.5 m x 9 m ‘double’ sheet) to give the sheet strength. The sheet was then attached to the wall via ropes and a pulley system was devised so as to pull the sheet off of the floor when not in use. The full sized goal, measuring 8 feet x 8 yards (2.44 m x 7.32 m), was split into the various scoring zones (see Figure 3.4 for exact measurements) and marked using 5-cm duck tape.
Figure 3.4 Diagrammatic representation of the layout of the LSST
3.6.3 Goalkeeper

To enhance the ecological validity of the shooting test a static, life-size goalkeeper was used (Figure 3.5). The figure was made from plywood and shaped into a goalkeeper in the ‘set’ position adopted when a goalkeeper readies himself for a shot (FA Coaching License recommendations, 1997). The figure measured 1.9 m tall and 1.22 m at its widest point at the base and the arm span. The arms were separate to the main body and connected via tarpaulin hinges. This was so that the arm would spring back in the event of the football hitting the arm.

The goalkeeper was mounted on a plywood base (1.22 m x 0.6 m) and set on four castor wheels to allow ease of movement between the left and right side of the goal centre during experimentation. The figure was anchored to the base using an L-shaped metal plate using nuts and bolts. Springs were also used along with nuts and bolts so that if the ball hit the goalkeeper, the figure would rebound back to its starting position.

Figure 3.5. Dimensions of the goalkeeper
3.6.4 SpeedChek personal sports radar

In order to prevent subjects passing the ball into the goal during the test at an 'unrealistic' speed for a shot at goal from the shooting zone, an arbitrary minimum shot speed (in miles per hour / mph) was set at which the ball had to exceed. A minimum value of 30 mph was decided upon for the shot to be valid within the modified test protocol.

The SpeedChek sports radar (Tribar Industries Inc., Coachwise 1st4sport, Leeds) utilises 'Doppler signal processing' to measure speeds of moving objects. The sports radar must be positioned directly in line (or facing) the direction of travel. The device is designed to measure and display the speed of objects approaching the unit, coming within 9 m from the front face, moving 9 m away, passing within 3 m over the top or passing 1.5 m either side of the unit. However, the manufacturer states that these distances are approximate and may vary with the size and characteristics of the target.

3.6.5 Role of investigators

The two investigators' were located at positions 'A' and 'B' (Figure 3.4). The role of investigator A was to call the player initially to either the left or the right cone, to make sure that the shot was taken from within the shooting area, to check the shot speed on the sports radar, to determine the points scored (if any) and to record all the relevant information. The tasks of the second researcher (B) included timing (using a hand held stopwatch, Accusplit, model 725 XP) the subjects' movement from the initial call to when they touched the goal. The other task was to move the goalkeeper to the appropriate position depending on the trial once the player turned his back to the goal.

3.6.6 Procedure for LSST

The ball was initially placed on the marked cross in the middle of the shooting zone (Figure 3.4). The starting position for the subject was facing away from the goal whilst within playing distance of the ball. On the investigator's call, the player sprinted to the appropriate cone, touched the top of it, and then returned to the start
position. He then played the ball towards the opposite end of the bench to where he had just run to, turned, controlled the ball if necessary, and then shot at the goal whilst within the shooting area. The subject then followed up his shot by sprinting past the goalkeeper and touching the goal. Each trial was made up of 10 shots with 1-min rest between each shot sequence. There were 6 different trial orders (see Appendix E); the goalkeeper was positioned to the opposite side to the ‘left/right’ call. The performance score was the total cumulative points accrued from all the shots on target, discounting those which: were attempted from beyond the shooting zone, took greater than 9 s to complete, were struck at less than 48 km.h\(^{-1}\) (30mph) and those which struck any part of the goalkeeper.

### 3.7 Composition of the test drinks

The compositions of the test drinks used during the experimental trials are presented in Table 3.2. The CHO-E solution was a commercially available drink (Lucozade Sport) whereas the control was a non-electrolyte artificially sweetened placebo. Both solutions looked, tasted and had the same mouth feel and were manufactured by the same company (GlaxoSmithKline, Brentford).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Lucozade Sport (CHO)</th>
<th>Lucozade Sport placebo (PLA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHO content (%)</td>
<td>6.4</td>
<td>0</td>
</tr>
<tr>
<td>CHO type</td>
<td>Blend of glucose syrup and maltodextrins</td>
<td>N/A</td>
</tr>
<tr>
<td>Sodium (mg/100 ml)</td>
<td>49.45</td>
<td>1.97</td>
</tr>
<tr>
<td>Potassium (mg/100 ml)</td>
<td>10.28</td>
<td>11.16</td>
</tr>
<tr>
<td>pH</td>
<td>3.45</td>
<td>2.86</td>
</tr>
<tr>
<td>Acidity (%ww CAMH)</td>
<td>0.50</td>
<td>0.29</td>
</tr>
<tr>
<td>Osmolality (mOsm)</td>
<td>287</td>
<td>26</td>
</tr>
</tbody>
</table>
3.8 Blood sampling

3.8.1 Sample collection

Venous blood samples were drawn from an antecubital vein in the forearm using either venepunctures (0.8 mm bore, Sabre International Products Ltd, Reading, Berks.) or via an intravenous cannula (Venflon, 16-18G, Becton Dickinson, Helsingborg, Sweden). The cannula was kept patent by frequent flushing with sterile saline (Stenpak Ltd, Runcorn). Prior to the cannula insertion a local anaesthetic was administered (0.5 ml of 1% lignocaine, Antigen Pharmaceuticals, Roscrea, Ireland).

Changes in body posture from lying to standing can result in decreases in plasma volume of up to 10 % (Rowell, 1974). Thus, subjects stood for 10 min before a 10 ml resting blood sample was drawn. Prior to the sampling a 2-ml syringe (Becton Dickinson, Helsingborg, Sweden) was used to clear the cannula of blood and saline. Further blood samples were obtained after every 30 min of the LIST.

3.8.2 Treatment, storage and analysis of venous blood samples

Of the 10-ml sample, 1 ml was immediately centrifuged for 2 min (Eppendorf, model 5415C, Hamburg, Germany). The plasma obtained was immediately placed in liquid nitrogen, and later stored at -70°C, for subsequent analysis of ammonia (within 48 hours) using a commercially available kit (Sigma Diasnostics, St.Louis, MO, US). Half of the blood sample (5 ml) was dispensed into EDTA containing tubes (Sarstedt, Numbrecht, Germany), with the remainder (4 ml), left to clot for 45-60 min to obtain serum.

Haemoglobin concentration was determined in duplicate (2 x 20 μl) by the cyanomethaemoglobin method (Boeringher Mannheim GmbH Diagnostica, Germany). Triplicate 50-μl samples of whole blood were collected using heparinised pipettes (Scientific Industries International Ltd, Loughborough, Leics.) and then micro-centrifuged (Gelman Hawksley Ltd, England) for 15 min at 11000 rev.min⁻¹. Packed cell volume was measured using a sliding micro-hematocrit reader (Gelman
Hawksley Ltd, England). From the changes in haematocrit and haemoglobin concentrations from rest to the end of exercise, percent changes in plasma volume were estimated using the formula described by Dill and Costill (1974).

The remaining whole blood was centrifuged at 4°C for 15 min at 6000 rev.min\(^{-1}\) (Koolspin, Burkand Scientific, Uxbridge, Middx.). The plasma obtained was divided into smaller aliquots for the determination of different metabolites. Plasma samples were stored at -70°C for later analyses of FFA, glycerol, glucose and lactate, using commercially available kits (NEFA C, Wako Chemicals GmbH, UK, Colorometric method, Randox Ltd, Ireland, GOD-PAP method, Boehringer Mannheim, Germany and ABX Diagnostics, Montpellier, France, respectively), and an automated system (COBAS Mira Plus, Roche Diagnostics Systems, Switzerland).

Serum was obtained by centrifuging 4 ml of coagulated whole venous blood for 15 min at 6000 rev.min\(^{-1}\) at 4°C. The serum was then dispensed into two plastic tubes (500 µl each), frozen at -20°C and then stored at -70°C for subsequent analysis of insulin, cortisol and prolactin via radio-immunoassay, using commercially available kits (Coat-a-Count, Diagnostica Products Corporation kit, Caernarfon, UK) and a gamma counter (Cobra 5000, Packard).

The coefficient of variation [(Standard deviation / mean) * 100] of the blood, plasma and serum assays is shown in Table 3.3.
Table 3.3 The coefficient of variation (%) of the blood, plasma and serum assays

<table>
<thead>
<tr>
<th>Constituents / metabolite</th>
<th>Coefficient of variation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haemoglobin</td>
<td>1.5</td>
</tr>
<tr>
<td>Hematocrit</td>
<td>1.0</td>
</tr>
<tr>
<td>Plasma ammonia</td>
<td>1.5</td>
</tr>
<tr>
<td>Plasma glucose</td>
<td>0.7</td>
</tr>
<tr>
<td>Plasma lactate</td>
<td>0.7</td>
</tr>
<tr>
<td>Plasma FFA</td>
<td>0.7</td>
</tr>
<tr>
<td>Plasma glycerol</td>
<td>0.7</td>
</tr>
<tr>
<td>Serum insulin</td>
<td>4.5</td>
</tr>
<tr>
<td>Serum cortisol</td>
<td>4.5</td>
</tr>
<tr>
<td>Serum prolactin</td>
<td>4.5</td>
</tr>
</tbody>
</table>

3.9 Statistical analyses

The data were examined using a two-factor (treatment x time of measurement) analysis of variance (ANOVA), with repeated measures for correlated data (SPSS version 10). Mauchly's test of sphericity was used to determine whether the assumption of sphericity was being violated by the data. Where this did occur, the Huynh-Feldt correction was applied (SPSS). When differences were found by the ANOVA, paired Student's t-tests, using the Bonferroni adjustment, were used to ascertain where the differences lay. Student's t-test for correlated data was also used to examine differences between trials. The relationships between a number of variables were investigated using a Pearson product moment correlation coefficient. Data are presented as means ± standard error of the mean (SE). The level of significance was accepted at $p<0.05$. 
CHAPTER 4

THE INFLUENCE OF CARBOHYDRATE-ELECTROLYTE INGESTION ON SOCCER SKILL PERFORMANCE

4.1 Introduction

Using the LIST protocol an earlier study found that soccer dribbling performance was reduced following 90 min of exercise without fluid ingestion (McGregor et al., 1999b). Such deterioration was prevented following the ingestion of water throughout the 90-min test. Thus, it was speculated that the mechanism for fatigue was either due to dehydration or critically low muscle glycogen concentrations. Furthermore, even after complete rehydration of fluid lost during the LIST, skill performance did not return to pre-exercise levels (McGregor, 1999). Therefore, it is possible that fatigue may be related more to low muscle glycogen concentrations rather than dehydration per se.

Match analysis shows that soccer players work at a rate of 70-80% V\text{O}_{2}\text{max} (Bangsbo, 1994a) and prolonged exercise at these intensities places a heavy reliance on glycogen as a substrate for energy metabolism (Romijn et al., 1993). As glycogen constitutes a relatively small store, many authors have suggested that fatigue during prolonged exercise is a result of a lack of this substrate (e.g. Karlsson, 1969; Saltin, 1973). Indeed, Karlsson (1969) and Saltin (1973) showed that low glycogen concentrations were associated with a lower work rate, a manifestation of fatigue, and this was especially evident in the second half of a soccer match. No mention was given to decrements in skill levels with the onset of fatigue. Furthermore, these studies were conducted in a field setting and so many of the extraneous factors that may have had an influence on the findings were not controlled. McGregor (1999) found no difference in skill performance when subjects ingested either a carbohydrate-electrolyte (CHO-E) solution or a flavoured water placebo during the LIST. This may have been because muscle glycogen concentration was not low enough to influence running performance.
Therefore, the aim of this study was to examine the influence of lowered muscle glycogen concentrations on soccer skill performance before and after completing the 90-min LIST. A further aim was to investigate whether ingestion of a CHO-E solution before and during exercise would have any beneficial effects on skill performance.
4.2 Methods

4.2.1 Subjects

Sixteen healthy male soccer players (age 21 ± 1 years, height 1.8 ± 0.02 m, body mass 74.6 ± 1.7 kg and VO₂ max 56 ± 0.4 ml.kg⁻¹.min⁻¹, mean ± SE), who were semi-professional, ex-professional or of at least University standard, volunteered to participate in the study. The subjects were from a range of outfield playing positions and were involved in regular training and matchplay.

4.2.2 Preliminary measurements

Subjects reported to the laboratory on two separate occasions for preliminary measurements. During the first session subjects' height, weight and VO₂ max were determined (see Chapter 3 for equipment and methods). Subjects were also fully familiarised with the skill tests and the LIST protocol during both sessions.

4.2.3 Experimental procedures

Subjects completed two main trials, each separated by at least 7 days. The order of trials was randomised to counteract order effects. Subjects were asked to record their food and drink consumption for the day prior to, and on the day of, the glycogen reduction exercise, and to maintain a similar level of intake prior to both trials. Each main trial took place over 2 days (Figure 4.1). The participants reported to the laboratory at approximately 17:00 hours on day 1. Following a standardised 10-min warm up, subjects performed the pre-exercise skill tests (LSPT and LSST, see Chapter 3), which were used to set the 'baseline' performance. The baseline tests were introduced to gauge subjects' skill levels prior to any exercise and at a time when low arousal (such as very early in the morning) would not hinder performance. To provide the most valid skill performance prior to any exercise, the baseline scores for both trials were combined. After a brief rest period (5-10 min), subjects were required to complete the glycogen reduction exercise (Chapter 3). At approximately
20:00 hours the participants were provided with a low carbohydrate meal (Chapter 3), and then instructed to fast until the following morning.

Upon arrival on the morning of day 2, subjects’ nude body mass was determined, after which the resting blood and expired gas samples were collected. Following the same standardised warm up procedure, subjects performed the second set of skill tests (‘pre-LIST’). The participants were then provided with the test drink. In the carbohydrate trial subjects were provided with a commercially available sports drink containing 6.4% CHO (Lucozade Sport, GlaxoSmithKline, Brentford). In the other trial, a placebo was provided which was manufactured to replicate the taste of the test drink, but containing neither carbohydrate nor electrolytes (PLA). Prior to the commencement of the LIST, subjects ingested a bolus equivalent to 5 ml.kg⁻¹ BM and then 2 ml.kg⁻¹ after every 15 min of exercise (Figure 4.1).

After ingestion of the test drink participants completed six 15-min blocks of the LIST punctuated by 3-min rest periods. Within the rest periods subjects ingested the equivalent of 2 ml.kg⁻¹ BM of the same drink. Expired gas samples were collected using the modified Douglas bag method (Chapter 3) towards the end of each block of the LIST. Rate of perceived exertion (RPE) and environmental temperature were measured on the last walk phase of each 15-min block of exercise. Heart rate (HR) was monitored continuously throughout exercise via short-range telemetry. The subjects were constantly encouraged to maintain the pace set by the audio signals and to perform maximally during the sprints. After completion of the LIST participants were given a brief (~5 min) rest prior to the post-LIST skill tests. Nude body mass was determined following the post-LIST skill tests after subjects had towel dried themselves to remove excess sweat.
Figure 4.1 Schematic representation of the experimental protocol and the Loughborough Intermittent Shuttle Running Test (LIST)
4.2.4 Blood analyses

Blood samples were withdrawn from an indwelling venous cannula (Chapter 3), in volumes of 10 ml, at rest and after 30, 60 and 90 min of the LIST. The blood was dispensed, treated and stored as previously described (Chapter 3). Changes in plasma volume were determined using haematocrit and haemoglobin values (Chapter 3). Plasma samples were analysed for ammonia, glucose, lactate and FFA concentration and serum samples for insulin and cortisol using methods described previously (Chapter 3).

4.2.5 Statistical analyses

The procedures used were as described under statistical analysis in Chapter 3. The results are presented as mean values and the standard errors of the mean (± SE). Statistical significance was accepted at $p<0.05$. 
4.3 Results

4.3.1 Performance on the LSPT

There was a main effect of time between baseline and post-LIST scores (48.8 ± 0.9 s vs. 52.4 ± 0.9 s, $F_{2,30} = 7.799$, $p<0.01$; Figure 4.2). When split into CHO and PLA trials separately, there was a tendency for performance to be maintained in the CHO trial from baseline to post-LIST (48.8 ± 0.9 s to 50.8 ± 1.2 s) whereas performance appeared to decline in the PLA trial (48.8 ± 0.9 s to 54.0 ± 1.3 s; Figure 4.3) but this change did not reach statistical significance.

![Figure 4.2 LSPT total performance time (s; combined data CHO+PLA; * significantly slower than Baseline performance, $p<0.01$, $n = 16$)]
As described earlier, the LSPT total performance time consists of time taken to complete the test plus any additional penalty time for inaccurate passes and poor control of the ball. The time taken to complete the LSPT was the same between trials (Table 4.1). There was a greater tendency for penalty time to increase from baseline (7.9 ± 0.7 s) to post-LIST in the PLA trial (11.5 ± 1.1 s) than the CHO trial (9.5 ± 1 s; Table 4.1), but this was not statistically significant.

**Table 4.1** Time taken to complete (s), and penalty time accrued (s), during the LSPT in the CHO and PLA trials (* significantly higher than Baseline, \( p<0.01 \), \( n=16 \))

<table>
<thead>
<tr>
<th>Time only (s)</th>
<th>Baseline</th>
<th>Pre-LIST</th>
<th>Post-LIST</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHO</td>
<td>40.9 ± 0.8</td>
<td>42.0 ± 0.9</td>
<td>41.3 ± 0.8</td>
</tr>
<tr>
<td>PLA</td>
<td></td>
<td>42.0 ± 0.9</td>
<td>42.5 ± 1.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Penalty time only (s)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CHO</td>
<td>8.5 ± 0.9</td>
<td>9.5 ± 1.0</td>
<td></td>
</tr>
<tr>
<td>PLA</td>
<td>7.9 ± 0.6</td>
<td>9.1 ± 0.9</td>
<td>11.5 ± 1.1</td>
</tr>
<tr>
<td>Combined</td>
<td>8.8 ± 0.9</td>
<td>10.5 ± 1.1*</td>
<td></td>
</tr>
</tbody>
</table>
4.3.2 Performance on the LSST

There was a tendency for the mean points scored per shot in the CHO trial to be maintained from baseline and pre-LIST (1.0 ± 0.1) to post-LIST (1.1 ± 0.1), whereas there was a tendency for a decrement in performance post-LIST in the PLA trial (0.9 ± 0.1; Figure 4.4a); however, this was not statistically significant.

The time taken to complete each shot sequence showed two main effects as well as an interaction effect. Players took longer to perform each shot in the PLA trial (main effect of treatment, 8.45 ±0.03 vs. 8.52 ±0.03 s, CHO vs. PLA, $F_{1,15} = 9.069, p<0.01$) and longer to perform each shot post-LIST (main effect of time, 8.36 ±0.04 vs. 8.59 ±0.04 s, baseline vs. post-LIST, $F_{2,30} = 13.332, p<0.01$). Furthermore, the post-hoc test revealed that subjects performed the test quicker in the CHO trial in the pre-LIST condition (interaction effect of time x treatment, 8.42 ±0.05 vs. 8.57 ±0.04 s, CHO vs. PLA, $F_{2,30} = 4.716, p<0.05$).

Mean shot speed was significantly faster in the CHO trial (46.5 ±0.5 vs. 46.4 ±0.5 mph, CHO vs. PLA, $F_{1,15} = 6.435, p<0.05$) but unchanged between time points, averaging 46 mph (Figure 4.4c).
Figure 4.4 Comparison of A) mean points scored per shot, B) mean shot speed (mph) and C) mean time taken (s) to complete each shot sequence of LSST between CHO and PLA trials (* significant difference between CHO and PLA trials, $p<0.05$, $n=16$)
4.3.3 15-m sprint performance

Mean sprint time during the 90 min of the LIST was better maintained in the CHO trial (2.50 ± 0.02 s vs. 2.53 ± 0.02 s, CHO vs. PLA, $F_{1,15} = 8.178$, $p<0.05$; Figure 4.5). There was also a main effect of time, with the combined (CHO + PLA) times during blocks 5 (2.56 ± 0.02 s) and 6 (2.57 ± 0.02 s) significantly slower than blocks 1 (2.49 ± 0.02 s) and 2 (2.48 ± 0.02 s; $F_{1.8,27.2} = 12.646$, $p<0.01$).

![Figure 4.5](image.png)

**Figure 4.5** Mean 15-m sprint time (s) per block of the LIST in CHO and PLA trials ($n = 16$)
4.3.4 HR and RPE

Although HR was consistently higher during the CHO trial, this was not statistically significant (Figure 4.6). However, there was a main effect of time with mean HR significantly lower during the first 15 min of exercise than all other time points (158.3 ±1.7 vs. 163-165 beats.min⁻¹, block 1 vs. blocks 2-6, $F_{2.6,29.1} = 9.146, p<0.01$).

![Figure 4.6 Mean HR (beat.min⁻¹) values per block of the LIST in CHO and PLA trials (n = 12)](image-url)
There was a main effect of time for RPE during the LIST, with both trials exhibiting higher values as the LIST progressed ($F_{2.4, 36.7} = 115.582, p<0.01$). There was also an interaction effect of treatment x time. Although the values after 45 min for the PLA trial were higher than those in the CHO trial there was a significant difference between trials in block 6 only ($17.4 \pm 0.4$ vs. $16.6 \pm 0.5$, PLA vs. CHO, $F_{3.4, 50.4} = 9.146, p<0.01$; Figure 4.7).

**Figure 4.7** Mean RPE values per block of the LIST in CHO and PLA trials (* significantly higher in PLA trial, $p<0.05$, $n=16$)
4.3.5 Oxygen uptake, RER and estimated energy expenditure

Oxygen uptake was consistently higher during the CHO trial, with the overall value significantly greater than the PLA trial (45.9 ± 0.2 vs. 44.2 ± 0.2 ml.kg⁻¹.min⁻¹, CHO vs. PLA, \( F_{1, 15} = 31.236, p<0.01 \); Table 4.2). Oxygen uptake was also higher in the first 30min of the LIST than the last two blocks of exercise (45.8 ±0.4 vs. 44.3 ±0.4 ml.kg⁻¹.min⁻¹, blocks 1 and 2 vs. blocks 5 and 6, \( F_{4,3,64.2} = 7.622, p<0.01 \)). This also equated to a consistently higher relative exercise intensity, expressed as a percentage of maximal oxygen uptake (% ŶO₂ max), in the CHO trial (82 ± 0.4% vs. 79 ± 0.3%, CHO vs. PLA, \( F_{1, 15} = 20.089, p<0.01 \); Table 4.2). Percent ŶO₂ max was also higher in blocks 1 and 2 than blocks 5 and 6 (82 ± 0.8% vs. 79 ± 0.8%, blocks 1 and 2 vs. blocks 5 and 6, \( F_{3,5,51.8} = 9.79, p<0.01 \)).

There was a main effect of time for RER values, with an increase from 0.87 ± 0.01 at rest to 0.91 ± 0.01 in blocks 1 and 2, and then a steady decline to 0.88 ± 0.01 during blocks 5 and 6 (\( F_{1.4, 20.6} = 9.663, p<0.01 \); Table 4.2). There were no differences between trials.
Table 4.2 Oxygen uptake (\(\dot{V}O_2\)), relative exercise intensity (% \(\dot{V}O_2\) max), RER and energy expenditure rates (kJ.min\(^{-1}\)) at rest, during each 15 min block and overall mean of the LIST in the CHO and PLA trials (* main effect of treatment, significantly higher than PLA trial, \(p<0.01, n=16\))

<table>
<thead>
<tr>
<th></th>
<th>Rest</th>
<th>1</th>
<th>2</th>
<th>LIST block number</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>Mean of trial</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\dot{V}O_2) (ml.kg(^{-1}).min(^{-1}))</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>CHO</td>
<td>6.3 ± 0.3</td>
<td>46.7 ± 0.7</td>
<td>46.3 ± 0.5</td>
<td>45.6 ± 0.6</td>
<td>45.9 ± 0.7</td>
<td>45.5 ± 0.7</td>
<td>45.3 ± 0.6</td>
<td>45.9 ± 0.2*</td>
<td></td>
</tr>
<tr>
<td>PLA</td>
<td>5.9 ± 0.3</td>
<td>44.9 ± 0.7</td>
<td>45.1 ± 0.7</td>
<td>44.8 ± 0.7</td>
<td>43.7 ± 0.9</td>
<td>43.2 ± 0.5</td>
<td>43.1 ± 0.5</td>
<td>44.2 ± 0.2</td>
<td></td>
</tr>
<tr>
<td>% (\dot{V}O_2) max</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>CHO</td>
<td>6.2 ± 0.2</td>
<td>83.2 ± 1.3</td>
<td>82.7 ± 1.1</td>
<td>81.6 ± 1.0</td>
<td>81.8 ± 1.2</td>
<td>81.4 ± 1.2</td>
<td>81.0 ± 1.1</td>
<td>82.0 ± 0.4*</td>
<td></td>
</tr>
<tr>
<td>PLA</td>
<td>6.2 ± 0.2</td>
<td>80.7 ± 1.1</td>
<td>80.9 ± 1.3</td>
<td>80.4 ± 1.2</td>
<td>79.2 ± 1.0</td>
<td>77.5 ± 0.9</td>
<td>77.3 ± 0.8</td>
<td>79.3 ± 0.3</td>
<td></td>
</tr>
<tr>
<td>Respiratory exchange ratio (RER)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHO</td>
<td>0.87 ± 0.02</td>
<td>0.92 ± 0.01</td>
<td>0.92 ± 0.01</td>
<td>0.91 ± 0.01</td>
<td>0.89 ± 0.01</td>
<td>0.89 ± 0.01</td>
<td>0.88 ± 0.01</td>
<td>0.90 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>PLA</td>
<td>0.86 ± 0.01</td>
<td>0.92 ± 0.01</td>
<td>0.91 ± 0.01</td>
<td>0.90 ± 0.01</td>
<td>0.89 ± 0.01</td>
<td>0.88 ± 0.01</td>
<td>0.89 ± 0.01</td>
<td>0.90 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>Energy expenditure rates (kJ.min(^{-1}))</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHO</td>
<td>10.1 ± 0.5</td>
<td>69.0 ± 2.1</td>
<td>68.5 ± 2.1</td>
<td>67.5 ± 2.1</td>
<td>67.7 ± 2.1</td>
<td>67.0 ± 2.1</td>
<td>66.6 ± 1.9</td>
<td>67.7 ± 0.9*</td>
<td></td>
</tr>
<tr>
<td>PLA</td>
<td>9.8 ± 0.6</td>
<td>66.8 ± 2.1</td>
<td>66.9 ± 2.0</td>
<td>66.3 ± 2.0</td>
<td>64.8 ± 2.1</td>
<td>63.9 ± 1.8</td>
<td>63.8 ± 1.8</td>
<td>65.4 ± 0.8</td>
<td></td>
</tr>
</tbody>
</table>
Estimated energy expenditure rates were found to be consistently higher in the CHO trial, with the overall mean significantly different from the PLA trial (67.7 ± 0.9 kJ.min⁻¹ vs. 65.4 ± 0.8 kJ.min⁻¹, CHO vs. PLA, $F_{1,15} = 8.394$, $p<0.05$). This equated to 205 kJ (50 kcal) greater total energy expenditure in the CHO trial (6093 ±183 kJ vs. 5888 ±171 kJ, CHO vs. PLA, $t = 4.821$, $p<0.01$; Figure 4.8).

Figure 4.8 Estimated total energy expenditure (kJ) during the LIST in CHO and PLA trials (* significantly greater than PLA trial, $p<0.01$, $n = 16$)
4.3.6 Plasma glucose and FFA

There were two main effects as well as an interaction effect for plasma glucose results. Plasma glucose concentrations were maintained in the CHO trial, but decreased with duration of exercise in the PLA trial. There was a significant difference between trials at 30 and 90 min (5.6 ± 0.1 vs. 5.1 ± 0.2 mmol⁻¹ (30 min) and 5.2 ± 0.3 vs. 3.9 ± 0.4 mmol⁻¹ (90 min), CHO vs. PLA, $F_{3,27} = 9.822, p<0.05$; Figure 4.9).

Conversely, plasma FFA concentrations were consistently higher during exercise in the PLA trial (Figure 4.10). Although there was an interaction effect of time x treatment ($F_{3,27} = 3.334, p<0.05$), no significant differences were found to exist between trials at any single sampling time. There was also a time effect with plasma FFA decreasing from rest to 30 min but then rising till the end of exercise ($F_{3,27} = 9.13, p<0.01$).

![Figure 4.9 Plasma glucose concentration (mmol.l⁻¹) during the LIST for CHO and PLA trials (* significantly higher in CHO trial, $p<0.05$, $n=10$)](image-url)
1.3
0.9
0.7
0.5
0.3

Plasma FFA concentration (mmol.l⁻¹) during the LIST for CHO and PLA trials (n = 10)

4.3.7 Plasma lactate and serum insulin

Plasma lactate concentrations at rest were significantly lower than during exercise ($F_{1.7, 15.3} = 9.822, p<0.01$; Table 4.3), but not different between trials. Similarly, although serum insulin concentration was consistently higher during exercise in the CHO trial, this was not significantly different from the PLA trial (Table 4.3).

Table 4.3 Concentration of plasma lactate (mmol.l⁻¹) and serum insulin (mIU.l⁻¹) during the LIST in the CHO and PLA trials (* significantly different to all exercise time points, $p<0.01$, n = 10)

<table>
<thead>
<tr>
<th>Exercise time (min)</th>
<th>0</th>
<th>30</th>
<th>60</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Plasma lactate (mmol.l⁻¹)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHO</td>
<td>$1.0 ± 0.1^*$</td>
<td>$4.4 ± 0.5$</td>
<td>$4.1 ± 0.5$</td>
<td>$4.1 ± 0.4$</td>
</tr>
<tr>
<td>PLA</td>
<td>$1.0 ± 0.1^*$</td>
<td>$4.0 ± 0.5$</td>
<td>$3.9 ± 0.5$</td>
<td>$4.2 ± 0.4$</td>
</tr>
<tr>
<td><strong>Serum insulin (mIU.l⁻¹)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHO</td>
<td>$8.6 ± 0.9^*$</td>
<td>$5.7 ± 0.8$</td>
<td>$4.6 ± 0.3$</td>
<td>$4.1 ± 0.3$</td>
</tr>
<tr>
<td>PLA</td>
<td>$9.0 ± 1.3^*$</td>
<td>$4.7 ± 0.6$</td>
<td>$4.2 ± 0.4$</td>
<td>$3.1 ± 0.5$</td>
</tr>
</tbody>
</table>
4.3.8 Plasma ammonia and serum cortisol

Plasma ammonia concentrations increased from rest to exercise (11.2 ±1.3 vs. 65-78 mmol.l⁻¹, rest vs. exercise, $F_{2.7,19.2} = 51.306$, $p<0.01$). Furthermore, the rise in plasma ammonia concentrations from resting values to 30 min of exercise were similar in both trials (Figure 4.11). Thereafter, the ammonia concentration continued to rise during the CHO trial but not in the PLA trial. Although an interaction effect was found ($F_{3,21} = 4.074$, $p<0.05$) there was no significant difference between trials at any of the sampling times.

![Graph showing plasma ammonia concentrations during exercise](image)

**Figure 4.11** Plasma ammonia concentration (μmol.l⁻¹) during the LIST for CHO and PLA trials (* main effect of time, significantly lower than all exercise time points, $p<0.01$, $n=8$)

There was a main effect of time for serum cortisol concentrations, with the post-hoc analysis showing that the values at 90 min were significantly higher than all other sampling times (35.2 ±2.3 vs. 25-30 μg.dl⁻¹, 90 min vs. all other sampling times, $F_{3,27} = 9.695$, $p<0.01$). Serum cortisol concentrations were similar between trials up to 30 min of exercise. However, from then on the rise in cortisol values showed a tendency to be greater in the PLA trial (interaction of treatment x time, $p = 0.051$, Figure 4.12).
4.3.9 Plasma volume

There was no significant difference between trials in the changes in plasma volume from rest to the end of exercise (-3.3 ± 1.2% and -4.1 ± 1.7%, CHO and PLA trials, respectively).

4.3.10 Secondary variables

Student’s t-tests on the secondary variables failed to show any significant differences between the CHO and PLA trials. There was no difference in the mean daily energy intake (11.2 ± 0.6 MJ and 12 ± 0.7 MJ, CHO and PLA trials, respectively) nor carbohydrate (393 ± 31 g and 415 ± 31 g, CHO and PLA trials, respectively) content of the 2-day diet prior to each main trial. The exercise intensity during the glycogen reduction exercise (62.5 ± 0.7% and 61.4 ± 1.1%, CHO and PLA trials, respectively) and the total energy (4200 ± 92 kJ) and carbohydrate (74.7 ± 2 g) content of the low CHO meal were the same between trials. Subjects covered the same distance during the LIST (12.3 km) and consumed the same volume of fluid during the main trials.
(1095 ± 23 ml). The loss in body mass, corrected for fluid intake, was also not
different between trials (2.4 ± 0.1 kg and 3.3 ± 0.1%, absolute and relative loss,
respectively). Ambient temperatures, both dry bulb (16-18°C) and wet bulb (10-
11°C), were similar between trials but increased with time ($F_{3.5,52.1} = 26.27$ and $F_{2.8, 42.1} = 6.663$, for dry and wet bulb temperature, respectively, $p<0.01$). Relative
humidity was also similar between trials (55-58%). Furthermore, two-way ANOVA
for correlated data failed to show an order effect in any performance, metabolic or
biochemical variable.
4.4 Discussion

The main finding of the present study was that performance of a soccer passing test decreased by 8% following 90 min of intermittent high-intensity shuttle running with reduced carbohydrate stores.

Carbohydrate ingestion was not shown to contribute significantly to maintaining skill performance. However, the decrease in the CHO trial was 4.5% whereas the decrement in the PLA trial was 11% (Figure 4.3). The LSPT consists of time taken to complete each sequence of passes, plus additional time penalty points imposed for inaccurate passes or poor ball control. As there were no differences between trials nor test occasions for the time taken element of the test, the decrement in the assessed performance was due to the additional penalty time (Table 4.1). This suggests that it was not gross motor performance that was affected by the exercise but a decrease in motor control. Furthermore, from baseline values, there was a 20% increase in penalty time in the CHO trial, whereas in the PLA trial it was 46%. Even though this difference failed to reach statistical significance, it could be postulated that there appears to be a role for an exogenous carbohydrate supply in the maintenance of skill performance following a simulated soccer game.

There was no difference between trials for mean points scored per shot of the LSST. Figure 4.4c shows that there was a tendency for shooting performance to be better maintained in the CHO trial, whereas the opposite appeared to be the trend in the PLA trial. Furthermore, the ingestion of carbohydrate appeared to enable the subjects to perform each shot sequence quicker than when the placebo solution was ingested (ns. Figure 4.4b). Thus, it would seem that subjects in the PLA condition were sacrificing speed of movement in order to maintain accuracy – the so-called ‘speed-accuracy trade-off’ (Fitts and Posner, 1967). This was within the constraints of the LSST but may not be acceptable in a match situation, as the player may be tackled before playing the shot.

Due to the relative lack of information on carbohydrate ingestion and skill performance during intermittent sports, it is difficult to compare the findings of the present study to others in the literature. An early study found that players consuming a
7% glucose syrup performed better than those who did not during match play (Muckle, 1973). As this study was a field test it can be criticised for lacking adequate control. Although Muckle (1973) reported greater player involvement and ball contacts following CHO ingestion, but the exact nature of these activities was not recorded and so one cannot assess whether these were performed skilfully. In a more controlled study, Abt and associates (1998) found that a 3-day high-CHO diet, when compared to a mixed diet, had no effect on dribbling and shooting performance. However, their protocol consisted of only 60 minutes of intermittent exercise, with limited maximal sprinting, and called for subjects to crawl beneath a 90-cm high obstacle and to perform closed soccer skills. Thus, the validity of the study as a means of firstly simulating the demands of soccer, and secondly determining soccer skill, is questionable. Zeederberg and colleagues (1996) reported no measurable benefits of CHO ingestion for soccer-related tasks during soccer matches. The subjective nature of the study, the fact it was a field test, along with the employment of non-competitive ('friendly' or exhibition) games, can again put the validity of the data into question.

McGregor et al. (1999b) found that soccer dribbling performance deteriorated by 5% in the absence of fluid ingestion during the LIST. The ingestion of a CHO solution had no greater benefit on soccer dribbling performance when compared to fluid ingestion alone (McGregor, 1999). Thus, it appears that the present study is the first controlled laboratory study that shows, even with fluid ingestion, a decrement in soccer skill performance following prolonged, high intensity intermittent shuttle running.

One reason for the decrease in skill performance could be due to the low muscle glycogen concentration of the subjects in the present study. McGregor (1999) postulated that the absence of any performance differences in his study could have been due to the level of muscle glycogen in both trials; i.e. the LIST alone does not decrease glycogen concentration to such a critical volume. Indeed, Jacobs (1981) suggested that muscle glycogen concentrations must fall below a critical threshold of 175 mmol.kg\(^{-1}\) dw for anaerobic performance to be seriously affected. Even though the anaerobic component of the skill tests is small, it may be suggested that the players' ability to produce better performances could have been hindered by the limited substrate availability. Nicholas et al. (1999) reported post-LIST muscle
glycogen concentrations of 160 ± 15 mmol.kg⁻¹.dw and 170 ± 24 mmol.kg⁻¹.dw following placebo and CHO ingestion, respectively. Moreover, although no muscle biopsies were taken following the glycogen reduction exercise, the results from a study using a similar protocol suggest that this exercise does significantly lower glycogen content (Bowtell et al., 1999). Thus, the addition of the glycogen reducing exercise, plus the effects of the LIST itself, would have lowered muscle glycogen concentration even further, and possibly compromised the ability of the subjects to perform skillfully. Of course, in the absence of muscle glycogen data we cannot be certain about this speculation.

Hypoglycaemia has been suggested as a possible reason for the deterioration in performance in sports such as soccer, which require both tactical thought and cooperative interaction between players (Shephard and Leatt, 1987). In the current study, plasma glucose was maintained above resting values in the CHO trial, whereas in the PLA trial plasma glucose concentrations fell from 30 min onwards to 3.9 mmol.l⁻¹ at the end of the LIST (Figure 4.9). It could be speculated that the lower glucose availability in the PLA trial may have had an influence on neuromuscular and/or CNS function, resulting in a less than optimal motor control during the skill tests. This may be part of the explanation for the greater increase in penalty time in the LSPT for the PLA trial (Table 4.2). Even though glucose concentrations were significantly lower, as hypoglycaemia was not reached (<3 mmol.l⁻¹, Costill, 1988) in the PLA trial, it still remains to be elucidated as to the possible effects of low plasma glucose concentrations on cognitive functioning and skill performance.

The greater availability of glucose as a substrate in the CHO trial, may have contributed to a reduction in the muscle glycogen utilisation. Indeed, a previous study using the LIST protocol did find that CHO supplementation during exercise led to higher muscle glycogen concentrations post-exercise (Nicholas et al., 1999). Thus, especially towards the end of exercise, this sparing of muscle glycogen could have delayed peripheral fatigue, resulting in not only maintenance of skill levels, but also sprint performance and overall metabolic rate. Indeed, the results of the present study do support such a possibility.
The availability of the exogenous CHO maintained the 15-m sprint performance throughout the LIST better than when no extra CHO was available ($p<0.01$, Figure 4.5). Consequently, there was a higher oxygen uptake and subjects maintained a higher relative exercise intensity in the CHO trial ($p<0.01$, Table 4.2). Using indirect calorimetry it was found that the higher oxygen consumption resulted in an elevated estimated energy expenditure rate, leading to a 205 kJ (50 kcal) extra energy expenditure during the CHO trial ($p<0.01$, Figure 4.8). Thus, the absence of a significant difference in skill performance between trials may be because any advantage accrued from the exogenous glucose supply was being utilised in the form of an elevated metabolic rate. Therefore, subjects ended up with similar carbohydrate stores at the end of exercise and the influence of the exogenous supply of CHO was negated.

Soccer players have been known to lose between 1-3.5 litres (1.5-5% body mass) in sweat during matches and as such players can be adversely affected by dehydration (Maughan and Leiper, 1994). Even a mild degree of dehydration may impair skilled performance and affect strength, stamina and speed (MacLaren, 1996). Saltin and Costill (1988) suggested that a 2% loss of body mass will impair endurance performance by ~10% and, should it reach as much as 5%, then performance losses of ~30% can be expected. In the present study there was no difference in percentage body mass loss during the trials, nor a difference in plasma volume. Thus, there would appear to be other reasons for the reduced work rate and sprint performance in the PLA trial.

Although the participants were sprinting faster and working harder in the CHO condition, the RPE results showed that subjects perceived that they were exerting themselves more in the PLA trial during the latter stages of exercise (Figure 4.7). This would suggest that central fatigue has a major role in helping to explain performance decrements towards the end of exercise.

Cortisol and catecholamines are hormones which reflect the level of physiological strain placed on the body (McGregor, 1999). Catecholamine activity has also been used as evidence for cognitive skill performance in the inverted-U hypothesis.
An increase in catecholamines in the CNS facilitates cognitive functioning, therefore moderate and high intensity exercise should improve skill performance. As subjects become ‘over-aroused’ they will become fatigued and this will lead to a loss in skill performance. In the current study catecholamines were not measured but there was a tendency for higher concentrations of cortisol to be exhibited in the PLA trial from 30 min of exercise. Indeed, the rise in cortisol from rest to post-LIST was 26 and 64% in the CHO and PLA trials, respectively (ns. \( p = 0.08 \)). The trend for a higher cortisol response in the PLA trial may be indicative of a greater catecholamine response, resulting in excessive accumulation of neurotransmitters and a random firing of nerve cells (McMorris et al., 1999), thus leading to ‘over-arousal’ and a decrement in performance. As catecholamines were not measured, this cannot be known for sure.

Increases in plasma ammonia occur during both short-term high-intensity exercise and prolonged exercise (Sahlin and Broberg, 1990). Ammonia is a potential neurotoxin and so it has been suggested that the increased plasma concentration could impair the function of the CNS (Mutch and Banister, 1983). Plasma ammonia concentration was higher in the CHO trial, probably a consequence of the faster sprint times, and therefore it is unlikely that this was the reason why skill performance tended to be worse in the PLA trial.

In the present study much of the metabolic and biochemical data showed significant differences between trials, but this was not reflected in the majority of the performance tests. This is probably as a result of the high day-to-day random variation in human skill performance and so it is suggested that a greater number of subjects be employed in future studies to account for this variability and so increase the statistical power of the study. Furthermore, the soccer skill tests used in the present study may still have areas of improvement and so a reassessment of the LSPT and LSST may be required for future research within the area.
4.4.1 Conclusions

In summary, it can be postulated that even though subjects were sprinting faster in the CHO trial, thus resulting in a greater metabolic rate and a higher energy expenditure, skill performance was still at least as good as in the PLA trial post-exercise. An exogenous CHO supply during exercise also aided the maintenance of plasma glucose concentration with a tendency to limit the increase in serum cortisol levels.
CHAPTER 5

THE RELIABILITY AND VALIDITY OF THE MODIFIED LOUGHBOROUGH SOCCER PASSING TEST (LSPT)

5.1 Introduction

The lack of valid and reliable tests has hindered research into soccer skill performance. Researchers in a previous investigation attempted to address this problem by examining the success in tackling opponents and in controlling, passing, dribbling, heading and shooting the ball during a match (Zeederberg et al., 1996). This approach does not assess skill per se and lacks experimental control due to the live match situation as well as the subjective judgements in deciding success and failure. In addition, it is questionable whether skilled performance can be determined only by successful and unsuccessful outcomes.

Other investigators have used soccer skill tests within a research context (Abt et al., 1998; McGregor et al., 1999b; Northcott et al., 1999). Abt et al. (1998), using a modified version of the Zelenka skills test (Zelenka et al., 1967), looked at the influence of a 2-day high-CHO diet on skill performance. They found no difference in passing accuracy nor time for completion of tests after the dietary regime and following 60 min of intermittent exercise. However, the use of 'athletic obstacles' (netting the subjects had to crawl under) must be questioned due to the irrelevance to soccer play. The use of static rather than dynamic passing also raises the question of whether the examiners were testing 'technique' rather than 'skill'. The specific feature of a skilled movement is where the player has a learnt ability to select and perform the correct technique as determined by the demands of the situation. Furthermore, no real statistics were performed and the investigators only suggested the test was valid and reliable based on no more than mean data. Northcott and colleagues (1999) devised a protocol that incorporated both the physiological (running and sprinting) and skill (static passing and shooting) elements of the game, to investigate the effects of CHO ingestion on soccer performance. However, they gave no information regarding the reliability and validity of the test.
Recognising the limitations of previous tests, the Loughborough Soccer Passing Test (LSPT) was recently developed to assess the multi-faceted aspects of soccer skill including passing, dribbling, control and decision-making within a dynamic context (McGregor et al., 1999a). This test has previously been used to investigate the effects of fluid (McGregor et al., 1999b) and CHO-E ingestion on soccer skill (Chapter 4). Although McGregor and co-workers addressed reliability issues, the validity criterion was not tackled as well. Furthermore, some modifications were made to the original test to make it more sensitive to skill performance. Thus, the purpose of the present study was to assess the reliability and validity of the modified LSPT for research purposes.
5.2 Methods

5.2.1 Subjects

Forty-eight healthy male soccer players (mean ± SE: age 20.2 ±0.2 years, height 1.8 ± 0.01 cm, body mass 74.5 ±0.7 kg and \( \dot{V}O_2 \text{max} \) 57.8 ±0.6 ml.kg\(^{-1}\).min\(^{-1}\)), who were of at least University standard, volunteered to participate in the study. Twenty-four of the players were from the 1st/2nd team squads (20.5 ±0.4 years, 1.8 ± 0.01 m, 74.5 ±1.4 kg and 60 ±0.6 ml.kg\(^{-1}\).min\(^{-1}\)) and twenty-four were from the 3rd/4th team squads (19.9 ±0.2 years, 1.8 ± 0.01 m, 74.5 ±1.7 kg and 55.8 ±0.9 ml.kg\(^{-1}\).min\(^{-1}\); \( p<0.01 \) for \( \dot{V}O_2 \text{max} \)).

5.2.2 Modifications to original test

Figure 5.1 shows a diagrammatic representation of the modified LSPT. The modifications will only be outlined here – please refer to Chapter 3 for full details of the LSPT.

- The overall target area was increased from 50 x 30 cm to 60 x 30 cm. In addition, a 10 x 15 cm piece of aluminium was taped vertically in the middle of the target areas. The strip was taped to the bench only on the top thus leaving the bottom hanging free, so that when the ball hit the centre of the strip, a distinctive noise was heard. This was added to replicate the 'perfect pass'.

- To make the test more sensitive to skill performance the scoring system was revised and penalty time was added for the following errors:
  - 5 s for missing the bench completely or hitting the wrong bench
  - 3 s for missing the target area (60 x 30 cm)
  - 3 s for handling the ball. This was added because in the original test players who lost control handled the ball to get it back under control
  - 2 s for passing the ball from outside of the designated area
  - 2 s for the ball touching any cone
1 s for every second taken over the allocated 43 s to complete the test. This time limit of 43 s was added to try to deter players from trading off speed for accuracy.

1 s was deducted from the total time if the ball hit the 10-cm strip in the middle of the target.

5.2.3 Experimental procedures

Subjects completed two main trials; each separated by at least one day. To account for any time-of-day effects, subjects were asked to come into the laboratory for the second trial within a time difference of no more than ±1 hour of the first. During both trials subjects were given 5 attempts to familiarise themselves with the protocol before recording the next 2 attempts, the mean of which was used as their performance score. Subjects came into the laboratory in groups of no more than five and the same group came together for the second trial. A 10-min standardised warm up, consisting of jogging, striding, sprinting and stretching exercises, preceded the trials.
Figure 5.1. Diagrammatic representation of the modified Loughborough Soccer Passing Test
5.2.4 Statistical analyses

Paired Student’s t-test was used to determine whether there were any differences in physiological characteristics between groups. Student’s t-test was also used to find out whether there were any differences in skill scores between trials (paired t-test) and between groups (unpaired t-test). Pearson’s correlation (r) and intraclass correlation coefficients (ICC) were also used to assess reliability between sets of scores. There are many ways of calculating ICCs and the method used here is the ‘two-way random’ method, as suggested by Atkinson and Nevill (1998), using SPSS (version 10.0). The standard error of measurement (SEM) was also used to assess test-retest reliability. The most common method is $SEM = SD\sqrt{1-ICC}$ (Atkinson and Nevill, 1998). The SEM covers only 68% of the population (1 SD). To make it applicable to 95% of the population (i.e. 2 SD), the 95% confidence intervals (95% CI) were also calculated by multiplying the SEM by two. The coefficient of variation (CV) was also calculated by multiplying the SEM by two. The coefficient of variation (CV) was also calculated by

$$CV = \frac{SD\text{ (of difference between two test scores)}}{overall\text{ mean (of both test scores)}} \times 100$$

The ‘95% absolute levels of agreement’ (LOA), as proposed by Bland and Altman (1986), was the final method of assessing repeatability. To compare the measurements by taking into account heteroscedastic errors via dimensionless ratios, the ‘ratio limits of agreement’ (RLOA), using log transformed measurements, were used as well.

The results are presented as mean values and the standard errors of the mean (± SE). Statistical significance was accepted at $p<0.05$. 
5.3 Results

5.3.1 Validity

A summary of the LSPT performance scores for all groups is presented in Table 5.1. The actual performance score is made up of two variables: the time taken to complete each circuit of the LSPT and any accrued penalty time for poor control or inaccurate passing. Trial 2 scores were significantly improved in all but one of the variables, thus highlighting a trial order effect (Table 5.1).

Table 5.1. Summary of LSPT performance times (s). (* significantly lower than Trial 1, p<0.05; b significantly lower than Trial 1, p<0.01; c significantly lower than mean of 3rds/4ths, p<0.05; d significantly lower than mean of 3rds/4ths, p<0.01)

<table>
<thead>
<tr>
<th></th>
<th>1sts/2nds (n=24)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Trial 1</td>
<td>Trial 2</td>
<td>Mean</td>
</tr>
<tr>
<td>Time only (s)</td>
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<td>39.6 (0.5)</td>
<td>40.2 (0.5)</td>
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</tr>
<tr>
<td>Pen time only (s)</td>
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<td>2.7 (0.9)</td>
<td>3.3 (0.7)</td>
<td></td>
</tr>
<tr>
<td>Performance time (s)</td>
<td>44.9 (0.8)</td>
<td>42.3 (1.0) *</td>
<td>43.6 (0.7) d</td>
<td></td>
</tr>
</tbody>
</table>

<table>
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<tbody>
<tr>
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<td></td>
<td>Trial 1</td>
<td>Trial 2</td>
<td>Mean</td>
</tr>
<tr>
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<td>41 (0.7) b</td>
<td>42.2 (0.8)</td>
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<tr>
<td>Pen time only (s)</td>
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<td>8.6 (1.2) a</td>
<td>10.3 (1.0)</td>
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<tr>
<td>Performance time (s)</td>
<td>55.2 (1.9)</td>
<td>49.9 (1.7) b</td>
<td>52.5 (1.5)</td>
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</table>

<table>
<thead>
<tr>
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<th>All (n=48)</th>
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<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Trial 1</td>
<td>Trial 2</td>
<td>Mean</td>
</tr>
<tr>
<td>Time only (s)</td>
<td>42.1 (0.6)</td>
<td>40.3 (0.4)</td>
<td>41.2 (0.5)</td>
<td></td>
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<tr>
<td>Pen time only (s)</td>
<td>7.9 (0.9)</td>
<td>5.6 (0.9) b</td>
<td>6.8 (0.8)</td>
<td></td>
</tr>
<tr>
<td>Performance time (s)</td>
<td>49.9 (1.3)</td>
<td>46 (1.1) b</td>
<td>48.0 (1.1)</td>
<td></td>
</tr>
</tbody>
</table>

112
Figure 5.2 also shows the contribution of the two variables that make up total performance time. The mean time taken (40.2 vs. 42.2 s, \( t = -2.603, p<0.05 \)), added penalty time (3.3 vs. 10.3 s, \( t = -6.187, p<0.01 \)) and overall performance time (43.6 vs. 52.5 s, \( t = -5.893, p<0.01 \)) was lower in the 1st/2nd team players.

Figure 5.2. LSPT performance time (s) between groups. (** significantly slower than 1st/2nd team players, \( p<0.01 \))

The results of the median-split table analysis shows that for the time taken aspect of the LSPT there does not appear to be any difference between the groups (Table 5.2). However, for the added penalty time, 22 of the 24 1sts/2nds players were in the ‘expected’ group (and vice-versa). Moreover, 21 of the 24 1st/2nd team players overall performance was in the expected group.
Table 5.2. Median-split table for LSPT performance between 1sts/2nds and 3rds/4ths

<table>
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<th>Below median</th>
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<tbody>
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<td></td>
</tr>
<tr>
<td>1sts/2nds</td>
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<td>14</td>
</tr>
<tr>
<td>3rds/4ths</td>
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<td>10</td>
</tr>
<tr>
<td><strong>Penalty time only</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1sts/2nds</td>
<td>2</td>
<td>22</td>
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<tr>
<td>3rds/4ths</td>
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<td>2</td>
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<tr>
<td><strong>Performance time</strong></td>
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<td>1sts/2nds</td>
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<td>21</td>
</tr>
<tr>
<td>3rds/4ths</td>
<td>21</td>
<td>3</td>
</tr>
</tbody>
</table>

5.3.2 Reliability

There were moderate correlations between trials for the time taken aspect of the skill test for the individual squads as well as the group as a whole ($r = 0.65 - 0.75, p<0.01$, Table 5.3). Although significant, the correlation for penalty time is low for the individual squads ($r = 0.37 - 0.38, p<0.05$) but this improved when the group was combined ($r = 0.58, p<0.01$). The correlation for the overall performance for the whole group is also significant but moderate ($r = 0.64, p<0.01$). Although calculated differently, the intraclass correlation coefficients (ICC) for the data shows nearly identical results as the Pearson’s correlation (Table 5.3).
Table 5.3. Pearson's correlation (r), intraclass correlation coefficients (ICC), standard error of measurements (SEM), 95% confidence intervals (95% CI) and coefficient of variation (CV) for LSPT performance. (*significant correlation between trials, p<0.05; ** significant correlation between trials, p<0.01) (NB as penalty time is not on ratio scale cannot use for CV analysis)

<table>
<thead>
<tr>
<th>Variable</th>
<th>r</th>
<th>ICC</th>
<th>SEM (s)</th>
<th>95% CI (s)</th>
<th>CV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1sts/2nds (n=24)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Time only</td>
<td>.75**</td>
<td>.75**</td>
<td>±1.4</td>
<td>±2.8</td>
<td>4.7</td>
</tr>
<tr>
<td>Penalty time</td>
<td>.37*</td>
<td>.36*</td>
<td>±3.1</td>
<td>±6.2</td>
<td>n/a</td>
</tr>
<tr>
<td>Performance time</td>
<td>.43*</td>
<td>.42*</td>
<td>±3.6</td>
<td>±7.1</td>
<td>11.2</td>
</tr>
<tr>
<td><strong>3rds/4ths (n=24)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Time only</td>
<td>.70**</td>
<td>.65**</td>
<td>±2.5</td>
<td>±4.9</td>
<td>8.0</td>
</tr>
<tr>
<td>Penalty time</td>
<td>.38*</td>
<td>.38*</td>
<td>±4.7</td>
<td>±9.4</td>
<td>n/a</td>
</tr>
<tr>
<td>Performance time</td>
<td>.51**</td>
<td>.51**</td>
<td>±6.2</td>
<td>±12.3</td>
<td>16.0</td>
</tr>
<tr>
<td><strong>All (n=48)</strong></td>
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<td></td>
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<tr>
<td>Time only</td>
<td>.73**</td>
<td>.70**</td>
<td>±2.0</td>
<td>±4.0</td>
<td>6.7</td>
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<tr>
<td>Penalty time</td>
<td>.58**</td>
<td>.58**</td>
<td>±4.0</td>
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<tr>
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<td>.64**</td>
<td>±5.0</td>
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<td>14.4</td>
</tr>
</tbody>
</table>

The SEM for time taken is the lowest for each group (±1.4 – 2.5s), indicating this is the most reliable aspect of the test. Furthermore, the SEM for the 1sts/2nds group is lower than the 3rds/4ths for overall performance (±3.6 vs. ±6.2s). The 95% CI is an extension of the SEM and shows the same data as the former but for 95% of the population (i.e. 2 SD). Table 5.3 also shows that the CV for the time aspect is lower than overall performance time for all groups (4.7 – 8% vs. 11.2 – 16%). Moreover, the CV for the 1sts/2nds players is lower than the 3rds/4ths (11.2 vs. 16% for overall performance).
Bland and Altman's (1986) limits of agreement (LOA) illustrate systematic bias as well as random error. Figure 5.3 shows the differences between trials against each individual subject mean for the different aspects of the LSPT. The scale on the Y-axis was kept constant to highlight the magnitude of the random error between the different variables making up LSPT performance in a visual fashion.

A rough indication of any systematic bias can also be observed using these plots. As the 'bias' line lies below the zero line for all variables, this indicates that scores were better in the second trial. The 'time taken' component has the smallest magnitude (±5.4s, Figure 5.3a), indicating that this has the least amount of random error, with penalty and overall performance time showing similar error (±10.9 and ±13.5s, Figure 5.3b and 5.3c).

When separating the two groups (Figure 5.4), it can be seen that LSPT performance was more repeatable in the elite players, both for systematic bias (-2.6 vs. -5.3s, 1sts/2nds vs. 3rds/4ths) and random error (±9.6 vs. ±16.5s, 1sts/2nds vs. 3rds/4ths).
Figure 5.3. 95% absolute levels of agreement between trials for all subjects (n = 48) for A) mean time taken to complete LSPT, B) mean penalty time and C) overall mean LSPT performance (s).
Figure 5.4 95% absolute levels of agreement between trials for (A) 1sts/2nds ($n = 24$) and (B) 3rds/4ths ($n = 24$) for LSPT performance (s)
Atkinson and Nevill (1998) have suggested that it is important to observe whether there is any heteroscedasticity within the data. This was examined by plotting the absolute differences against the individual means and calculating the correlation coefficient. As positive correlations were found, then heteroscedasticity was present within the data and thus ratio limits of agreement (RLOA) were also calculated (Table 5.4). The mean (bias) ratio multiplied or divided by the agreement ratio indicated greater repeatability for the time component as opposed to overall performance (0.96 */÷ 1.13 vs. 0.92 */÷ 1.32). Furthermore, due to the higher mean (bias) ratio and lower agreement ratio, LSPT performance was more repeatable in the 1sts/2nds group (0.94 */÷ 1.25 vs. 0.90 */÷ 1.37, 1sts/2nds vs. 3rds/4ths).

Table 5.4. Bland and Altman’s absolute limits of agreement (LOA) and ratio limits of agreement (RLOA) for LSPT performance

<table>
<thead>
<tr>
<th>Variable</th>
<th>LOA (Mean bias ± 2 SD (s))</th>
<th>RLOA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1sts/2nds (n=24)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time only</td>
<td>-1.4 ± 3.7</td>
<td>0.97 (*/÷ 1.10)</td>
</tr>
<tr>
<td>Penalty time</td>
<td>-1.2 ± 8.6</td>
<td>n/a</td>
</tr>
<tr>
<td>Performance time</td>
<td>-2.6 ± 9.6</td>
<td>0.94 (*/÷ 1.25)</td>
</tr>
<tr>
<td><strong>3rds/4ths (n=24)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time only</td>
<td>-2.4 ± 6.6</td>
<td>0.95 (*/÷ 1.16)</td>
</tr>
<tr>
<td>Penalty time</td>
<td>-3.4 ± 12.6</td>
<td>n/a</td>
</tr>
<tr>
<td>Performance time</td>
<td>-5.3 ± 16.5</td>
<td>0.90 (*/÷ 1.37)</td>
</tr>
<tr>
<td><strong>All (n=48)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time only</td>
<td>-1.8 ± 5.4</td>
<td>0.96 (*/÷ 1.13)</td>
</tr>
<tr>
<td>Penalty time</td>
<td>-2.3 ± 10.9</td>
<td>n/a</td>
</tr>
<tr>
<td>Performance time</td>
<td>-3.9 ± 13.5</td>
<td>0.92 (*/÷ 1.32)</td>
</tr>
</tbody>
</table>
5.4 Discussion

The aim of this study was to assess the validity and reliability of the modified LSPT as a tool to determine soccer skill for research purposes. The time taken, added penalty time as well as overall performance in the LSPT, was significantly better in the 1st/2nd team players. Although there was good repeatability for the group as a whole, this was improved in the 1st/2nd team players. However, a trial order effect was also found, with improved performance in Trial 2.

5.4.1 Validity

To determine the validity of a test, the researcher seeks to answer the question, ‘does the test tell the truth; does it measure what it sets out to measure?’ Indeed, Baumgarter and Jackson (1987) suggested that unless a test is valid, it serves no function. In this study we attempted to measure ‘construct validity’, that is, if a test score is to have real meaning then the person(s) who is believed to possess a lot of the characteristic being investigated should logically receive the higher score. Thus, the 1sts/2nds players should possess more skill than 3rd/4th team players. In addition, the greater the difference between the two groups the higher the validity of the test (Baumgarter and Jackson, 1987).

For the time taken component of the LSPT, there was a 5% better performance by the more elite group ($p<0.05$, Table 5.1). The added penalty time showed a more marked difference between the groups, with a 212% improved performance by the 1st/2nd team players ($p<0.01$, Table 5.1). Overall, the 1st/2nd team players’ performances were 20% better than those of the 3rd/4th team players ($p<0.01$, Figure 5.2). Therefore, it would appear that players who are perceived to possess a superior soccer playing ability (i.e. 1st/2nd team players) better perform the LSPT.

Figure 5.2 shows the contribution of the various components of the LSPT towards the overall performance. As can be seen it, is the added penalty time that makes up the majority of the difference between groups. Therefore, it can be suggested that the difference is due to the better passing accuracy and control of the ball by the more
elite group (fine motor skill), rather than the speed of completing the circuit (gross motor skill), although both aspects are required to form skilled soccer movements.

Criterion validity is another form of validity and is a measure of a test's correlation to some specified criterion. For example, a coach ranks players into different groups (e.g., 1sts/2nds and 3rds/4ths squads); the question is, 'does the ranking on the skill test reflect this criterion?' To assess criterion validity a median-split table was devised to look at expected and observed outcomes. All the scores for the different variables were ranked in order and the median score found. If there was perfect correlation between the coaches' subjective opinions and the scores on the LSPT, then all of the 1st/2nd team players would be below this median score, whereas all of the 3rds/4ths players scores would lie above. Although the scores for the 'time taken' aspect of the skill test was not as clear cut, it can be seen that for penalty time and overall performance, nearly all of the players 'fit' into their respective groups (22 and 21 out of 24 for penalty time and overall performance, respectively, Table 5.2). As a result, it is reasonable to suggest that the LSPT also has high criterion validity.

It is difficult to compare the results of this study to previous attempts to validate a soccer skills test in this way because, to the best of the author's knowledge, no other study has done likewise. However, comparisons can be made on a different aspect of validity, that of 'ecological validity'. Zeederberg and co-workers (1996) attempted to make their judgement on whether CHO ingestion aided soccer playing ability during a game by observing actual aspects of play, thus achieving high ecological validity, but the lack of control does weaken these findings. Apart from the use of 'athletic obstacles' by Zelenka and associates (1967) and later Abt et al. (1998), the biggest drawback to ecological validity in other tests lies in the investigators' definitions of skill.

Soccer has been proposed to involve the application of three types of skill, namely cognitive, perceptual and motor skill, which operate simultaneously in a rapidly changing environment (Bate, 1996). Although there are some closed skills in operation during soccer (e.g., free kicks and corner kicks) the majority of play is open skill. For that reason, isolating one aspect of the game, for example passing from a static situation, a method used by numerous researchers (Zelenka et al., 1967; Reilly
and Holmes, 1983; Abt et al., 1998; Northcott et al., 1999) may make it an execution of ‘technique’ rather than ‘skill per se. The skill aspect is where the player has a learnt ability to select and perform the correct technique as determined by demands of the situation. The essence of this view is that the cognitive component, in the form of decision making, is a fundamental element of the skill. Due to the dynamic nature of the test, while completing the LSPT, players have to constantly decide upon how best to control the ball, how to position themselves for the next pass, where the next target lies and so on. Knapp (1963) suggested that skill is also synonymous with the minimum outlay of time and energy. Consequently, the more skilful the players, the quicker they are able to perform the skill test. They will still be able to make the accurate passes and keep good control of the ball. The results of this study suggest that the more elite players were able to do this whilst performing the LSPT.

5.4.2 Reliability

Barrow et al. (1989) suggested that reliability is the degree to which a measurement instrument consistently measures whatever it measures. This can also be referred to as test-retest reliability. There are a number of ways in which reliability can be assessed and some of these ways will be discussed here.

One way of detecting whether systematic bias has occurred is by the use of t-tests. Based on this information it would appear that there was an improvement in performance from Trial 1 to Trial 2 (Table 5.1). This indicates that a learning effect may be apparent whereby, due to greater exposure to the skill test, players were able to improve their performance second time around. However, t-tests provide no indication of random bias/error, for example biological or day-to-day variation, within the data.

The traditional method of looking for agreement between two sets of data is by using correlation coefficients (r). Statistically significant moderate correlations were observed between Trial 1 and Trial 2 for the different aspects of the skill test (r = 0.58 – 0.73, p<0.01, n = 48, Table 5.2). Reilly and Holmes (1983) reported correlation coefficients of between 0.65 and 0.96 for a battery of skill tests. Thus, it would initially appear that the LSPT is not as reliable as those tests. However, the subjects in
Reilly and Thomas' study included players who had a wide range of footballing ability. This method for assessing reliability has been criticised as the more heterogeneous the sample, the greater the likelihood of achieving a high $r$ value (Bland and Altman, 1986, Atkinson and Nevill, 1998). Therefore, because the subjects in this study were very homogenous, with a similar playing ability (University standard), age, weight, height etc, then this will have affected the $r$ value achieved.

Intraclass correlation coefficients (ICC) are becoming increasingly common for reliability testing in sports medicine (Atkinson and Nevill, 1998). Table 5.3 shows that ICC values were nearly identical to $r$, even though they were calculated differently. Furthermore, ICC has similar problems to Pearson’s correlation, e.g. problems with dealing with homogenous data, and so is a poor method for assessing repeatability.

The use of standard deviation (SD) in the equation for SEM and 95% CI cancels out the inter-individual variation as seen in Pearson’s $r$ and ICC and so are better methods for gauging reliability (Atkinson and Nevill, 1998). With both of these analyses the smaller the result, the greater the reliability. As the 95% CI is more appropriate, due to its being applicable to 95% of the population (as opposed to 68% for SEM), the results of this will be discussed. The ‘time only’ component of the LSPT was more reliable ($\pm 4$ s) than penalty ($\pm 7.9$ s) and overall performance ($\pm 10$ s). Thus, it would appear that the gross motor component of the test is more repeatable than the fine motor aspect of control and accuracy of passing. In addition, the values for the more elite group are lower than the 3rds/4ths players for all aspects, indicating that the test is more reliable in these players (Table 5.3). However, as no other study has performed such analyses with their protocol, then it is difficult to say how reliable this test is compared to others. Moreover, there are many problems with using SEM and 95% CI (see Atkinson and Nevill, 1998) so one must use caution when interpreting these results.

Analysis of CV has appeal for reliability testing due to its use of dimensionless ratios and the fact that it takes into account measurement heteroscedasticity (Atkinson and
Nevill, 1998). Even still, the results echo the pattern of earlier analyses, that is, the time component is more repeatable than the overall performance and the elite players show better repeatability than the 3rd/4th team players (Table 5.3). With CV analysis it is left to the researcher to decide the percentage of error allowed to make the test reliable, usually based on comparison with other methods/tests. However, it is impossible to do this as no other skill test has been analysed using this method.

Bland and Altman’s (1986) limits of agreement (LOA) method has been suggested as a much better means of assessing measurement repeatability in sports science (Atkinson, 1995). The main difference between this and SEM and CV is that LOA assumes a population of individual test-retest differences, whereas, the former assumes a population of repeated measurements around a ‘true’ value for each individual (Atkinson and Nevill, 1998). The Bland and Altman plots (Figure 5.3) graphically illustrate systematic bias and random variation (by the direction and magnitude of the scatter around the zero line, respectively) for the various aspects of LSPT performance. Once again, the data highlight the fact that the speed or gross motor aspect of the test (time taken) is more repeatable than passing accuracy and control (penalty time) and overall performance. Figure 5.4 also clearly shows that there is not only a larger systematic bias but also a greater random variation in performance for the 3rds/4ths players than 1st/2nd team players, thus suggesting that the test is more repeatable amongst better players.

Due to the existence of measurement heteroscedasticity within the data, Bland and Altman’s (1986) ratio limits of agreement (RLOA) were also calculated (Table 5.4). Based on the limitations of the methods already discussed, it can be argued that this is possibly the best method for assessing reliability. It can also be easily understood and interpreted and, due to the use of dimensionless ratios, different variables and tests can be easily compared with each other. In terms of systematic bias, there was a 4% improvement in time taken (1 - 0.96) and an 8% improvement in overall performance (1 - 0.92) in the second trial. Therefore, again showing the existence of a trial order effect. Also, the random variation was 32% for overall performance for the whole group (1 - |1.32|), but this was reduced to 25% for the 1st/2nd team players (1 - |1.25|, Table 5.4), highlighting that there was lower variability in performance amongst the better players.
Many methods of determining reliability were used in this study for a number of reasons. Firstly, for comparison with previous methods that may have used only one or two of the methods were used here. Future studies also have the opportunity to compare different ways of analysing this data. In addition, the use of different methods enables the advantages of each method to be exploited and so be very stringent in the reliability assessment.

5.4.3 Conclusions

The modified LSPT has been shown to be a valid and reliable method of assessing soccer skill performance for research use with University standard soccer players. It also appears to be more repeatable for better players who have less variability in skill levels. In order to reduce learning effects, a longer period of familiarisation may need to be applied before using it for research purposes.
CHAPTER 6

THE RELIABILITY AND VALIDITY OF THE MODIFIED LOUGHBOROUGH SOCcER SHOOTING TEST (LSST)

6.1 Introduction

The fundamental principle of soccer is to score more goals than the opposing team and, therefore, perhaps the most highly valued and important skill element within the game is the ability to score goals (Jinshen et al., 1991). It has been observed through match analysis that most goals are scored towards the end of a game (Reilly and Thomas, 1976) and this has been suggested to be due to the detrimental effects of fatigue on work rate leading to an increase in playing errors, and also a debilitating effect from 'mental fatigue' leading to lapses in concentration possibly associated with poor decision making (Reilly, 1996). However, it is difficult to research such a topic more expansively due to the lack of valid and reliable soccer shooting tests.

Although there are tests popular with coaching organisations, such as the Coca-Cola Soccer Star skill tests (Russell, 1991), these are yet to be validated and so have limited research use. Reilly and Holmes (1983) obtained preliminary data on the validity and reliability of a battery of soccer skills tests in young players using relatively simple protocols, with shooting being one of these tests. The players had to shoot a total of 9 times from 8.2 m to a goal measuring 3.6 x 2.4 m from either a position slightly to the left (with left foot, 3 times), the middle (with dominant foot, 3 times) or right side (with right foot, 3 times) of the goal. A single point was awarded for hitting the middle of goal (1.8 x 2.4 m) and 3 points for either side (0.9 x 2.4 m). There was no significant difference between trials and a moderate correlation between week 1 and week 2 scores (r = 0.65) was observed. However, as the shots were taken from a static position, it can be argued whether the test was assessing 'technique' rather than 'skill' per se. In addition, there was no information as to the speed of the shot, thus players could have hit the ball at speeds unrealistic to the game itself. Furthermore, due to the distance of the goal from the shooting position, it may have resembled more of a 'pass' than a 'shot' in it's truest sense.
Some researchers have incorporated elements of shooting within protocols to assess soccer skill. Northcott and colleagues (1999) devised a test that incorporated both the physiological (running and sprinting) and skill (passing and shooting) elements of the game, to investigate the effects of CHO ingestion on soccer performance. However, they gave no information regarding the reliability and validity of the test and also included static passing and shooting within the protocol.

Understanding the limitations of previous tests, the Loughborough Soccer Shooting Test (LSST) was recently developed to assess shooting ability of soccer players within a dynamic context (Reddin, 1999). A few modifications were made to the original test (Chapter 3) to try to make it more sensitive to skill performance and to improve its ecological validity. Thus, the purpose of the present study was to assess the reliability and validity of the modified LSST for research purposes.
6.2 Methods

6.2.1 Subjects

Forty-eight healthy male soccer players (mean ± SE: age 20.2 ± 0.2 years, height 1.8 ± 0.01 m, body mass 74.5 ± 0.7 kg and VO\textsubscript{2} max 57.8 ± 0.6 ml.kg\textsuperscript{-1}.min\textsuperscript{-1}), who were of at least University standard, volunteered to participate in the study. Twenty-four of the players were from the 1st/2nd team squads (20.5 ± 0.4 years, 1.8 ± 0.01 m, 74.5 ± 1.4 kg and 60 ± 0.6 ml.kg\textsuperscript{-1}.min\textsuperscript{-1}) and twenty-four were from the 3rd/4th team squads (19.9 ± 0.2 years, 1.8 ± 0.01 m, 74.5 ± 1.7 kg and 55.8 ± 0.9 ml.kg\textsuperscript{-1}.min\textsuperscript{-1}; \(p<0.01\) for VO\textsubscript{2} max).

6.2.2 Modifications to original test

Figure 6.1 is a diagrammatic representation of the set up of the modified LSST. The modifications will only be outlined here – please refer to Chapter 3 for full details of the LSST.

- The scoring zones were re-examined to try to make the test more sensitive to skill performance. The optimal placement of a ball to beat the opposing goalkeeper is at the top and bottom corners of the goal and so the revised zones reflect this.

- Within soccer a coach will encourage players to shoot across the goalkeeper towards the open space of the goal. To replicate this within the LSST the players were told that they could only score points if the ball struck the open side of the goal \textit{i.e.} the half the goalkeeper was not covering.

- Players displaying greater shooting ability will invariably be able to shoot using either foot. Therefore, the trial orders were revised so that players had 5 shots off of each foot per trial.
• Previously there were only 2 trial orders but the investigating team discovered that players were able to predict which way to turn and so 6 trial orders were now available for the modified test.

• For the original protocol, whilst ‘following up’ their shot, players finished each shot sequence after touching the goal. However, there were incidents where players were susceptible to injury when sprinting so quickly into a wall. Thus, in the modified test players were informed that they only had to sprint past the goalkeeper or 6 yard (5.5m) line. However, to reflect the fact that they were running a slightly reduced distance the time constraint was also lowered by 0.5 s to 8.5 s.

• The original protocol instructed players to strike the ball at a minimum speed of 48 km.h\(^{-1}\) (30 mph) but this was deemed to be too slow. Initial findings from the research team were compared with data from the FA Premier League along with the subjective opinions of some of the researchers based on coaching and playing experiences. A minimum value of 64 km.h\(^{-1}\) (40 mph) was decided upon for the shot to be valid within the modified test protocol.

• The research team also experimented with the optimal placement of the radar equipment and decided the best option was to position it on the base of the goalkeeper (Figure 6.1).
Figure 6.1 Diagrammatic representation of the modified LSST
6.2.3 Experimental procedures

Subjects completed two main trials; each separated by at least one day. To account for any time-of-day effects, players were asked to come into the laboratory for the second trial within a time difference of no more than ±1 hour of the first. During both trials subjects were given 3 attempts to familiarise themselves with the protocol before recording the next 10 attempts (one trial). Subjects came into the laboratory in groups of no more than 5 and the same group came together for the second trial. A 10-min standardised warm up, consisting of jogging, striding, sprinting and stretching exercises, preceded the trials.

6.2.4 Statistical analyses

The results were analysed using the same statistical procedures described in Chapter 5.
6.3 Results

6.3.1 Validity

A summary of the LSST performance variables is shown in Table 6.1. The mean points scored per shot for the 1sts/2nds group was identical (1.34), whereas there was an improvement from 1.15 to 1.4 for the 3rds/4ths players (ns). Mean shot speed for trials was nearly identical from trial to trial for all groups. Although there was no difference for the 1sts/2nds, there was a significant improvement in the time taken to complete each shot sequence for the 3rds/4ths group (7.99 vs. 8.16s, Trial 2 vs. Trial 1, \( t = 2.117, p<0.05 \)). This also led to the overall group's \( n = 48 \) time taken to be improved in Trial 2 (7.91 vs. 8.04s, Trial 2 vs. Trial 1, \( t = 2.531, p<0.05 \)).

Table 6.1. Summary of LSST performance (mean ± SE) (\( ^a \) significantly lower than Trial 1, \( p<0.05 \); \( ^b \) significantly higher than mean of 3rds/4ths, \( p<0.01 \))

<table>
<thead>
<tr>
<th></th>
<th>1sts/2nds (n=24)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trial 1</td>
<td>Trial 2</td>
<td>Mean</td>
<td></td>
</tr>
<tr>
<td>Time taken (s)</td>
<td>7.91 (0.08)</td>
<td>7.83 (0.05)</td>
<td>7.87 (0.06)</td>
<td></td>
</tr>
<tr>
<td>Shot speed (mph)</td>
<td>49.5 (0.6)</td>
<td>50.3 (0.8)</td>
<td>49.9 (0.6)(^b)</td>
<td></td>
</tr>
<tr>
<td>Points per shot</td>
<td>1.34 (0.11)</td>
<td>1.34 (0.12)</td>
<td>1.34 (0.09)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>3rds/4ths (n=24)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trial 1</td>
<td>Trial 2</td>
<td>Mean</td>
<td></td>
</tr>
<tr>
<td>Time taken (s)</td>
<td>8.16 (0.09)</td>
<td>7.99 (0.07)(^a)</td>
<td>8.07 (0.07)</td>
<td></td>
</tr>
<tr>
<td>Shot speed (mph)</td>
<td>46.5 (0.6)</td>
<td>46.4 (0.9)</td>
<td>46.5 (0.5)</td>
<td></td>
</tr>
<tr>
<td>Points per shot</td>
<td>1.15 (0.13)</td>
<td>1.4 (0.14)</td>
<td>1.28 (0.11)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>All (n=48)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trial 1</td>
<td>Trial 2</td>
<td>Mean</td>
<td></td>
</tr>
<tr>
<td>Time taken (s)</td>
<td>8.04 (0.06)</td>
<td>7.91 (0.05)(^a)</td>
<td>7.97 (0.05)</td>
<td></td>
</tr>
<tr>
<td>Shot speed (mph)</td>
<td>48 (0.5)</td>
<td>48.4 (0.7)</td>
<td>48.2 (0.5)</td>
<td></td>
</tr>
<tr>
<td>Points per shot</td>
<td>1.24 (0.09)</td>
<td>1.37 (0.09)</td>
<td>1.31 (0.07)</td>
<td></td>
</tr>
</tbody>
</table>
Figure 6.2a shows that although the more elite group of players tended to perform better than the 3rds/4ths (1.34 vs. 1.28 points per shot), this was not statistically significant. However, the former had a higher mean shot speed (49.9 vs. 46.5mph, \( t = 4.297, p<0.01 \), Figure 6.2b) and showed a tendency to perform each shot sequence quicker (7.87 vs. 8.07s, \( t = -2.016, p = 0.056 \), Figure 6.3c).

The median-split table shows that for the mean points scored per shot there is no difference between the groups (Table 6.2). However, for the shot speed, 17 of the 24 1sts/2nds players were in the ‘expected’ group (and vice-versa). Moreover, 14 out of 24 1sts/2nds players were in the ‘expected’ group for the time taken aspect of the LSST.

Table 6.2. Median-split table for LSST performance between 1sts/2nds and 3rds/4ths

<table>
<thead>
<tr>
<th>Time taken</th>
<th>Above median</th>
<th>Below median</th>
</tr>
</thead>
<tbody>
<tr>
<td>1sts/2nds</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>3rds/4ths</td>
<td>14</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shot speed</th>
<th>Above median</th>
<th>Below median</th>
</tr>
</thead>
<tbody>
<tr>
<td>1sts/2nds</td>
<td>17</td>
<td>7</td>
</tr>
<tr>
<td>3rds/4ths</td>
<td>7</td>
<td>17</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Points scored</th>
<th>Above median</th>
<th>Below median</th>
</tr>
</thead>
<tbody>
<tr>
<td>1sts/2nds</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>3rds/4ths</td>
<td>12</td>
<td>12</td>
</tr>
</tbody>
</table>
Figure 6.2. Comparison of A) mean points scored per shot, B) mean shot speed (mph) and C) mean time taken (s) to complete each shot sequence between groups. (** significantly greater than 3rds/4ths, p<0.01)
6.3.2 Reliability

There were moderate correlations between trials for the time taken aspect of the skill test for the individual squads as well as the group as a whole ($r = 0.51–0.68$, $p<0.05$). The correlation for shot speed and points scored was much lower, with only the shot speed for the group as a whole being statistically significant ($r = 0.36$, $p<0.05$). Although calculated differently, the intraclass correlation coefficients (ICC) for the data showed nearly identical results as the Pearson’s correlation (Table 6.3).

Table 6.3. Pearson’s correlation (r), intraclass correlation coefficients (ICC), standard error of measurements (SEM), 95% confidence intervals (95% CI) and coefficient of variation (CV) for LSST performance. (* significant correlation between trials, $p<0.05$; ** significant correlation between trials, $p<0.01$)

<table>
<thead>
<tr>
<th>Variable</th>
<th>r</th>
<th>ICC</th>
<th>SEM</th>
<th>95% CI</th>
<th>CV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1sts/2nds (n=24)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time taken</td>
<td>.68**</td>
<td>.64**</td>
<td>± 0.19s</td>
<td>± 0.39s</td>
<td>3.5</td>
</tr>
<tr>
<td>Shot speed</td>
<td>.31</td>
<td>.30</td>
<td>± 2.9mph</td>
<td>± 5.9mph</td>
<td>8.4</td>
</tr>
<tr>
<td>Points scored</td>
<td>.32</td>
<td>.31</td>
<td>± 0.46</td>
<td>± 0.93</td>
<td>49.4</td>
</tr>
<tr>
<td><strong>3rds/4ths (n=24)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time taken</td>
<td>.51*</td>
<td>.50**</td>
<td>± 0.30s</td>
<td>± 0.59s</td>
<td>5.1</td>
</tr>
<tr>
<td>Shot speed</td>
<td>.07</td>
<td>.06</td>
<td>± 3.5mph</td>
<td>± 6.9mph</td>
<td>10.7</td>
</tr>
<tr>
<td>Points scored</td>
<td>.24</td>
<td>.23</td>
<td>± 0.59</td>
<td>± 1.19</td>
<td>65.3</td>
</tr>
<tr>
<td><strong>All (n=48)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time taken</td>
<td>.60**</td>
<td>.58**</td>
<td>± 0.25s</td>
<td>± 0.50s</td>
<td>4.4</td>
</tr>
<tr>
<td>Shot speed</td>
<td>.35*</td>
<td>.33*</td>
<td>± 3.2mph</td>
<td>± 6.4mph</td>
<td>9.5</td>
</tr>
<tr>
<td>Points scored</td>
<td>.26</td>
<td>.26*</td>
<td>± 0.54</td>
<td>± 1.07</td>
<td>57.8</td>
</tr>
</tbody>
</table>
The SEM for all the variables of the test for the 1sts/2nds group was smaller than the 3rds/4ths (Table 6.3). The 95% CI is an extension of the SEM and shows the same data as the former but for 95% of the population (i.e. 2 SD). Table 6.3 shows that the CV for the time aspect is lowest out of the three variables for all groups (3.5 - 5.1% vs. 8.4 - 10.7% vs. 49.4 - 65.3%, time taken, shot speed and points scored, respectively). Moreover, the CV for the 1sts/2nds group is lower than the 3rds/4ths for all the variables (Table 6.3).

Bland and Altman’s (1986) LOA shows systematic and random variation in absolute terms, whereas the RLOA shows the same data but using dimensionless ratios (Table 6.4). The latter will be discussed further due to the ease in comparing between variables in percentages and due to it taking into account measurement heteroscedasticity. Based on the RLOA data in Table 6.4, there is a low systematic variation for all of the variables, thus indicating minimal learning effects took place. For example, for the time taken aspect for all players (n = 48), the systematic variation is 2% (1 - 0.98). There is also relatively low random variation for the gross motor aspects of LSST performance – 9 and 21% for time taken and shot speed for all players (1 - 1.09 and 1 - 1.21, n = 48), respectively. However, there is relatively high random variation for the points scored element (429%). Furthermore, Table 6.4 also highlights that for all variables both systematic and random variation is lower in the 1st/2nd team players.
Table 6.4. Bland and Altman’s absolute limits of agreement (LOA) and ratio limits of agreement (RLOA) for LSST performance.

<table>
<thead>
<tr>
<th>Variable</th>
<th>LOA (Mean bias ± 2 SD)</th>
<th>RLOA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1sts/2nds (n = 24)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time taken (s)</td>
<td>-0.08 ± 0.54</td>
<td>0.99 (*/± 1.07)</td>
</tr>
<tr>
<td>Shot speed (mph)</td>
<td>0.9 ± 8.2</td>
<td>1.02 (*/± 1.19)</td>
</tr>
<tr>
<td>Points scored</td>
<td>-0.01 ± 1.3</td>
<td>0.98 (*/± 3.20)</td>
</tr>
<tr>
<td><strong>3rds/4ths (n = 24)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time taken (s)</td>
<td>-0.18 ± 0.81</td>
<td>0.98 (*/± 1.10)</td>
</tr>
<tr>
<td>Shot speed (mph)</td>
<td>-0.1 ± 9.7</td>
<td>0.995 (*/± 1.23)</td>
</tr>
<tr>
<td>Points scored</td>
<td>0.26 ± 1.63</td>
<td>1.14 (*/± 5.54)</td>
</tr>
<tr>
<td><strong>All (n = 48)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time taken (s)</td>
<td>-0.13 ± 0.68</td>
<td>0.98 (*/± 1.09)</td>
</tr>
<tr>
<td>Shot speed (mph)</td>
<td>0.4 ± 8.9</td>
<td>1.01 (*/± 1.21)</td>
</tr>
<tr>
<td>Points scored</td>
<td>0.13 ± 1.48</td>
<td>1.06 (*/± 4.29)</td>
</tr>
</tbody>
</table>
6.4 Discussion

The results of this study show that although the mean points scored between the two groups were similar, the 1st/2nd team players had a higher shot speed and showed a tendency to complete each shot sequence quicker. The test was also more repeatable amongst the elite group of players. Furthermore, the time taken and shot speed aspects of the test showed greater reliability than the points scored element.

6.4.1 Validity

Validity is a term used to describe if a particular test measures what it sets out to measure i.e. does the test tell the truth. It has been suggested that unless a test is valid it serves no function (Baumgarter and Jackson, 1987). One of its forms is construct validity, that is, if a test score is to have real meaning then a person(s) who is believed to possess a lot of the characteristic being investigated should receive a higher score. Thus, the 1st/2nd team players should logically possess more skill than the 3rd/4th team players.

Although there was only a marginal difference in terms of points scored between the two groups, the more elite players showed a tendency to perform each shot sequence quicker and struck the ball harder (Figure 6.2). Knapp (1963) claimed that a skilled performer will execute the movement using the least amount of time and energy or both by virtue of her definition of skill. Furthermore, Fitts and Posner (1967) contend that a person who is less skilled or is still learning the technique will trade off one aspect of the movement to satisfy another. Therefore, it can be suggested that the 3rd/4th team players were sacrificing speed of movement and technique on the ball to maintain the accuracy of shooting at the goal and thus it can be argued that they were demonstrating a lower degree of 'skill'. Therefore, this line of reasoning can help establish the validity of the test.

Another form of validity is criterion validity – a measure of a tests correlation to some specified criterion. For example, a coach ranks players into different groups (1st/2nd and 3rd/4th team squads), the question being, does the ranking on the skill test reflect this? The median-split table shows that there was no difference in ranking for points
scored (Table 6.2). However, there was a trend for the shot speed and time taken as aspects to be favourable for the more elite players, thus again helping to demonstrate the validity of the test.

As no other soccer-shooting test has been analysed in the same way it is difficult to compare these results to previous research. However, comments can be made on a third type of validity, that of ecological validity. Soccer involves the application of three types of skill, namely cognitive, perceptual and motor skill, which operate simultaneously in a rapidly changing environment (Bate 1996). Although there are some closed skills in operation during soccer (e.g. free kicks and corner kicks) the majority of play is open skill. Thus, isolating one aspect of the game, for example shooting from a static situation, may make it an execution of 'technique' rather than skill \textit{per se}. The skill aspect is where the player has a learnt ability to select and perform the correct technique as determined by the situation demands. The essence of this view is that the cognitive component in the form of decision making is a fundamental element of the skill.

Previous tests have incorporated static shooting as part of their make-up and so can be criticised for investigating technique rather than skill (Northcott \textit{et al.}, 1999; Reilly and Holmes, 1983). Within a game situation players often do not get the space nor time to execute a shot at their leisure and have other obstacles in the way such as a goalkeeper and opposing defenders pressurising them. Players performing the LSST need to display aspects of soccer play other than just shooting at goal, such as reaction time and passing and control of the ball, as well as having to deal with time constraints. Thus, due to the dynamic nature of the test, it can be argued that the LSST also demonstrates a high degree of ecological validity.

6.4.2 Reliability

Reliability or test-retest repeatability is the degree to which a measurement instrument consistently measures whatever it measures (Barrow \textit{et al.}, 1989). Paired t-tests were used to detect systematic bias between groups (Table 6.1). Based on this it would appear that there was no difference in points scored nor shot speed between the group as a whole \((n = 48)\) but players were performing each shot sequence quicker in Trial 2.
(p<0.01), thus displaying a learning effect. However, this trial order effect did not occur in the 1st/2nd group, thus suggesting the test was more repeatable with more elite players.

Student’s t-test can only be used to distinguish systematic bias and so other statistical procedures must be employed to detect random error. For a more comprehensive discussion on the relative merits of the various methods of assessing agreement between two sets of data please refer to Chapter 5.

Pearson’s r and ICCs, some of the more traditional methods of assessing reliability, show moderate correlations for the time taken aspect of the shooting test (Table 6.3). There are also low SEM, 95% CI and CV measures for the time taken element. Although there appear to be low correlations for shot speed, this is misleading because of the homogenous nature of the data. The SEM, 95% CI and CV measures for the shot speed aspect are relatively low as well, thus demonstrating the repeatability of this facet of the skill test. Even though there was a low correlation for points scored there was also relatively high SEM, 95% CI and CV. However, it may be too simplistic to state the test is unreliable because of this (see below).

From the Bland and Altman limits of agreement (LOA) analysis it can be seen that there is a low systematic and error variance for the time taken and shot speed aspects of the test (Table 6.4). Even though the systematic variance was low for the points scored, there was a high random variation. As there was measurement heteroscedasticity evident within the data the ratio limits of agreement (RLOA) were calculated as well (Table 6.4). Moreover, in this way the amount of variance for the different facets of the test could be compared using dimensionless ratios.

Based on the RLOA data in Table 6.4 there was a low systematic variation for all of the variables. For example, for the time taken aspect for all players (n = 48), the systematic variation was 2% (1 - 0.98). There was also relatively low random variation for the gross motor aspects of LSST performance: 9% (1 - 1.09) and 21% (1 - 1.21) for time taken and shot speed for all players (n = 48), respectively. However, there was relatively high random variation for the points scored element (429%).
Therefore, it would appear that the gross motor aspects of the test, *i.e.* time taken and shot speed, were more repeatable than the fine motor element of points scored. Even though the random variation of the points scored appears relatively high, this reflects the very nature of the game itself, where players of the highest calibre can have varying degrees of consistency with their shooting ability from match-to-match. Also, the fact that the skill test has high ecological validity may have reduced the reliability aspect. It is the author's opinion that this is justified so as to make the test as valid as possible, even though the test-retest repeatability may be hindered. Furthermore, when used for research purposes the investigating team may need to increase the sample size so as to account for the variability in day-to-day performance of the shooting test. In addition, Table 6.4 also highlights that for all variables, both systematic and random variation is lower in the 1st/2nd team players. Therefore, it is recommended that future research using the LSST utilise the highest calibre of players possible, as they will have less random day-to-day variation in shooting performance.

As with the results for the LSPT in the previous chapter, many methods have been used to determine reliability for comparison with previous and future studies as well as the fact that the use of different methods gives a better overall picture and the advantages of the various methods can be exploited.

### 6.4.3 Conclusions

In summary, the LSST has been shown to be a valid and reliable test of soccer skill for use with University soccer players for research purposes. The LSST is the only shooting skill test that has been properly validated and so is the leading test of its kind for research purposes. It appears to be more reliable for better players who have less variability in skill levels. Due to the relatively high random variation of the points scored facet of the test a large number of subjects may need to be used to offset this.
CHAPTER 7

THE INFLUENCE OF CARBOHYDRATE-ELECTROLYTE INGESTION ON SOCCER SKILL PERFORMANCE DURING AND FOLLOWING THE LIST

7.1 Introduction

Soccer dribbling performance has been found to deteriorate following 90-min of intermittent high-intensity shuttle running exercise in the absence of fluid ingestion (McGregor et al., 1999b). Moreover, soccer passing performance was found to decrease following a similar bout of exercise even with fluid ingestion, with a tendency for subjects to maintain performance better when CHO was added to the fluid (Chapter 4). Other studies have also examined skill performance before and after intermittent exercise (Abt et al., 1998; McGregor, 1999; McGregor et al., 1999b). However, using such experimental designs gives no indication as to when the skill decrement may have occurred, i.e. is it gradual over the duration of exercise or is it a sudden phenomenon that occurs right at the end of the test (game)?

Northcott and colleagues (1999) examined this question by having subjects perform 10 m, 20 m and 30 m passes and a 15-m shooting task after every 15 min of intermittent running exercise. For each skill element, error was dependent on the distance from a specified target. In the placebo condition, performance improved from pre-test score up to 60 min of exercise and then returned to resting levels after the 90 min of intermittent exercise. However, in the CHO trial all activity 'skill' test scores were better than pre-test values. Nevertheless, such static passing and shooting drills may be more representative of technique rather than skill per se.

Reflecting on the strengths and weaknesses of the LSPT and LSST, we identified some areas of the tests that could be improved. Therefore, the tests were modified to try to make them more sensitive to skill performance (Chapters 5 and 6).

Previous studies employing the LSPT and LSST recruited University standard soccer players as subjects, who had a range of skill levels (Chapter 4; McGregor et al.,
1999b; McGregor, 1999). From the results of the reliability analyses of the modified LSPT and LSST (Chapters 5 and 6), it was evident that the 1st/2nd team players displayed much lower variability in day-to-day performance than players from the 3rd/4th teams. Therefore, the recruitment of a better standard of players would increase the likelihood of detecting any beneficial aspects of the intervention due to the lower random variation.

Therefore, the purpose of the present study was to use the design as previously reported (Chapter 4) but with some modifications. Furthermore, only 1st/2nd team players would be used as participants for this study. Subjects would also perform the LSPT during the rest intervals between each 15-min block of the LIST as well as both tests at baseline, pre- and post-LIST.
7.2 Methods

7.2.1 Subjects

Sixteen healthy male soccer players (age 20.1 ± 0.3 years, height 1.8 ± 0.02 m, body mass 71.9 ± 1.3 kg and $\dot{V}O_2$ max 59.7 ± 0.7 ml.kg$^{-1}$.min$^{-1}$, mean ± SE), who were semi-professional, ex-professional or of at least 1st/2nd team University standard players, volunteered to participate in the study. The subjects were from a range of outfield playing positions and were involved in regular training and matchplay.

7.2.2 Preliminary measurements

Subjects reported to the laboratory on two separate occasions for preliminary measurements. During the first session subjects' height, weight, and $\dot{V}O_2$ max were determined. Subjects were also fully familiarised with the skill tests and the LIST protocol during both sessions.

7.2.3 Experimental procedures

Subjects completed two main trials, each separated by at least 7 days. The order of trials was randomised to counteract order effects. Subjects were asked to record their diet for the day prior to, and on the day of, the glycogen reduction exercise, and to maintain a similar level of intake prior to both trials. Each main trial took place over 2 days (Figure 7.1). The participants reported to the laboratory at approximately 17:00 hours on day 1. Following a standardised 10-min warm up, subjects performed the pre-exercise skill tests (the modified LSPT and LSST, see Chapters 5 and 6 respectively), which were used to set the baseline performance. To provide the most valid skill performance prior to any exercise, the baseline scores for both trials were combined. After a brief rest period (5-10 min), subjects were required to complete the glycogen reduction exercise (Chapter 3). At approximately 20:00 hours the participants were provided with a low carbohydrate meal (Chapter 3), and then instructed to fast until the following morning.
Upon arrival on the morning of day 2, subjects' nude body mass was determined, after which the resting blood and expired gas sample was collected. Following the same standardised warm up procedure, subjects performed the second set of skill tests (pre-LIST). The participants were then provided with the test drink. In the carbohydrate treatment subjects were provided with a commercially available sports drink containing 6.4% CHO (Lucozade Sport, GlaxoSmithKline, Brentford). In the other treatment, a placebo was provided which was manufactured to replicate the taste of the test drink, but containing neither carbohydrate nor electrolytes. Prior to the commencement of the LIST, subjects ingested a bolus equivalent to 5ml.kg⁻¹ BM and then 2ml.kg⁻¹ BM after every 15min of exercise (Figure 7.1).

After ingestion of the test drink participants completed six 15-min blocks of the LIST punctuated by 4-min rest periods. The rest period was increased by 1 min so as to give the subjects the same 'rest' between each block of exercise as before. Within these rest periods subjects performed the LSPT after which they ingested the equivalent of 2 ml.kg⁻¹ BM of the same drink. Expired gas samples were collected using the modified Douglas bag method (Chapter 3) towards the end of each block of the LIST. Perceived exertion (RPE) and environmental temperature were measured on the last walk phase of each 15-min block of exercise. Heart rate (HR) was monitored continuously throughout exercise via short-range telemetry. The subjects were constantly encouraged to maintain the pace set by the audio signals and to perform maximally during the sprints. After completion of the LIST, participants were given a brief (~5 min) rest prior to the post-exercise skill tests. Nude body mass was determined after the post-LIST skill tests after subjects had towel dried themselves to remove excess sweat.
Figure 7.1 Schematic representation of the experimental protocol and the Loughborough Intermittent Shuttle Running Test (LIST)
7.2.4 Blood analyses

Blood samples were withdrawn from an indwelling venous cannula (Chapter 3), in volumes of 10 ml, at rest and after 30, 60 and 90 min of the LIST. The blood was dispensed, treated and stored as previously described (Chapter 3). Changes in plasma volume were determined using hematocrit and haemoglobin values (Chapter 3). Plasma samples were analysed for ammonia, glucose, lactate and FFA concentration and serum samples for insulin, prolactin and cortisol using methods described previously (Chapter 3).

7.2.5 Statistical analyses

The procedures used were as described under statistical analysis in Chapter 3. The results are presented as mean values and the standard errors of the mean (± SE). Statistical significance was accepted at $p<0.05$. 
7.3 Results

7.3.1 Performance of LSPT

Although there was a 4% decrease in LSPT performance from baseline to post-LIST this was not statistically significant (39.5 ± 0.7 vs. 41.1 ± 1.1s, baseline vs. 90min, ns; Figure 7.2). There were also no statistically significant differences in any LSPT performance variable between CHO and PLA trials (Table 7.1)

Figure 7.2 LSPT total performance time (s; combined data CHO+PLA, n = 16)
Table 7.1 Time taken to complete, penalty time accrued, and overall LSPT performance (s) in the CHO and PLA trials (n = 16)

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>0</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
<th>75</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time only (s)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHO</td>
<td>38.3 ± 0.9</td>
<td>38.6</td>
<td>38.2</td>
<td>37.9</td>
<td>38.2</td>
<td>38.3</td>
<td>37.8</td>
<td></td>
</tr>
<tr>
<td>PLA</td>
<td>± 0.5</td>
<td>± 0.8</td>
<td>± 0.8</td>
<td>± 0.6</td>
<td>± 0.9</td>
<td>± 0.9</td>
<td>± 0.7</td>
<td></td>
</tr>
<tr>
<td><strong>Penalty time only (s)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHO</td>
<td>2.3 ± 0.7</td>
<td>1.7</td>
<td>2.8</td>
<td>1.9</td>
<td>1.4</td>
<td>1.7</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>PLA</td>
<td>± 0.5</td>
<td>± 1.3</td>
<td>± 1.3</td>
<td>± 1.7</td>
<td>± 1.3</td>
<td>± 1.2</td>
<td>± 1.3</td>
<td></td>
</tr>
<tr>
<td><strong>Overall performance (s)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHO</td>
<td>40.8 ± 1.2</td>
<td>40.4</td>
<td>40.0</td>
<td>39.7</td>
<td>39.6</td>
<td>39.9</td>
<td>41.7</td>
<td></td>
</tr>
<tr>
<td>PLA</td>
<td>± 0.7</td>
<td>± 2.4</td>
<td>± 1.5</td>
<td>± 2.1</td>
<td>± 1.6</td>
<td>± 2.0</td>
<td>± 1.9</td>
<td></td>
</tr>
</tbody>
</table>

7.3.2 Performance of LSST

There was no difference in points scored between time points nor conditions (~1.5 points per shot, Figure 7.3a). However, players mean shot speed decreased from baseline to post-exercise (51.5 ± 0.5 vs. 49.5 ± 0.5 mph, baseline vs. post-LSST, $F_{2,30} = 7.681, p<0.01$), with no difference between trials (Figure 7.3c). Subjects also took longer to perform each shot sequence from baseline to pre-LSST to post-LSST (7.65 ± 0.04 vs. 7.74 ± 0.04 vs. 7.91 ± 0.05 s, baseline vs. pre-LSST vs. post-LSST, $F_{1.5,22} = 14.898, p<0.01$). Although there was a trend for the time taken to be lower post-exercise in the CHO trial this was not statistically significant (7.87 ± 0.06 vs. 7.95 ± 0.07 s, CHO vs. PLA, ns, Figure 7.3b).
Figure 7.3 Comparison of A) mean points scored per shot, B) mean shot speed (mph) and C) mean time taken (s) to complete each shot sequence between CHO and PLA trials (n = 16)
7.3.3 15-m sprint performance

Subjects' 15-m sprint performance deteriorated with the ongoing duration of the LIST and the post-hoc analysis showed that the mean time in blocks 5-6 (~2.61 s) was significantly slower than blocks 1-3 (~2.55 s, $F_{1.8, 27.2} = 9.929$, $p<0.01$). Mean sprint times were consistently quicker in the CHO condition but there was no treatment effect ($2.55 \pm 0.01$ vs. $2.58 \pm 0.01$ s, CHO vs. PLA, ns, Figure 7.4).

![Figure 7.4 Mean 15-m sprint time (s) per block of the LIST in CHO and PLA trials (n = 16) ](image)

7.3.4 HR and RPE

Even though at the start and end of exercise there was a tendency for HR to be higher in the CHO trial there was no significant difference between trials (Figure 7.5). Mean HR increased from block 1 and was higher from 15-75 min of exercise ($157 \pm 1.6$ vs. $162$ beats.min$^{-1}$, block 1 vs. blocks 2-5, $F_{2, 19.8} = 4.859$, $p<0.01$) but not from 75-90 min ($160 \pm 2$ beats.min$^{-1}$).
There was a main effect of time for RPE during the LIST, with both trials exhibiting higher values as the LIST progressed \((F_{2, 30.6} = 65.837, p<0.01)\). There was also an interaction effect of treatment x time. Mean RPE values were significantly higher in blocks 5 and 6 during the PLA trials (15.5 ± 0.4 vs. 14.8 ± 0.5 (block 5), 16.6 ± 0.3 vs. 15.4 ± 0.5 (block 6), PLA vs. CHO, \(F_{5, 75} = 4.67, p<0.01\), Figure 7.6).

**Figure 7.5** Mean HR values (beat.min\(^{-1}\)) per block of the LIST in CHO and PLA trials (\(n = 11\))

**Figure 7.6** RPE values per block of the LIST in CHO and PLA trials (** significantly higher in PLA trial, \(P<0.01\), 11 ---: 16)
7.3.5 Oxygen uptake, RER and energy expenditure

Mean oxygen uptake was maintained in the CHO trial throughout exercise but decreased after 30 min of the LIST in the PLA condition (interaction effect of treatment x time, $F_{4.6,63.7} = 3.928, p<0.01$) but the post-hoc analysis did not highlight any differences at any specific time points (Figure 7.7). The relative exercise intensity, expressed as %VO$_2$ max, showed similar results to mean oxygen uptake (interaction effect of treatment x time, $F_{4.5,63.3} = 3.775, p<0.01$, Table 7.2). Even though there was a difference of over 5% between trials during block 6 (79 ± 1.5% vs. 73.8 ± 1.9%, CHO vs. PLA) there were no differences between conditions at any single sampling times.

Figure 7.7 Mean oxygen uptake values (ml.kg$^{-1}$.min$^{-1}$) during the LIST in CHO and PLA trials ($n = 15$)
Table 7.2 Relative exercise intensity (% VO_2 max), RER and energy expenditure rates (kJ.min^{-1}) at rest, during each 15min block and overall mean of the LIST in the CHO and PLA trials (** significantly higher than PLA trial, p<0.01; * significantly higher than PLA trial, p<0.05; n = 15)

<table>
<thead>
<tr>
<th></th>
<th>Rest</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>Mean of trial</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(exercise only)</td>
</tr>
<tr>
<td>% VO_2 max</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>CHO</td>
<td>10.5 ± 0.5</td>
<td>79.1 ± 1.4</td>
<td>78.4 ± 1.4</td>
<td>79.9 ± 1.2</td>
<td>79.7 ± 1.4</td>
<td>79.4 ± 1.2</td>
<td>79.0 ± 1.5</td>
<td>79.2 ± 0.4</td>
</tr>
<tr>
<td>PLA</td>
<td>10.7 ± 0.5</td>
<td>78.9 ± 1.6</td>
<td>79.5 ± 1.7</td>
<td>77.7 ± 1.7</td>
<td>77.5 ± 1.3</td>
<td>76.0 ± 1.5</td>
<td>73.8 ± 1.9</td>
<td>77.2 ± 0.5</td>
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<tr>
<td>Respiratory exchange ratio (RER)</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>CHO</td>
<td>0.85 ± 0.01</td>
<td>0.92 ± 0.01</td>
<td>0.91 ± 0.01</td>
<td>0.90 ± 0.01</td>
<td>0.91 ± 0.01</td>
<td>0.89 ± 0.01</td>
<td>0.90 ± 0.01</td>
<td>0.90 ± 0.01</td>
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<tr>
<td>PLA</td>
<td>0.88 ± 0.02</td>
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<td>0.91 ± 0.01</td>
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<td>Energy expenditure rates (kJ.min^{-1})</td>
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<td></td>
</tr>
<tr>
<td>CHO</td>
<td>9.0 ± 0.5</td>
<td>68.0 ± 1.6</td>
<td>67.3 ± 1.5</td>
<td>68.5 ± 1.2</td>
<td>68.3 ± 1.4</td>
<td>68.1 ± 1.6*</td>
<td>67.8 ± 1.8*</td>
<td>68.0 ± 1.5**</td>
</tr>
<tr>
<td>PLA</td>
<td>9.1 ± 0.4</td>
<td>67.2 ± 1.5</td>
<td>67.5 ± 1.1</td>
<td>65.9 ± 1.1</td>
<td>65.9 ± 1.4</td>
<td>64.5 ± 1.4</td>
<td>62.3 ± 1.1</td>
<td>65.6 ± 1.0</td>
</tr>
</tbody>
</table>
Although there were no differences between trials, RER was higher from blocks 1-4 (0.91-0.92) than at rest (0.87 ± 0.01; main effect of time, $F_{5,70} = 7.374, p<0.01$, Table 7.2). However, RER was not statistically significant between resting values and during the last 30min of exercise (0.87 ± 0.01 vs. 0.89 ± 0.01, rest vs. blocks 5-6, ns).

Energy expenditure rates, estimated using indirect calorimetry equations, showed two main effects as well as an interaction effect of treatment x time. Further analyses showed that energy expenditure rates were higher in blocks 5 and 6 in the CHO trial (68.1 ± 1.6 vs. 64.8 ± 1.4 kJ.min$^{-1}$ (block 5), 67.8 ± 1.8 vs. 62.3 ± 1.1 kJ.min$^{-1}$ (block 6), CHO vs. PLA, $F_{4.6,63.9} = 4.171$, $p<0.05$, Table 7.2). Moreover, the estimated total energy expenditure was 220 kJ (55 kcal) higher in the CHO trial (6120 ± 131 vs. 5901 ± 92 kJ, CHO vs. PLA, $t = 2.583$, $p<0.05$, Figure 7.8).

**Figure 7.8** Estimated total energy expenditure (kJ) during the LIST in CHO and PLA trials. (* significantly greater than PLA trial, $p<0.05$, $n = 15$)
7.3.6 Plasma glucose

Plasma glucose concentrations showed time and interaction effects. Plasma glucose concentrations were maintained in the CHO condition to at least resting levels throughout exercise, but declined in the PLA trial (main effect of treatment x time, $F_{3, 33} = 4.171$, $p<0.05$, Figure 7.9). However, the post-hoc analysis did not show any differences between any sampling times.

![Graph showing Plasma glucose concentrations (mmol.l$^{-1}$) during the LIST for CHO and PLA trials (n = 12)](image)

Figure 7.9 Plasma glucose concentrations (mmol.l$^{-1}$) during the LIST for CHO and PLA trials ($n = 12$)
7.3.7 Plasma FFA

There were time and interaction effects for plasma FFA concentrations as well. Mean concentrations were maintained in the CHO trial at near resting values but increased sharply during exercise in the PLA treatment with a significant difference at 90 min (0.9 ± 0.1 vs. 1.6 ± 0.2 mmol.l⁻¹, CHO vs. PLA, $F_{3, 33} = 18.118$, $p<0.01$, Figure 7.10).

![Graph showing plasma FFA concentrations over time for CHO and PLA trials.](image)

**Figure 7.10** Plasma FFA concentrations (mmol.l⁻¹) during the LIST for CHO and PLA trials (* significantly higher in PLA trial, $p<0.01$, $n = 12$)
7.3.8 Plasma lactate

Plasma lactate concentrations were significantly higher during exercise than at rest (1.0 ± 0.04 vs. 4-5 mmol.l⁻¹, rest vs. exercise, $F_{3, 27} = 4.171, p<0.01$, Figure 4.11). Figure 4.11 shows that plasma lactate concentrations showed a tendency to be higher in the CHO trial but this did not reach statistical significance.

![Figure 7.11 Plasma lactate concentrations (mmol.l⁻¹) during the LIST for CHO and PLA trials (* significantly lower than all exercise time points, $p<0.01$, $n = 12$)](image-url)

**Figure 7.11** Plasma lactate concentrations (mmol.l⁻¹) during the LIST for CHO and PLA trials (* significantly lower than all exercise time points, $p<0.01$, $n = 12$)
7.3.9 Serum insulin

Serum insulin concentrations were lower post-exercise than at rest (main effect of time, 18.3 ± 1.1 vs. 11.4 ± 0.5 mIU.1⁻¹, rest vs. 90 min, \( F_{3, 12} = 5.248, p<0.05 \)). Even though there was an interaction effect of treatment x time, with insulin higher during exercise in the CHO trial (\( F_{3, 12} = 3.614, p<0.05 \), Figure 4.12), there was no significant difference at any single time point.

Figure 7.12 Serum insulin concentrations (mIU.1⁻¹) during the LIST in the CHO and PLA trials (\( n = 5 \))
7.3.10 Plasma ammonia

Plasma ammonia concentrations increased from rest and was significantly higher during all exercise time points (main effect of time, 17.7 ± 3.0 vs. 55-70 mmol.l⁻¹, rest vs. exercise, $F_{3, 15} = 10.852, p<0.01$, Figure 7.13). There was no difference between trials even though plasma ammonia concentration appeared to be higher at 60 min in the CHO trial (76 ± 19 vs. 58 ± 9 mmol.l⁻¹, CHO vs. PLA, $p = 0.1$, ns).

![Figure 7.13 Plasma ammonia concentrations (μmol.l⁻¹) during the LIST for CHO and PLA trials (* main effect of time, significantly lower than all exercise time points, $p<0.01$, n= 6)](image.png)
7.3.11 Serum cortisol and prolactin

Serum cortisol concentrations decreased from rest to 30 min and then increased to 90 min of exercise (main effect of time, 30 ± 1.9 vs. 24.4 ± 1.7 vs. 33.8 ± 3.0 μg.dl⁻¹, rest vs. 30 min vs. 90 min, $F_{2,21.8} = 3.719$, $p<0.05$, Figure 7.14). Cortisol appeared to be maintained at resting concentrations throughout exercise with CHO supplementation, but increased in the PLA trial. However, this did not reach statistical significance ($p = 0.09$).

![Figure 7.14 Serum cortisol concentration (μg.dl⁻¹) during the LIST for CHO and PLA trials (n = 12)](image)

Serum prolactin concentrations also showed a main effect of time, with concentrations at 90 min significantly higher than at all other time points (8-11 vs. 14.9 ± 2 ng.ml⁻¹, 0-60 min vs. 90 min, $F_{1.5, 16.4} = 4.425$, $p<0.01$). Figure 7.15 shows that prolactin concentrations were maintained at around resting values in the CHO trial but increased sharply in the PLA trial (interaction effect of treatment x time, $F_{3, 33} = 3.202$, $p<0.05$) but there were no differences between trials at any sampling times.
Figure 7.15 Serum prolactin concentration (ng.ml\(^{-1}\)) during the LIST for CHO and PLA trials (n = 12)

7.3.12 Plasma volume

There was no significant difference between trials in the changes in plasma volume from rest to the end of exercise (-4.2 ± 1.0% and -2.5 ± 1.6%, CHO and PLA trials, respectively).

7.3.13 Secondary variables

Student’s t-tests on the secondary variables failed to show any significant differences between the CHO and PLA trials. There was no difference in the mean daily energy intake (11.05 ± 0.75 MJ and 11.2 ± 0.9 MJ, CHO and PLA trials, respectively) nor carbohydrate content (421 ± 37 g and 400 ± 39 g, CHO and PLA trials, respectively) of the 2-day diet prior to each main trial. The exercise intensity during the glycogen reduction exercise (61 ± 1% and 62 ± 1%, CHO and PLA trials, respectively) and the total energy (4000 ± 56 kJ) and carbohydrate (71.5 ± 1 g) content of the low CHO meal were the same between trials. Subjects travelled the same distance during the LIST (12.3 km), consumed the same volume of fluid during the main trials (1060 ± 21 ml), and the loss in body mass, corrected for fluid intake, was also not different.
between trials (2.4 ± 0.1 and 2.5 ± 0.1 kg, CHO and PLA trials, respectively). Ambient temperature, both dry bulb (14.5-16°C) and wet bulb (10-11°C) were similar between trials but increased with time ($F_{5, 75} = 55.447$ and $F_{2.8, 38} = 42.224$, for dry and wet bulb temperature, respectively, $p<0.01$). Relative humidity was also similar between trials (52-57%). Furthermore, two-way ANOVA for correlated data failed to show an order effect in any performance, metabolic or biochemical variable.
7.4 Discussion

The main finding was a 4% decline in LSPT performance from baseline to post-LIST but this did not reach statistical significance. Furthermore, even though there was no difference in the points scored from baseline to post-LIST in the LSST, there was a decrease in shot speed and an increase in time taken to complete each shot sequence. There were no improvements in any of the skill test variables with CHO-E ingestion. Nevertheless, RPE was significantly lower with CHO-E ingestion during the last 30 min of exercise.

When investigating the influence of CHO or fluid ingestion on skill performance, the majority of studies have examined performance before and after a period of exercise (Abt et al., 1998; Burke et al., 1997; McGregor et al., 1999b; Ostojic and Mazic, 2002; Chapter 4). Therefore, the primary purpose of the present study was to determine whether there was a gradual (i.e. throughout exercise) or rapid (i.e. immediately at the end) decline in skill performance through repeated trials of the LSPT during the LIST. Ignoring any statistical significance, the best performance occurred prior to any exercise (baseline) and, on the main trial day itself, performance appeared to improve from pre-LIST and after 15 min of the LIST followed by a gradual decrease to post-LIST (Figure 7.2). There were no differences between the CHO and PLA trials (Table 7.1).

Zeederberg and colleagues (1996) assessed the skill proficiency in tackling opponents and controlling, passing, dribbling, heading and shooting the ball throughout a game. They did not report any difference in soccer skill throughout the game whether subjects consumed CHO or not during the game. The lack of experimental control during this field study reduces the validity of the investigation. Northcott et al. (1999), using a more controlled laboratory protocol, showed that passing and shooting performance in a placebo trial improved from the pre-test score up to 60 min of exercise and then deteriorated to pre-exercise levels (i.e. U-shaped performance curve). In their CHO trial, all activity skill test scores were better than pre-test (i.e. L-shaped curve), with significant differences between trials at 75 and 90 min. Therefore, it would appear that there are similarities between the combined data of the present study and the data from the placebo trial of Northcott et al. (1999). As there was no
blood, HR, or RPE data from that investigation it was difficult for the authors to speculate why skill performance was maintained in the CHO trial.

The improvement in skill performance from pre-exercise to 30 min of exercise in the current study and in the study of Northcott et al. (1999) could be due to an increase in core and muscle temperature. It has been shown that increased muscle temperature from moderate exercise results in improved speed of nerve transmission (Astrand and Rodahl, 1986), which aids gross body movement, including co-ordination (McMorris et al., 1994). As muscle and core temperature would increase with prolonged exercise, this does not explain why skill performance drops towards the end of exercise.

Easterbrook (1959) suggested that there is an inverted-U relationship between arousal and performance. The theory states that when arousal levels are low, i.e. at rest, then performance is also low. With moderate exercise, arousal levels increase and this is associated with peak cognitive and motor performance (i.e. top of inverted-U). Further increases in arousal, i.e. with fatiguing exercise, results in a decrease in performance back to baseline levels. Indeed, it would appear that LSPT performance in the current study, and passing and shooting performance in the study by Northcott et al. (1999), followed such a pattern. A relationship between arousal and concentrations of catecholamines have also been reported (Cooper, 1973). As catecholamine concentrations were not measured during this study, then this association can only be speculated.

Hypoglycaemia has been suggested as a possible cause of loss of performance in soccer because these sports require tactical and decision making processes (Shephard and Leatt, 1987). In Chapter 4 it was shown that there was a tendency for penalty time (of the LSPT) to be higher in the PLA trial. Furthermore, there was a significant drop in plasma glucose in the later stages of the LIST in the PLA trial but values were maintained above resting concentrations with CHO ingestion. Even though plasma glucose values were similar in the present study (Figure 7.9) there were no differences in added penalty time between the CHO and PLA trials (Table 7.1). Therefore, the exact nature of the relationship between glucose availability and skill performance remains unclear.
Figure 7.3 shows the performance variables for the LSST. At first glance it appears that there is no effect of exercise on the overall performance as there were no differences in points scored between baseline and post-LIST. Due to the changes in shot speed and time aspects there appears to be a ‘speed-accuracy trade-off’ (Fitts and Posner, 1967) for LSST performance i.e. to maintain points scored players were reducing shot speed and taking longer to perform each shot sequence (Figure 7.3). Therefore, it may be too simplistic to say that there was no effect of exercise on shooting performance as the shot itself is a ‘technique’, and how it is performed and under what circumstances makes it an application of a skilful movement.

The time taken to complete each shot sequence of the LSST increased from 7.8 to >8 s post-exercise (Figure 7.3b). Furthermore, although not significant, there was a tendency for quicker performance in the CHO trial post-LIST. The shot sequence time consisted of various aspects of the LSST, namely reaction time and time to pass, control, shoot and sprint. It would be interesting to determine which aspects of this was being reduced due to the effect of exercise and if CHO ingestion was having a beneficial impact. Without more sophisticated timing equipment this cannot be ascertained. Nevertheless, as sprint performance showed a tendency to be better maintained in the CHO trial it is possible that this was also reflected in the LSST, i.e. players were able to maintain the speed of performing the test better after CHO ingestion than fluid alone.

The speed at which the ball was struck in the LSST trials also reduced significantly from baseline to post-LIST (Figure 7.3c). Therefore, it would appear that leg power deteriorated following the 90 min of exercise. Chiu et al. (1998) and Cabri et al. (1988) showed that better players possessed greater isokinetic leg strength, and this was correlated with a greater speed and distance travelled by the ball. Moreover, Oberg et al. (1986) suggested that elite players possess a greater degree of fast-speed muscle isokinetic strength. Although not measured in the current study, a previous investigation showed that peak and average torque (Nm), total work (J) and average power (Watts) during isokinetic and isometric contractions of the quadriceps was reduced following 90 min of the LIST (Ali, 1999). Therefore, with a decrease in leg power the speed at which the subjects struck the ball was also reduced. There was no influence of CHO ingestion on maintaining the ball speed.
Soccer dribbling performance has been shown to deteriorate by 5% in the absence of fluid ingestion (McGregor et al., 1999b) and CHO ingestion (Ostojic and Mazic, 2002) during 90 min of intermittent exercise. Furthermore, there was an 8% decrease in skill performance, even with fluid ingestion, as determined by the LSPT (Chapter 4). However, in the present study, although there was a 4% decrease in performance (even with fluid and CHO ingestion) this was not statistically significant. There are a number of possible reasons for this. It may be due to random day-to-day variation in skill or general human variability. In the present study, a better cohort of players was employed relative to those used previously (Chapter 4; McGregor et al., 1999b). Nevertheless, it still is an issue that cannot be readily ignored, especially as many factors impinge on skill performance (Bate, 1996). Although the skill tests were re-assessed so as to improve their ecological validity and sensitivity to skill performance (Chapters 5 and 6), they may yet require further modification. It may be too simplistic to try and examine skill performance through quantitative measures alone and qualitative evaluation, for example video analysis by elite coaches, may be required.

Due to the trend towards faster sprint performance with CHO ingestion (see below), the subjects maintained a higher oxygen uptake and relative exercise intensity in the CHO trial (Figure 7.7 and Table 7.2). This resulted in subjects expending more energy during the LIST in the CHO trial (Figure 7.8). (This information must be treated with caution, as the use of RER to estimate energy expenditure during intermittent exercise can be open to question because of the non-steady state exercise.) Therefore, the exogenous energy provided in the CHO trial was being utilised during the exercise. Thus, if the net energy expenditure was similar at the end of exercise why should one expect any improvements in skill performance in the CHO trial? In terms of practical guidelines to soccer players, the implication of this can be very important. In other words, CHO ingestion during soccer will enable players to maintain a higher overall work rate and yet they will be able to maintain skill performance to at least the level if only fluid was provided. Also, if the extra energy provided in the CHO trial was being utilised, then what may be the effect of providing CHO at a higher rate? Indeed, whereas CHO was administered at a rate of ~30 g per hour in the present study, investigations that have shown a significant beneficial impact of CHO ingestion on skill and motor performance have provided CHO at much higher rates (50-70.
g.hour\(^{-1}\); Graydon et al., 1998; Northcott et al., 1999; Welsh et al., 2002). Therefore, future studies could increase the rate of CHO provision and so widen the independent variable.

Although the influence of CHO ingestion on skill performance was equivocal, there does appear to be other physiological and psychological benefits of CHO supplementation. Sprint performance showed a tendency to be better maintained in the CHO trial throughout the LIST, but this was not statistically significant (Figure 7.4). The greater lactate and ammonia concentration in the CHO trial (although not statistically significant) also highlights the metabolic effects of the better sprint performance with supplementation (Figures 7.11 and 7.13).

In the PLA trials subjects reported higher RPE scores towards the end of exercise, with significant differences at 75 and 90 min of the LIST (Figure 7.6). This finding is in agreement with the results of Chapter 4. Therefore, subjects perceived that they were exerting themselves to a greater extent towards the end of the PLA trials. This seems paradoxical as during the same period of time sprint times were slower (Figure 7.4), and oxygen uptake (Figure 7.7), relative exercise intensity (Table 7.2) and HR (Figure 7.5) was lower in the PLA trial. DeMarco et al. (1999) reported a clear and strong relationship between blood glucose concentration and RPE. It may be that the glucose availability in the PLA trial was affecting brain cognition, thus leading to increased perceptions of effort. In the present study, although significant, there was a weak inverse correlation between plasma glucose and RPE ($r = -0.30$, $p<0.05$). It may be that subjects were actually ‘feeling’ worse in the PLA trials and they were indicating this via RPE measures. The RPE scale is a measure of exercise intensity and not ‘affect’. Therefore, future studies may wish to examine this notion further i.e. are subjects perceiving that they are exercising at a higher intensity or are they ‘feeling’ worse? Nevertheless, as there was no difference in performance scores between conditions then the significance of this is not clear.

7.4.1 Conclusions

In summary, soccer skill performance appeared to improve initially with the onset of exercise and then gradually decrease until post-exercise. The 4% overall decline in
LSPT performance was not statistically significant. There was a speed-accuracy trade-off for LSST performance from baseline to post-LIST; to maintain shooting accuracy subjects reduced their shot speed and the time taken to complete each shot sequence. There was no apparent benefit of CHO ingestion on skill performance. The benefits of CHO ingestion seemed to be in maintaining sprint performance and reducing the perception of effort during the later stages of the LIST. Therefore, although the effects of CHO ingestion on skill performance are unclear there appears to be other physiological and psychological benefits, which may be just as important for soccer performance.
CHAPTER 8

THE INFLUENCE OF INTERMITTENT HIGH-INTENSITY RUNNING AND CARBOHYDRATE-ELECTROLYTE INGESTION ON GASTRIC EMPTYING

8.1 Introduction

One of the considerations athletes should make when planning a drinking strategy to improve performance is the gastric emptying potential of the fluid. Maughan (1991) suggests that the rate of emptying is one of the major determinants of the availability and hence the efficacy of ingested solutions.

A number of studies propose that the rate at which CHO-E solutions are emptied from the stomach is influenced primarily by the volume of fluid ingested and the carbohydrate content of the solution (Coyle and Montain, 1992; Mitchell and Voss, 1991; Vist and Maughan, 1994). It appears that the greater the volume ingested, the greater the rate of emptying. Shi and Gisolfi (1998) suggested that this could be due to the distension and pressure created by the increased volume in the stomach. Furthermore, the fact that increasing the CHO content may increase substrate availability but decrease the availability of water is of concern and so most sports drinks have a CHO content of <10% (Coombes and Hamilton, 2000). Indeed, it appears that solutions containing less than 8% CHO appear to have little effect on gastric emptying rate (Noakes et al., 1991) and such solutions are considered optimal for both fluid and CHO delivery.

Most studies using prolonged continuous exercise advocate that exercise intensity plays a minor role in gastric emptying rate until the intensity exceeds 70% VO_2 max, after which gastric emptying is considerably slowed (Leiper et al., 2001b). In many sports the average exercise intensity is over 70% VO_2 max, even though this may consist of low, moderate and high intensity periods punctuated by infrequent maximal sprints. Several studies have shown the benefits of CHO-E supplementation on performance using intermittent protocols (Hargreaves et al., 1984; Nicholas et al.,...
Therefore, the low intensity periods during intermittent exercise may allow for adequate emptying to take place (Leiper et al., 2001a).

Leiper et al. (2001a) examined the effect of CHO-E ingestion during intermittent high-intensity cycle exercise on gastric emptying. Subjects either cycled at an intensity of 66% $\dot{V}O_2$ max for 60 min or at an average intensity of 66% made up of alternating periods of exercise at 60 and 100% $\dot{V}O_2$ max. Even though the fluid loss was similar between the trials, the delivery of fluid and CHO from the stomach was higher in the continuous protocol. Therefore, at the same average exercise intensity, fluid and energy delivery is compromised when subjects perform intermittent exercise. The protocol involved cycling and so may not be readily extrapolated to free running. Indeed, many studies examining gastric emptying have used cycling as the mode of exercise and then extrapolated to sports in general. Free running is much more common within most sports and, due to the weight bearing nature of running, there may be differences in gastric emptying of fluids. Anecdotal evidence suggests that elite runners do not consume a great deal of fluid before races because it may cause them stomach cramps. Although some studies reported no differences in emptying between cycling and running (e.g. Rehrer et al., 1990), other researchers have suggested that emptying may actually improve during running (Costill, 1990).

A previous investigation specifically investigated the influence of consuming a 6% CHO-E beverage on gastric emptying during 30 min of 5-a-side soccer (Leiper et al., 2001b). They found that 21% of the CHO drink was emptied in the soccer trial compared to 49% in the low intensity walking trial. Therefore, of the 60 g of CHO consumed, 14 g was emptied in to the duodenum in the soccer trial and nearly 30 g in the walking trial. The average exercise intensity, calculated from heart rate during the exercise, was less than 60% $\dot{V}O_2$ max. As the exercise intensity of competitive soccer has been shown to be much higher (70-80% $\dot{V}O_2$ max; Bangsbo, 1994a) the results of this study may lack applicability. The Loughborough Intermittent Shuttle running Test (the LIST) is an intermittent running protocol that closely simulates the demands of competitive soccer (Nicholas et al., 1995; 2000) and may be a better tool to investigate gastric emptying during soccer.
Therefore, the purpose of the current study was to determine the gastric emptying rate of fluid during prolonged high-intensity shuttle running. A further aim was to assess whether there were any differences in the gastric emptying rate after ingestion of either a 6.4% carbohydrate-electrolyte solution or a flavoured water placebo solution at rest and during exercise.
8.2 Methods

8.2.1 Subjects

Eight healthy male games players (age 20 ± 1 years, height 1.8 ± 0.02 m, body mass 82.9 ± 3.6 kg and \( \text{VO}_2 \text{max} \) 53.2 ± 1.6 ml.kg\(^{-1}\).min\(^{-1}\), mean ± SE), volunteered to participate in the study. They were in regular training for various team and individual sports (rugby, soccer and tennis).

8.2.2 Preliminary measurements

Initially, all of the potential subjects reported to the laboratory and were screened to identify individuals who could be successfully intubated with the oro-gastric aspiration tube used to determine gastric emptying. Those subjects who were successful completed the progressive multi-stage shuttle running test to estimate \( \text{VO}_2 \text{max} \) and were also fully familiarised with the LIST protocol (Chapter 3). Furthermore, measurements of height and weight were also obtained (Chapter 3).

8.2.3 Experimental procedures

Subjects completed four main trials; each separated by at least 2 days. In two of the trials subjects were required to perform 2 x 15-min blocks of the LIST separated by a 3-min rest (LIST) and in the other two trials subjects were required to walk slowly in the sports hall for the same duration of time (Walk). In the carbohydrate trial subjects were provided with a commercially available sports drink containing 6.4% carbohydrate (Lucozade Sport, GlaxoSmithKline, Brentford; CHO). An artificially sweetened placebo, which was manufactured to replicate the taste of the test drink, but containing neither CHO nor electrolytes was provided in the other trial (PLA). The order of trials was determined using a Latin square order design and all subjects completed all four trials. Subjects were asked to record their diet for the day prior to the first main trial and to maintain a similar level of intake prior to the second trial. The participants reported to the laboratory after a 10-12-hour overnight fast.
Upon arrival in the morning, and after emptying their bladders, subjects' nude body mass was determined. Nude body mass was also ascertained following the completion of exercise after subjects had towel dried themselves to remove excess sweat. A standardised 10-min warm up was performed before the LIST trials but not prior to the Walk trials. Subjects were then fitted with the HR monitors (Chapter 3) and set to record every 15 s. During the exercise trials RPE was monitored on the last walk stage of each block of the LIST (Figure 8.1).

**Figure 8.1** Schematic representation of the experimental protocol and the LIST

### 8.2.4 Gastric emptying procedure

Subjects passed the gastric aspiration tube (French Levine, 14 gauge, Vygon Ltd, France) orally and positioned it in their stomach. The tube was positioned such that the stomach could be effectively emptied and the length of tube that each subject required to swallow was established during the preliminary session. The fasting
gastric contents were then emptied from the stomach via the tube using a 50-ml catheter tipped syringe (Becton Dickinson, Drogheda, Ireland). The stomach was washed with 100 ml of distilled water and a recovery test was carried out to ascertain that the aspiration tube was correctly positioned (Hassan and Hobsley, 1970).

Subjects then consumed a volume of the test drink equivalent to 5 ml.kg⁻¹ BM and containing 25 mg.l⁻¹ phenol red (water-soluble, BDH, Poole, UK). The stomach contents were thoroughly mixed by repeated aspiration and re-injection of the stomach contents using the 50-ml syringe. A 2.5-ml aliquot of gastric contents was also collected. The gastric tube was removed and subjects began exercising within 2-3 min after ingesting the drink.

Exactly 15 min after starting exercising they sat down and re-introduced the gastric tube. The stomach contents were mixed as before and a 2.5-ml aliquot of stomach contents was collected. One millilitre of phenol red, at a concentration of 1000 mg.l⁻¹ was injected into the stomach, and the contents mixed as before, and a further 2.5-ml aliquot was collected. The gastric tube was removed and the subjects were given a smaller volume of the test drink (2 ml.kg⁻¹ BM) containing 25 mg.l⁻¹ phenol red and they began exercising for a further 15 min.

After the second bout of exercise subjects again sat down and re-introduced the gastric tube. The gastric contents were mixed as before and a 2.5-ml sample collected, 1 ml of phenol red, at a concentration of 1000 mg.l⁻¹ injected into the stomach, and the contents mixed once more before another 2.5-ml aliquot was collected. One hundred millilitres of distilled water was then injected into the stomach, mixed with the gastric contents and the total fluid volume of the stomach was then emptied as completely as possible by aspiration. This volume, minus the 100 ml of distilled water, was recorded and used to compare whether the total gastric volume at the end of each trial was similar as calculated by the method of Beckers et al. (1988) and by direct aspiration.

As phenol red dye is poorly absorbed by the stomach (Bloom et al., 1967), the difference in concentration of the dye in the original test drink and the collected samples can be used to calculate the total volume in the stomach and the volume of
test drink remaining in the stomach at the specific time points (Beckers et al., 1988). The difference between the total gastric volume and the test drink volume is the volume of secretions and swallowed saliva.

8.2.5 Chemical analysis

The phenol red concentration of test solutions and aspirated samples was measured spectrophotometrically at a wavelength of 560 nm after dilution (1:10) with NaOH-NaHCO₃ buffer (250:500 mmol.l⁻¹, pH 9.7). The carbohydrate content of drinks and aspirates was determined using a glucose oxidase method (GOD perid; Roche-Boehringer, East Sussex, UK) following acid hydrolysis of the sample (Jansson, 1981). Osmolality was determined by freezing point depression (Gonotec Osmometer 034, Clanden Scientific, Hants, UK).

8.2.6 Statistical analysis

A 2 x 2 x 2 ANOVA with repeated measures for correlated data was performed for total fluid and drink volume emptied and HR, with factors for mode of exercise, drink and time. The rest of the analysis was the same as described under statistical analysis in Chapter 3. The results are presented as mean values and the standard errors of the mean (± SE). Statistical significance was accepted at p<0.05.
8.3 Results

8.3.1 Total fluid and drink volume in the stomach

Table 8.1 shows the volume of fluid and test drink in the stomach at the start of the first and second periods of exercise. Based on this, the amount of fluid ingested and the concentration of phenol red, the amount of fluid and drink emptied from the stomach into the duodenum was determined. Furthermore, Table 8.1 shows that there was no difference in gastric volume measurement as determined by the method of Beckers et al. (1988) and by direct aspiration.

Table 8.1 The mean (± SEM) of the test drink (ml) and total volume of fluid (ml) in the stomach in the four trials

<table>
<thead>
<tr>
<th></th>
<th>Walk trials</th>
<th>LIST trials</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>CHO PLA</td>
<td>CHO PLA</td>
</tr>
<tr>
<td>Start of first 15min of exercise</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test drink volume (ml)</td>
<td>420 ± 12</td>
<td>420 ± 12</td>
</tr>
<tr>
<td>Total fluid volume (ml)</td>
<td>451 ± 16</td>
<td>456 ± 16</td>
</tr>
<tr>
<td>Start of second 15min of exercise</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test drink volume (ml)</td>
<td>428 ± 13</td>
<td>360 ± 20</td>
</tr>
<tr>
<td>Total fluid volume (ml)</td>
<td>516 ± 19</td>
<td>423 ± 20</td>
</tr>
</tbody>
</table>

Table 8.2 Comparison of gastric volume (ml) as calculated by the method of Beckers et al., (1988) and direct aspiration

<table>
<thead>
<tr>
<th></th>
<th>Walk trials</th>
<th>LIST trials</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CHO PLA</td>
<td>CHO PLA</td>
</tr>
<tr>
<td>Calculated gastric volume (ml) (Beckers et al., 1988)</td>
<td>359 ± 27</td>
<td>233 ± 23</td>
</tr>
<tr>
<td>Aspirated gastric volume (ml) (minus the wash out volume)</td>
<td>327 ± 34</td>
<td>228 ± 21</td>
</tr>
</tbody>
</table>
8.3.2 Total fluid volume emptied from stomach

Figure 8.2 shows the total volume of fluid emptied from the stomach into the small intestine. A greater volume of fluid was emptied during the Walk than LIST trials (main effect of mode of exercise, $459 \pm 17$ vs. $327 \pm 19$ ml, Walk vs. LIST, $F_{1,7} = 12.528, p<0.01$). There was a trend for fluid to empty to a greater extent in the PLA than the CHO trials, but this did not reach statistical significance ($424 \pm 22$ vs. $361 \pm 20$ ml, PLA vs. CHO, $p = 0.13, ns$). Moreover, there was a tendency for emptying to be higher during the second than the first 15-min test period, but again not statistically significant ($172 \pm 18$ vs. $220 \pm 15$ ml, first 15 min vs. second 15 min, $p = 0.10, ns$).

![Graph showing fluid volume emptied from stomach during trials](image.png)

**Figure 8.2** Mean fluid volume emptied from the stomach during the trials ($n = 8$).

The magnitude of the decrease in emptying from the Walk to LIST trials of the fluid volume was similar and so there was no interaction effect of mode x drink. Fluid emptied at similar volumes between sampling times in the Walk trial ($227 \pm 22$ vs. $232 \pm 21$, first 15 min vs. second 15 min). Although there was an increase in emptying from the first to the second 15-min period of the LIST trials ($118 \pm 20$ vs. $208 \pm 22$, first 15 min vs. second 15 min), there was no significant interaction of mode x time ($p = 0.16$). There were similar emptying rates in the first and second 15 min periods in the PLA trials ($206 \pm 28$ vs. $218 \pm 18$ ml, first 15 min vs. second 15 min). Although
there was an increase in emptying from the first to second 15 min of the test period in the CHO trials (139 ± 19 vs. 222 ± 24 ml, first 15 min vs. second 15 min), there was no significant interaction of drink x time (p = 0.13).

### 8.3.3 Total drink volume emptied from the stomach

Figure 8.3 shows the drink volume emptied from the stomach in to the small intestine during the various trials. There was a greater drink volume emptied during the Walk than the LIST trials (main effect of mode of exercise, 344 ± 16 vs. 210 ± 16 ml, Walk vs. LIST, $F_{1,7} = 75.513, p<0.01$). There was a tendency for a greater amount of the placebo drink to be emptied than the CHO solution during the trials (303 ± 23 vs. 250 ± 15 ml, PLA vs. CHO, $p = 0.14$, ns). There were no differences in the amount of the test drink emptied between sampling times (145 ± 16 vs. 132 ± 14 ml, first 15 min vs. second 15 min).

![Figure 8.3](image)

Figure 8.3 Mean drink volume emptied from the stomach during the trials ($n = 8$).
There was a greater decrease in emptying from Walk to LIST for the placebo drink (396 ± 18 vs. 211 ± 27 ml, Walk vs. LIST) than the CHO drink (293 ± 18 vs. 208 ± 21 ml, Walk vs. LIST) but there was no significant interaction of mode x drink (p = 0.16). There was also no significant interaction of mode x time i.e. during the Walk trials drink volume was emptied at a higher rate than the LIST trials during both sampling times. There was a tendency for greater emptying of the placebo solution in the first 15 min compared with the CHO solution (176 ± 26 vs. 115 ± 17 ml, PLA vs. CHO), with similar rates between the test solutions during the second 15 min of the test period (128 ± 19 vs. 135 ± 20 ml, PLA vs. CHO), but no significant interaction of drink x time (p = 0.09).

Figure 8.4 shows the fate of the ingested drinks during the trials. The same total volume of test drink was ingested on all four trials (587 ± 24 ml). The mean volume of the test drink emptied over the whole 30 min, expressed as a percentage of the total volume ingested, was greater during Walk than LIST trials (58 ± 3 vs. 35 ± 4%, Walk vs. LIST, $F_{1,7} = 77.481, p<0.01$). There was a trend for a greater percentage of the total placebo solution to empty from the stomach than the CHO drink (51 ± 5 vs. 43 ± 3%, PLA vs. CHO, $p = 0.13, ns$). There was no difference in emptying between drinks in the LIST trials (35%) but, even though a greater percentage of the placebo drink emptied during the Walk trial, there was no significant interaction of mode x drink (67 ± 2 vs. 50 ± 3%, PLA vs. CHO, $p = 0.14, ns$).
There was no difference in mean sprint times between LIST trials (2.59 ± 0.02 vs. 2.59 ± 0.02 s, CHO vs. PLA, ns.) nor sampling times (2.60 ± 0.02 vs. 2.58 ± 0.02 s, block 1 vs. block 2, ns.).

### 8.3.5 HR and RPE

There were three main effects for HR during the trials (Figure 8.5). Heart rate was higher during LIST than Walk trials (169 ± 2 vs. 68 ± 1 beats.min⁻¹, LIST vs. Walk, \( F_{1,6} = 1312.133, p<0.01 \)), CHO than PLA trials (120 ± 10 vs. 117 ± 10 beats.min⁻¹, CHO vs. PLA, \( F_{1,6} = 9.99, p<0.05 \)), and second 15 min than first 15-min test period (119 ± 10 vs. 117 ± 10 beats.min⁻¹, second 15 min vs. first 15-min, \( F_{1,6} = 10.206, p<0.05 \)). There were no interaction effects between any of the variables.
Furthermore, there was no difference in RPE between trials (14.2 ± 0.3 vs. 13.6 ± 0.4, CHO vs. PLA, ns.).

8.3.6 Secondary variables

There were no differences in body mass before any of the trials (~82.7 kg). The body mass loss, corrected for fluid intake, was greater after the LIST than Walk trials (1.3 ± 0.1 vs. 0.4 ± 0.1 kg, LIST vs. Walk, $F_{1,7} = 41.806, p<0.01$), but not between CHO and PLA trials. Furthermore, ambient conditions were similar during all four trials (16°C, 10-11°C and 45-50%, dry bulb temperature, wet bulb temperature and relative humidity, respectively).
8.4 Discussion

The main finding of the present study was that gastric emptying of fluids was reduced during the LIST compared to low-intensity walking exercise. There was also a trend for emptying to be reduced during the low intensity walking with ingestion of a CHO-E solution relative to an artificially sweetened water solution. There was no difference in gastric emptying between CHO-E and PLA solutions during the LIST.

There was a significant reduction in gastric emptying during the LIST trials relative to the low intensity walking exercise. Furthermore, this was evident in the total volume of fluid (Figure 8.2), as well as the total amount of drink (Figure 8.3), emptied into the small intestine. Disregarding the type of solution, 58% of the drink was emptied during the Walk trials whereas only 35% emptied in the LIST trials (p<0.01, Figure 8.4).

It has been reported that gastric emptying is not affected by exercise at intensities below 70-75% \( \dot{V}O_2 \) max, and intensities above this reduce emptying (Brouns et al., 1993; Costill and Saltin, 1974; Shi and Gisolfi, 1998). Moreover, some studies have shown that moderate intensity exercise actually increases the rate of emptying relative to no exercise (Neufer et al., 1989). Relative exercise intensity was not measured in the present study but previous investigations, using the modified Douglas bag method or a portable analyser (KB1-C, AeroSport Inc.), showed that subjects were working at an intensity equivalent to 70-80% \( \dot{V}O_2 \) max during the LIST (Chapter 4; McGregor, 1999). Furthermore, the mean HR during exercise in those investigations was between 160-165 beat.min\(^{-1}\). In the present study, the mean HR was 169 beat.min\(^{-1}\), thus suggesting subjects were exercising to at least similar relative intensities. Therefore, in agreement with previous research, it would appear that the LIST is completed at exercise intensities that decrease gastric emptying relative to rest or low intensity walking.

Intermittent exercise at relative intensities of <70% \( \dot{V}O_2 \) max has been shown to impair gastric emptying compared to continuous exercise at the same average intensity (Leiper et al. 2001a). Moreover, 5-a-side soccer, played at relative intensities
of 55-60% \( \dot{VO}_2 \text{max} \) has been shown to decrease emptying relative to low intensity walking exercise similar to the present study (Leiper et al. 2001b). Leiper et al. (2001b) suggested that this could have been due to the high-intensity running and sprinting during the soccer activity.

There are a number of possible mechanisms responsible for this decrease in emptying during the LIST. Gastric emptying is brought about by a higher gastric than duodenal pressure caused by muscular contractions controlled via neural and hormonal factors (Minami and McCallum, 1984). Any exercise-induced release of vasoactive hormones, many of which inhibit gastric contractility, could slow emptying (Murray, 1987). As the high-intensity periods of the LIST results in a concomitant increase in blood flow (anecdotal evidence suggests that many subjects are near HRmax following the 15-m sprints), then this effect on gastric contractility may be exacerbated. The mean HR during the LIST was 169 beat.min\(^{-1}\), but the body shunts the increased blood flow to the working muscles. Therefore, a greater reduction in splanchnic blood flow produced by the intermittent exercise could also reduce emptying (Rowell, 1974). This may cause a reduction in the rate of intestinal absorption and therefore lead to a build up of nutrients in the intestinal lumen. As the rate of emptying is regulated to limit the rate at which the constituents enter the small intestine (Minami and McCallum, 1984; Murray, 1987) then this may be one of the mechanisms involved. Furthermore, Neufer et al. (1989) suggested that it could be a mechanical effect whereby emptying could be slowed due to the amount of upper body movement that effects gastric motility. Other authors have suggested that this mechanical effect may actually help increase emptying (Costill, 1990). Due to the disparity in results there is as of yet no clear evidence of why exercise intensity influences gastric emptying. What is clear is that soccer type exercise, either due to the relatively high average exercise intensity (70-80% \( \dot{VO}_2 \text{max} \)) or the frequent bouts of high-intensity running and sprinting, causes a reduction in gastric emptying of CHO and water solutions.

There was a trend for faster gastric emptying with the placebo drink. Interestingly, this difference only occurred during the low intensity exercise; whereas 67% of the PLA drink was emptied over the 30 min, this was reduced to 50% when the CHO-E
solution was consumed \(p = 0.14, \text{ns, Figure 8.4}\). There was no difference in emptying between drinks during the LIST, with 35% of the ingested solution emptied into the small intestine (Figure 8.4). Therefore, this is the first study to show conclusively that there is no difference in gastric emptying between a commercially available sports drink and an artificially sweetened (water) solution during soccer type intermittent exercise.

There appears to be some debate within the literature as to the optimal concentration of a CHO-E beverage for the most favourable delivery of both water and energy. Noakes et al. (1991) suggested that solutions containing less than 8% CHO have no discernible effect on emptying. Coombes and Hamilton (2000) reported other studies which show that CHO concentrations of up to 10% made no difference in emptying relative to water. Others proposed that gastric emptying is reduced when the carbohydrate concentration of the beverage exceeds 6% (Leiper, 2001; Maughan, 1997). In the present study a 6.4% CHO-E solution did not reduce gastric emptying relative to an artificially sweetened beverage containing no CHO during high-intensity exercise. Therefore, other features of the solutions, such as CHO type, osmolality, temperature, pH and so on (see Chapter 2) may have led to the inconsistent findings. The disparity in the data is most probably due to large inter-individual variation in the rates of gastric emptying in humans. Costill (1990) claimed that whereas some individuals may empty 80-90% of the solution within 15-20 min of ingestion, others empty less than 10%. Therefore, in some studies the cohort of participants may have naturally had a tendency to empty faster than others.

The ingestion of CHO-E during the LIST has been shown to improve exercise capacity by 33% (Nicholas et al., 1995) and tendency to maintain sprint and skill performance (Chapter 4). Therefore, even though the results of the present study suggest that gastric emptying is reduced during such exercise, enough of the fluid and, more importantly, the CHO must have been delivered to the small intestine to produce performance benefits. Subjects consumed 587 ml of the test solution, thus in the CHO trial 37.6 g of CHO was ingested – a rate of \(~64\text{ g.h}^{-1}\). In the walking trial this resulted in 18.7 g (32 g.hour\(^{-1}\)) being emptied into the small intestine, while it was 13.3 g (23 g.hour\(^{-1}\)) in the LIST trial. However, this rate of glucose delivery is close to the 0.5 to 1.0 g.min\(^{-1}\) carbohydrate intake proposed as being sufficient to delay fatigue by
maintaining blood glucose oxidation (Coyle and Mountain, 1992). Furthermore, although during the first 15 min of the LIST the placebo drink appeared to empty faster than the CHO solution, the rate of emptying for the latter was improved to that of the placebo solution in the second block of exercise (Figures 8.3 and 8.4). This was probably as a result of the increased volume at the start of the second 15-min period in the CHO-LIST trial (Table 8.1). Therefore, it would appear that CHO ingestion during continual performance of the LIST will promote increased CHO delivery and oxidation thus sparing muscle glycogen and improving exercise capacity (Nicholas et al., 1995) and maintaining sprint and skill performance (Chapter 4).

Thus, the ingestion of a commercially available sports drink enabled the same delivery of fluid as water during soccer type exercise and also provided an exogenous supply of CHO. Consequently, players should be recommended to ingest such solutions as it has been shown to improve endurance capacity during soccer type activity, reduce muscle glycogen utilisation, and show trends towards maintaining sprint and skill performance towards the end of game.

Although there was an expected increase in HR from the Walk to LIST trials, it was also significantly higher during the CHO trials (Figure 8.5). Heart rate has been shown to increase during exercise when individuals are dehydrated due to the need to maintain cardiac output when stroke volume is reduced due to the increased viscosity of the blood from a decreased plasma volume (Hamilton et al., 1991). However, the same amount of fluid emptied into the small intestine during the LIST trials. Furthermore, there were no differences in corrected body mass loss between the trials (1.1 kg (1.4%) vs. 1.5 kg (1.8%), CHO vs. PLA), thus indicating no differences in sweat rates. In addition, when consuming either CHO-E or PLA solutions, there is the same decrease in plasma volume (Chapter 4). In Chapter 4 it was shown that the improved sprint performance in the CHO trial might have led to the higher HR values. In the present study, sprint times were the same between the trials (2.59 s). Therefore, the reason for this increase in HR during the CHO trials remains to be elucidated.

Elite runners have been found to report more gastrointestinal distress with fluid ingestion than cyclists (Brouns et al., 1987). Indeed, the drinking regime used in the current study was one devised with elite runners in mind. No gastrointestinal distress
was reported by any subjects in this study or previous studies (e.g. Chapter 4) to the amount or type of solution. The subjects used in the current study were games players who were also sports science students and regularly practised drinking during training and competition. Therefore, they may have become accustomed to drinking during high intensity intermittent exercise and felt comfortable with the amount and type of solution.

8.4.1 Conclusions

In summary, compared to low-intensity walking, gastric emptying was reduced during the LIST. This was postulated to be due either to the high average intensity of the exercise or the frequent bursts of sprinting and high-intensity running. Although there was a tendency for the placebo solution to empty faster during low intensity walking, there was no difference during the LIST. Therefore, the ingestion of CHO drinks containing ~6-8% CHO should be encouraged because they deliver fluid at the same rate as water and also deliver an exogenous supply of CHO which has been shown to improve exercise capacity and possibly maintain sprint and skill performance towards the end of a soccer game.
CHAPTER 9

THE INFLUENCE OF CARBOHYDRATE-ELECTROLYTE INGESTION ON SOCCER SKILL PERFORMANCE BEFORE AND DURING THE LIST: WITH SPECIAL REFERENCE TO THE AMOUNT OF CARBOHYDRATE

9.1 Introduction

The initial investigation using the Loughborough Intermittent Shuttle Test employed a drinking regime of 5 ml/kg -1 BM prior to exercise and smaller boluses of 2 ml/kg -1 BM after every 15-min block of exercise (Nicholas et al., 1995). Subsequent studies have used the same drinking pattern (e.g. McGregor et al., 1999b; Chapters 4, 7 and 8). This design was largely based on the amount of fluid given to athletes during continuous running protocols. Therefore, an individual of 70-kg body mass would typically be receiving approximately 350 ml prior to exercise and 140 ml after every 15 min of the LIST. The general recommendation is that soccer players should consume 500 ml of fluid prior to exercise (Broad et al., 1996). Furthermore, anecdotal evidence from players who have previously participated in studies involving the LIST seems to suggest that they were not receiving enough fluid during the exercise. In addition none of these participants complained that it was too much fluid nor reported any gastrointestinal distress.

Saltin and Costill (1988) claimed that a 2% loss in body mass through dehydration will lead to a ~10% reduction in exercise performance. Indeed, the drinking regime described above has led to subjects exhibiting a relative loss in body mass in the region of ~2% (not corrected for fluid intake) whilst performing the LIST (Chapters 4 and 7). Therefore, to nullify any potential role of dehydration on performance, whether it be gross or fine motor performance, a greater availability of fluid may be required.

Nicholas and co-workers (1995) provided subjects with a CHO delivery rate of approximately 50 g.hour -1. However, whilst utilising the aforementioned drinking regime with the extra 15-min block of exercise in conjunction with the added time
element of the skill tests, the CHO delivery rate fell to \(~30\) g.hour\(^{-1}\) (Chapters 4 and 7), and the benefits of CHO supplementation were not wholly clear. Zeederberg et al. (1996) gave players 25 g.hour\(^{-1}\) of CHO during the exhibition matches but failed to show any beneficial effects on skill performance. McGregor (1999) provided subjects with a rate of 40 g.hour\(^{-1}\) and failed to show any benefits of CHO supplementation. The previous investigations that did show some benefits of consuming a CHO-E drink during intermittent exercise on skill performance employed a drinking regime whereby subjects received 50-70 g.hour\(^{-1}\) of CHO (Graydon et al., 1998; Northcott et al., 1999; Welsh et al., 2002). Therefore, a dose-response of CHO intake on skill performance may be present.

Ratings of perceived exertion (RPE) have been shown to be higher towards the end of exercise in the placebo condition (Chapters 4 and 7). Participants were sprinting faster and working at higher exercise intensities in the CHO-E treatment. Therefore, it would appear that the CHO supplementation was not only displaying peripheral benefits but also exhibiting psychological effects. It is difficult to examine this 'feel-good' factor of CHO ingestion using the RPE scales alone and other constructs may need to be employed.

Therefore, the purpose of the present study was twofold. Firstly, the aim was to replicate the conditions of the previous study (Chapter 7) with an increased fluid supply to the subjects – equivalent to 8 ml.kg\(^{-1}\) BM before and 3 ml.kg\(^{-1}\) BM after every 15 min of exercise. This revised protocol will also widen the independent variable, i.e. in the amount of CHO given, thus enhancing chances of establishing a difference (if one exists). Furthermore, to investigate the 'feel-good' factor of CHO ingestion further, two scales of affect will be used in conjunction with the RPE scale.
9.2 Methods

9.2.1 Subjects

Seventeen healthy male soccer players (age 21 ± 0.6 years, height 1.7 ± 0.01 m, body mass 71.5 ± 1.4 kg and \( \dot{V}O_2 \) max 59 ± 0.8 ml.kg\(^{-1}\).min\(^{-1}\), mean ± SE), who were semi-professional, ex-professional or of at least 1st/2nd team University standard, volunteered to participate in the study. The subjects were from a range of outfield playing positions and were involved in regular training and matchplay.

9.2.2 Preliminary measurements

Subjects reported to the laboratory on two separate occasions for preliminary measurements. During the first session subjects' height, weight, and \( \dot{V}O_2 \) max were determined. Subjects were also fully familiarised with the skill tests and the LIST protocol during both sessions.

9.2.3 Experimental procedures

Subjects completed two main trials, each separated by at least 7 days. The order of trials was randomised to counteract order effects. Subjects were asked to record their diet for the day prior to, and on the day of, the glycogen reduction exercise, and to maintain a similar level of intake prior to both trials. Each main trial took place over 2 days (Figure 9.1). The participants reported to the laboratory at approximately 17:00 hours on day 1. Following a standardised 10-min warm up, they performed the pre-exercise skill tests (modified LSPT and LSST, see Chapters 5 and 6, respectively), which were used to set the 'baseline'. To provide the most valid skill performance prior to any exercise, the baseline scores for both trials were combined. After a brief rest period (5-10 min), subjects were required to complete the glycogen reduction exercise (Chapter 3). At approximately 20:00 hours the participants were provided with a low carbohydrate meal (Chapter 3), and then instructed to fast until the following morning.
Upon arrival on the morning of day 2, subjects' nude body mass was determined, after which the resting blood and expired gas sample was taken. Following the same standardised warm up procedure, subjects performed the second set of skill tests (pre-LIST). The participants were then provided with the test drink. In the carbohydrate treatment subjects were provided with a commercially available sports drink containing 6.4% CHO (Lucozade Sport, GlaxoSmithKline, Brentford). In the other treatment, a placebo was provided which was manufactured to replicate the taste of the test drink, but containing neither carbohydrate nor electrolytes. Prior to the commencement of the LIST, subjects ingested a bolus equivalent to 8 ml/kg-1 BM and then 3 ml/kg-1 BM after every 15 min of exercise (Figure 9.1).

Subjects were given 15 min to consume the initial bolus of fluid and then completed six 15-min blocks of the LIST punctuated by 4-min rest periods. Within these periods subjects performed the LSPT after which ingested the equivalent of 3 ml/kg-1 BM of the same drink. Expired gas samples were collected using the modified Douglas bag method (Chapter 3) towards the end of each block of the LIST. Environmental temperature was measured using a whirling hygrometer prior to exercise and during the last walk phase of each 15-min block of exercise. Heart rate (HR) was monitored continuously throughout exercise via short-range telemetry. The participants were constantly encouraged to maintain the pace set by the audio signals and to perform maximally during the sprints. After completion of the LIST participants were given a brief (~5 min) rest prior to the post-LIST skill tests. Nude body mass was determined following the post-LIST skill tests after subjects had towel dried themselves to remove excess sweat.

9.2.4 Measures of exertion, affect, thirst and gut fullness

The rating of perceived exertion (RPE) scale was used as a measure of effort during exercise. The RPE is a 15-point scale ranging from 6 to 20, with anchors ranging from 'Very, very light' to 'Very, very hard'. Subjects were asked to indicate their perceived ratings of exertion during the last walk stage of each 15-min block of the LIST (Figure 9.1).
The Feeling Scale (FS; Hardy and Rejeski, 1989) was used as a measure of affective valence and the Felt Arousal Scale (FAS; Svebak and Murgatroyd, 1985) was used as a measure of perceived activation. The FS is an 11-point, single item, bipolar measure of pleasure-displeasure, which is commonly used for the assessment of affective responses during exercise (Ekkekakis and Petruzzello, 1999). The scale ranges from -5 to +5. Anchors are provided at zero (‘Neutral’) and at all odd integers, ranging from ‘Very Good’ (+5) to ‘Very Bad’ (-5). The FAS is a 6-point, single item measure of perceived activation/arousal. The scale ranges from 1 to 6, with anchors at 1 (‘Low Arousal’) and 6 (‘High Arousal’). These scales were administered pre-LIST, after every 15-min block of exercise, after the post-LIST skills tests and then 15-min afterwards (Figure 9.1).

In order to monitor the subjects' perception of thirst (Thirst scale) and degree of abdominal discomfort (Gut Fullness Scale), two 15-point linear rating scales were used. The anchors on the Thirst scale ranged from ‘Not thirsty’ to ‘Very, very thirsty’, while the anchors for the Gut Fullness Scale ranged from ‘Not full’ to ‘Very, very full’. These scales were administered during the middle walk stage of each 15-min block of the LIST (Figure 9.1).

9.2.5 Blood analyses

Blood samples were withdrawn from an indwelling venous cannula (Chapter 3), in volumes of 10 ml, at rest and after 30, 60 and 90 min of the LIST. The blood was dispensed, treated and stored as previously described (Chapter 3). Changes in plasma volume were determined using hematocrit and haemoglobin values (Chapter 3). Plasma samples were analysed for ammonia, glucose, lactate and FFA concentrations and serum samples for insulin and cortisol using methods described previously (Chapter 3).
9.2.6 Statistical analyses

The FS and FAS data were analysed via repeated measures multivariate analysis of variance (MANOVA) with condition (CHO vs. PLA) and time specified as within subjects factors. In the MANOVA analysis, where significant differences were found, a follow up univariate analysis was completed. Where significant differences were found paired t-tests, using the Bonferroni adjustment for the number of pairwise comparisons, were conducted. The remainder of the procedures used were the ones described under statistical analysis in Chapter 3. The results are presented as mean values and the standard errors of the mean (± SE). Statistical significance was accepted at $p<0.05$. 
Figure 9.1 Schematic representation of the experimental protocol and the Loughborough Intermittent Shuttle Running Test (LIST)
9.3 Results

9.3.1 Performance of the LSPT

Figure 9.2 shows the combined (CHO + PLA) data for LSPT performance. For the time taken aspect, there was no difference between trials nor time with values between 37 and 38s (Table 9.1, Figure 9.2a). There appeared to be an initial improvement in performance from rest to the initial stages of exercise and then a further decline till the end of exercise (Figure 9.2a, ns).

There was an increase in penalty time with duration of exercise. The post-hoc analysis showed that penalty time was maintained at baseline, pre-LIST and blocks 1-3, at approximately 2-3s, but was significantly higher after block 5 (6.8 ± 1s, \( F_{7, 112} = 3.226, p<0.05 \), Figure 9.2b). There were no differences between trials (Table 9.1).

A similar maintenance at rest and initial stages of exercise was displayed in LSPT total performance time; pre-LIST and blocks 1-3 (39-40.5 s) were significantly quicker than after block 5 (44.7 ± 1.3 s, \( F_{7, 112} = 3.392, p<0.05 \), Figure 9.2c). Furthermore, performance was significantly slower after block 6 than block 1 (39 ± 1.2 vs. 43.5 ± 1.2 s, block 1 vs. block 6, \( F_{7, 112} = 3.226, p<0.05 \)). There were no differences in performance between trials (Figure 9.3).
Figure 9.2 LSPT total performance time (s; combined data CHO+PLA; a significantly lower than 75 min, $p<0.05$; b significantly lower than 75 min, $p<0.01$; c significantly lower than 90 min, $p<0.05$, $n=17$)
Table 9.1 Time taken to complete (s), and penalty time accrued (s), during the LSPT in the CHO and PLA trials (* significantly higher than Baseline, $p<0.01$, $n=17$)

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<td>± 0.6</td>
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Figure 9.3 Total performance time (s) in LSPT for CHO and PLA trials ($n=17$)
9.3.2 Performance of the LSST

There were no main effects for the points scored aspect of the LSST. However, there was a tendency for performance to deteriorate from baseline to post-LIST for the combined data (1.4 ± 0.1 vs. 1.3 ± 0.1 mean points per shot, baseline vs. post-LIST, ns, Figure 9.4a).

Subjects were taking longer to perform each shot sequence from baseline (7.78 ± 0.05 s) and pre-LIST (7.81 ± 0.05 s) to post-LIST (8.04 ± 0.07 s, $F_{1.5, 24.6} = 11.233, p<0.01$, Figure 9.4b). Moreover, there was a tendency for players to be slower post-LIST in the PLA trial (7.97 ± 0.07 vs. 8.11 ± 0.11 s, CHO vs. PLA, ns).

Mean shot speed decreased from baseline (51 ± 1mph) and pre-LIST (50 ± 0.5 mph) to post-LIST (48.5 ± 0.5 mph, $F_{2, 32} = 4.419, p<0.05$, Figure 9.4c). There were no differences between trials.
Figure 9.4 Comparison of A) mean points scored per shot, B) mean shot speed (mph) and C) mean time taken (s) to complete each shot sequence between CHO and PLA trials (n = 17)
9.3.3 15-m sprint performance

Sprint times decreased with duration of the LIST. More specifically, performance was significantly slower during the last 30 min than the first 30 min of exercise (main effect of time, 2.62 vs. 2.72 s, block 1-2 vs. block 5-6, $F_{2.3, 36.8} = 9.026, p<0.05$). Although not statistically significant, there was a trend for performance to be maintained in the CHO condition in the last block of exercise whereas there was a trend for further decrease in the PLA trial (2.7 ± 0.03 vs. 2.76 ± 0.04 s, CHO vs. PLA, ns, Figure 9.5).

![Graph showing mean 15-m sprint time per block of the LIST in CHO and PLA trials](image)

**Figure 9.5** Mean 15-m sprint time per block of the LIST in CHO and PLA trials ($n = 17$)

9.3.4 HR and RPE

Heart rate values were consistently higher, by approximately 3 beats min$^{-1}$, in the CHO trial, but this was not statistically significant (Figure 9.6). There was a main effect of time, with HR lower in block 1 than blocks 2-5 (152 ± 1 vs. 155-156 beats min$^{-1}$, block 1 vs. blocks 2-5, $F_{3.4, 51.2} = 7.264, p<0.05$).
There was a main effect of time for RPE with the mean value during each block of exercise significantly higher than the previous one \((F_{1.7, 26.7} = 38.637, p<0.01, \text{Figure 9.7})\). Furthermore, an interaction effect of treatment x time was found \((F_{3.5, 55.5} = 3.091, p<0.05)\), but no differences between trials at any sampling times.
9.3.5 Felt Arousal Scale (FAS) and Feeling Scale (FS)

There was a strong trend for activation/arousal to be higher with CHO ingestion throughout the test period (3.7 ± 0.1 vs. 3.2 ± 0.1, CHO vs. PLA, \(F_{1,16} = 4.567, p = 0.053\)). The analysis showed an interaction of drink x time, with significantly higher responses in the CHO trial following blocks 5 and 6 of the LIST (4.1 ± 0.3 vs. 3.0 ± 0.3, CHO vs. PLA post-block 5, 3.8 ± 0.4 vs. 2.7 ± 0.4, CHO vs. PLA post-block 6, \(F_{6.2,99.7} = 6.575, p<0.05\), Figure 9.8).

![Figure 9.8 Mean Felt Arousal Scale (FAS) ratings during the CHO and PLA trials (* significantly higher in CHO trial, \(p<0.05\), \(n = 17\)).](image)

There was a main effect of time for FS responses with significantly higher ratings post-skills tests (1.9 ± 0.4) and 15 min after the skills tests (2.4 ± 0.3) than after block 6 (0.6 ± 0.5, \(F_{3.3,52.6} = 4.567, p<0.01\)). Although FS ratings appeared to be higher towards the end of the LIST in the CHO trial, there was no effect of treatment or interaction of treatment x time (Figure 9.9).
Figure 9.9 Mean Feeling Scale (FS) ratings during the CHO and PLA trials (n = 17).

As the FS and FAS are co-related a repeated measures MANOVA was also performed on the data. The results showed that there were strong tendencies for differences in affect with time (Wilks’ $\lambda = 0.806, F_{10,158} = 1.804, p = 0.064$) and drink (Wilks’ $\lambda = 0.682, F_{2,15} = 3.502, p = 0.056$) in the responses given during exercise. The MANOVA failed to show an overall effect due to the differences in FAS being masked because of the non-significant effect on the FS ($p = 0.22$).
9.3.6 Oxygen uptake, estimated energy expenditure and RER

Oxygen uptake increased from block 1 to block 3 but then decreased again to block 6 (main effect of time, 44.5 ± 0.9 vs. 46.6 ± 0.5 vs. 44.9 ± 0.6 ml.kg\(^{-1}\).min\(^{-1}\), block 1 vs. block 3 vs. block 6, \(F_{3.9, 62.7} = 2.72, p<0.05\)). After 60 min of exercise there was maintenance of oxygen uptake in the CHO trial (~46 ml.kg\(^{-1}\).min\(^{-1}\)) but a further decrease in the PLA condition (<44 ml.kg\(^{-1}\).min\(^{-1}\), Table 9.2), but there was no statistically significant treatment or interaction effect.

The relative exercise intensity, expressed in terms of % \(\text{VO}_2\) max, showed similar results to oxygen uptake. There was a main effect of time with an initial increase from the start of exercise to block 3 and then a drop to block 6 (76 ± 2 vs. 79 ± 1 vs. 76 ± 1%, block 1 vs. block 3 vs. block 6, \(F_{3.9, 62.8} = 2.591, p<0.05\)). Even though there was a 4% difference between trials in the last 15 min of exercise there was no statistically significant treatment or interaction effect (Table 9.2).

Estimated energy expenditure, calculated via indirect calorimetry, also showed a time effect with an increase from block 1 to block 3 and then a decrease to block 6 (63 ± 1 vs. 66 ± 1 vs. 63 ± 1 kJ.min\(^{-1}\), block 1 vs. block 3 vs. block 6, \(F_{3.8, 60.7} = 2.686, p<0.05\)). However, there was no difference between trials (Table 9.2). The estimated total energy expenditure, based on mean expenditure rate, was not different between trials (5846 ± 108 vs. 5804 ± 74 kJ, CHO vs. PLA, ns).
Table 9.2 Oxygen uptake (ml.kg\(^{-1}\).min\(^{-1}\)), relative exercise intensity (% \(\dot{V}O_2\) max) and energy expenditure rates (kJ.min\(^{-1}\)) at rest, during each 15min block and overall mean of the LIST in the CHO and PLA trials (n = 17)

<table>
<thead>
<tr>
<th></th>
<th>Rest</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>Mean of trial (exercise only)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\dot{V}O_2) (ml.kg(^{-1}).min(^{-1}))</td>
<td></td>
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<tr>
<td>CHO</td>
<td>5.5 ± 0.2</td>
<td>44.1 ± 1.0</td>
<td>45.4 ± 1.2</td>
<td>47.0 ± 0.7</td>
<td>46.1 ± 0.8</td>
<td>45.8 ± 0.7</td>
<td>45.9 ± 0.9</td>
<td>45.7 ± 0.4</td>
</tr>
<tr>
<td>PLA</td>
<td>5.2 ± 0.1</td>
<td>44.9 ± 1.5</td>
<td>46.7 ± 0.9</td>
<td>46.2 ± 0.8</td>
<td>46.4 ± 0.8</td>
<td>45.3 ± 0.8</td>
<td>43.8 ± 0.9</td>
<td>45.6 ± 0.4</td>
</tr>
<tr>
<td>% (\dot{V}O_2) max</td>
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<td></td>
<td></td>
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<tr>
<td>CHO</td>
<td>9.3 ± 0.5</td>
<td>74.9 ± 1.9</td>
<td>77.0 ± 1.8</td>
<td>79.8 ± 1.5</td>
<td>78.3 ± 1.4</td>
<td>77.7 ± 1.5</td>
<td>78.0 ± 1.7</td>
<td>77.6 ± 0.7</td>
</tr>
<tr>
<td>PLA</td>
<td>8.9 ± 0.3</td>
<td>76.1 ± 2.4</td>
<td>79.2 ± 1.4</td>
<td>78.3 ± 1.2</td>
<td>78.7 ± 1.6</td>
<td>76.9 ± 1.5</td>
<td>74.4 ± 1.7</td>
<td>77.3 ± 0.7</td>
</tr>
<tr>
<td>Energy expenditure rates (kJ.min(^{-1}))</td>
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<td></td>
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<tr>
<td>CHO</td>
<td>7.7 ± 0.3</td>
<td>62.8 ± 1.6</td>
<td>64.5 ± 1.7</td>
<td>66.7 ± 1.3</td>
<td>65.5 ± 1.3</td>
<td>64.9 ± 1.5</td>
<td>65.3 ± 1.7</td>
<td>65.0 ± 0.7</td>
</tr>
<tr>
<td>PLA</td>
<td>7.4 ± 0.2</td>
<td>63.6 ± 2.0</td>
<td>66.2 ± 1.2</td>
<td>65.4 ± 1.0</td>
<td>65.7 ± 1.1</td>
<td>64.2 ± 1.1</td>
<td>61.9 ± 1.0</td>
<td>64.5 ± 0.5</td>
</tr>
</tbody>
</table>
Mean RER was significantly higher in the CHO condition throughout exercise (0.89 ± 0.004 vs. 0.86 ± 0.004, CHO vs. PLA, $F_{1, 16} = 4.993$, $p<0.05$, Figure 9.10). Furthermore, when the data were combined (CHO + PLA), RER increased from rest to blocks 1 and 2, but then decreased to the end of exercise (main effect of time, 0.83 ± 0.02 vs. 0.89 ± 0.01 vs. 0.87 ± 0.01, rest vs. blocks 1-2 vs. blocks 5-6, $F_{3.6, 57.1} = 5.924$, $p<0.05$).

![Figure 9.10 Mean RER values during the LIST in CHO and PLA trials ($n = 17$)](image)
9.3.7 Plasma glucose

There were two main effects as well as an interaction effect of treatment x time for plasma glucose concentration during the LIST. Plasma glucose concentrations were maintained above resting values during the CHO condition but there was a marked fall after 30 min of exercise in the PLA treatment; significant differences were found at 60 and 90 min (5.4 ± 0.2 vs. 4.6 ± 0.2 mmol.l⁻¹ (60 min) and 5.2 ± 0.1 vs. 4.0 ± 0.3 mmol.l⁻¹ (90 min), CHO vs. PLA, \( F_{3, 27} = 9.612, p<0.05 \) and \( p<0.01 \), respectively, Figure 9.11).

![Figure 9.11](image)

**Figure 9.11** Plasma glucose concentrations (mmol.l⁻¹) during the LIST for CHO and PLA trials (* significantly higher in CHO trial, \( p<0.05 \); ** significantly higher in CHO trial, \( p<0.01 \), n = 10)
9.3.8 Plasma FFA

Plasma FFA concentrations showed two main effects as well as an interaction of treatment x time. Mean concentrations were maintained at near resting values in the CHO trial but increased sharply in the PLA trial. Statistically significant differences were found at 60 and 90min of exercise (0.5 ± 0.1 vs. 0.9 ± 0.1 mmol.l⁻¹ (60 min) and 0.6 ± 0.1 vs. 1.1 ± 0.2mmol.l⁻¹ (90 min), CHO vs. PLA, F₃,2₇ = 5.594, p<0.05 and p<0.01, respectively, Figure 9.12).

Figure 9.12 Plasma FFA concentrations (mmol.l⁻¹) during the LIST for CHO and PLA trials (* significantly higher in PLA trial, p<0.05; ** significantly higher in PLA trial, p<0.01, n = 10).
9.3.9 Plasma glycerol

Plasma glycerol concentrations increased throughout exercise, with each value significantly higher than the last sampling time (main effect of time, $F_{1.2.10.6} = 75.304, p<0.01$). Glycerol concentrations were higher in the PLA trial throughout exercise (interaction of treatment x time, $F_{1.5.13.2} = 5.513, p<0.05$). However, there were no significant differences between any sampling times (Figure 9.13).

![Figure 9.13 Plasma glycerol concentrations (mmol.l⁻¹) during the LIST for CHO and PLA trials (n = 10)]
9.3.10 Plasma lactate

Plasma lactate concentrations increased from rest and were higher during exercise (main effect of time, 1.0 ± 0.04 vs. 3.3-3.6 mmol.l\(^{-1}\), rest vs. exercise, \(F_{1.5, 13.2} = 5.513, p<0.01\), Figure 9.14). Although the concentrations of lactate were consistently higher in the CHO condition there were no statistical difference between trials (Figure 9.14).

![Figure 9.14 Plasma lactate concentrations (mmol.l\(^{-1}\)) during the LIST for CHO and PLA trials (* significantly lower than exercise, \(p<0.01, n = 10\))](image-url)
9.3.11 Serum insulin

There was a drop in serum insulin concentration from rest to exercise (main effect of time, 19.2 ± 1.2 vs. 13-14 mIU.l⁻¹, rest vs. exercise, \( F_{1.2,10.6} = 75.304, p<0.01 \)). Insulin concentrations showed a tendency to be higher during all exercise sampling times in the CHO trial but this was not statistically significant (14-15 vs. 12-13 mIU.l⁻¹, CHO vs. PLA, \( p = 0.07, \text{ ns} \), Figure 9.15).

![Figure 9.15](image)

**Figure 9.15** Serum insulin concentration (mIU.l⁻¹) during the LIST for CHO and PLA trials (* significantly higher than exercise, \( p<0.01, n = 11 \))
9.3.12 Plasma ammonia

Plasma ammonia concentration increased from rest and was higher during exercise (main effect of time, 21.8 ± 2.7 vs. 50-60 μmol.l⁻¹, rest vs. exercise, $F_{3, 24} = 22.54$, $p<0.01$, Figure 9.16). There was a trend for ammonia concentration to be higher in the CHO condition, especially post-LIST but there was no significant difference between trials (69.2 ± 8.9 vs. 50.6 ± 4.2 μmol.l⁻¹, CHO vs. PLA at 90 min, ns).

![Figure 9.16](image)

**Figure 9.16** Plasma ammonia concentrations (μmol.l⁻¹) during the LIST for CHO and PLA trials (* main effect of time, significantly lower than exercise, $p<0.01$, n = 11)
9.3.13 Serum cortisol

There was a main effect of time for serum cortisol concentration during the LIST. Cortisol concentrations initially decreased from rest until 60 min into exercise (main effect of time, $15.9 \pm 0.6 \, \text{vs.} \, 10.8 \pm 0.8 \, \mu\text{g.dl}^{-1}$, rest vs. 60 min, $F_{3, 30} = 14.607$, $p<0.01$), but then increased until 90 min ($10.8 \pm 0.8 \, \text{vs.} \, 13.6 \pm 1.4 \, \mu\text{g.dl}^{-1}$, 60 min vs. 90 min, $F_{3, 30} = 14.607$, $p<0.05$). When examined separately, there was a trend for maintenance of cortisol in the CHO trial but a continued rise during exercise in the PLA condition (interaction of treatment x time, $p = 0.08$, ns).

![Figure 9.17](image.png)

**Figure 9.17** Serum cortisol concentration ($\mu\text{mol.l}^{-1}$) during the LIST for CHO and PLA trials ($n = 11$)

9.3.14 Plasma volume

The change in plasma volume marginally increased from pre- to post-LIST, and there was no significant difference between trials ($+1.0 \pm 1.2\%$ and $+1.8 \pm 1.4\%$, CHO and PLA trials, respectively).
9.3.15 Gut fullness and thirst scales

There were no differences in gut fullness ratings between trials and sampling times, with mean ratings of 10-11. There was no difference in subjects perception of thirst between trials (~11). There was a main effect of time, with ratings increasing from blocks 1 and 2 to blocks 5 and 6 (10 ± 0.5 vs. 12 ± 0.6, blocks 1 and 2 vs. blocks 5 and 6, $F_{3.6,36.2} = 7.735, p<0.05$).

9.3.16 Secondary variables

Student's t-tests on the secondary variables failed to show any significant differences between the CHO and PLA trials. There was no difference in the mean daily energy intake (10.9 ± 0.7 MJ and 11.2 ± 1.0 MJ, CHO and PLA trials, respectively) nor carbohydrate content (396 ± 36 g and 386 ± 44 g, CHO and PLA trials, respectively) of the 2-day diet prior to each main trial. The exercise intensity during the glycogen reduction exercise (62 ± 1%) and the total energy (990 ± 15 kcal) and carbohydrate (69 ± 2 g) content of the low CHO meal were the same between trials. Subjects covered the same distance during the LIST (12.3 km), consumed the same volume of fluid during the main trials (1625 ± 30 ml), and the loss in body mass, corrected for fluid intake, was also not different between trials (2.2 ± 0.1 and 2.3 ± 0.1 kg, CHO and PLA trials, respectively). Ambient temperature, both dry bulb (15-16°C) and wet bulb (11-12°C) were similar between trials. Relative humidity was also similar between trials (61-65%). Furthermore, two-way ANOVA for correlated data failed to show an order effect in any performance, metabolic or biochemical variable.
9.4 Discussion

The main finding of the present study was that even with an increased CHO delivery rate, soccer skill performance during and after the LIST was not significantly improved relative to an artificially sweetened placebo. Carbohydrate supplementation appeared to improve feelings of affect towards the end of exercise.

From baseline and pre-LIST there was an initial improvement in LSPT performance, maintenance from 15-60 min, followed by a marked decrease in the last 30 min of exercise (Figure 9.2c); a pattern similar to the results of Chapter 7. Whereas the overall decline in that study was 4%, there was an 8% overall drop in performance from baseline to post-LIST – similar to the findings of Chapter 4. Although this difference was not statistically significant, the 12% drop in performance from 15 min to post-LIST did achieve statistical significance (p<0.05). Therefore, it appears that soccer skill performance, as determined by the LSPT, follows an inverted-U relationship during the LIST. Figure 9.2 also shows that the constituent parts of the LSPT, time taken and added penalty time, display a similar pattern to overall performance. As the added penalty time contributed to a greater degree, it seems that fine rather than gross motor performance was being affected by the exercise. Even though there was a decrement in skill performance, there were no statistically significant differences between CHO and PLA trials. There appeared to be a more marked drop in performance from 45-60 min to 75-90 min during the PLA trial. The drop in performance was in the order of 4-8% in the CHO trial but 10-16% in the PLA trial (Figure 9.3).

As with previous studies (Chapters 4 and 7) there was no difference in points scored during the LSST between trials and sampling times. As before, a 'speed-accuracy trade-off' appears to exist, with subjects increasing time to complete each shot sequence and reducing shot speed to maintain the accuracy of shooting (Figure 9.4). In addition, although there was a tendency for faster shot sequences following the LIST in the CHO condition (7.97 vs. 8.11s, Figure 9.4b), there were no significant differences between the trials.
Therefore, there does not seem to be any added benefits of increasing the CHO delivery rate from 30 g.hour\(^{-1}\) to 45 g.hour\(^{-1}\) on maintenance of skill performance. Moreover, although sprint performance appeared to be better maintained in the last 30 min of the LIST with CHO ingestion, there was no statistically significant difference between trials (Figure 9.5). Therefore, the extra CHO delivery did not influence sprint performance to a greater extent either.

In previous experiments (Chapters 4 and 7) there was no difference on RER between trials. The extra CHO delivery resulted in significantly higher RER values in the CHO trial throughout exercise (Figure 9.10). Therefore, there is some effect of the increased delivery of CHO on metabolism i.e. higher carbohydrate oxidation with CHO ingestion. This was not reflected in other variables. Oxygen uptake and relative exercise intensity showed a tendency to be better maintained with CHO ingestion (Table 9.2) but were similar to previous studies (Chapters 4 and 7). Estimated energy expenditure rates were also similar and, even with the extra CHO intake, the same absolute energy was expended during exercise between trials. Furthermore, no difference in estimated total energy expenditure was observed between trials.

Plasma glucose concentrations were maintained above resting values throughout exercise but fell below 4 mmol.\(\text{l}^{-1}\) post-LIST in the PLA trial (Figure 9.11). Serum insulin (Figure 9.15) concentrations were marginally greater with CHO ingestion whereas plasma FFA (Figure 9.12) concentrations were higher in the PLA trial throughout exercise. These concentrations are similar to previous studies (Chapters 4 and 7) which employed the previous drinking regime. Therefore, the increased CHO delivery rate does not seem to have altered much in terms of metabolism during the LIST.

There are a number of possible reasons why there was a lack of dose-response of CHO delivery rate on skill performance and metabolism during the LIST. Even though the concentration of the CHO was the same between studies, the gastric emptying potential may have been reduced during the CHO trial due to the cumulative energy provided in the drink. It has been shown that the rate of emptying was the same between the PLA and CHO solutions during the LIST (Chapter 8). Indeed, this was evident when subjects were provided with a CHO intake of ~60
g. hour\(^{-1}\) and so it would appear that the extra energy content of the CHO drink was not further compromising fluid delivery during the LIST. Furthermore, many studies show that increasing the volume of the ingested fluid increases emptying (Coyle and Montain, 1992; Mitchell and Voss, 1991; Noakes et al., 1991), and so this may have actually aided the gastric emptying rate during this study. The gastric emptying rate associated with the increased fluid and energy does not appear to be the reason why there were no added performance and metabolic benefits.

Even though a greater amount of CHO was delivered, the plasma glucose concentrations did not show an increase relative to previous experiments (Chapters 4 and 7). As gastric emptying does not seem to be the reason then could it be that intestinal absorption was the limiting factor? Thus, there may be a maximal rate at which carbohydrate can be absorbed in the small intestine during this type of activity when a 6.4% CHO-E solution is consumed. Evidence to suggest that exogenous glucose oxidation may be limited by intestinal absorption comes from the studies of Ravussin et al. (1979) and Massicote et al. (1990) in which fasted or glycogen depleted subjects were given CHO during moderate intensity exercise. Although such interventions would be expected to increase the reliance on exogenous CHO oxidation, the overall rates of glucose oxidation in the glycogen depleted and fasted subjects were similar to glycogen replete controls. Therefore, it would appear that there was a limitation in the absorption of exogenous CHO in the small intestine. The extrapolation of these findings to the present study may be unwise due to the differences in intensity (40-50% vs. 75-80% % \(\text{VO}_2\max\)) and nature (continuous vs. intermittent) of exercise. Without further investigation using appropriate methodologies, this speculation cannot be confirmed. 

Coyle and Montain (1992) proposed that a carbohydrate delivery rate of 30-60 g.hour\(^{-1}\) is sufficient to delay fatigue during prolonged exercise by maintaining blood glucose concentrations and carbohydrate oxidation. Therefore, it may be that a rate of 30 g.hour\(^{-1}\) is sufficient to maintain higher plasma glucose concentrations and increased carbohydrate oxidation rates, however, there may be a threshold for oxidation of exogenous CHO during this type of activity. As mentioned previously, the RER showed a significantly higher contribution of carbohydrate oxidation in the CHO trial,
with the overall rates during the CHO and PLA trials 2.4 and 2.0g.min\(^{-1}\), respectively. This was lower than the overall carbohydrate oxidation rates in previous studies (2.5-2.7g.min\(^{-1}\), Chapters 4 and 7, \(ns\)) and so there may be a threshold for carbohydrate oxidation during this type of exercise. Nevertheless, whether there was a difference in the oxidation of the exogenous CHO due to the different supply rates (30 vs. 45 g.hour\(^{-1}\)) cannot be determined without the use of naturally \(^{13}\)C or radioactive \(^{14}\)C labelled carbohydrates as tracers to follow the metabolism of ingested CHO.

Although the increased CHO and fluid delivery did not affect skill performance and metabolism, it incurred other benefits during exercise. The change in body mass, corrected for fluid intake, was 2.3 kg (3.2%) in both trials. This amount was similar to the sweat loss in previous studies (Chapters 4 and 7; McGregor, 1999). The actual body mass loss from pre- to post-LIST was in the region of 0.7kg (0.9%) and so the extra fluid intake better offset the loss due to sweating. However, this could be due to more fluid being retained in the gut. Nevertheless, the mean change in plasma volume from pre- to post-LIST actually increased by 1 and 1.8% in CHO and PLA trials, respectively, and thus, plasma volume was also better maintained by the revised drinking regime. Moreover, even though little or no dehydration occurred, there was still deterioration in sprint and skill performance. Consequently, this is more evidence to suggest that dehydration per se may not be the cause of fatigue in temperate conditions – whether it be gross (e.g. sprint) or fine (e.g. skill) motor performance.

Anecdotal evidence from previous investigations showed that subjects were not receiving enough fluid during the LIST. Even with the 50% extra fluid delivery in the current study, the mean rating of thirst was \(\sim 11\) i.e. ‘fairly thirsty’. With the increased CHO ingestion the subjects may have felt some abdominal discomfort but the ratings of gut fullness were not different between trials (10-11, ‘fairly full’) but increased with time. This may indicate that not all of the fluid was being emptied and sufficient fluid remained in the stomach to possibly cause some discomfort – but this was a function of the volume of fluid rather than the energy content. However, there were no reports of gastrointestinal distress from any of the subjects during the trials. Therefore, trained games players are able to ingest commercially available CHO-E solutions at 3ml.kg\(^{-1}\) BM during high-intensity shuttle running without any discomfort. The same may not necessarily apply to competitive runners.
Ratings of perceived exertion (RPE) increased from 11/12 at start to 15/16 at the end of exercise (Figure 9.7). Furthermore, RPE showed a trend to be maintained in the last 30 min of exercise in the CHO trial but carried on increasing in the PLA condition; again, similar to previous studies (Chapters 4 and 7). However, as in those studies, sprint performance, oxygen uptake and relative exercise intensity started to deteriorate in the PLA trial at this time. Therefore, even though subjects were working harder in the CHO trial they perceived that their exercise intensity was higher in the PLA trial. Graydon et al. (1998) examined the influence of CHO ingestion on shot accuracy during controlled squash matches and found a beneficial impact of supplementation relative to the placebo condition. They also reported higher RPE values in the fluid only trial. However, as no physiological or biochemical data were collected in their study, the reason for this greater perception of effort in the placebo trial could not be determined. It may be that due to the reduced plasma glucose the CNS reacts by increasing the perception of effort so as to reduce exercise intensity. In this way it can be postulated that the CNS is promoting feelings of fatigue and so acting as a ‘safety mechanism’ (Edwards, 1981). Indeed clear and strong relationships have been reported between RPE and blood glucose concentrations during exercise (DeMarco et al., 1999). In the present study, although it was statistically significant, there was only a modest inverse relation ($r = -0.40, p<0.05$) between those variables.

The RPE scale measures subjective perceptions of effort and exertion during exercise but does not indicate whether these were positive or negative feelings or give an indication of activation (arousal). Therefore, a further aim of this study was to examine whether CHO ingestion had a ‘feel-good’ effect during the LIST. Affective valence, as determined by the Feeling Scale (FS) showed a tendency to go from positive towards neutral feelings with exercise. Furthermore, whereas there was a trend for maintenance around a rating of $-1$ (‘fairly good’) in the last 30 min of exercise with CHO ingestion, there was a shift to neutral feelings (0) in the PLA condition (Figure 9.9). There was an increase in FS, which tended to be more marked in the PLA trial, following the post-LIST skill tests ($p<0.05$). The ratings of activation (FAS) showed very strong tendencies ($p = 0.053$) to be higher throughout exercise with CHO ingestion. More importantly, there was an interaction of treatment x time, with significant differences between trials during the last 30 min of exercise (Figure
In the absence of CHO ingestion, subjects felt less activated/aroused towards the latter stages of exercise. Moreover, as affective valence and activation are interrelated within a circumplex model (Russell, 1980), a multivariate analysis of variance (MANOVA) was also conducted on the data. There were strong tendencies for an influence of time \((p = 0.068)\) and drink \((p = 0.056)\) on affect and activation. Based on the circumplex model (Hall et al., 2002; Russell, 1980), subjects in the CHO trial tended to be in a more activated pleasant state (excitement and enthusiasm) towards the end of exercise, whereas in the control condition subjects were in a more neutral state. These findings are similar to a study by Hall et al. (2002) who showed that subjects went from an unactivated pleasant state (rest) to activated pleasant (moderate intensity exercise) to activated unpleasant state (fatigue) during different stages of exercise.

The question that arises therefore is, what is the significance of this improved affective valence during soccer? Hall et al. (2002) suggested that as fatigue is approached due to heavy exercise, affective responses represent an 'evolutionary primitive 'alarming' function, which, much like pain, is aimed to stop and withdraw from the activity that is causing the severe homeostatic perturbation' (cf. Edwards (1981) definition of fatigue as a 'safety' mechanism). Therefore, it would appear that in the PLA trial subjects were feeling worse and so were likely to reduce the intensity of exercise. Indeed, sprint performance, relative exercise intensity and to a lesser degree, skill performance as well, were weaker in the fluid only trial. Although statistically significant, there were weak to modest inverse correlations \((r = -0.30\) to \(-0.45, p<0.01)\) between FS + FAS and sprint + LSPT performance. Thus, there does appear to be some relation between affect and skill and sprint performance. Furthermore, as with RPE and plasma glucose, there were weak correlations between FS + FAS and plasma glucose \((r = 0.23, p<0.05)\); the main point is that CHO ingestion exerts positive feelings of affect during high-intensity shuttle running.

### 9.4.1 Conclusions

In summary, even with an increased CHO supply there was no added benefits on soccer skill and metabolism during prolonged, high-intensity shuttle running. This was possibly due to a limitation in the rate of intestinal absorption and/or CHO
oxidation rates within the muscle. Furthermore in the CHO trial, subjects maintained higher activation and positive affective valence throughout exercise relative to the fluid only trial, thus demonstrating a 'feel-good' factor of CHO ingestion. These positive feelings possibly helped to maintain a higher relative exercise intensity, sprint and skill performance throughout exercise.
CHAPTER 10

GENERAL SUMMARY

10.1 Introduction

There is a dearth of information in the general scientific literature on the effects of fatigue on soccer skill performance. This is surprising, as the skill elements would appear to be critical in producing successful outcomes i.e. the winning of games. The main reason for this seems to be due to the lack of valid and reliable tests of soccer skill. Fluid ingestion has been shown to maintain soccer skill following high-intensity intermittent shuttle running, but dehydration per se was not the reason for the deterioration in performance (McGregor, 1999). Carbohydrate-electrolyte (CHO-E) ingestion improves exercise capacity during intermittent exercise and field studies also suggest a role in improving soccer skill performance. Therefore, the main aims of these series of experiments were as follows:

- Determine the extent of deterioration in soccer skill following 90 min of prolonged, high-intensity shuttle running
- Determine the influence of ingesting CHO-E on maintenance of soccer skill performance during controlled conditions
- Determine why soccer skill may deteriorate during a game, and why CHO ingestion may help to maintain performance, using physiological, biochemical and psychological variables

The main findings of the experiments described in this thesis are summarised as follows:

- The Loughborough Soccer Passing (LSPT) and Shooting (LSST) tests are valid and reliable methods of assessing soccer skill for research purposes
- Soccer skill performance deteriorates following 90 min of intermittent high-intensity running, even with fluid ingestion
The ingestion of a CHO-E solution during exercise shows tendencies for better maintenance of skill performance towards the end of exercise.

The ingestion of a CHO-E solution better maintains sprint performance and a higher relative exercise intensity during exercise.

The ingestion of a CHO-E solution reduces the perception of effort and improves feelings of affective valence during exercise.

The CHO-E solution used in this study delivers water at the same rate as water during intermittent high-intensity shuttle running. Therefore, it is better than ingesting water alone because it also provides an exogenous supply of energy which has been shown to have physiological and psychological benefits during such exercise.

The following discussion will attempt to summarise the possible reasons why soccer skill deteriorates and why CHO ingestion during exercise may have beneficial effects on performance. Furthermore, where possible, practical guidelines to improve or maintain soccer performance will be offered. The discussion will draw on performance data as well as physiological, biochemical and psychological information collated during the experiments already presented in this thesis.

10.2 What is the effect of exercise on LSPT performance?

One of the main findings of these series of experiments was that soccer skill performance (as determined by time to perform the LSPT) showed a deterioration after 90 min of soccer related activity (i.e. the LIST). The difference was not statistically significant in all experimental studies, but this could have been due to the random day-to-day variation and the low statistical power (see below). When the results of the skill tests for baseline, pre- and post-LIST are combined from the three main studies (Chapters 4, 7 and 9), there was a 6.5% deterioration in LSPT performance from baseline to post-LIST ($p<0.01$). Furthermore, there was a 4% decrease in performance from pre- to post-LIST ($p<0.05$). As different experimental procedures were used in the 3 studies, and indeed the instructions for the LSPT differed, combining the data in this way may be questioned. Nevertheless, the procedures were the same for the different treatments in each experiment and so it
seems one way of overcoming the problems of low sample sizes and hence low statistical power.

In all of the studies the difference in skill performance with time in LSPT seems to be due to the increase in the added penalty time rather than the time taken to complete the test. Therefore, this highlights the fact that fine (accuracy of passing, control and dribbling of ball) rather than gross (speed of movement) motor skill is being affected by the exercise. This also emphasises the ability of the LSPT as a test that can detect fine and gross motor aspects of soccer skill.

Reilly (1996) suggested that the reason why most goals are scored towards the end of a game could be due to the detrimental effects of fatigue on work rate leading to an increase in playing errors and lapses in concentration associated with poor decision making. Therefore, this effect of fatigue on skill performance may manifest itself right at the end of a game. Indeed, results presented in this thesis seem to suggest that skill performance improves from rest, is maintained through the middle part of exercise, and then deteriorates right at the end of exercise, thus following an inverted-U shaped performance curve. This finding has also been demonstrated in a previous study by Northcott et al. (1999). There are a number of reasons why skill performance during soccer may follow this pattern of an initial improvement followed by steady state performance followed by a decline towards the end.

In these series of experiments (Chapters 4, 7 and 9) a 10-min warm-up preceded the pre-LIST skill tests. This may not have had the desired effect on, for example, increasing body core and muscle temperature to optimal levels for the most favourable effects on skill performance. Moreover, Northcott and colleagues (1999) administered a 5-min warm-up and also found that skill performance was better after 30 min than 0 and 15 min of intermittent exercise. Therefore, soccer players should be encouraged to pursue at least a 15-min bout of warm-up for skill performance to be at optimal levels right from the start of a game.

Furthermore, core temperature continues to rise during the LIST (Ali, 1999; Morris et al., 1998), but LSPT performance has been shown to deteriorate (Chapters 4, 7, 9). Therefore, it may be that above a certain core temperature skill performance
deteriorates, possibly due to the effects of heat stress on cognitive functioning (Brück and Olschewski, 1987; Nielsen et al., 1990; Nielsen et al., 1993). It has been suggested that an elevated core temperature may reduce the function of motor centres and the ability to recruit motor units for activity, perhaps via an effect on the motivation to maintain performance (Nielsen et al., 1990). Thus, an increased core temperature may have reduced performance towards the end of the LIST and immediately post-LIST due to a reduced cognitive functioning. However, core temperature returned to resting levels after 90 min of the LIST and yet performance times for the LSPT did not (McGregor, 1999). Therefore, the mechanism(s) by which an increased muscle and core temperature may initially improve and then cause a deterioration in skill performance remains to be elucidated and warrants further investigation.

Another reason for the inverted-U pattern of LSPT performance could relate to levels of arousal during exercise. It has been hypothesised that an increase in arousal may lead to a better performance in cognitive and fine motor tasks (Davey, 1973; McMorris et al., 1994; McMorris et al., 1999). The authors that investigated this idea have drawn on Easterbrook’s (1959) cue utilisation theory, which suggests that exercise affects cognitive functioning in an inverted-U fashion. According to Easterbrook (1959), at low levels of arousal an individual’s focus of attention is too broad and both task relevant and irrelevant cues are attended to. As arousal increases to moderate levels (top of inverted-U), attention will be optimal i.e. focus on relevant cues only. Further increases in arousal result in greater narrowing of attention and even task-relevant cues are missed and hence performance returns to baseline. Therefore, subjects performing the LSPT may have attended to the cues required for optimal performance better during the middle phase of the LIST, but then their attention wavered towards the end of exercise when fatigued, leading to a poorer performance. Furthermore, RPE data showed that subjects’ perception of effort was quite high at the end of exercise thus suggesting high perceptions of fatigue. Physical discomfort during fatiguing exercise may result in subjects focussing on their perceptions of pain rather than attending to the performance cues (Tomporowski and Ellis, 1986). Therefore, important task relevant cues may have been missed due to a narrowing of perception towards the end of the LIST thus resulting in a deterioration in performance.
The results of much of the literature examining this link between arousal and cognitive performance remain equivocal, with the results of some (e.g. Davey, 1973) but not all (e.g. Isaacs and Pohlman, 1991) studies supporting the theory. The disparity is probably due to the different tasks employed between studies and/or ones that may be too simplistic to be affected by fatiguing exercise. Furthermore, these simple reaction tests or visual tracking tasks may not be representative of skilled tasks within popular sports such as soccer, rugby and hockey. Therefore, McMorris et al. (1994) investigated the effect of moderate and fatiguing exercise on the performance of a soccer wall-volley test. They reported that moderate exercise improved passing accuracy and number of passes relative to rest. Moreover, the number of passes performed in the allocated time period was significantly reduced after fatiguing exercise. Therefore, the results of McMorris et al. (1994) are in agreement with the experiments conducted as part of this thesis. Thus, there does appear to be an association between arousal and skill performance. In terms of practical guidelines to soccer players, this highlights again the benefits of an adequate warm-up to increase arousal to optimal levels prior to the commencement of a game for the most favourable effects on skill performance. Moreover, as fatiguing exercise may lead to a failure to maintain arousal at optimal levels, then it may be of benefit for players to practice skilled movements when physiologically stressed so as to ‘acclimatise’ to such conditions during a game.

Moderate exercise results in an increase in catecholamines (Astrand and Rodahl, 1986) which is thought to increase arousal (Cooper, 1973). Indeed, several authors have shown a relationship between increases in plasma adrenaline and noradrenaline and cognitive arousal (Chmura et al., 1994; Cooper, 1973; Sothmann et al., 1991). Therefore, the measurement of catecholamines during the LIST would appear to help clarify this association between arousal and skill performance and warrants further investigation.

10.3 What is the effect of CHO-E ingestion on LSPT performance?

So far this discussion has suggested possible reasons why soccer skill performance deteriorated during and following the LIST even with fluid ingestion. One of the principal aims of these series of experiments was to determine the extent, if any, of
the beneficial impact of CHO ingestion during exercise on soccer skill. Although not unequivocal there was a trend for soccer skill to be better maintained towards the end of the LIST in the CHO trials. The reason for the lack of a statistical significance could relate to the relatively high standard errors in performance data. When the data from the three main studies are combined (Chapters 4, 7 and 9, \( n = 49 \)), there was a 4% decline in LSPT performance with CHO ingestion but a 9% decrease in the PLA condition (baseline vs. post-LIST, \( p = 0.09 \) for interaction of treatment x time). This 5% difference between conditions is in agreement with the recent findings of Ostojic and Mazic (2002). These authors used a soccer-dribbling test to show that skill performance was improved by 5% after CHO ingestion during a 90-min soccer match. Therefore, there appears to be a role for the supply of exogenous energy on maintaining skill performance towards the end of soccer games. There are a number of possible reasons for this beneficial impact of CHO ingestion during exercise on skill performance.

Zeederberg et al. (1996) found no benefit in soccer skill performance following CHO ingestion and suggested that this could have been due to no evidence of hypoglycaemia when the placebo solution was consumed. Low blood glucose concentrations may reduce cognitive functioning during sports such as soccer as these sports require tactical and thought processing (Shephard and Leatt, 1987). Indeed, during the LIST, there was maintenance of plasma glucose throughout exercise but a marked fall towards the end of exercise in the fluid only trials. Therefore, there may be a possible link between a fall in plasma glucose and reduction in skill performance. Although statistically significant, there was a weak inverse correlation between plasma glucose and LSPT performance \( (r = -0.26, p<0.01; \text{data from Chapters 7 and 9 were combined for the correlation i.e. } n = 21) \). Not only was this relationship weak but correlations give an indication of association and not necessarily a causal relationship. Therefore, a possible link between low blood glucose concentrations and skill performance remains to be established with clearer empirical data.

Many studies have shown that CHO ingestion can improve intermittent running performance (e.g. Nicholas et al., 1995; Quanz, 1999), probably as a result of a reduced utilisation of endogenous stores and hence sparing of muscle glycogen (Nicholas et al., 1999; Tsintzas et al., 1996). Therefore, it may be surmised that
reduced glycogen content may also affect motor skill performance. Moreover, it may be that the reason why fluid ingestion maintained skill performance was not due to dehydration *per se* but reduced glycogen utilisation (McGregor, 1999) as fluid ingestion reduces muscle glycogenolysis (Hargreaves et al., 1996). Nicholas et al. (1999) reported significantly lower glycogen utilisation during the LIST following CHO-E ingestion, and this was especially evident in type II muscle fibres. As anaerobic ability (speed/sprinting) is crucial in successful soccer performance, then glycogen sparing may help maintain skill performance towards the end of a game. Indeed, there was a tendency for the time taken aspect of the LSST to be quicker post-LIST with CHO ingestion (see below). As the ‘time taken’ component of the LSPT was not affected by CHO ingestion during any of the studies then the exact role of glycogen availability on skill performance is unclear.

Ratings of perceived exertion (RPE) were consistently higher during the later stages of exercise, thus suggesting subjects had a greater perception of fatigue, in the fluid only trials (Chapters 4, 7 and 9). Furthermore, subjects indicated greater affective positivity (Feeling Scale, FS) and a tendency for higher activation (Felt Arousal Scale, FAS), during the last 30 min of exercise in the CHO trial (Chapter 9). Based on a circumplex model of affect (Hall et al., 2002; Russell, 1980), it seems that subjects tended to be in a more ‘activated pleasant’ state (feelings of excitement and enthusiasm) during the CHO trial but in a more ‘neutral’ state in the PLA condition. As fatigue has been defined as a ‘safety mechanism’ (Edwards, 1981), then affective responses may be a way of the CNS reacting to the fatiguing exercise in an effort to withdraw from the activity that is causing severe homeostatic perturbation (Hall et al., 2002). Therefore, in the PLA trial, possibly due to the energy crisis as a result of low muscle glycogen or plasma glucose concentrations, the subjects were feeling worse and hence reduced relative exercise intensity and sprint performance with a tendency to reduce soccer skill performance as well.

The release of cortisol is increased due to physical and mental stress (Norman and Litwack, 1987; Wilmore and Costill, 1999). There were strong tendencies for serum cortisol concentrations to be higher in the last 30 min in the PLA trials (Chapters 4, 7 and 9). With the data combined from the 3 studies, there was a significant interaction of treatment x time, with a difference between trials after 90 min of the LIST.
Serum cortisol was maintained at resting concentrations in the CHO trial (24 μg.dl\(^{-1}\)) but increased by 32% after 90 min of the LIST in the PLA condition (30.4 μg.dl\(^{-1}\)). Therefore, the possibility exists that the CNS is attempting to reduce muscular activity due to the stress of exercise when low glycogen or blood glucose concentrations may prevail, thus, resulting in poorer sprint performance and a tendency for weaker skill performance in the PLA trials. However, cortisol induces a breakdown of amino acids and increases mobilisation of FFA which can then undergo gluconeogenesis to ensure an adequate fuel supply during exercise (Hedge et al., 1987, op cit. Deschenes et al., 1991; Wilmore and Costill, 1999). Indeed, there was a significantly higher availability of FFA and glycerol in the PLA trials during these experiments (Chapters 4, 7 and 9). Therefore, the release of cortisol may just be a way of liberating other sources of energy during exercise i.e. body trying to accommodate the consequences of exercise. Nevertheless, there may be a role for cortisol in fatigue but the stress signals mediated by the brain and the exact feedback role of cortisol on brain function remain unclear (Norman and Litwack, 1987).

Serotonin (or 5-HT) has been found to be associated with feelings of tiredness or lethargy and in the perception of pain (Wilson and Maughan, 1992). It has also been associated with levels of arousal and mood (Young, 1986; op cit. Davis, 1995). Therefore, Newsholme et al. (1987) proposed that serotonin may be a potential mediator of the so-called 'central fatigue' (see Davis, 1995 for a review). In general, this hypothesis suggests that increased concentrations of brain 5-HT can impair CNS function during prolonged exercise and thereby cause a deterioration in sport and exercise performance (Newsholme et al., 1987). During these experiments (Chapters 4, 7 and 9) plasma FFA concentrations were significantly elevated in the PLA trial and thus may have led to an increase in the free-tryptophan delivery to the brain, resulting in an increase in brain 5-HT synthesis (Davis, 1995). Furthermore, measurements of serotonin per se are not available and so changes in prolactin concentrations have been used as a surrogate measure of serotonergic activity (Wilson and Maughan, 1992). Serum prolactin was maintained at resting concentrations in the CHO trial but increased markedly towards the end of the LIST in the PLA condition (interaction of treatment x time, \(p<0.05\); Chapter 7). Therefore, in the PLA condition, subjects may have reported higher RPE values due to higher brain 5-HT activity and this may have led to the decreased gross muscular (sprint) and trend towards
decreased fine motor (skill) performance. Of course, this remains speculative, as we are presently unable to determine serotonin concentrations in humans during exercise.

Therefore, there are a number of possible means by which CHO ingestion may enhance skill performance. As the supplementation appears to incur other benefits (see below) and so trying to isolate a single mechanism for the reduction in skill performance may not be appropriate. Nevertheless, there does appear to be a strong influence of CNS function on skill performance and future investigations need to be conducted to realise these associations using, where necessary, alternative methodologies and techniques (e.g. other psychological measures) and/or measurement of other hormones (e.g. catecholamines).

10.4 What is the effect of exercise and CHO-E ingestion on LSST performance?

For LSST performance, a consistent finding during the experiments was that subjects traded off speed of shot and time taken to complete each shot sequence to maintain accuracy (what they perceived as the main performance indicator). Although this is within the confines of the test, this may not be acceptable within a game situation. They may not have the time to shoot as defending players are likely to close down the space and if they did shoot, then the speed of the ball may not be quick enough to beat the goalkeeper. From a practical point of view it would therefore appear that as players become fatigued towards the end of a game then their movements are slowed or weakened but they are still able to retain shooting accuracy.

Shot speed decreased from baseline and pre-LIST to post-LIST in the studies. Chiu et al. (1998) found that better players had greater leg strength and this enabled them to strike the ball faster and further. Additionally, Ali (1999) found that leg strength, as measured by an isokinetic dynamometer was significantly reduced following the LIST. Therefore, it would appear that players' leg strength deteriorated following the LIST and this was associated with a reduced shot speed.

The reasons for this decrease in leg power may relate to glycogen depletion and an inefficient restoration of PCr, neuromuscular fatigue and/or muscle damage. The ATP-PCr energy system is crucial for anaerobic resynthesis of ATP during such tasks.
as shooting. The rapid resynthesis of PCr is primarily due to the breakdown of glucose and glycogen. As there is a considerable decrease in muscle glycogen following the LIST (Nicholas et al., 1999), then there may be inadequate restoration of PCr, thus leading to a lower work capacity. Following 90 min of intermittent exercise, Mercer et al. (1998) found that isokinetic torque in the knee flexors was reduced by 16% and that electromechanical delay (EMD) increased by 30% pre- to post-exercise. Thus, they suggested that muscle function deterioration after a simulated game was due to an impairment of neuromuscular control. In addition, considerable muscle damage has been shown to occur whilst performing the LIST (Thompson et al., 1999). Therefore, muscle damage may have had the effect of reducing tension generation when players were shooting at the goal. The exact mechanism for the reduced shot speed could therefore be due to one or more of these reasons. However, there was no beneficial impact of CHO ingestion during the LIST on the players’ ability to strike the ball.

Time taken to complete each shot sequence was also reduced. During a game defending players will close down a player about to strike a ball very quickly and so the opportunity to strike the ball may be taken from them. Furthermore, there did appear to be a beneficial impact of CHO ingestion on this aspect of the LSST as subjects tended to be quicker post-LIST during the CHO trials. Players need to perform a number of actions during the LSST and therefore the time taken aspect is made up of time to react to the investigator’s call, move to and from the cones, pass, control and shoot the ball, and then ‘follow-up’ each shot by sprinting past the goalkeeper. Furthermore, players have to make decisions as to where to shoot i.e. by taking into account the position of the goalkeeper. As CHO ingestion tended to maintain sprint performance better towards the end of the LIST, possibly as a consequence of glycogen sparing in type II fibres (Nicholas et al., 1999, see below), then it may be the sprint aspects of the LSST that is influenced by the exogenous energy supply. It cannot be ruled out that CHO ingestion may also have positive effects on reaction time, decision making and the ability to pass and control the ball better (cf. LSPT performance), but as of yet this cannot be determined without more sensitive timing equipment.
10.5 Why were there no graded effects of CHO-E ingestion?

The results of Chapter 9 showed that there was no graded effect of CHO ingestion on soccer skill and metabolism *i.e.* CHO ingestion at a rate of 45 g. hour\(^{-1}\) showed no extra benefits to that of 30 g. hour\(^{-1}\). This was suggested to be either due to a limitation in the rate of intestinal absorption of the extra delivery of CHO, as plasma glucose concentrations were not significantly altered relative to previous studies (Chapters 4 and 7), or that maximal CHO oxidation rates had already been achieved with the lower rate. Therefore, fluid ingestion rates of 2 ml. kg\(^{-1}\)BM every 15 min of exercise can be recommended to soccer players to maintain a high exercise intensity and sprint and skill performance. That is, the extra fluid delivery, although not inducing gastrointestinal distress, did not have any additive benefits. Moreover, the extra fluid may have actually had a negative impact on performance, as sprint times tended to be lower relative to previous studies (Chapters 4 and 7). This may have been due to the extra weight of the fluid in the stomach, which may have caused some discomfort, but was not indicated by the subjects (Gut Fullness Scale).

10.6 Why were there no clearer benefits of CHO-E ingestion?

There are a number of possible reasons why the ingestion of CHO did not result in more clear benefits on skill performance. Firstly, the question of why skill should deteriorate may be asked. As skill is such an ingrained phenomenon, it may not deteriorate in such large magnitudes after 90 min of exercise. Therefore, even small changes in performance may have more than just statistical significance. To achieve statistical significance for smaller percentage differences between conditions, the power of the study must be increased. This can be achieved either by improving the sensitivity and repeatability of the experimental protocols (in this case the soccer skill tests) or by increasing the number of subjects (Atkinson *et al.*, 1999).

The modified LSPT has been found to have ratio limits of agreement of 1.25 for 1st/2nd team players (Chapter 5) while it is 3.2 for the points scored aspect of the LSST (Chapter 6). Based on their nomogram, to achieve statistical power of 0.9, the sample size to achieve a 5% change between trials would have to increase to ~60 for the LSPT and hundreds of subjects for the LSST (Atkinson *et al.*, 1999). It is easier to
achieve such sample sizes in many social science experiments where questionnaires are employed, but virtually impossible for physiological testing. Therefore, the more logical approach would be to try to improve the repeatability of the skill tests further and to try to make them more sensitive to small changes in skill performance.

Skilled performance is not only reflected by quantifiable data, such as points scored during the shooting test, but also has other qualities e.g. technique employed, decision making, cognitive and other perceptual aspects (Bate, 1996). Therefore, qualitative information may need to be employed as well to determine whether skilled performance changes occur with CHO ingestion. For instance, soccer coaches could evaluate changes in technique, whether correct decisions were being made and so on, via video analysis. Although this procedure would place a greater strain on time and resources, the results from this triangulation of methods may provide clearer information as to the benefits of CHO ingestion on soccer skill performance.

The reason why CHO ingestion did not reveal the true extent of its possible beneficial impact on skill performance may also be related to affective valence. Carbohydrate ingestion appears to provide less displeasurable feelings during the LIST relative to fluid alone (Chapter 9) and this may have helped players better maintaining skill performance. However, as soon as fatiguing exercise is stopped there is a pronounced and instantaneous rebound from affective negativity to affective positivity (Hall et al., 2002). Therefore, as the post-LIST skill tests were completed following a few minutes of rest then the negative feelings may have reversed to positive feelings. Indeed, it was found that there was a pronounced change from a neutral affective state following the completion of the LIST to a clear affective positivity after the post-LIST skill tests (Chapter 9). Therefore, future studies investigating the influence of CHO ingestion on soccer skill may wish to incorporate the skill test aspects within the intermittent running protocol itself. Interestingly, Northcott and co-workers (1999) did absorb the skill elements within their intermittent running circuit and showed significant differences in skill between CHO and placebo solutions at 75 and 90 min of exercise.
10.7 Were there any other benefits of CHO-E ingestion?

Although the effects of CHO ingestion on skill performance were not completely unequivocal, there were other benefits of supplementation during exercise. Sprint performance was significantly faster during the LIST with CHO ingestion during one of the experiments (Chapter 4) but not the others (Chapters 7 and 9). In all experiments there were trends for performance to be maintained in the last 30 min of exercise in the CHO trials but a further decrease in the PLA trials. Although there were slight differences in experimental procedures during each of these tests, combining the data revealed two main effects of treatment \((p<0.05)\) and time \((p<0.01)\) as well as an interaction of treatment x time \((p<0.05)\). Whereas the times were maintained during the last 30 min in the combined CHO trials (2.61s), sprint times slowed to 2.63 and 2.66 s during blocks 5 and 6, respectively, in the combined PLA trials. Although the difference between the conditions was only 0.05 s, within a game situation this may be the difference between reaching the ball or not. Moreover, if a player cannot get to ball, then he cannot perform the skill, be it shooting or passing – thus, highlighting the association between gross muscular and fine muscular actions in footballing ability.

The faster sprint times in the CHO trials led to a greater demand on the body and this was highlighted (although not all parameters reached statistical significance) via an increased heart rate, oxygen uptake, average exercise intensity, plasma lactate and ammonia concentrations, and an overall increased energy expenditure during the LIST. Therefore, it may be surmised that the overall work rate during soccer is improved with CHO ingestion. Even with this greater strain placed on the body, soccer skill performance was still maintained to at least the same level as when fluid alone was ingested during exercise.

Many authors have suggested that the benefits of CHO ingestion during exercise on performance is due to the supplementation counteracting the fall in blood glucose with prolonged exercise (Coggan and Coyle, 1986; Coyle et al., 1986). Indeed, blood glucose was shown to fall to \(~4\) mmol.l\(^{-1}\) after the 90 min of the LIST in the PLA trials. However, plasma glucose was maintained above resting concentrations with CHO ingestion throughout the exercise period. Therefore, the decrement in sprint
performance and overall exercise intensity may have been due to the higher CHO oxidation possible due to the maintenance of plasma glucose. Indeed, when the data were combined the overall CHO oxidation rates was higher in the CHO trial (2.6 vs 2.4 g.min⁻¹, p<0.05). Furthermore, there was a strong trend (p = 0.06) for higher maintenance of oxidation rates in the CHO trial, with a decline in the PLA condition, towards the end of exercise.

Of course, using RER as a method of estimating CHO oxidation rates during intermittent exercise may be questioned because of the non-steady state exercise and the periods of high-intensity exercise. This is because the increased lactate produced can increase CO₂ production and reduce the HCO₃⁻ pool, thus leading to an overestimation of carbohydrate oxidation and an underestimation of fat oxidation (Christmass et al., 1999a). However, a constant HCO₃⁻ pool is required for the reliable measurements of VCO₂ in expired gas collections (Romijn et al., 1992). Nevertheless, after an initial increase in lactate (which reduces the HCO₃⁻ pool), constant lactate concentrations are associated with stable HCO₃⁻ concentrations during sustained heavy constant work (Wasserman, 1986, op cit. Christmass et al., 1999a). In the present experiments (Chapters 4, 7 and 9), after an initial increase, there were stable plasma lactate concentrations during exercise. Furthermore, in experiments where subjects performed high-intensity intermittent running, the HCO₃⁻ concentrations were stable during the exercise period (Christmass et al., 1999a; 1999b; 2001). In addition to the constant lactate concentrations, the relatively constant values for ÑE during the experiments (Chapters 4, 7 and 9) also indicate a stable HCO₃⁻ pool (Christmass et al., 1999b; 2001). Therefore, this supports the validity of using indirect calorimetry to estimate substrate oxidation rates during such intermittent exercise.

Other researchers have suggested that the reason why performance is improved during continuous (Tsintzas et al., 1995) and intermittent running (Nicholas et al., 1999) with CHO ingestion is not due to maintenance of blood glucose and CHO oxidation rates (as the rates were similar in CHO and PLA trials), but a reduced utilisation of glycogen leading to glycogen sparing. In the present experiments it must be realised that subjects were already in a low muscle and liver glycogen state due to the
glycogen reduction exercise and low carbohydrate meal of the night before. Therefore, this may have led to the increased oxidation of CHO. This is not to say that a lower glycogenolysis took place during exercise in the CHO trial. Tsintzas and Williams (1998) claimed that a lower glycogen utilisation is observed when there is hyperinsulinaemia and hyperglycaemia in the CHO trial compared to the control. In these experiments, there was maintenance of insulin and glucose concentrations with CHO ingestion whereas decreases with ongoing exercise in the PLA condition. Furthermore, CHO ingestion during the LIST has previously been found to spare muscle glycogen content, especially in type II fibres (Nicholas et al., 1999). Therefore, the exogenous CHO may have had a dual effect of maintaining CHO oxidation rates and sparing muscle glycogen (especially in type II fibres) and these were probably the reasons for the improved sprint performance and exercise intensity towards the end of the LIST. As mentioned previously, there may also have been an influence of these factors on better maintaining skill performance as well.

In these series of experiments the ingestion of CHO-E also reduced the perception of effort in the last 30 min of the LIST (Chapters 4, 7 and 9). This was surprising as the relative exercise intensity and, to a certain degree, sprint performance, indicated that subjects were actually exerting themselves to a greater extent in the CHO trial. Although the RPE scale gives an indication of the perception of effort, it does not indicate whether these are positive or negative feelings or give an indication of the level of arousal/activation. Therefore, psychological scales of affect (Feeling Scale (FS) and Felt Arousal Scale (FAS)) were used to further examine this 'feel-good' factor of CHO-E ingestion (Chapter 9). It was found that in the absence of CHO-E ingestion subjects felt less activated/aroused in the last 30 min of the LIST. Furthermore, there were trends for subjects to indicate feeling 'fairly good' in the last 30 min with CHO-E ingestion, with a shift to neutral feelings in the fluid only trial. Moreover, when these two continuums were incorporated within a circumplex model (Russell, 1980), subjects tended to be in a more activated pleasant state (excitement and enthusiasm) towards the end of exercise with CHO-E ingestion, but in a state of neutrality in the PLA trial. Therefore, CHO-E ingestion exerts a 'feel-good' factor during high-intensity intermittent exercise and this may be a possible reason why there were tendencies for better sprint and skill performance in those trials.
In addition to the physiological and psychological benefits, there may also be clinical benefits from ingesting CHO-E during such exercise. In a related experiment to Chapter 4, the blood samples of 6 subjects (including an extra sample 30 min post-LIST) were analysed for plasma cortisol, interleukin-6 (IL-6), tumor necrosis factor-α (TNF-α) and lipopolysaccharide (LPS)-stimulated neutrophil degranulation (Bishop et al., 2002). A discussion into the exact findings of this study are beyond the scope of this discussion (see Bishop et al., 2002) but briefly, the elevation of these responses due to the high intensity exercise was largely attenuated by the ingestion of CHO-E during the LIST. Therefore, the authors suggested that games players should consume adequate amounts of CHO during such exercise in order to maintain immune cell function (Bishop et al., 2002).

10.8 Conclusions

In summary, soccer skill performance deteriorated following 90 min of prolonged, high-intensity intermittent shuttle running. Moreover, skill performance followed an inverted-U pattern i.e. an improvement in performance from rest to the middle part of exercise and then deterioration at the end, possibly as a result of changes in arousal levels. The ingestion of CHO-E showed tendencies to maintain skill performance better than when fluid alone was consumed. Furthermore, CHO-E ingestion better maintained sprint performance and resulted in higher overall exercise intensity during the LIST. This is an important finding as players who are unable to sprint to get to the ball will not be able to perform the skilled movement. In addition, CHO-E ingestion led to lower perceptions of exertion and more positive feelings of affect, especially towards the latter stages of exercise – this may help to explain the trend towards better skill maintenance in those trials. Furthermore, CHO-E ingestion reduced the physiological stress placed on the body during exercise. Therefore, the ingestion of CHO-E drinks over water alone should be encouraged to soccer players as it incurs physiological, biochemical and psychological benefits during such exercise.
10.9 Potential for future research

- Investigate further the relationship between muscle glycogen concentrations and skill performance
- Examine the influence of habitual diet and diets containing high and/or low CHO on skill performance
- Further examination of skill tests to include qualitative aspects and also incorporation within the intermittent exercise itself
- Examine further the effect of CHO-E on markers of central fatigue to investigate link between arousal and mood and skill performance
REFERENCES


Appendix A: Health screen questionnaires

Appendix B: Rate of Perceived Exertion (RPE), Feeling Scale (FS) and Felt Arousal Scale (FAS)

Appendix C: Gut Fullness (GF) and Thirst scales

Appendix D: Loughborough Soccer Passing Test (LSPT) trial order sheet

Appendix E: Loughborough Soccer Shooting Test (LSST) trial order sheets

Appendix F: Low carbohydrate meal
It is important that volunteers participating in research studies are currently in good health and have had no significant medical problems in the past. This is to ensure (i) their own continuing well being and (ii) to avoid the possibility of individual health issues confounding study outcomes.

Please complete this brief questionnaire to confirm fitness to participate:

1. **At present**, do you have any health problem for which you are:
   - (a) on medication, prescribed or otherwise ...................... Yes □ No □
   - (b) attending your general practitioner ............................. Yes □ No □
   - (c) on a hospital waiting list ............................................. Yes □ No □

2. **In the past two years**, have you had any illness that required you to:
   - (a) consult your GP ........................................................ Yes □ No □
   - (b) attend a hospital outpatient department ...................... Yes □ No □
   - (c) be admitted to hospital .............................................. Yes □ No □

3. **Have you ever** had any of the following:
   - (a) Convulsions/epilepsy .................................................. Yes □ No □
   - (b) Asthma ........................................................................ Yes □ No □
   - (c) Eczema ........................................................................ Yes □ No □
   - (d) Diabetes ...................................................................... Yes □ No □
   - (e) A blood disorder ......................................................... Yes □ No □
   - (f) Head injury ................................................................. Yes □ No □
   - (g) Digestive problems ..................................................... Yes □ No □
   - (h) Heart problems......................................................... Yes □ No □
   - (i) Problems with bones or joints .................................... Yes □ No □
   - (j) Disturbance of balance/co-ordination ......................... Yes □ No □
   - (k) Numbness in hands or feet .......................................... Yes □ No □
   - (l) Disturbance of vision .................................................. Yes □ No □
   - (m) Ear / hearing problems ............................................ Yes □ No □
   - (n) Thyroid problems..................................................... Yes □ No □
   - (o) Kidney or liver problems ........................................... Yes □ No □
   - (p) An allergic reaction, eg., swelling or breathing difficulties ...... Yes □ No □

4. Has any, otherwise healthy, member of your family under the age of 35 died suddenly during or soon after exercise? ................. Yes □ No □

If YES to any question, please describe briefly if you wish (e.g. to confirm problem was/is short lived, insignificant or well controlled.)

Thank you for your co-operation!
The influence of low muscle glycogen concentration on soccer skill following intermittent, high intensity shuttle running

Health Questionnaire

Please complete the following brief questions to confirm your fitness to participate:

At present do you have any health problems for which you are:

1) On medication, prescribed or otherwise  YES ☐  NO ☐ .

2) Attending your general practitioner  YES ☐  NO ☐ .

Have you any symptoms of ill health, such as those associated with a cold or other common infection?  YES ☐  NO ☐ .

If you have answered yes to any of the above questions please give more details below:

Do you want to take part in today's experiments?  YES ☐  NO ☐ .

Signature:_________________________ Date:____________
RPE Scale

6

7 Very Very Light

8

9 Very Light

10

11 Fairly Light

12

13 Fairly Hard

14

15 Hard

16

17 Very Hard

18

19 Very Very Hard

20
Feeling Scale (FS)

+5 ______ Very good
+4 ______
+3 ______ Good
+2 ______
+1 ______ Fairly good
0 ______ Neutral
-1 ______ Fairly bad
-2 ______
-3 ______ Bad
-4 ______
-5 ______ Very bad
Felt Arousal Scale (FAS)

1  Low arousal

2

3

4

5

6  High arousal
Gut Fullness Scale

6
7 NOT Full
8
9
10
11 Fairly Full
12
13
14
15 Full
16
17
18
19 Very Very Full
20
Thirst Scale

6
7  NOT Thirsty
8
9
10
11  Fairly Thirsty
12
13
14
15  Thirsty
16
17
18
19  Very Very Thirsty
20
# Loughborough Soccer Passing Test

## Order of Trials

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<th>Trial B</th>
<th>Trial C</th>
<th>Trial D</th>
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*LSST Trial Order - Subject Direction*
The meal consumed by the subjects following the glycogen reduction exercise was designed to be isocaloric but low in carbohydrate content. The energy content was 56kJ.kg\(^{-1}\) BM and the CHO content was 1g.kg\(^{-1}\) BM.

The energy and CHO content per 100g of the foodstuffs is highlighted below:

<table>
<thead>
<tr>
<th>Foodstuff</th>
<th>Energy (kJ)</th>
<th>CHO (g)</th>
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<tbody>
<tr>
<td>Chicken breast (uncooked)</td>
<td>148</td>
<td>0</td>
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<tr>
<td>Kurma sauce (uncooked)</td>
<td>127</td>
<td>8</td>
</tr>
<tr>
<td>Rice (cooked)</td>
<td>127</td>
<td>27.8</td>
</tr>
<tr>
<td>Onion bhajis (cooked)</td>
<td>224</td>
<td>31.6</td>
</tr>
<tr>
<td>Vegetable oil</td>
<td>90</td>
<td>0</td>
</tr>
</tbody>
</table>

Typical meal for a subject with a body mass of 70kg:

<table>
<thead>
<tr>
<th>Foodstuff</th>
<th>Weight of food (g)</th>
<th>Energy content (kJ)</th>
<th>CHO content (g)</th>
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</thead>
<tbody>
<tr>
<td>Chicken breast (uncooked)</td>
<td>250</td>
<td>584</td>
<td>0</td>
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<tr>
<td>Kurma sauce (uncooked)</td>
<td>210</td>
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<td>16.8</td>
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<tr>
<td>Rice (cooked)</td>
<td>115</td>
<td>1480</td>
<td>32</td>
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<tr>
<td>Onion bhajis (cooked)</td>
<td>67</td>
<td>600</td>
<td>21.2</td>
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<tr>
<td>Vegetable oil</td>
<td>5</td>
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Total 647 3912 70