Chapter 1 - Introduction

1.1 Literature Review

The body is a complex system that requires nutrients in sufficient amounts for tissue maintenance, repair and growth. This complex system can become compromised if fluid, nutrient and energy intake is less than optimal. An insufficient diet can affect thermoregulatory function, substrate availability, exercise capacity and recovery from exercise (Mc Ardle, Katch & Katch, 2006). Conversely physical activity, performance and recovery from exercise are enhanced by consuming an optimal diet. Physically active individuals must therefore maintain a diet sufficient in nutrients to maintain body weight, replenish muscle glycogen and liver stores, and provide adequate protein for repair and growth of tissue. Fat intake should be sufficient to provide essential fatty acids and fat soluble vitamins (American College Sports Medicine [ACSM], 2000; Mc Ardle et al., 2006).

At rest and during exercise the body is dependent on the availability of two fuel sources: carbohydrate (plasma glucose) and fat (free fatty acids) (Erlenbusch, Haub, Munoz, MacConnie & Stillwell, 2005). During exercise the contribution of carbohydrate (CHO) and fat as a source of fuel is dependent on a number of factors; gender, intensity, duration, fitness level and pre-exercise diet. Fat contributes to the energy pool over a wide range of intensities, but the proportion of energy that fat contributes decreases as exercise intensity increases whilst the contribution of CHO increases (ACSM, 2000; Bean, 2006; Erlenbusch et al., 2005). Exercise at low intensity (<50% $\dot{V}O_2max$) is fuelled predominantly by fat. During moderate intensity exercise (50-70% $\dot{V}O_2max$) the ratio of muscle glycogen to fat is approximately 50:50. As exercise intensity increases (>70% $\dot{V}O_2max$) fat cannot be broken down and transported fast enough to be utilised by the body therefore glycogen provides approximately 75% of energy requirements. During anaerobic exercise muscle glycogen is the primary source of fuel (ACSM, 2000; Bean, 2006).

Body fat stores are relatively plentiful however the body's CHO stores are limited. As exercise duration increases muscle glycogen stores become depleted and blood glucose is required to maintain the body's energy requirements. There is approximately enough muscle glycogen present to fuel 90 - 180 minutes of moderate intensity exercise (Bean, 2006). A well nourished 80 kg individual stores approximately 500 g of CHO. Approximately 400 g of glycogen is stored in the muscles, 90 - 110 g stored in the liver and the remaining 2 - 3 g is blood glucose (McArdle et al., 2006). The body's upper limit for glycogen storage is approximately 15 $g \cdot kg^{-1}$ body mass (McArdle et al., 2006). Exercise at higher intensities depletes muscle glycogen faster. Exercise that uses the aerobic and anaerobic system will deplete glycogen stores after 45 - 90 minutes. Anaerobic exercise will deplete muscle glycogen in 30 - 45 minutes (Bean, 2006). During sub-maximal or intermittent high-intensity exercise of greater than 90 minutes the limited availability of CHO as a substrate for the muscles and central nervous system is a limiting factor in exercise performance (Burke, Kiens & Ivy, 2004).

Ingestion of CHO has been shown to improve exercise performance compared to exercising in a fasted state (DeMarco, Sucher, Cisar & Butterfield, 1999; Febbraio, Chiu, Angus, Arkinstall & Hawley, 2000a; Guerra, Chaves, Barros & Tirapegui, 2004; Kirwan, Cyr-Campbell, Campbell, Scheiber & Evans, 2001a; Kirwan, O'Gorman & Evans, 1998; Thomas, Brotherhood & Brand, 1991). This benefit is attributed to an increased ability to resynthesise ATP at a given intensity of exercise for a longer duration, maintained levels of blood glucose and particularly in intermittent high intensity exercise the sparing of muscle glycogen (Nicholas, Tsintzas, Boobis & Clyde, 1999; Winnick, Davis, Welsh, Carmichael, Murphy & Blackmon, 2005). In a study by Nicholas et al., (1999) six trained games players completed six 15 minute periods of intermittent running, incorporating sprinting, running and walking. During each trial subjects ingested a 6.9% CHO solution or a non-carbohydrate solution immediately before and every 15 minutes throughout the exercise period. Nicholas found that total muscle glycogen utilisation was lower during the CHO (192.5 ± 26.3 mmol) compared with control trial (245.3 ± 22.9 mmol) ($P < 0.05$). In this study muscle glycogen utilisation was reduced by 22% in CHO compared with the control trial. The ability to perform prolonged exercise at a range of intensities (65 to 85% $\dot{V}O_2max$) is related to pre-exercise concentrations of muscle glycogen. A low CHO diet jeopardises glycogen stores forcing an individual to train in a state of glycogen depletion which is known to be associated with fatigue during exercise (Nicholas, Green, Hawkins & Williams, 1997). Nicholas et al. (1997) showed that a diet consisting of 10 g $CHO \cdot kg^{-1} \cdot day^{-1}$ improved intermittent high intensity running capacity ($P < 0.05$) compared to a diet consisting of 5.4 g $CHO \cdot kg^{-1} \cdot day^{-1}$. Subjects ran for 5.8 ± 1.7 min longer in the high CHO trial compared to low CHO trial. In a study by Achten et al. (2003) of seven trained runners, found that a diet consisting of 8.5 g $CHO \cdot kg^{-1} \cdot day^{-1}$ compared to 5.4 g $CHO \cdot kg^{-1} \cdot day^{-1}$ resulted in better maintenance of exercise performance and mood state over a period of intensified training. Similar findings were found in a study by Balsom, Wood, Olsson & Ekblom (1999) of six male football players. Players competed in a 90 minute game on two occasions following a low (30%) and high (65%) CHO diet. Players performed significantly ($P < 0.05$) more (33%) high intensity running in the game played following the high CHO diet compared to the low CHO diet. In study by Bangsbo, Norregaard & Thoroe (1992) of seven professional soccer players, performance during intermittent running was enhanced ($P < 0.05$) following the ingestion of high CHO (65%) compared to low CHO (39%) diet. Research would suggest therefore that in order to optimise performance in both endurance and intermittent exercise a high CHO diet should be consumed. Due to the limited availability of glycogen physically active individuals should strive to have a diet containing approximately 55 to 60% of calories from CHO or between 6 and 10 g CHO▪kg^{-1}▪day^{-1} (Mc Ardle et al., 2006).

The brain's energy requirements are also met exclusively through the availability of glucose. At rest and during exercise the level of blood glucose is normally 100 mg▪dL^{-1} (5.5 mmol). During prolonged intense exercise blood glucose is depleted and the body goes into a state of hypoglycaemia (<45 mg▪dL^{-1}) causing symptoms including weakness, hunger and dizziness and in extreme hypoglycaemia loss of consciousness (Mc Ardle et al., 2006). The brains energy stores are extremely small and are in constant need of glucose replacement. Cognitive function like physical performance is directly influenced by levels of available glucose (Benton & Parker, 1998; McArdle et al., 2006; Meeusen, Watson & Dvorak, 2006). CHO has also been shown to positively influence cognitive function (e.g., visual and auditory reaction times, visual and auditory memory, arithmetic and recall) in both adults and children compared to those in a fasted state (Benton & Parker, 1998; Gibson & Green, 2002; Pollitt & Mathews, 1998). The beneficial effect of CHO is related to increased substrate delivery for the brain potentially delaying impaired central nervous system (CNS) function, this of great importance in exercise performance particularly during the latter stages of exercise (Meeusen et al., 2006, Winnick et al., 2005). Studies have found that the higher the blood glucose concentration, the better the performance in cognitive function (Benton & Parker, 1998; Gibson & Green, 2002). Hypoglycaemia has been shown to cause deterioration in exercise performance as well as deterioration in cognitive function (Bottoms, Hunter & Galloway, 2006). It is thought that exercise induced hypoglycaemia reduces brain glucose uptake and overall cerebral metabolic rate which is linked to a reduction in voluntary activation during continuous muscular contractions. This reduction in CNS activation is eliminated when euglycaemia is maintained (Meeusen et al., 2006). In fasted individuals a delay in consuming a morning breakfast results in a gradual reduction in blood glucose and insulin concentrations, along with other metabolic (neurotransmitter concentrations) changes that has the potential to interfere with aspects of cognitive performance. The extent to which cognitive performance is affected may be dependent on a number of factors; duration of fast, timing, size, and composition of the breakfast meal. The meal characteristics, composition, size and time of consumption can result in a number of metabolic changes in, blood glucose, insulin and neurotransmitter concentrations, which may affect cognitive function (Pollitt & Mathews, 1998). CHO ingestion has been shown to positively influence; choice visual reaction times and auditory reaction times pre and post exercise (Bottoms et al., 2006; Collardeau, Brisswalter, Vercruyssen, Audiffren & Goubault, 2001). Collardeau et al. (2001) examined the effects of prolonged exercise and CHO ingestion on single (SRT) and choice (CRT) reaction times in eight trained triathletes. Subjects performed two 15 minute sub-maximal treadmill runs before and after a 70 minute track run. During each experimental trial subjects ingested a 5.5% CHO solution or an artificially sweetened placebo. A SRT test was performed before, during the first and second sub-maximal test and post exercise. CRT test was performed before and after exercise. Collardeau found that CHO ingestion during exercise lead to an improvement in cognitive performance for CRT test following 100 minutes of running. Blood glucose concentrations during this study were significantly higher for the CHO trial compared with placebo ($P < 0.05$). There was a significant ($P < 0.05$) decrease in CRT from 688.5 ± 61 ms pre-exercise to 654 ± 63 ms post exercise for the CHO trial, while CRT pre-exercise (688 ± 104 ms) and post exercise (676 ± 73.4 ms) remained stable during the placebo trial. No significant differences were observed for SRT. In a study of CHO ingestion on skill maintenance in squash players by Bottoms et al. (2006) significant improvements ($P = 0.03$) were observed in visual reaction times in the CHO trial verses the placebo no CHO trial. A significant difference was observed in blood glucose between trials ($P < 0.01$). Bottoms found no overall effect of CHO ingestion on skill maintenance ($P = 0.10$) but did note that significantly fewer balls landed outside the scoring zone in the CHO trial compared to placebo ($P = 0.03$). Perhaps the elevated blood glucose concentrations associated with the CHO trials for both of these studies contributed to the improvements observed in visual and choice reaction times.

A number of studies have investigated the effect of CHO ingestion on skill maintenance during game sports such as tennis, squash and other intermittent high intensity sports. Some studies have reported no performance advantage in skill maintenance (Bottoms et al., 2006; Zeederberg et al., 1996) whilst others have shown a favourable performance advantage in skill maintenance following CHO ingestion (Graydon, Taylor & Smith, 1998; Ostojic & Mazic, 2002; Welsh, Davis, Burke & Williams, 2002; Winnick et al., 2005). In a study by Zeederberg et al. (1996) of soccer players, they found that ingestion of 6.9% glucose-polymer (GP) solution ingested fifteen minutes before each match and again at half time did not have any favourable effect on motor and skill performance during the games played. However, perhaps the lack of performance advantage can be explained. Plasma glucose concentrations were maintained >5 mmol/L irrespective of whether they ingested CHO throughout the duration of the match. If a difference in blood glucose had been observed between trials the outcome of this study may have differed. The pre-exercise diet of participants was not controlled prior to the study and each participant consumed their own light meal 3 - 4 hours before each game. This may have played some part in the fact that the players post game blood glucose concentrations were the same (5.3 ± 0.7 mmol and 5.1 ± 0.9 mmol) in both the GP and placebo trials respectively. Perhaps the pre-exercise meal was of sufficient CHO content to keep muscle glycogen and plasma glucose concentrations elevated throughout the duration of the match in both the GP and placebo trials. In addition, current recommendations for exercise lasting more than one hour is to consume a beverage containing 4 to 8% concentration of CHO in 150 to 350 ml of fluid every 15 to 20 minutes (ACSM, 2000). Gastric emptying is maximised when the amount of fluid in the stomach is high (ACSM, 2000; Leiper, Broad & Maughan, 2000). During this study 5 ml/kg body mass of GP solution was only taken on 15 minutes prior to the game and again at half time. Perhaps the amount of CHO ingested or the volume of fluid taken during the trial was not of sufficient volume and frequency to maximise gastric emptying and absorption. It is possible therefore that the gastric emptying rate of ingested CHO and/or amount of CHO ingested was insufficient to give subjects the benefit during the match. Graydon et al. (1998) studied the effects of CHO ingestion on shot accuracy during a conditioned squash match. In this study accuracy of performance was maintained during the CHO trial but not in the placebo no CHO trial ($P < 0.01$). The placebo trial experienced a drop in performance accuracy of 19%. Deterioration in performance of this magnitude could prove detrimental in a game of evenly matched individuals. In a study by Welsh et al. (2002), ten trained men and women, performed intermittent high intensity shuttle running, closing simulating the demands of actual competitive sports such as basketball, hockey, etc. The trial consisted of four 15 minutes quarters of intermittent shuttle running at differing levels of intensity separated by a 20 minute half time rest period, followed by a shuttle run to fatigue. In addition to physical performance, mental function (whole body motor skill) was also assessed. A CHO drink or placebo containing no CHO was consumed prior to and during the experimental trial. Welsh found that CHO ingestion resulted in a 37% longer run time to fatigue and faster 20 m sprint time during quarter four ($P < 0.05$). Whole body motor skill was also significantly improved during the CHO trial compared to the placebo trial. The total score for the motor skill test was significantly lower ($P = 0.02$) after quarter four when subjects consumed the CHO compared to placebo.

These results indicate that CHO ingestion may play a beneficial role on physical and mental function during intermittent exercise where the physical and mental requirements are similar to that of other game sports. In a similar study by Winnick et al. (2005) twenty active men (10) and women (10) performed two experimental trials during which they were fed either a 6% CHO solution (CHO) or flavoured water (CON). Each experimental trial consisted of four 15 minutes quarters of intermittent shuttle running at differing levels of intensity separated by a 20 minute half time rest period and 5 minute break after the first and third 15 minute quarters. Before each experimental trial, at each quarter break and at trial completion subjects performed a battery of tests designed to measure physical and CNS function. Compared with CON, the CHO trial resulted in faster 20 m sprint times ($P < 0.01$) and higher average jump height ($P = 0.002$) in the fourth quarter. CHO also improved motor skills and mood during exercise compared to CON ($P < 0.05$). These results lend further support the beneficial role of CHO on both peripheral and CNS function particularly in the later stages of exercise.

The mechanisms by which glycogen depletion affects skill maintenance and performance during exercise could be due to different mechanisms; cognitive function and/or fatigue (MacLaren, 1998). The mechanisms by which CHO affects endurance exercise may be different to that in intermittent high intensity exercise in which the exercise intensity, duration and rest intervals and the skill requirements are in constant change (Welsh et al., 2002). Racket sports by their nature require a high degree of skill therefore any reduction in cognitive performance may lead to inaccuracy, reduced reaction times, impaired decision making, and the ultimately loss of a match (MacLaren, 1998). On the other hand if a player is not capable of reaching the ball in time and making accurate shots performance will invariably deteriorate (Bottoms et al., 2006; Graydon et al., 1998). Fatigue has been shown to negatively influence performance and skill performance in games requiring high levels of cognitive and motors skills (Davey, Thorpe & Williams, 2002; McGregor, Nicholas, Lakomy & Williams, 1999; Vergauwen, Brouns & Hespel, 1998). CHO plays a positive role in delaying fatigue through sparing of endogenous muscle glycogen stores (McArdle et al., 2006). CHO ingestion has also been shown to improve reaction times following fatiguing exercise (Bottoms et al. 2006; Collardeau et al., 2001). It is possible therefore that CHO ingestion prior to and during exercise is a potential mechanism to maintain skill in games where there is a relationship between cognitive and motor skills (Bottoms et al., 2006). It is very difficult if not impossible to compare these studies due to various methodological differences. These conflicting results may be due to differences in the cognitive and skills tests used, timing of tests in relation to CHO ingestion, use of control trials, intensity and duration of exercise and the assessment criteria pre and post exercise (Bottoms et al., 2006) (Table 1).

There is substantial evidence that CHO plays a beneficial role in exercise performance and positively influences games requiring a high degree of cognitive and motor skills. Much less is known about the potential effects of different types of CHO where the glucose response can vary. Could the type of CHO further influence peripheral and CNS function? Certain foods produce a gradual glucose response, whilst others produce a steep rise in glucose followed by a severe drop in blood glucose concentration (Pollitt & Mathews, 1998). The type of CHO is important they should be starches from fibre rich, unprocessed grains, fruits and vegetables (Mc Ardle et al., 2006). CHO and food containing CHO are digested and absorbed at different rates (Mc Ardle et al., 2006) (Figure 1). This is particularly important in sports performance as the rate at which CHO is absorbed from the small intestine into the bloodstream influences how rapidly this CHO can be taken up and used by the muscle cells and other cells in the body before, during and after exercise. The glycemic index (GI) was developed to provide a numerical classification of CHO rating from 0 - 100. The GI is a measure of increase in blood glucose concentration in the 2 hours after ingestion of food containing 50 g of CHO. This figure is then compared to the standard food generally white bread or glucose whose value is 100. The GI is given as a percentage of test food against the standard food. For example the GI of Kelloggs® All Bran is 30 and Kelloggs® Cornflakes is 81, they produce a rise in blood glucose which is 30% and 81% as great as ingesting glucose respectively (Foster-Powell, Holt, & Brand-Miller, 2002; McArdle et al., 2006). These foods are then classified as high GI (60-100), medium GI (40-59) and low GI (<40). The higher the GI the higher the blood glucose levels after ingesting that food (Bean, 2006; McArdle et al., 2006).

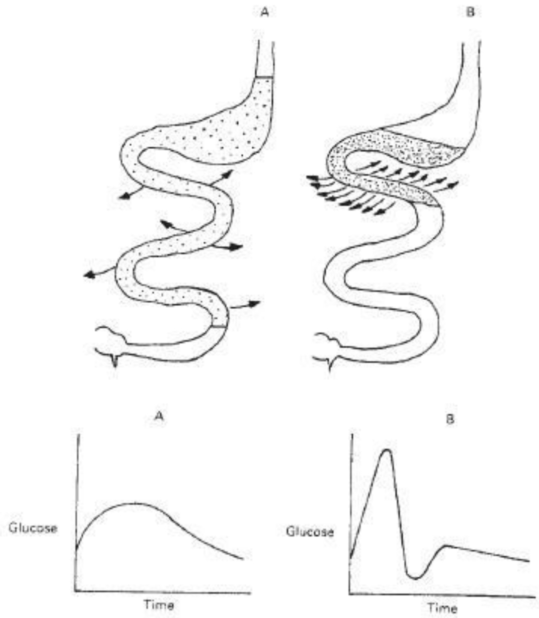

Figure 1 Response of intestinal glucose absorption following a low (A) or high (B) glycemic index meal (Jenkins et al. (2002))

A high CHO meal is recommended in the hours before exercise in order to: provide a sustained source of CHO during exercise, increase both muscle and liver glycogen stores, maintain levels of blood glucose and minimise insulin release prior to exercise (ACSM, 2000; Wu, Nicholas, Williams, Took & Hardy, 2003).

Consuming a meal that has a low glycemic index (LGI) will result in; a reduced rate of glucose absorption, more sustained form of energy, reduced postprandial rise in gut hormones and insulin (Brand-Miller, Holt, Pawlak & McMillan (2002); Febbraio & Stewart, 1996; Jenkins et al., 2002; Sparks, Selig & Febbraio, 1998; Stevenson, Williams & Nute, 2005; Stevenson, Williams, Nute, Swaile & Tsui, 2005; Thomas et al., 1991), increased fat oxidation (Febbraio & Stewart, 1996; Sparks et al., 1998; Wee, Williams, Gray & Horabin, 1999; Wee, Williams, Tsintzas & Boobis, 2005; Wu & Williams, 2006), increased levels of plasma glucose during the latter stages of exercise (DeMarco et al., 1999; Stannard, Thompson & Brand-Miller, 2000) and reduced level of blood lactate (Stannard et al., 2000; Thomas et al., 1991). The greater rate of fat oxidation and as a consequence lower rate to CHO oxidation as a result of consuming LGI meal prior to exercise is beneficial during endurance exercise and may delay reduction in CHO stores (Wu and Williams, 2006) (Table 2).

Consuming a meal that has a high glycemic index (HGI) can result in; a faster rate of glucose absorption, increased postprandial rise in gut hormones and insulin (Brand-Miller et al., (2002); Febbraio & Stewart, 1996; Jenkins et al., 2002; Sparks et al., 1998; Stevenson et al., 2005; Stevenson et al., 2005; Thomas et al., 1991), a dramatic reduction in blood glucose at the onset of exercise (Febbraio et al., 2000b; DeMarco et al., 1999; Sparks et al., 1998; Stannard et al., 2000; Wee et al. 1999; Wee et al. 2005), higher utilisation of CHO during the exercise bout (Febbraio et al., 2000a; Febbraio & Stewart, 1996; Sparks et al., 1998; Wee et al., 2005; Wu et al., 2003; Wu and Williams, 2006), greater muscle glycogen utilisation (Wee et al., 2005), increased level of blood lactate (Stannard et al., 2000; Thomas et al., 1991) and reduced plasma glucose during the latter stages of exercise (DeMarco, et al., 1999; Stannard et al., 2000) (Table 2).

A significant number of studies carried out have examined the effects of pre-exercise LGI and HGI meals on performance during exercise (DeMarco et al., 1999; Fabbraio, et al., 2000a; Fabbraio et al., 2000b; Febbraio & Stewart, 1996; Kirwan et al., 1998; Kirwan et al., 2001a; Kirwan, et al., 2001b; Sparks et al., 1998; Stannard et al., 2000; Thomas et al., 1991; Wee et al., 1999; Wee, et al., 2005; Wu and Williams, 2006) (Table 2). There is conflicting evidence however on the benefit of LGI verses HGI meal on exercise performance. Few studies have reported a performance advantage by consuming a LGI meal (DeMarco et al., 1999; Kirwan et al., 1998; Kirwan et al., 2001a; Thomas et al., 1991; Wu and Williams, 2006) whilst a number of studies have reported no difference in performance between HGI and LGI meals (Erith et al., 2006; Fabbraio et al., 2000b; Febbraio & Stewart, 1996; Kirwan, et al., 2001b; Sparks et all., 1998; Stannard et al., 2000; Wee et al., 1999;).

CHO takes 3 to 4 hours to digest, absorb and get stored as muscle and liver glycogen (McArdle et al., 2006). Current pre-exercise CHO recommendations in order to maximise muscle and liver glycogen storage and provide readily available glucose for absorption during exercise is 3 to 5 g/kg of body mass where sufficient time, three to four hours, exists prior to exercise bout (McArdle, et al. 2006) or 1 g/kg of body mass for pre-exercise meal one hour prior to exercise (Bean, 2003). Ingestion of CHO one hour prior to exercise results in a large increase in plasma glucose and insulin concentrations with a rapid fall in blood glucose concentration at the onset of exercise. FFA oxidation is reduced due to lower plasma FFA availability and as a consequence there is increased CHO oxidation after ingestion of CHO one hour prior to exercise (Hargreaves, Hawley & Jeukendrup, 2004). Several studies were conducted on the effects of LGI verses HGI meal on exercise performance where ingestion of the meal was in the hour prior to exercise (DeMarco et al., 1999; Febbraio et al., 2000a; Febbraio et al., 2000b; Febbraio and Stewart, 1996; Kirwan et al., 2001a; Kirwan et al., 2001b;

Kirwan et al., 1998; Sparks et al., 1998; Stannard et al., 2000; Thomas et al., 1991).

One of the first studies to test the effect of pre-exercise LGI verses HGI meal on exercise performance was carried out by Thomas et al. (1991). Eight trained cyclists cycled to exhaustion one hour after ingestion of four test meals; a LGI lentil meal, a HGI potato meal, glucose and water. They reported that endurance time ($P < 0.05$) was 20 min longer after ingestion of LGI lentil meal than after HGI potato meal. This improvement in endurance time was associated with lower postprandial levels of blood glucose and insulin and resulted in a more consistent supply of blood glucose during the exercise bout after consumption of LGI lentil meal (Kirwan et al., 1998; Thomas et al. 1991). In addition to the ingestion of LGI lentil meal and HGI potato meal participants also ingested a meal that consisted of just glucose. This meal however did not result in a decreased exercise time, a matter that was not discussed by researchers (Sparks et al., 1998). In a subsequent study by Stannard et al. (2000) of ten trained male cyclists resulting in similar postprandial blood glucose and insulin response before exercise and a more sustained level of blood glucose during exercise found no differences in performance as a result of consuming pre-exercise LGI meal compared with the HGI meal. In another study carried out by DeMarco, et al. (1999) of ten trained male cyclists found that postprandial levels of plasma insulin were lower before exercise and increased levels of blood glucose during exercise particularly during the latter stages resulted in an increased time to exhaustion following the pre-exercise LGI meal. Time to exhaustion was 59% longer after LGI (206 ± 43.5 sec) than after HGI (129 ± 22.8 sec) meal. In a study by Kirwan et al. (2001a) six male participants ingested 75 g CHO in the form of two different breakfast cereals, moderate GI (GI = 61) or HGI (GI = 82) or consumed just water, 45 minutes before performing cycling to exhaustion. Exercise time was enhanced ($P < 0.05$) after the moderate GI meal compared to

HGI and control meals, but the HGI meal was not different from the control (MOD GI, 165 ± 11 min; HGI, 141 ± 8 min; control, 134 ± 13 min). In another study by Kirwan, et al. (2001b) six active women ingested 75 g CHO in the form of regular whole grain rolled oats (moderate GI) or just water, 45 minutes before performing cycling to exhaustion. Exercise duration was 5% longer during moderate GI trial compared to control trial (253.6 ± 6 min and 242 ± 15 min) ($P > 0.05$). This difference however was not statistically significant. Although statistically insignificant it is possible that the variation in times between trials could be a significant factor in performance during a competitive event and even the smallest margins could be the difference between winning and losing, further demonstrating the beneficial effect of CHO ingestion prior to exercise and the potential benefit of ingesting a moderate or low GI meal prior to exercise.

It is difficult to compare these studies as study designs differ greatly across all studies. The conflicting results may be due to variations in the amount of CHO ingested (ranging from 1 to 2.5 g CHO•kg^{-1} body mass or 75 g of CHO irrespective of body weight), the GI value of test meals (LGI meal GI: 29 to 52 and HGI meal GI: 60 to 100), timing of CHO ingestion (30 min to 3 hours prior to exercise), the type of meal ingested (mixed foods, single foods or drinks), macronutrient content (CHO: 60% to 87%, fat: 3% to 25%, protein: 10% - 30%), gender, fitness level of participants and type, intensity and duration of exercise.

The vast majority of this research has focused primarily on the effects of LGI and HGI pre-exercise meals on endurance performance for exercise such as cycling and running, there is a scarcity of literature of the influences of LGI and HGI pre-exercise meal on subsequent exercise capacity during intermittent high-intensity exercise or game sports that demand high levels of cognitive and motor skills. Erith et al. (2006) examined the effects of high CHO meals with different glycemic indices on performance during prolonged intermittent high intensity shuttle running. Seven male soccer players took part in the study. On day one of the trial participants performed 90 min of intermittent high intensity shuttle running. Following exercise they consumed either a LGI (GI = 35) or HGI (GI = 70) recovery diet providing 8 g CHO▪kg^{-1} body mass. On day two, 22 hours later the subjects performed 75 minutes of intermittent high intensity shuttle running followed by alternate sprinting and jogging to fatigue. Erith found no differences between trials in time to fatigue in HGI (25.3 ± 4.0 min) verses LGI (22.9 ± 5.6 min) trials (P = 0.649). No differences were observed between trials for the number of sprints (HGI 43 ± 7, LGI 39 ± 10) and distance covered (HGI 3474 ± 531 m, LGI 3097 ± 793 m). Due to the intermittent high intensity shuttle running protocol used during this study it is possible that there was a greater reliance on CHO as a source of fuel. Ingestion of HGI meal has been known to reduce plasma glucose during the latter stages of exercise (DeMarco, et al., 1999; Stannard et al., 2000). However, during this study blood glucose concentrations were not different between trials which may suggest that there was sufficient circulating blood glucose at all time points but particularly during the latter stages of exercise for both trials to perform equally.

The game of badminton and the physical demands placed upon players is quite different than those of an endurance athlete. Badminton is a racket sport played on a relatively small court using a shuttlecock. Badminton is an explosive sport, involving a unique movement pattern around the court carried out at high intensity of short duration, with a work rest ratio of approximately 1:2 (Hughes, 1995; Manrique & González-Badillo, 2003; Wonisch, Hofmann, Schwaberger, Duvillard & Klein, 2003). A badminton match at elite level can last 45-60 minutes with the shuttlecock in play for 60 - 70% of the match (Liddle & O'Donogue, 1998). Badminton bears many similarities to the game of squash in terms of level of intensity, heart rate response, lactate build up and energy expenditure. The physiological demands of elite badminton players combine speed, power and endurance (Liddle & O'Donoghue, 1998). The game of badminton is predominantly intermittent aerobic activity with a modest contribution from the anaerobic energy system (Hughes, 1995; Hughes & Fullerton, 1995). Hughes (1995) found that the heart rate (HR) response during practice games on eight players tested was > 80% of maximum HR (HR max) for over 85% of the time. However players felt that the quality of play was low during the practice game compared to that of a typical competitive game. During the competitive game players sustained a HR > 80% of HR max for 96% of the playing time. Therefore during practice games there may be a greater reliance on the aerobic energy system with lower contribution from the anaerobic energy system compared to competition badminton where there is likely to be a greater reliance on the anaerobic energy system. Manrique and González-Badillo (2003) studied eleven badminton players with international experience from four different countries (France, Italy, Spain and Portugal). They found that badminton matches over 28 minutes resulted in very high physical demands on its subjects, with a maximum heart rate of 190.5 bpm and an average heart rate of 173.5 bpm with performance intervals of 6.4 sec and rest intervals of 12.9 sec between points. The maximum heart rate experienced during match play was very close to the real maximum heart rate of participants studied. Manrique found that as the matches progressed there was a tendency for all players to increase their average heart rate in relation to their maximum heart rate of the interval being played, indicating that demands placed on the cardiovascular system gradually increase as games progress.

Badminton requires a high degree of physical fitness (aerobic and anaerobic), speed, skill, flexibility, balance, co-ordination, motor and cognitive skills. Given these many characteristics make badminton a good model to investigate the effects of CHO ingestion with different glycemic indices on skill maintenance and aerobic performance in badminton players. No known research has been carried out on the effects of pre-exercise LGI and HGI meal on intermittent, multi sprint game sports such a tennis, squash and in particular the game of badminton. The purpose of this study was to compare the effects of pre-exercise ingestion of foods with high and low glycemic indices on skill maintenance during badminton specific skills test, aerobic performance during maximal multistage fitness test and on performance during an all-out simulated badminton performance test to six positions on the court.

Table 1. Studies of the effects of CHO, fatigue and fluid intake on cognitive function and skill in game sports.

Author	Subjects	Assessed	Study Protocol	Results
Zeederburg et al. (1996)	Soccer players	CHO / Skill / Soccer	Players performed 90 minute match, ingested CHO 15 min before and again at half time. CHO – Glucose polymer solution (6.9%) CON - Placebo	←→ Blood glucose ←→ Passing ←→ Control ←→ Tackling ←→ Heading ←→ Dribbling ←→ Shooting ↑↑ Passing 2nd half CHO, CON ↑↑ Ball control 2nd half CHO, CON
McGregor et al. (1998)	9 Soccer players (9 M)	Fluid / Performance / Skill/ Soccer	Player performed a soccer skills test before and after 90 minutes of intermittent shuttle running (SHR). Players allocated to either fluid of no fluid group. FLUID NO-FLUID	↓↓ Performance soccer skill test pre v post SHR NO-FLUID ←→ Performance soccer skill test pre v post SHR FLUID ↑↑ RPE NO-FLUID ←→ SHR
Vergauwen et al. (1998)	13 well trained tennis players (13 M)	CHO / Skill / Tennis	Players performed a pre-test (LTPT & SHR) followed by 2 hour strenuous training session followed post-test (LTPT & SHR) Test: Leuven Tennis Performance Test (LTPT) and Shuttle Run (SHR) CON - Placebo CHO - CHO (.7g/kg body mass) CHO+CAF - CHO + Caffeine	↓↓ % error rate CHO v CON ↓↓ non reached balls defensive rallies CHO v CON ↑↑ Second service ball velocity CHO, CHO+CAF v CON ←→ RPE ↑↑ SHR CHO, CHO+CAF v CON

Table 1. Continued

Author	**Subjects**	**Assessed**	**Study Protocol**	**Results**
Collardeau et al. (2001)	8 Triathletes	CHO / Reaction Times	Subjects performed 2 x 15 minute sub maximal treadmill runs before and after 70 minute track run. Single reaction test was performed before, during the first and second sub maximal test and after exercise. Choice reaction test was performed before and after exercise. CHO - 5.5% CHO solution CON - artificially sweetened placebo.	←→ Single reaction time ↑↑ Choice reaction time CHO post exercise ↑↑ Blood glucose CHO
Davey et al. (2001)	18 county tennis players (9 M, 9 F)	Fatigue / Skill / Tennis	Players performed test 1 before and after test 2. Test 1: Loughborough Tennis Skill Test (groundstroke's and service) Test 2: Loughborough Intermittent Tennis, test to fatigue	↓↓ Test 1 - Service accuracy (30%) right hand court pre v post exercise ↓↓ Test 2 - Groundstroke accuracy (69%) pre v post exercise ↑↑ Blood glucose skills test pre v post exercise ↑↑ Blood glucose intermittent test pre v post exercise
Ostojic et al. (2002)	22 professional soccer players (22 M)	CHO / Skill / Performance / Soccer	Players played 90 minute soccer match followed by four soccer specific skill tests. CHO - CHO drink (7% CHO) CON - Placebo	↑↑ Blood glucose post match ↑↑ RPE post match CON ↓↓ Time dribble test CHO ↑↑ Rating of precision CHO ←→ Co-ordination ←→ Power Test ↑ Skills performance CHO
Welsh et al. (2002)	10 active (5 M, 5 F)	CHO / Physical & Mental Performance / IHI Exercise	Subjects performed 4 x 15 min quarters of IHI shuttle running (walking, jogging, run, sprint, jump) followed by shuttle run to fatigue. Various physical and mental functions were performed throughout the trial. CHO – CHO electrolyte drink CON - Placebo	↑↑ Blood glucose CHO ↑↑ Time to fatigue CHO ↑↑ 20m sprint time QTR 4 CHO ↑↑ Whole body motor skill test time QTR 4 CHO ←→ Profile of mood states ←→ Stroop colour-word test

Table 1. Continued

Author	Subjects	Assessed	Study Protocol	Results
Winnick et al. (2005)	20 active (10 M, 10 F)	CHO / Physical & CNS Function / IHI Exercise	Subjects performed 4 x 15 min quarters of IHI shuttle running (walking, jogging, run, sprint, and jump). Various physical and mental functions were performed throughout the trial. CHO – CHO electrolyte drink CON - Placebo	↑↑ 20m sprint time QTR 4 CHO ↑↑ Jump height QTR 4 CHO ↑↑ Profile of mood states ←→ Stroop colour-word test ↑↑ Whole body motor skill test time CHO
Bottoms et al. (2006)	16 squash players (16 M)	CHO/ Skill / Squash	Players performed skill tests before and after shuttle running for 20 minutes. CHO – CHO drink (6.4% CHO) CON - Placebo	↑↑ Blood glucose CHO ↓↓ Balls landed outside zone CHO v CON ←→ Visual reaction time pre & post CON ↑↑ Visual reaction time pre & post CHO v CON ↑↑ Auditory reaction time CHO, CON ←→ Skill maintenance

↑ - increase non-significant ↓ - decrease non-significant ↑↑ - increase significant ↓↓ - decrease significant ←→ - no difference F – Female M – Males
CON - Control CHO – Carbohydrate RPE – Rate of Perceived Exertion IHI – Intermittent High Intensity SHR – Shuttle Running

Table 2. Studies of pre-exercise CHO of different glycemic indices on substrate utilisation and exercise performance.

Author	Subjects	Dietary Intake	Study Protocol	Postprandial blood glucose response	Exercise	Performance advantage with LGI
Thomas et al. (1991)	Trained Cyclists (8)	HGI Meal – potato HGI Glucose Meal - glucose LGI Meal – lentils CON – water	LGI or HGI or Water 60 min pre-exercise Cycle to exhaustion.	↑↑ Plasma glucose HGI ↑↑ Plasma insulin HGI	↑↑ Plasma lactate ↑↑ Endurance time LGI	Yes
Febbraio & Stewart (1996)	Trained Cyclists (6 M)	HGI Meal LGI Meal CON	LGI or HGI or Water 45 min pre-exercise Cycle @ 70% VO2 Peak for 120 min 15 min performance ride	↑↑ Plasma glucose HGI = 15 min ←→ Plasma glucose > 15 min ↑↑ Plasma insulin HGI	←→ Performance ride	No
Kirwan et al. (1998)	Trained Cyclists (6 F)	75g CHO HGI (75g CHO + 3g fibre) LGI (75g CHO + 7g fibre) CON (75g CHO + 300ml Water)	HGI, LGI or Water 45 min pre-exercise 60% Peak Oxygen Consumption to exhaustion	↑↑ Plasma glucose HGI + LGI < 30 min ↑↑ Plasma insulin HGI + LGI	↑↑ Plasma insulin HGI v LGI < 120 min ←→ Plasma glucose ←→ Total FAT Oxidation ←→ Total CHO Oxidation ←→ Muscle Glycogen ↑↑ Time to exhaustion LGI	Yes
Sparks et al. (1998)	Trained Cyclists (8 M)	1g CHO/kg body mass HGI Meal (GI: 80) – mashed potato LGI Meal (GI: 29) - lentils CON – placebo drink	LGI or HGI or Water 45 min pre-exercise Cycle @ 67% VO2 Max for 50 min 15 min performance ride	↑↑ Plasma glucose HGI v LGI + CON ↑↑ Plasma insulin HGI	↓↓ Plasma glucose HGI < 30 min ↑↑ Plasma insulin HGI ←→ Plasma lactate ←→ Plasma glucose > 30 min ←→ Performance ride	No

Table 2. Continued

Author	Subjects	Dietary Intake	Study Protocol	Postprandial blood glucose response	Exercise	Performance advantage with LGI
DeMarco et al. (1999)	Trained Cyclists (10 M)	1.5g CHO/kg body mass HGI meal LGI meal CON	HGI or LGI or Water 30 min prior to exercise Cycle @ 70% VO2 Max for 2hr + cycle to exhaustion @ 100% VO2 Max	↑↑ Plasma insulin HGI + LGI v CON ↑↑ Plasma insulin HGI v LGI ↑ Plasma glucose HGI + LGI	↓↓ Plasma glucose HGI + LGI < 20 min ↓ Plasma glucose HGI v LGI < 20 min ↑↑ Plasma glucose LGI v HGI + Water ↑↑ CHO oxidation HGI ↑↑ Performance ride LGI ↑↑ Time to exhaustion LGI ↑↑ RPE HGI v LGI	Yes
Wee et al. (1999)	Trained Runners (5 M, 3 F)	2g CHO/kg body mass HGI meal LGI meal	HGI or LGI 3hr pre-exercise Run @ 70% Vo2 Max to exhaustion	↑↑ Plasma glucose HGI ↑↑ Plasma insulin HGI < 60 min ↑↑ CHO oxidation HGI	↑↑ Plasma insulin HGI < 20 min ↓↓ Plasma glucose < 20 min HGI ←→ Plasma glucose ↓↓ CHO Oxidation LGI ↑↑ Fat Oxidation LGI ←→ Time to exhaustion	No
Febbraio et al. (2000b)	Trained Cyclists (8 M)	1g CHO/kg body mass HGI Meal LGI Meal FAST	HGI or LGI or No meal 30 min pre-exercise Cycle @ 70% VO2 Peak to exhaustion	↑↑ Plasma glucose HGI v LGI + FAST ↑↑ Plasma insulin HGI v LGI + FAST	↓↓ Plasma glucose HGI v LGI + CON < 30 min ↓↓ Plasma insulin HGI v LGI + CON < 30 miin ←→ Plasma glucose > 30 min ↑↑ Total CHO Oxidation HGI ↑↑ Total Fat Oxidation LGI + FAST ←→ Work Output	No

Table 2. Continued

Author	Subjects	Dietary Intake	Study Protocol	Postprandial blood glucose response	Exercise	Performance advantage with LGI
Stannard et al. (2000)	Trained Cyclists (10 M)	HGI meal (GI: 100) - 400ml Glucose Solution LGI meal (GI: 41)- 1g CHO/kg body mass CON – 400ml Artificially Sweetened Water	HGI or LGI or Water 65 min pre-exercise Cycle, incremental exercise to fatigue	↑↑ Plasma glucose HGI v LGI	↓ Plasma glucose LGI < 150W ↓ Plasma glucose HGI < 200W ↑↑ Plasma glucose LGI v HGI > 200W workload ↑↑ Plasma lactate HGI < 200W workload ←→Plasma lactate HGI > 200W workload ←→ Time to exhaustion	No
Kirwan et al. (2001a)	Active men (6 M)	75g CHO MGI Meal (GI: 61) – rolled oats HGI Meal (GI: 82) – puffed rice CON - water	MGI or HGI or Water 45 min pre-exercise Cycle @ 60% VO2 Peak to exhaustion	↑↑ Plasma glucose HGI v MGI, CON > 30 min	↑↑ Plasma glucose HGI at 0 min ↑↑ Plasma glucose MGI at 60 & 90 min ←→ Plasma glucose at exhaustion ↑↑ Time to exhaustion	Yes
Kirwan, et al. (2001b)	Trained Cyclists (6 F)	75g CHO MGI Meal – rolled oats CON - water	MGI or No meal 45 min pre-exercise Cycle @ 60% VO2 Peak to exhaustion	↑↑ Plasma glucose MGI ↑↑ Plasma insulin MGI	↓ Plasma glucose MGI < 30 min ←→Plasma glucose ←→Muscle glycogen ←→ Total CHO Oxidation ↑ Time to exhaustion MGI	No
Wu et al. (2003)	Trained Runners (9 M)	2g CHO/kg body mass HGI Meal (GI: 77) LGI Meal (GI: 37) CON	HGI or LGI or No meal 3hr pre-exercise Run @ 65% VO2 Max for 60 min	↑↑ Serum insulin HGI ↑↑ Plasma glucose HGI ↑↑ CHO Oxidation HGI + LGI ↑↑ Fat Oxidation FAST	↓↓ Plasma glucose HGI ↑↑ Total Fat Oxidation FAST v LGI + HGI ↑↑ Total Fat Oxidation LGI v HGI ↑↑ Total CHO Oxidation HGI	Not applicable

Table 2. Continued

Author	Subjects	Dietary Intake	Study Protocol	Postprandial blood glucose response	Exercise	Performance advantage with LGI
Stevenson et al. (2005a)	Trained Runners (9 M)	2g CHO/kg body mass LGI breakfast (GI: 44) LGI lunch (GI: 34) HGI breakfast (GI: 76) HGI lunch (GI: 73)	LGI breakfast + LGI lunch, or HGI breakfast + HGI lunch, 3hr pre-exercise Run @ 70% VO2 Max for 60 min	↑↑ Plasma glucose HGI ↑↑ Serum insulin HGI ↑↑ Fat oxidation LGI ↑↑ CHO oxidation HGI	↑↑ Plasma glucose LGI at 45 & 60 min ←→ Blood lactate ←→ Total CHO oxidation ←→ Total Fat oxidation	Not applicable
Stevenson et al. (2005b)	Trained Runners (7 M)	2g CHO/kg body mass LGI Evening Meal (GI: 34) HGI Evening Meal (GI: 72) HGI breakfast (GI: 79)	LGI or HGI evening meal, HGI breakfast, 3hr pre-exercise Run @ 65% VO2 Max for 60 min	↑↑ Plasma glucose HGI ↑↑ Serum Insulin HGI ↑↑ Blood lactate HGI + LGI	←→ Plasma glucose ←→ Total CHO oxidation ←→ Total Fat oxidation	Not applicable
Wee et al. (2005)	Trained Runners (7 M)	2.5g CHO/kg body mass HGI Meal (GI: 77) LGI Meal (GI: 37)	LGI or HGI meal 3hr pre-exercise Run @ 71% Max oxygen uptake for 30 min	↑↑ Plasma glucose HGI ↑↑ Serum insulin HGI ↑↑ Muscle Glycogen storage HGI	↓↓ Plasma glucose HGI at 10 min ↑↑ Plasma glucose HGI at end of exercise ↑↑ Plasma lactate ↑↑ Muscle glycogen HGI ↓↓ Total CHO Oxidation LGI ↑↑ Total Fat Oxidation LGI	Not applicable

Table 2. Continued

Author	**Subjects**	**Dietary Intake**	**Study Protocol**	**Postprandial blood glucose response**	**Exercise**	**Performance advantage with LGI**
Erith et al. (2006)	Trained Soccer Players (7 M)	8g CHO/kg body mass HGI diet LGI diet	Exercise (R1) + LGI or HGI diet for 22hrs + Exercise (R2) R1 - Run (intermittent shuttle running) for 90 min R2 – Run (intermittent shuttle running) for 75 min + sprints + jog to fatigue	NA	←→ Plasma glucose ←→ Plasma lactate ↓↓ Serum insulin ←→ Run time ←→ Sprint performance ←→ Distance covered	No
Wu & Williams (2006)	Trained Runners (8 M)	2g CHO/kg body mass LGI Meal (GI: 37) HGI Meal (GI: 77)	LGI or HGI meal 3hr pre-exercise Run @ 70% VO2 Max to exhaustion	↑↑ Plasma glucose HGI ↑↑ Serum insulin HGI	↑↑ Plasma glucose LGI < 30 min ←→ Plasma glucose > 30 min ←→ Plasma lactate ←→ Plasma insulin ↑↑ Total Fat oxidation LGI ↓↓ Total CHO oxidation LGI ↑↑ Running time LGI	Yes

↑ - increase non-significant ↓ - decrease non-significant ↑↑ - increase significant ↓↓ - decrease significant ←→ - no difference F – Female GI – Glycemic Index
LGI – Low Glycemic Index M – Males MGI – Moderate Glycemic Index HGI – High Glycemic Index FAST – Fasting CON - Control CHO – Carbohydrate
FFA – Free Fatty Acids RPE – Rate of Perceived Exertion W - Watts

1.2 Rationale

Existing research supports the beneficial role of CHO ingestion on physical and mental performance. The beneficial role of CHO ingestion together with the glycemic index on endurance exercise is well documented. Whilst the beneficial role of CHO together with the glycemic index on cognitive function and skill maintenance is less understood. Badminton requires a high degree of physical fitness, cognitive and motor function for optimal performance. No known research has been carried out on the effects of pre-exercise LGI and HGI meal on intermittent, multi sprint game sports such a tennis, squash and badminton. Therefore, more research is needed from controlled studies designed to reflect the actual physical and mental demands of multi-sprint sport such as Badminton.

1.3 Study aim

This study was designed to investigate the effects of high and low glycemic index meal, containing 1g CHO•kg-1 BW, ingested 60 minutes prior to exercise on subsequent aerobic performance and skill maintenance in trained badminton players following a 12 hour overnight fast.

1.4 Research question

Does the glycemic index of a pre-exercise meal ingested 60 minutes prior to exercise influence subsequent aerobic performance and skill maintenance in trained Badminton Players?