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ORIGINAL RESEARCH

The Effects of Carbohydrate Loading 48 Hours Before a Simulated Squash Match

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The aim of this study was to ascertain whether a high carbohydrate diet in the days before movement patterns simulating a squash match would increase carbohydrate oxidation during the match, and alter physical performance. Nine New Zealand level squash players were recruited to complete a simulated squash match on two occasions: 1) following a 48-hr high carbohydrate ($11.1 g \cdot kg^{-1}$); and 2) following a calorie-matched low carbohydrate ($2.1 g \cdot kg^{-1}$) diet. The interventions were assigned in a randomized, single-blind, cross-over design. The match simulation was designed to mimic a five-game match lasting approximately 1 hr. Performance was measured as time to complete each game. Expired respiratory gases and heart rate were continuously collected throughout the trial using a portable gas analysis system. Capillary blood glucose and lactate samples were obtained during a 90 s rest period between each game. Rating of perceived exertion was also recorded after each set. Respiratory exchange ratio was significantly higher during exercise following the high CHO diet (0.80 vs. 0.76) $p < .001$) and this was associated with significantly faster time to complete the games (2340 ± 189 s vs. 2416 ± 128 s, $p = .036$). Blood glucose and lactate concentrations were also significantly higher in the high carbohydrate condition ($p = .038$ and $p = .021$ respectively). These results suggest that ingestion of a diet high in carbohydrate (>10 g/kg body weight) preceding simulated competitive squash produces increased rates of carbohydrate oxidation and maintains higher blood glucose concentrations. These metabolic effects were associated with improved physical performance.

Keywords: racket sports, nutritional intervention, sports performance

Squash is a popular racket sport played by over 15 million people worldwide (Eime & Finch, 2002), with matches played over three to five games using the Point-a-Rally Scoring to 11 (PARS-11) system (WSF.2010), on a court (dimensions 6.40 × 9.75 × 4.57 m, Figure 1; WSF.2010), lasting up to 1 hr with some matches lasting up to 2 hr As a result it can be classified as a high intensity intermittent sport (Todd et al., 1998) requiring good endurance, power, speed, agility and flexibility to be successful at elite levels (Lees, 2003).

Despite its widespread popularity the majority of peer-reviewed literature for squash focuses on quantitative performance analysis (Hughes, 1985; McGarry & Franks, 1994, 1995; McGarry & Walter, 2007; Vučković et al., 2009) and therefore the physiological stresses during match play, along with training and nutritional requirements or strategies are poorly understood, limiting athlete advancement.

The performance enhancing effects of CHO on sports performance has long been known (Bergström et al., 1967; Haldi & Wynn, 1946). More recently, research involving intermittent high-intensity exercise has shown a reliance on muscle glycogen to support prolonged strenuous intermittent activity (Balsom et al., 1999; Krustrup et al., 2006; Winnick et al., 2005) and such performance is subsequently enhanced if a H-CHO diet ($8–10 g \cdot kg^{-1}$ of lean body mass) is provided in the days before exercise (Balsom et al., 1999; Sedlock, 2008; Winnick et al., 2005). The nutritional strategy known as CHO loading (Bergström et al., 1967; Bussau et al., 2002; Sherman et al., 1981) is used to increase muscle glycogen stores beyond normal values by delaying fatigue (Hawley et al., 1997; Karlsson, 1971; Williams et al., 1992). However, little is known regarding the influence of this strategy on game sports like squash that are long duration, intermittent in effort, and weight bearing. The latter point is particularly important since: a) CHO loading is associated with significant increases in body weight (Karlsson, 1971; Olsson & Saltin, 1970); and b) body weight increase must alter the muscular work requirement—even more so if the intermittent activity requires repeated accelerations of the center of mass.

Unlike weight-supported exercise such as ergometer cycling, ergogenic effects of CHO-loading are not found

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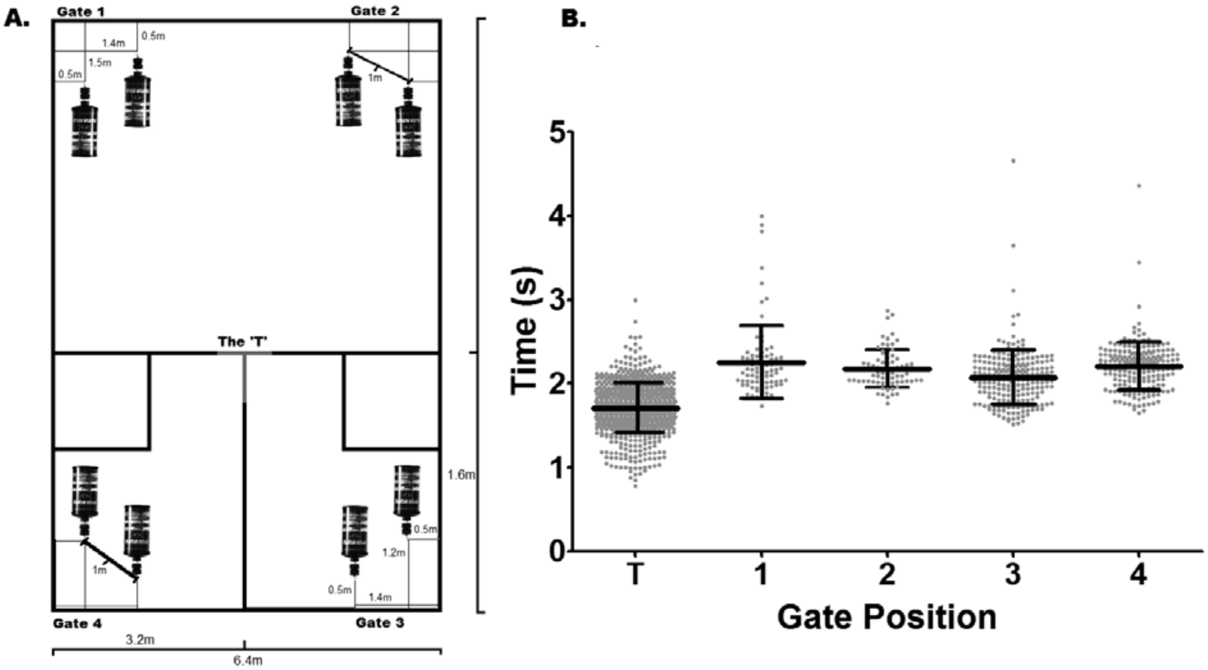

Figure 1 — A. On-court schematic and position of Fusion timing gates. B. The distribution of simulated shots taken from each position and the means ± *SD* times for subject 3 over a complete simulated match.

in running from mean durations of (approx.) 10 min, 83 min, and 2 hr (Karlsson, 1971; Sherman et al., 1981; Sherman et al., 1993). These observations could perhaps be explained by the increased body weight in the glycogen loaded state (Karlsson, 1971). In other words, the associated water retention may negate the metabolic benefits of CHO loading in exercise, such as squash, which involves prolonged repeated accelerations of the body.

The rationale behind the current study was twofold in that it aimed to gain a better understanding of the metabolic, physiological, and nutritional aspect of match play simulation via court-ghosting (Kingsley et al., 2006). Secondly, to investigate whether a very high carbohydrate diet in the days before a simulated squash match would increase carbohydrate oxidation during the match, but also increase body weight and thus not improve simulated match performance.

Methods

Nine healthy and physically fit males agreed to participate in this study. All were active squash players ranging from a good club level to players competing in National Opens and/or Internationally. Using the Squash New Zealand grade system (iSquash: http://www.squash.org.nz/sit/homepage) participants ranged from C1 to A2 and all had been competing for at least five years. The subjects' characteristics were (mean ± *SD*): age 24 ± 8 years, height 1.8 ± 0.1 m, weight 76.9 ± 6.8 kg, with a pooled mean Yo-Yo IR1 test (Bangsbo, Iaia, & Krustrup, 2008) distance covered 1182 ± 414 m and a HR_{max} 183 ± 7 bpm. The study protocol was approved by the institutional Human Ethics Committee. Each subject was fully informed of the experimental procedures and possible risks before giving informed, written, consent in accordance with the Declaration of Helsinki.

General Design

Each participant completed a preliminary (familiarization) trial and two main trials performed in a single-blind (participant), counter-balanced order with an 8- to 10-day washout period. Each trial was performed at the same time of day (19:00–20:30) to avoid circadian variations, involved a simulated squash match following 48 hr of a dietary intervention and physical activity control. The protocol developed was aimed to simulate the physical requirements of a squash match.

Simulated Squash Match

The squash match protocol was created to simulate a five game match with each game lasting (including rest periods between rallies) a total of 11–12 min with a 90-s break between games (WSF.2010). Five timing gates with a single beam system and microprocessor functionality (SmartSpeed, Fitness Technology, Fusion Sport, AUS) were used to simulate typical shot play combinations (rallies) experienced during match play (McGarry & Franks, 1994; Vučković et al., 2009) and used in previously validated squash-specific tests (Wilkinson et al., 2009; Wilkinson et al., 2009a). Racket-ball contact was simulated by the participant breaking the infrared beam with the racket head (World Squash Specifications (WSF.2010)) at one of the four designated points (Figure

1A, Gates 1–4) and returning to the 'T', designated as the start position. The movement from 'T' to any particular gate and back on 5 occasions constituted a rally, with each game consisting of 30 such rallies and separated by 10 s recovery periods (Girard et al., 2007; Montpetit, 1990). The movement sequence required of the participants was random and performed at maximal effort. Visual cues were provided by the specific gate flashing with an LED light (red, green, blue). The proportion of shots played in the front (74%) and back court (26%) along with the random distribution to the four gates were based on real match analysis data (McGarry & Franks, 1994, 1995; Reilly, Hughes, Lees, World Congress on, & Racket), meaning the total distance covered during the match simulation was identical for all participants and realistic in comparison with top level players.

Preliminary Session

Participants reported to the squash courts (SquashGym, Palmerston North, NZ) for a familiarization with the simulated squash match protocol, the equipment and the physical demands of the experiment. This included the completion of several rallies at a low intensity until familiarization was achieved (based on participants comfortably being able to perform the required sequences) and followed by a simulated game (30 rallies) at maximal effort while wearing the portable gas analyzer (Cortex Metamax 3B, Cortex, Biophysik, Leipzig Germany).

Main Trial

Subjects were requested to refrain from exercise, caffeine and alcohol for at least 24 hr before the glycogen depletion phase described below.

The glycogen depletion phase (Bergström, et al., 1967) was performed before the experimental trial involving the completion of the Yo-Yo Intermittent Recovery Level 1 (IR1; Bangsbo et al., 2008) test to exhaustion plus a further 30-min treadmill run at 85% of heart rate max (determined from the IR1); this was followed by a standardized 48 hr L-CHO (1. 1 g·kg^{-1} of BM·d^{-1}) diet. Participants were then assigned to either a H-CHO (11.1 g·kg^{-1} of BM·d^{-1}, mean macronutrient content of 90% CHO; 2% fat; and 8% protein) or L-CHO (2. 1 g·kg^{-1} of BM·d^{-1}, mean macronutrient content of 23% CHO; 34% fat; and 42% protein) treatment for a further 48 hr involving an iso-caloric diet including food substances composed of mainly fat and protein with the addition of a 2.1L, premade solution. The solution determined the CHO content of the diet. The H-CHO treatment was made up of maltodextrin with a dextrose equivalent of 10 units and is consistent with CHO-Loading strategies of short duration high-glycaemic content successful in providing a supercompensatory effect of muscle glycogen (Bussau et al., 2002). The L-CHO treatment consisted of 200 g whole milk powder (Pams, Auckland, New Zealand) and 120 g of protein powder (DNA Nutrition, Palmerston North, NZ) to create a standard base of energy content, flavor and palatability. The formula was based on that previously and successfully applied in blinding the CHO content of a supplement beverage (Johnson et al., 2003). The difference in energy content between was calculated and balanced with olive oil (Pams, Auckland, NZ). These procedures were standardized for both trials and verbal communication following trials emphasized the blinding effect as participants were unable to distinguish between drinks.

After 48 hr of the dietary intervention participants arrived at the squash courts to complete the simulated squash match, were weighed (naked) and then seated (clothed) for five minutes before resting blood lactate (Lactate Pro, Arkray Inc, Kyoto, Japan) and glucose (Accu-Chek Advantage, USA) were collected via finger prick blood sampling (KDK corporation, Kyoto, Akray Factory Inc. Japan). The Lactate Pro has been shown to be accurate and reliable when measured against laboratory standard equipment (Baldari et al., 2009; Tanner et al., 2010) with reported coefficient of variation of 5.7 with 95% confidence limits of 5.0–6.9% (Tanner, et al., 2010). This was followed by a period involving fitting participants with the portable gas analyzer and a subsequent five minute standardized warm-up consisting of light running and whereon they completed the simulated squash match previously described. Participants were given a standardized volume (2 ml·kg^{-1}) of water to drink between games to standardize fluid intake and attempt to minimize dehydration. At the end of the trial participants dried off and were weighed (naked) again

Measurements

During the test, performance was determined by the duration (s) to complete each rally, game and the whole match. Expired gas data were collected continuously, logged every second and along with heart rate (Polar T11, Polar Electro, Finland) wirelessly transmitted and recorded into the software (Metamax, Cortex, Germany). Time-point markers were manually entered into this software to identify the beginning and ending of each game (90 s recovery period) whereupon a rating of perceived exertion (RPE)(Borg, 1970) was recorded and followed by the collection of finger prick blood for immediate analysis of lactate and glucose.

Substrate oxidation rates were calculated from standard tables, in accordance to previously published work (Frayn, 1983), and assuming a nonprotein contribution. Although, this method has been traditionally applied to submaximal steady state exercise a valid overall picture of fuel utilization is possible when work and recovery period are combined (Christmass et al., 1999).

Statistical Analyses

All data are reported as mean ± *SD* throughout. In the first instance data (L-CHO and H-CHO) was pooled to provide specifics regarding physical and physiological aspects of the simulated squash match. Comparison of nutritional interventions were analyzed for dependent variables (performance, $\dot{V}O_2$, RER, RPE, CHO and fat oxidation, heart rate, blood glucose, blood lactate, body

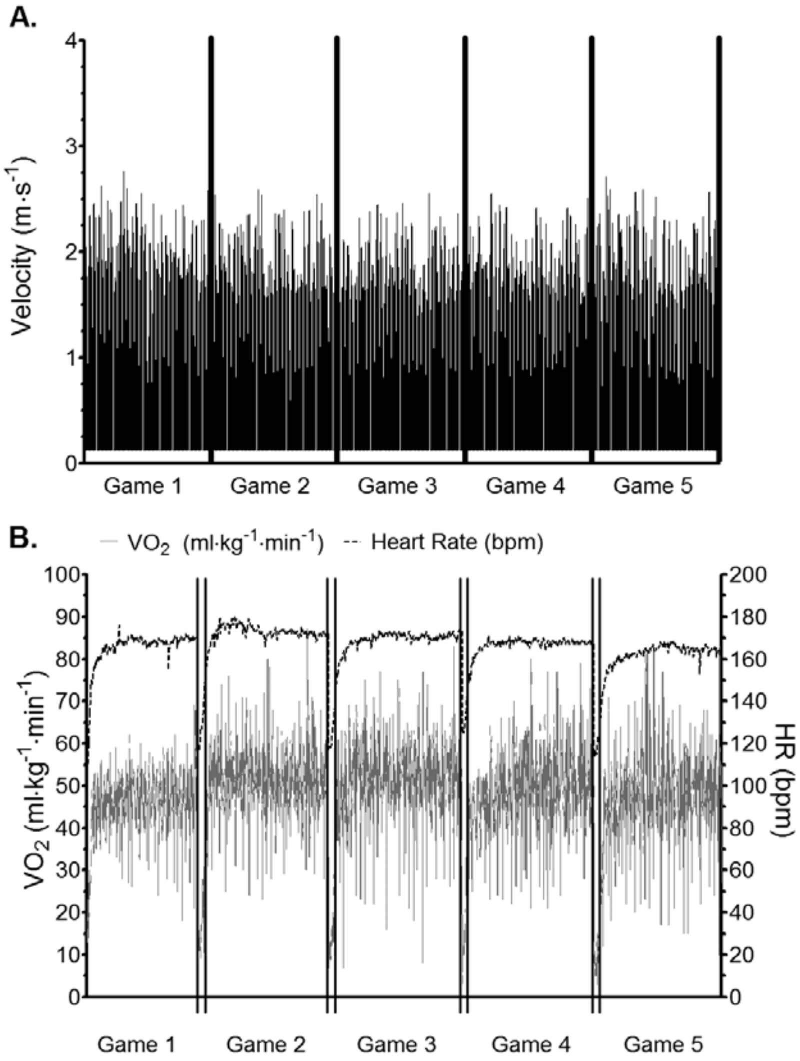

Figure 2 — An individual participant's data over the whole simulated match for: A. Mean velocity to make shot or return to the 'T'; B. Percentage $\dot{V}O_{2\,max}$ and HR_{max} for the same time period.

weight and performance time) using a two-way repeated measures analysis of variance (Treatment × Game). Where a significant time effect was present, post hoc analysis to determine specific differences was used using the Bonferroni correction. Prematch body weight was compared through a paired *t*-test. All data were analyzed using SPSS statistical software (V. 18, Chicago, IL, USA) with a priori statistical significance set at $p < .05$.

Results

Figure 2 A-B shows a typical velocity trace and the corresponding O_2 utilization and heart rate for participant 1 during one trial. Each trial consisted of 300 changes of direction per game with a work:rest ratio of 1.5:1 within each game and a 1.3:1 for the whole game. The pooled data ($n = 16$) for all simulated games provided a mean ± *SD* of: $\dot{V}O_2$ 3.82 ± 0.45 $L{\cdot}min^{-1}$; $\dot{V}O_2$ ($ml{\cdot}kg^{-1}{\cdot}min^{-1}$) 49.2 ± 6.8; RER 0.79 ± 0.03; HR 166 ± 9 bpm; BLa 4.8 ± 2.0 $mmmol{\cdot}l^{-1}$; RPE 18 ± 1.

Performance

Total time taken to complete the five games, excluding rest periods, was less in the H-CHO treatment (2340 ± 188.6 s) when compared with the l-CHO treatment (2416 ± 128.3 s). Accordingly, two-way ANOVA (Figure 3) revealed a main effect for the H-CHO treatment ($p = .036$) and game order ($p = .033$) but there was no Treatment × Game effect ($p = .852$).

Physiological Measures

There was no significant interaction (Treatment × Game; $p = .742$; $p = .951$), no main effect for treatment ($p = .329$; $p = .449$) nor game number ($p = .374$; $p = .247$) for $\dot{V}O_2$ or heart rate, respectively.

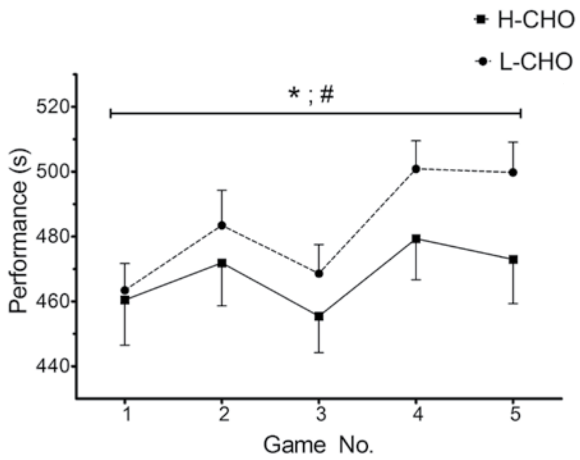

Figure 3 — Mean (*SD*) times to complete games, excluding 10 s rests between rallies per five game match simulation for H-CHO and L-CHO interventions (n = 9). Main effects of nutritional intervention * and game number #, at $p < .05$.

There was also no interaction Treatment × Game (p = .522) or main effect of treatment (p = .235) for RPE, though perhaps not surprisingly there was a significant increase ($p < .0001$) in RPE from game 1–5.

Blood Biochemistry

Blood lactate (mmol·L^{-1}) showed Treatment × Game interaction (p = .744) or main effect for game number, however a main effect for treatment (p = .0209) was apparent (Figure 4A). Similarly, there was a main effect of treatment for blood glucose concentration (p = .038), and no Treatment × Game interaction (p = .876), however a main effect for game number ($p < .0001$) was revealed (Figure 4B).

Respiratory Gas Analysis

There were significant main effects for treatment (p = .0002), and game number ($p < .001$) for RER; RER decreased in both trials from 0.86 ± 0.02–0.76 ± 0.02 and 0.80 ± 0.01–0.75 ± 0.01 in the H-CHO and L-CHO trial, respectively (Figure 5A). However there was no significant Treatment × Game between (p = .537). Accordingly, calculated rates of CHO oxidation revealed a significant effect of treatment ($p < .001$), and game ($p < .001$), with CHO oxidation rates decreasing from 1.38 ± 0.21–0.40 ± 0.16 g·min^{-1} and 2.32 ± 0.45–0.64 ± 0.39 g·min^{-1} for L-CHO and H-CHO, respectively (Figure 5B). There was no significant Treatment × Game number interaction (p = .537). For rate of fat oxidation (Figure 5C) there was a significant effect of treatment (p = .022) but not game number (p = .073) or Treatment × Game number interaction (p = .344).

Body Weight

Body weight was not different at the start of the trials (79.0 ± 7.9 kg H-CHO vs 79.2 ± 8.2 kg L-CHO, p = .625), nor was there any interaction between trial and time (before vs after match, p = .699).

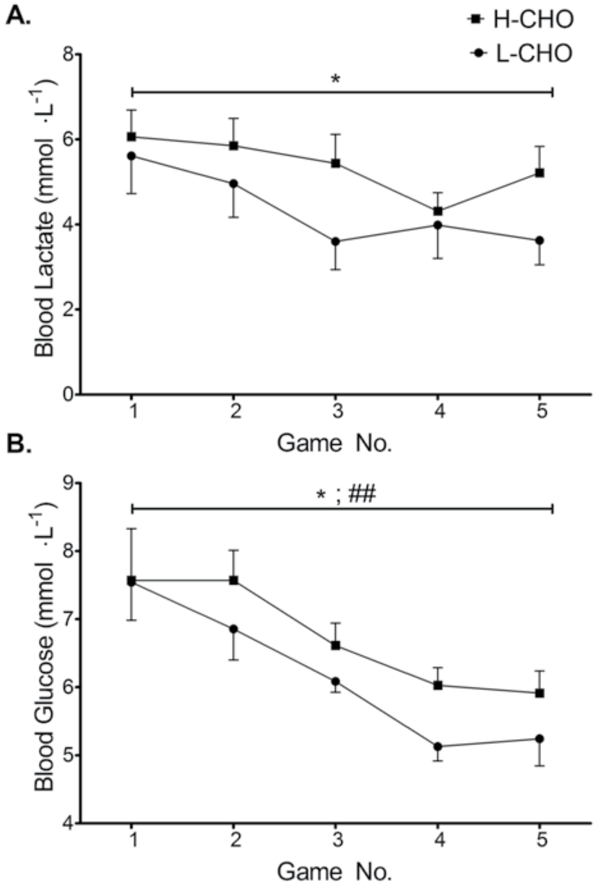

Figure 4 — Mean ± *SD* (n = 8) after each game for: A. Blood lactate (mmol·l^{-1}); and B. Blood glucose (mmol·l^{-1}). * main effect of treatment ($p < .05$); ## main effect of game number ($p < .001$).

Discussion

This study was undertaken primarily to ascertain whether a high carbohydrate diet in the days leading to simulated squash performance will: 1) produce an increase in carbohydrate utilization during exercise; 2) alter physical performance, when compared with a low carbohydrate diet.

In confirmation of the primary aim, whole body respiratory gas measurements indicate a significantly greater rate of carbohydrate utilization during match simulation following a high carbohydrate diet. Secondly, the time taken to complete the five simulated games was 76 s longer in the L-CHO condition. Together these findings indicate that physical performance (at least) in a squash match of approximately 60 min duration can be improved when dietary CHO intake is sufficient to support high rates of CHO utilization. Our observations are in accordance with others who have shown that a high carbohydrate diet before exercise is associated with

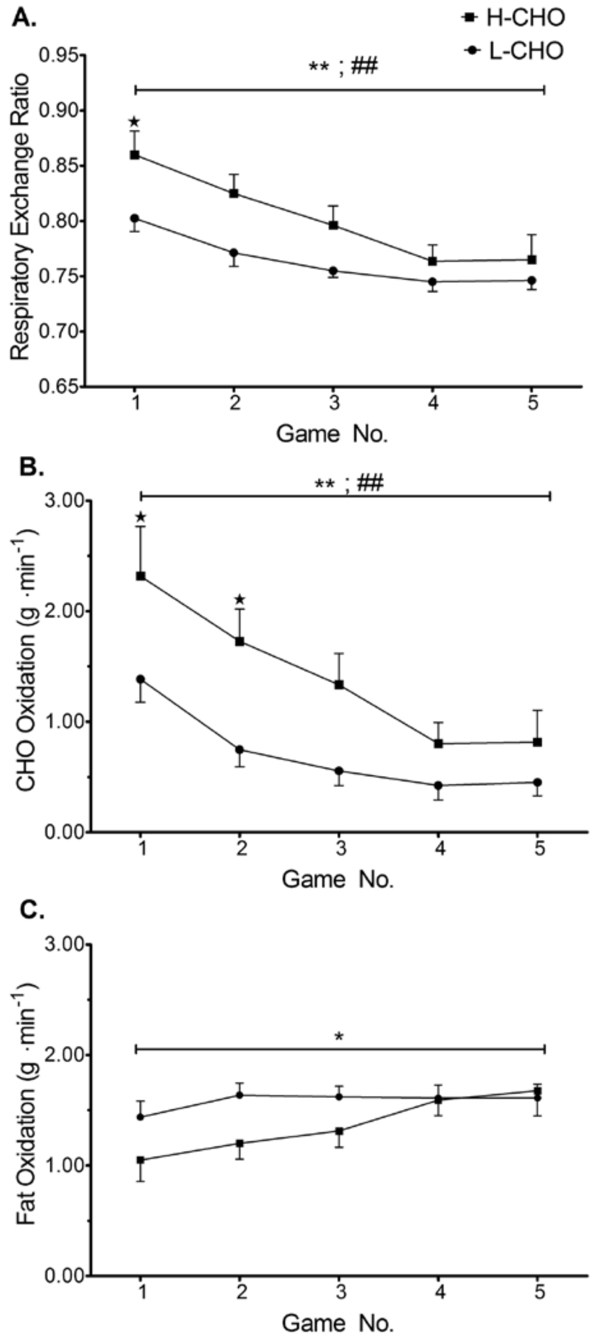

Figure 5 — Mean ± *SD* (*n* = 8) for; A. Respiratory exchange ratio; B. Carbohydrate oxidation rate; C. Fat oxidation rate; measured over the whole duration of the simulated match. * main effect of treatment ($p < .05$); ** main effect of treatment ($p < .001$); ## main effect of game number ($p < .001$); H post hoc difference between treatment and game.

greater work capacity during a set time period of simulated game-sport performance (Balsom et al., 1999; Skein et al., 2012). They are, however, at odds with others who have shown that CHO loading does not improve running-based performance of a similar (Sherman et al., 1981) or longer (Karlsson, 1971) duration. The dissonance of our study with those aforementioned is likely because we were unable to significantly increase body weight with the H-CHO diet.

The average RER values of the low-carbohydrate and high-carbohydrate trials, including the short rest periods between the games, were 0.76 and 0.80, respectively. The difference in proportional fuel utilization is most likely explained by the increased amount of muscle glycogen able to be stored in the high carbohydrate condition (Bergström et al., 1967), however, as muscle glycogen was not measured this cannot be confirmed. Further, that there was no significant difference in body weight before the start of each simulated match does not support the evidence that muscle glycogen stores differed at the onset of exercise in each trial. Nevertheless, similar dietary protocols before strenuous intermittent exercise show that higher muscle glycogen concentrations before the onset of work are associated with improved performance (Foskett et al., 2008). Since the consequence of carbohydrate loading is now a well-established physiological effect, it was assumed that the capacity of muscle glycogen storage from a dose of 9 $g{\cdot}kg^{-1}$ of additional carbohydrate intake would synthesize muscle glycogen to an equivalent magnitude to other studies (Bussau, et al., 2002; Hawley, et al., 1997).

Some caution needs to be exercised when interpreting the use of respiratory gas analysis to indicate muscular fuel selection. Firstly, RER represents proportional fuel use in the sum of all the metabolically active tissues not solely muscle. However, the metabolic demands of contracting muscle dominate during intense exercise so RER will largely reflect the fuel selection of that tissue. Secondly, to buffer changes in systemic acidity during intense effort, there is a reduction in the circulating bicarbonate "pool" which presents as total CO_2 production in excess of metabolic CO_2 production, inflating RER and calculated CHO usage. However, if the recovery period, where the bicarbonate pool is replenished, is included in the period of assessment of fuel selection, then RER provides a suitable representation of fuel selection. In the current study, work and recovery periods were combined and averaged, although total replenishment of the bicarbonate pool may not have occurred at the conclusion of the data collection period resulting in the potential for a slight overestimation of CHO contribution; albeit in both conditions.

The observed HR (average of 167 and 169 bpm in the low- and high-carbohydrate trial, respectively) is comparable to previous levels observed during a competitive squash match (Montpetit, 1990). However, despite a greater rate of work in the H-CHO trial, both heart rate and RPE were not significantly different between trials. Balsom et al. (1999) similarly observed no significant elevation in HR but improved performance in a high CHO vs low CHO condition with simulated football competition.

The literature indicates that self-paced intensity is strongly related to fuel selection (Brooks & Mercier, 1994), though cause and effect is hard to establish. That is, it is difficult to determine whether a higher intensity mediates a higher RER, or whether the higher RER, due to increased CHO availability permits a greater intensity. In the current study, it is possible that the greater rate of CHO utilization in the H-CHO trial simply reflects the greater work rate compared with the L-CHO trial, and that some other factor related to increased dietary carbohydrate was (relatively) ergogenic. Blood glucose concentration is a possible candidate. Hypoglycemia is associated with reduced self-paced muscular work rate (Widrick et al., 1993), and this was significantly higher in the H-CHO trial. Certainly liver glycogen stores are increased with CHO loading (Hultman, 1978) and could therefore have supported blood glucose concentration for longer than the L-CHO condition. However, mean blood glucose did not fall below 5 mM at any point (in either trial) so probably did not fall low enough to be inhibiting of performance, even in the L-CHO condition. The significantly greater plasma lactate concentrations seen in the H-CHO trial could be indicative of either the higher work rate or increased muscle glycogenolysis, so cannot help resolve the mechanism(s) behind our observations.

Rauch et al. (2005) propose a novel theory involving an intrinsic pacing strategy which is influenced by the CHO status of the individual (Rauch et al., 2005). The theory is supported by the authors' observations that muscle glycogen concentrations in non-CHO loaded subjects at the point of fatigue were the same as the muscle glycogen concentration in CHO-loaded subjects. The theory suggests that noncarbohydrate loaded subjects pace themselves at a lower workload throughout the trial to reach a similar endpoint. The suggested mechanism is that there is a chemoreceptor in the working skeletal muscle that is used by the central nervous system to calculate optimum pacing strategy (Raunch et al., 2005).

Although subjects of the current study were instructed to exercise maximally in both trials to maintain the consistency of the high-intensity nature of the sport, a pacing strategy cannot be disregarded as subjects were aware of the endpoint of the trial; in a real match, the endpoint, is decided during the course of the game. However, RPE in both experimental trials were the same, providing evidence that subjects were fully committed to maximal performance in each trial.

Design of Match Simulation

There are perhaps a number of reasons to why the scientific description of racket sports such as squash are not as comprehensive as tennis or other high-intensity intermittent sports such as football. These include the level of professionalism of the game; more money linked to performance outcomes means a greater scientific effort in investigating effectors of optimal performance. Another issue is the practicality of research in a small environment and a general lack of research interest in the sport. However, scientific research on squash is progressing with several relevant studies being undertaken in more recent times (Bottoms et al., 2006; Chin et al., 1995; Girard et al., 2007; Girard et al., 2005; Kingsley et al., 2006; Montpetit, 1990; Romer et al., 2001; Sharp et al., 1998; Todd et al., 1998; Wilkinson et al., 2009; Wilkinson et al., 2009a; Wilkinson et al., 2009b).

The current simulation protocol was similar to that of Kingsley et al. (2006) who designed a squash simulation protocol that lasted for 12.2 min and consisted of 24 rallies which included between 6 and 11 shots in each rally. This resulted in a total of 186 simulated shots. On the other hand, the current study completed 120 simulated shots from 30 rallies. More importantly, it should be kept in mind that the purpose of this simulation was to simulate prolonged intermittent exercise (at least 60 min) and that the design of the simulation had to be reliable to allow for a treatment effect to be resolved. This goal was achieved as most subjects were able to complete both trials with maximal effort, simulating the physical effort intensity of a real squash match. Feedback from the participants certainly indicated that the design of the protocol was successful in replicating a squash match and that it was as hard, if not harder than a squash match, especially during the last two sets. The average lactate concentration during all squash sets were 4.3 and 5.4 mmol·L^{-1} in the L-CHO and H-CHO trials, respectively. Individual values here are comparable (9.1 mmol·L^{-1}) to that of Mercier et al. (1987) who reported lactate values as high as 8 mmol·L^{-1} for highly skilled players against an opponent of equal ability. This further suggests that the simulation protocol we employed was of a similar work rate to that experienced in a competitive squash match.

Practical Applications

The application of this study is to provide knowledge regarding dietary carbohydrate intake over two days before competition and the subsequent effect on squash performance. The results suggest that a high dietary carbohydrate intake is significant to simulated squash performance, compared with a low carbohydrate diet. It is important to note that the L-CHO diet is likely to result in underperformance during a squash match and as such has possibly exaggerated the effects of the H-CHO diet.

Extrapolation of the findings to women squash players should be approached with caution, as there is some evidence that women do not respond as well to a carbohydrate loading, both in terms of glycogen accretion and improved performance (Tarnopolsky et al., 1995). Nevertheless, ingesting additional carbohydrates on top of a normal diet would unlikely be harmful nor detrimental to performance in squash and if two matches were schedule for the same day the likelihood of a better performance with two days of prior carbohydrate supplementation, in both genders, is high.

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