The aim of this study was to investigate the effects of a carbohydrate (CHO) gel on performance after prolonged intermittent high-intensity shuttle running. Seven male soccer players performed 2 exercise trials, 7 d apart. On each occasion, participants completed five 15-min periods of intermittent variable-speed running, interspersed with periods of walking (Part A), followed by an intermittent run to exhaustion (Part B). Participants consumed either a CHO gel or placebo (PLA) immediately before exercise (0.89 mL/kg body mass [BM]) and every 15 min thereafter (0.35 mL/kg BM). In addition, water was consumed at a rate of 5 mL/kg BM before and 2 mL/kg BM every 15 min during exercise. Blood glucose levels were higher ($P < 0.05$) at 15, 30, and 60 min of exercise and at exhaustion in CHO than in PLA. During Part B, run time to exhaustion was longer ($P < 0.05$) in the CHO trial (CHO 6.1 ± 1.3 min vs. PLA 4.2 ± 1.2 min). These results indicate that ingesting a CHO gel, along with water, improves performance after prolonged intermittent running in healthy male subjects, possibly by maintaining blood glucose levels during exercise.

**Key Words:** exogenous CHO, soccer, L.I.S.T.

A common theme across intermittent sports such as soccer is a decrease in performance in the latter stages of a game, with less distance being covered, a lower fractional work intensity, and reduced blood glucose levels (10). The causes of fatigue are multifaceted and can occur as a result of either central or peripheral factors (28). Fatigue during prolonged exercise at intensities of 65–85% maximal oxygen uptake ($\text{VO}_{2\text{max}}$) has been associated with depletion of muscle glycogen (14, 16, 27), hypoglycemia (6, 7), and dehydration (1, 4). In previous well-controlled studies it has been found that ingesting a carbohydrate (CHO) solution immediately before and during exercise can delay fatigue during intermittent high-intensity exercise (9, 21, 28). The potential mechanisms for this effect could be attributed to either a reduction in muscle glycogen utilization (20, 26, 27) or maintenance of blood glucose levels (6, 8) during exercise. Furthermore, it has been reported that blood glucose is an important energy source for the brain (22), and, as such, its levels in the blood could alter neurotransmitter activity (8), subsequently influencing cognition, mood, motivation, and motor-skill performance (28).
Previous studies using CHO supplementation and intermittent running have found enhancements in performance (9, 21, 28). Performance improvements have ranged from 33% to 37% after ingestion of a CHO supplement; however, in all of the aforementioned studies CHO was administered in the form of a liquid solution. CHO in the form of a gel is now widely accepted and used by both professional and recreational athletes. Using sports gels along with water during exercise should give the athlete the same benefits as a sports drink, but as yet there has been no scientific evidence to indicate that they work to help improve performance.

To our knowledge, only 2 studies have been undertaken that investigated the effects of ingesting a CHO gel on physiological and performance variables during exercise. In a study by Brooks et al. (3), which was published in abstract form only, there was a significantly ($P < 0.05$) greater increase in blood glucose concentration and a smaller change in blood volume ($–0.75\%$) in the CHO-gel trial than in the control (CHO in solid form: $–3.28\%$) or placebo (water only: $–1.83\%$). The authors did not present any performance data, however, despite the fact that the exercise protocol was a 5-km-time trial (3). In a study by Burke et al. (5) the effect of a commercially available CHO gel on endurance performance was investigated during a half-marathon. It was noted that there was only a very slight improvement ($0.3\%$) in half-marathon time in the CHO trial compared with a placebo, which was not statistically significant. Thus, although previous research has found improvements in endurance performance with CHO in liquid forms, the effect of CHO-gel ingestion on performance, although gels are widely used by athletes, is yet unproven.

The aim of this study, therefore, was to examine the effects of ingesting a commonly available CHO sports gel on running capacity after prolonged intermittent high-intensity shuttle running. It was hypothesized that there would be a significant improvement in performance after CHO-gel ingestion compared with control and that this improvement would be associated with maintained blood glucose levels in the CHO trial.

**Methods**

**Participants**

Seven healthy, trained university male soccer players (age $21.3 \pm 1.1$ y, body mass $65.5 \pm 4.6$ kg, height $175.4 \pm 2.8$ cm, percentage body fat $12.9\% \pm 1.9\%$, $VO_{2\text{max}}$ $52.3 \pm 1.6$ ml·kg$^{-1}$·min$^{-1}$; mean $\pm$ standard deviation) volunteered to participate in the study, which was approved by Napier University’s ethics committee. Before commencement of the study, all participants were required to sign a letter of informed consent, having previously had all possible risks and discomforts fully explained to them in both written and verbal form.

**Preliminary Measurements**

$VO_{2\text{max}}$ was estimated by means of a progressive shuttle-run test to volitional exhaustion (23), modified from the original protocol (17). From this estimate of $VO_{2\text{max}}$, running speeds corresponding to 55% and 95% of each individual’s $VO_{2\text{max}}$ were calculated using tables for predicted $VO_{2\text{max}}$ values (23). During this visit
participants also performed the Loughborough Intermittent Shuttle Test (L.I.S.T.) for 15 min to familiarize themselves with the required running speeds involved in the test. Furthermore, before exercise, percentage body fat was estimated from skinfold thickness measured at 4 sites (biceps, triceps, subscapular, and suprailiac) (11) using constant-pressure calipers (Harpenden, British Indicators Ltd., West Sussex, England).

**The L.I.S.T.**

The test consisted of 2 parts. The first part of the L.I.S.T. (Part A) consisted of five 15-min exercise bouts of varying intensity, with the 15-min periods separated by 3 min of passive recovery. During each exercise period, participants were required to continuously travel between 2 lines, 20 m apart, at various speeds related to estimated individual VO$_{2\text{max}}$, in a fixed pattern designed to be similar to the activity pattern recorded during a soccer match (19). The running and walking speeds during each 20-m shuttle of the test were dictated by an audio signal from a CD player, and the pattern of exercise was repeated approximately 11 times during each 15-min period (see 20 for precise details of protocol).

The second part of the test (Part B) involved participants’ running at speeds alternating between 55% and 95% of their estimated VO$_{2\text{max}}$ every 20 m until exhaustion. Exhaustion was defined as the inability to maintain the prescribed running speed for 2 consecutive distances of 20 m at the higher running speed.

**Experimental Design**

All participants completed 2 trials separated by a period of at least 7 d, under the same laboratory conditions (20–21 °C). The order of these trials was randomized. On each occasion, participants consumed either an isotonic CHO gel, osmolality 300 mOsmol/g (Go Gel, SIS Ltd., Blackburn, UK), or a noncarbohydrate orange drink artificially sweetened with aspartame (PLA; J. Sainsbury plc, London, UK). The gel or drink was consumed immediately before the start of exercise (0.89 mL/kg BM) and every 15 min thereafter (0.35 mL/kg BM). These volumes were selected to provide a CHO content (43 g/h) that would allow comparison with other studies using a similar supplementation and exercise protocol (9, 21). The substances ingested were of the same color, taste, and temperature to enable the administration of a single-blind design. Participants were also given 5 mL/kg BM of water immediately before exercise and 2 mL/kg BM every 15 min thereafter in an attempt to offset any effects of dehydration. Participants were instructed to monitor their food intake and physical activity levels for 2 d before the first experimental trial and to replicate these exactly before the subsequent trial. Participants were also asked to refrain from caffeine and alcohol consumption 24 h before each trial. Participants were reminded of these guidelines before each experimental session, but no formal evaluation of their physical activity or dietary habits was made.

**Experimental Protocol**

Participants reported to the laboratory on the day of each experiment 3 h postprandial and at the same time of day in an attempt to control variation resulting from circadian function (24). All testing took place in the human-performance laboratory. Nude
body mass was recorded before each trial, determined to the nearest 0.1 kg, using beam balance scales (Avery Ltd., Model 3306). Participants then rested in a supine position on an examination plinth for 10 min. After this 10-min period, heart rate (HR) was recorded using a Polar S610 HR monitor (Polar, Finland), and a resting fingertip blood sample was obtained from the right index finger. After ingesting the prescribed gel supplement or placebo drink subjects performed a standardized warm-up consisting of jogging, stretching, and striding for 10 min before beginning the L.I.S.T. HR was measured every 5 s during the L.I.S.T., and a mean HR was recorded for each 15-min exercise period during the L.I.S.T. Blood samples were collected during the recovery periods after 15, 30, and 60 min of exercise and at the end of Part B of the protocol. Fingertip blood samples were analyzed for blood lactate concentration using the Lactate Pro (Arkray, Inc., Kyoto, Japan) and for blood glucose concentration using the One Touch Ultra analyzer (LifeScan, Inc., Milpitas, California).

Subjective ratings of perceived exertion (RPE) (2), gut fullness (GF; scale of 0–10), and abdominal discomfort (AD; scale of 0–10) were also obtained during all recovery periods. On completing Part A, and after a final 3-min recovery period, participants performed the variable-speed run to exhaustion (Part B). On completion of Part B of the protocol, time to exhaustion was recorded, but participants were not informed of their exercise duration at any stage during the study. Nude body weight was again obtained on completion of the run to exhaustion.

Statistical Analysis

A 2-way (experimental treatment and sampling time) analysis of variance (ANOVA) with repeated measures was used to determine differences between trials for blood glucose, blood lactate, HR, RPE, AD, and GF. A paired t-test was used to identify differences between trials at specific time points. A paired t-test was used to determine differences in time to exhaustion and percentage body-weight loss between trials. Significance was accepted as P < 0.05. Results are presented as mean ± standard deviation.

Results

Exercise Time to Fatigue

There was a 45% increase (P < 0.05) in run time to exhaustion during Part B of the L.I.S.T. after CHO ingestion compared with PLA (6.1 ± 1.3 min vs. 4.2 ± 1.2 min, respectively; Figure 1).

Blood Glucose

Blood glucose concentrations were higher (P < 0.05) at the end of 15, 30, and 60 min of exercise during Part A of the L.I.S.T. in the CHO trial (5.8 ± 1.2, 6.9 ± 1.3, and 5.9 ± 0.8 mmol/L, respectively) than in PLA (5.2 ± 1.1, 5.1 ± 0.5, and 5.1 ± 0.4 mmol/L, respectively; Figure 2). Furthermore, concentrations of blood glucose were significantly (P < 0.05) higher at exhaustion in Part B of the L.I.S.T. in the CHO trial than in PSA (6.1 ± 1.1 vs. 5.2 ± 0.6 mmol/L, respectively; Figure 3).
Figure 1 — Time to exhaustion in Part B of the Loughborough Intermittent Shuttle Test in the placebo and carbohydrate trials, mean ± standard deviation. *Significantly different from placebo ($P < 0.05, N = 7$).

![Time to exhaustion graph]

Figure 2 — Blood glucose concentration before (pre) and during the first 15, 30, and 60 min of the Loughborough Intermittent Shuttle Test in the placebo (PLA) and carbohydrate (CHO) trials, mean ± standard deviation. *Significantly different from PLA ($P < 0.05, N = 7$).

![Blood glucose concentration graph]

**Blood Lactate**

There were no significant differences in blood lactate concentration between trials during Part A of the L.I.S.T. (Figure 4). Concentrations of this metabolite were elevated ($P < 0.05$) above preexercise values in both trials at 15 and 30 min into exercise (Figure 4). There were no differences in blood lactate between trials at exhaustion in Part B of the L.I.S.T. ($9.4 \pm 1.9$ vs. $9.2 \pm 1.5$ mmol/L for CHO and PLA, respectively).
Subjective Ratings and Heart Rate

There were no differences either between trials or over time for ratings of AD or GF during Part A of the L.I.S.T. Similarly, there were no differences in either HR response or RPE between trials during the L.I.S.T. Both HR and RPE, however, increased ($P < 0.05$) from preexercise values at every time point during Part A of the L.I.S.T. (Tables 1 and 2).

Figure 3 — Blood glucose concentration at the end of Part B of the Loughborough Intermittent Shuttle Test in the placebo and carbohydrate trials, mean ± standard deviation. *Significantly different from placebo ($P < 0.05$, $N = 7$).

Figure 4 — Blood lactate concentration before (pre) and during the first 15, 30, and 60 min of the Loughborough Intermittent Shuttle Test in the placebo (PLA) and carbohydrate (CHO) trials, mean ± standard deviation. *Significantly different from preexercise values ($P < 0.05$, $N = 7$).

Subjective Ratings and Heart Rate

There were no differences either between trials or over time for ratings of AD or GF during Part A of the L.I.S.T. Similarly, there were no differences in either HR response or RPE between trials during the L.I.S.T. Both HR and RPE, however, increased ($P < 0.05$) from preexercise values at every time point during Part A of the L.I.S.T. (Tables 1 and 2).
Changes in Body Mass

Body-mass changes, which were corrected for fluid intake, equated to a loss of 2.6% and 2.7% for PLA and CHO, respectively. There were no differences in the loss of body mass during each trial (1.7 kg vs. 1.8 kg for PLA and CHO, respectively).

Discussion

The main and novel finding of the present study was that supplementation with an isotonic CHO gel immediately before and throughout prolonged intermittent high-intensity shuttle running delayed fatigue and improved endurance-running capacity by 45% compared with the same volume of artificially sweetened PLA. This improvement in high-intensity-endurance capacity is consistent with previous research investigating CHO ingestion and using running as a mode of exercise (9, 21, 28) but is the first to show an improvement after ingesting CHO in the form of a gel.
In the present study the L.I.S.T. exercise protocol (Part A) consisted of five 15-min fixed bouts of variable-intensity shuttle running followed by a combination of high- (95% $\text{VO}_2\text{max}$) and low-intensity (55% $\text{VO}_2\text{max}$) intermittent running until volitional fatigue. Nicholas et al. (21) found that ingesting a 6.9% CHO drink immediately before and during 75 min of high-intensity shuttle running improved endurance capacity by 33% when compared with a placebo. Davis et al. (9), using the L.I.S.T. without the 4-s recovery period at the end of each sprint, found that CHO ingestion (6% solution) before and during exercise improved high-intensity running performance by 32% when compared with a placebo. Welsh et al. (28) found that ingesting a 6% CHO liquid before the start of each 15-min bout of exercise, in addition to ingesting an 18% CHO liquid halfway through 60 min of intermittent running, extended intermittent-run time to exhaustion by 37%. In the study by Welsh et al. (28), however, the shuttle run to fatigue consisted of repeated 20-m intervals at 120% $\text{VO}_2\text{max}$ and 55% $\text{VO}_2\text{max}$. The findings of the current study therefore support previous results demonstrating improvements in running performance after CHO ingestion. This result occurred despite the fact that the CHO was administered as a gel in this study and as a liquid in the earlier studies by Davis et al. (9), Nicholas et al. (21), and Welsh et al. (28).

To our knowledge there have only been 2 other studies that have investigated the effects of ingesting a CHO gel during exercise. In the study by Brooks et al. (3) subjects completed a 5.2-km training-run session and then consumed a 70-g sachet of an isotonic CHO gel containing 25 g of CHO. After ingesting CHO subjects performed a 5-km-run time trial. Although ingesting CHO significantly increased blood glucose concentration and resulted in a smaller decline in blood volume than in control or water conditions, no performance data were reported by Brooks et al. (3). Burke et al. (5) were the second group to investigate the effects of a CHO gel on performance. They reported that the effect on performance was minimal—time was only improved by 14 s. Because this study was conducted in well-trained athletes, a 14-s difference might seem like a significant improvement in time. When looking at athletes competing in international events, however, it is believed that the smallest worthwhile improvement in performance is between 0.4% and 0.7% of the typical within-athlete random variation in performance between events (13), so the 0.3% difference in the study by Burke et al. (5) would not appear to be noteworthy. Because these previous 2 studies (3, 5) did not report any positive significant effects of CHO gel on performance, the current study is the first to report a significant improvement in running performance after ingestion of a CHO gel.

The metabolic data measured in the present study show significantly ($P < 0.05$) higher blood glucose concentrations after 15, 30, and 60 min of intermittent exercise and also at exhaustion in the CHO trial than in the PLA trial. Again, this finding is comparable to those of Nicholas et al. (21), Davis et al. (9), and Welsh et al. (28). The increase in blood glucose levels could be the mechanism behind the observed improvement in running performance noted in this and other studies (9, 21, 28). It has been suggested that CHO ingestion can delay fatigue by reducing muscle glycogen utilization or increasing muscle glycogen resynthesis during periods of rest or lower intensity exercise (12, 15, 20, 29). Indeed, in the study by Nicholas et al. (20), the ingestion of a 6.9% CHO solution during 90 min of high-intensity intermittent running resulted in a 22% reduction in muscle glycogen utilization.
Thus, although muscle glycogen content was not measured in the current study, it is possible that the 31% increase in running capacity was the result of exogenous CHO administration’s increasing the availability of blood glucose and thereby reducing muscle glycogen utilization during a prior 75-min bout of intermittent shuttle running.

It has been reported that fatigue can occur as a result of impairment of one or more links in the chain from the central nervous system (CNS) to the contractile machinery (25). Nybo (22) investigated the effects of the administration of a 6% glucose polymer solution every 15 min during a 3-h cycling trial (200 W at 90 rpm) on voluntary force production. They noted that, during exercise, glucose homeostasis was maintained during the glucose trial but decreased to hypoglycemic levels (~3.0 mmol/L) in the placebo trial. Furthermore, the exercise-induced hypoglycemia lowered the average force produced during a sustained maximal muscle contraction, and this reduced force development was associated with a diminished activation drive from the CNS (22). Because, however, in the current study blood glucose levels did not decrease below a mean value of 5.0 mmol/L in the PLA trial, we do not think that central fatigue was the cause of the decreased exercise time to exhaustion in the PLA trial. This observation again points to the possibility that an elevation in blood glucose after CHO ingestion spares muscle glycogen (20) in the early stages of exercise.

Optimal performance in competitive sporting situations also relies on maintaining a positive mood state, an important function of the CNS (28). Welsh et al. (28) investigated the effects of CHO ingestion on both physical and mental performance during intermittent exercise to fatigue. They observed that, as well as an extended exercise time to exhaustion after ingestion of a CHO solution, motor-skill proficiency (as measured in a pseudo hopscotch test) was better maintained during the latter stages of exercise. Furthermore, Welsh et al. (28) observed that subjects reported a lower sensation of fatigue at the end of the shuttle run to fatigue in their CHO trial, suggesting that subjects felt less fatigued even though they were unable to maintain shuttle-run speed during the latter stages of exercise. In the current study, however, there was no difference between trials in self-reported perceptions of fatigue as measured by RPE scores. The lack of any significant difference between trials in terms of RPE scores suggests that CNS fatigue is not a contributory factor to the shorter exercise time observed in the PLA trial in the current study.

Similar to the studies by Nicholas et al. (21) and Davis et al. (9), blood lactate concentrations were not different between trials during either Part A or Part B of the L.I.S.T. It has widely been reported that accumulation of blood lactate results in a concomitant increase in hydrogen (H\(^+\)) ions and a reduction in pH, which might contribute to the development of fatigue (25). Because in this study there was no difference in blood lactate concentrations between trials, it is unlikely that the earlier onset of fatigue during the PLA trial was a result of increased acidity of the muscle or blood.

Dehydration has been shown to result in an earlier onset of fatigue in both aerobic endurance events (1, 9) and high-intensity exercise (4, 18). In the current study, despite consuming water throughout the trials subjects lost 2.6% and 2.7% of their body mass by the end of the L.I.S.T. for the PLA and CHO trials, respectively. It has been reported that a body-water deficit of as little as 2% can impair athletic performance (1). Dehydration does not appear to be the cause of the earlier
onset of fatigue in the PLA trial in the current study, however, because percentage body-water loss was not different between trials.

In conclusion, ingesting an isotonic CHO gel before and every 15 min during intermittent exercise improved subsequent running capacity by 45% in comparison with an artificially sweetened placebo. We do not think that the differences in performance were caused by a hypoglycemic effect on the CNS affecting force production or perception of fatigue, increased muscle acidity, or dehydration in the PLA trial. Instead, we suggest that the improved performance in the CHO trial is related to a sparing of muscle glycogen after CHO ingestion, which can then be utilized in the latter stages of intense intermittent exercise. Although the current study did not directly compare a CHO liquid drink with CHO gel, the observation of similar improvements in performance between this and previous studies using CHO drinks suggests that isotonic CHO gel could be used as an alternative to liquid CHO solutions during prolonged exercise. The positive findings of the use of CHO gel suggest that further investigation of the effects of CHO-gel intake during different exercise intensities is warranted.

References