Human Kinetics

ORIGINAL RESEARCH

Hydrothermally Modified Corn Starch Ingestion Attenuates Soccer Skill Performance Decrements in the Second Half of a Simulated Soccer Match

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Hydrothermally modified non-genetically modified organisms corn starch (HMS) ingestion may enhance endurance exercise performance via sparing carbohydrate oxidation. To determine whether similar effects occur with high-intensity intermittent exercise, we investigated the effects of HMS ingestion prior to and at halftime on soccer skill performance and repeated sprint ability during the later stages of a simulated soccer match. In total, 11 male university varsity soccer players (height = 177.7 ± 6.8 cm, body mass = 77.3 ± 7.9 kg, age = 22 ± 3 years, body fat = $12.8 \pm 4.9\%$, and maximal oxygen uptake = 57.1 ± 3.9 ml·kg BM^{-1}·min^{-1}) completed the match with HMS (8% carbohydrate containing a total of 0.7 g·kg BM^{-1}·hr^{-1}; 2.8 kcal·kg BM^{-1}·hr^{-1}) or isoenergetic dextrose. Blood glucose was lower ($p < .001$) with HMS at 15 min (5.3 vs. 7.7 mmol/L) and 30 min (5.6 vs. 8.3 mmol/L) following ingestion, there were no treatment differences in blood lactate, and the respiratory exchange ratio was lower with HMS at 15 min (0.84 vs. 0.86, $p = .003$); 30 min (0.83 vs. 0.85, $p = .004$); and 45 min (0.83 vs. 0.85, $p = .007$) of the first half. Repeated sprint performance was similar for both treatments ($p > .05$). Soccer dribbling time was slower with isoenergetic dextrose versus baseline (15.63 vs. 14.43 s, $p < .05$) but not so with HMS (15.04 vs. 14.43 s, $p > .05$). Furthermore, during the passing test, penalty time was reduced (4.27 vs. 7.73 s, $p = .004$) with HMS. During situations where glycogen availability is expected to become limiting, HMS ingestion prematch and at halftime could attenuate the decline in skill performance often seen late in contests.

Keywords: dietary supplements, fat oxidation, high-intensity intermittent exercise, low glycemic starch, mental fatigue, motor skills, muscular fatigue

Toward the latter stages of many athletic contests, fatigue and the associated decrease in exercise intensity often becomes a concern. For example, soccer players cover ~5–10% less total distance (Bangsbo et al., 1991; Mohr et al., 2003) and perform ~10% less high-intensity running as the second half progresses (Rampinini et al., 2007). Furthermore, this fatigue is often accompanied by a deterioration in critical technical skills, such as passing, shooting, and/or dribbling in both simulated (Russell et al., 2011) and actual soccer matches (Rampinini et al., 2009), and this skill deterioration would be expected to affect game outcome adversely (Lago-Peñas et al., 2010). Consistent with this is the observation that the majority of goals in soccer matches are scored in the final 30 min (Ostojic & Mazic, 2002; Yiannakos & Armatas, 2006). Consequently, losing can be the result of a fatigue-related decrement in performance by one team not necessarily by enhanced performance of the other.

Carbohydrate (CHO) depletion is the major factor associated with the onset of fatigue during prolonged (1–2 hr), high-intensity (≥60% maximal oxygen uptake [$\dot{V}O_2max$]) continuous or intermittent exercise like that seen in many sporting activities including soccer (Krustrup et al., 2006; Russell & Kingsley, 2014; Stone & Oliver, 2009). As a result, CHO supplementation strategies designed to delay fatigue onset are of considerable interest to many.

It is well known that CHO stores can be improved with CHO ingestion before and regularly during exercise (every 15 min or so), and this enhances performance (Cermak & Van Loon, 2013;

Nicholas et al., 1995; Patterson & Gray, 2007; Welsh et al., 2002; Winnick et al., 2005). However, these studies may not be applicable to soccer where regular CHO supplementation is more difficult because of the continuous play (e.g., players have more limited fluid ingestion opportunities and may even be limited to before the match and/or at halftime). Furthermore, most sports drinks are composed of simple sugars (sucrose or fructose) or maltodextrin, which are digested and absorbed very rapidly (e.g., have a high glycemic index and reduce exercise fat utilization because of greater circulating insulin; Bonadonna et al., 1990). Sometimes, they can even produce exercise hypoglycemia (Russell & Kingsley, 2014). In contrast, hydrothermally modified non-GMO corn starch (HMS) is a low glycemic index CHO that is better than conventional treatments for patients with glycogen storage disease, a condition characterized by the inability to utilize liver glycogen stores resulting in chronic hypoglycemia (Bhattacharya et al., 2007; Correia et al., 2008). In the only previous exercise study with HMS, Roberts et al. (2011) reported that vs. maltodextrin, HMS ingestion (1 g·kg BM^{-1}) consumed 30 min before exercise blunted serum glucose and insulin response (eightfold lower) and increased fat oxidation during 150 min of cycling without any gastrointestinal disturbances. Any resulting sparing of endogenous CHO should improve high-intensity exercise performance, especially late in prolonged exercise efforts. In fact, Roberts et al. (2011) did note that HMS improved time to fatigue at 100% $\dot{V}O_2max$ following a 150-min cycling task by 8% but with considerable between participant variability. Consequently, the apparent performance benefit was not statistically significant (perhaps a Type II statistical error). Moreover, there

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is some recent evidence that ingestion of a low glycemic index CHO might enhance soccer performance based on blood chemistry responses (Stevenson et al., 2017), but no studies have investigated the effects of HMS on intense, intermittent exercise activity. Therefore, our purpose was to assess the effects of HMS ingestion on sprinting or soccer skill performance during the final 30 min of a simulated soccer match. We hypothesized that HMS would minimize decrements in performance compared with dextrose due to differences in CHO utilization.

Methods

Participants

A total of 11 healthy, male soccer players (height = 177.7 ± 6.8 cm, body mass = 77.3 ± 7.9 kg, age = 22 ± 3 years, body fat = 12.8 ± 4.9%, and $\dot{V}O_2max = 57.1 ± 3.9$ ml · kg BM^{-1} · min^{-1}) volunteered to participate. All were experienced university varsity soccer players who were from a range of outfield playing positions and who had been involved in soccer training at least 3 days per week for 6 months prior to the study. Each athlete completed a health information form and a physical activity readiness questionnaire (Thomas et al., 1992) to minimize any potential contraindications to exercise. All potential risks were explained fully prior to any testing, and the athletes provided written, informed consent of the study protocol approved previously by the Western University's Office of Research Ethics.

Familiarization Sessions

Prior to the 2 experimental days, participants visited the laboratory on three separate occasions for familiarization and baseline measures. During the first visit, body composition (Bod Pod®, COSMED, Concord, CA), $\dot{V}O_2max$ (running treadmill test; Hazell et al., 2014), and maximal sprinting speed (treadmill test) were assessed. On a subsequent day, at least 48 hr after the first visit, each individual was acclimatized to the high-intensity intermittent running protocol to be used in the simulated soccer match and to the experimental soccer skill tests to eliminate potential learning effects during our experiment. On a third laboratory visit, participants completed the baseline skill tests.

Experimental Sessions

A double-blind, crossover research design was implemented involving two experimental treatments, HMS (UCAN Co., Woodbridge, CT) or dextrose monohydrate (DEX). The two trials were separated by at least 1 week. To avoid order effects, the first participant was randomized to treatment order via a coin flip, and each subsequent individual had the experimental treatments rotated systematically. To minimize food intake differences across treatments, each participant recorded all food/drink intake for the 2 days prior to the first experimental session and replicated this from written records for the 2 days preceding the second trial. In addition, a standardized low-CHO meal (9 kcal·kg BM^{-1} with a CHO content of 1 g·kg BM^{-1} [~40% CHO, 30% fat, and 30% protein]) was consumed at ~07:30 p.m. of the evening before testing to minimize the intra- and intervariability of nutritional status (Jeacocke & Burke, 2010).

Each athlete reported to the laboratory at 07:30 a.m. after a 12-hr overnight fast (water was allowed) having abstained from strenuous exercise, caffeine, or alcohol consumption for 24 hr. This dietary control was utilized not only to standardize CHO for both treatments but also to ensure that low CHO availability resulted toward the latter stages of our simulated soccer match. This was critical because significant glycogen depletion occurs with soccer matches (Bangsbo et al., 2007; Krustrup et al., 2006), and we wanted to test our hypothesis under similar conditions.

Upon arrival at the laboratory, measures of baseline blood glucose (FreeStyle Freedom Lite®; Abbott Diabetes Care Limited, Mississauga, ON, Canada) and blood lactate (Lactate Scout+; EKF Diagnostics, Elkhart, IN) concentration using finger prick blood samples, as well as resting metabolic rate (Vmax Legacy; Sensor-Medics, Yorba Linda, CA) were obtained. Forty-five minutes after arriving at the laboratory and 30 min prior to the simulated soccer match (to allow for digestion/absorption), participants drank 497 ± 48 ml (0.5 g CHO·kg BM^{-1}) of HMS or DEX. Both experimental drinks consisted of an 8% CHO solution containing a total of 0.7 g·kg BM^{-1}·hr^{-1} (2.8 kcal·kg BM^{-1}·hr^{-1}) of the corresponding CHO divided between two intakes. (The second intake was 199 ± 18 ml containing 0.2 g·kg BM^{-1} and was consumed at halftime of the simulated match.) The quantity of CHO ingested and the volume of water used to prepare the beverages were determined based on American College of Sports Medicine guidelines (American College of Sports Medicine, 2017). The electrolyte concentration in both beverages was the same and controlled using a noncaloric flavored electrolyte replacement powder (UCAN Hydrate®, Woodbridge, CT) that contained 94 mg/L of magnesium, 282 mg/L of chloride, 563 mg/L of sodium, 188 mg/L of potassium, and 28 mg/L of calcium. The treatment blinding was successful (only 18% detected the treatment correctly). In addition, participants were allowed water ad libitum throughout. Trial 1 intake was recorded (588 ± 258 ml) and reproduced during Trial 2.

The simulated soccer match was comprised of 60 min of intermittent running on a treadmill followed by the sprinting and soccer skill tests completed during the next 30 min of the experimental match. Specifically, the 60-min treadmill run was comprised of 4 × 15-min intermittent running blocks interspersed with 3 min of passive recovery (Figure 1). The intensities and times used during each block were full stopping (15 s), walking (35 s), jogging (46 s at 55% $\dot{V}O_2max$), cruising (42 s at 95% $\dot{V}O_2max$), and sprinting (17 s at 90% of peak sprinting speed). This simulated match was adapted from a protocol developed previously by Drust et al. (2000) and modified by Clarke et al. (2008). The latter investigators used the same absolute speeds for every individual, whereas for our study, the athletes ran at the same relative intensities based on their $\dot{V}O_2max$ and at exercise intensities known to occur in soccer games (Nicholas et al., 2000). The first three blocks corresponded to the first half of the game. Halftime was a 15-min passive recovery break (seated) while the second half consisted of a fourth, 15-min block followed by the repeated sprint ability (RSA) and the soccer skill testing (see below).

Expired breath-by-breath samples were collected for $\dot{V}O_2$ and respiratory exchange ratio (RER; Vmax Legacy, SensorMedics) during the last 4 min of each exercise block. In addition, heart rate was monitored throughout (Cardio 660™; Sportline, Oakville, ON, Canada), and finger prick measures of blood glucose and blood lactate were collected during the passive recovery period after each exercise block (Figure 1). Ten minutes after completion of the final block, participants performed the RSA test, followed by two soccer skill tests: the slalom dribbling test (SDT) and the Loughborough soccer passing test (LSPT; described below). A final measure of blood glucose and lactate were collected following the SDT.
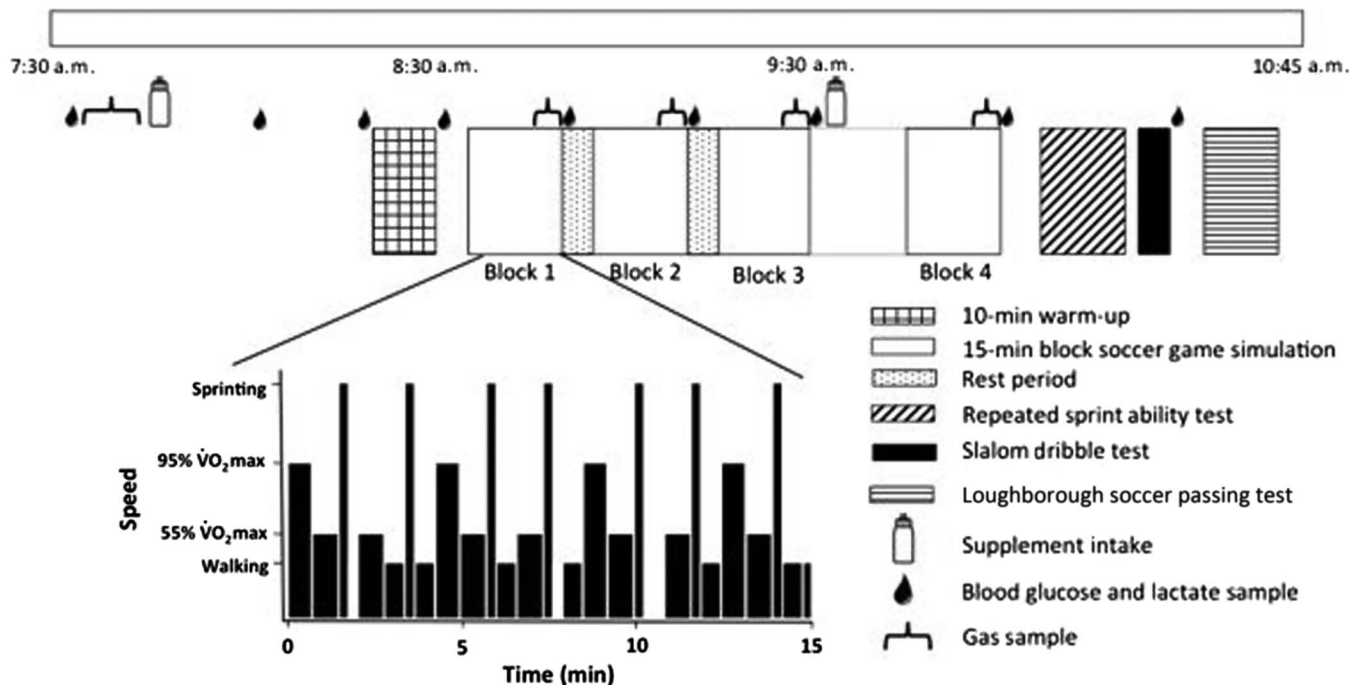
Figure 1 — Study protocol.

Repeated Sprint Ability Test

The RSA test was used to assess physical performance toward the end of the simulated soccer match. This test was comprised of 12×30-m sprints each interspersed with 35 s of recovery (Glaister et al., 2008). All sprints were performed in a gymnasium on a flat, nonslippery wooden surface. Timing gates (Western Engineering Electronic Shop, London, Canada) were placed at zero and at 30 m. The athletes initiated each sprint 1 m before the start line to avoid false triggering of the first timing gate and finished 1 m past the last timing gate to ensure that they did not slow down before crossing the 30-m point. Participants were asked to give a maximal effort in each sprint. Mean sprint time, best sprint time, and percent sprint decrement {[(fastest sprint – slowest sprint)/fastest sprint] $\times 100$} were determined.

Skill Tests

Slalom Dribble Test

Dribbling skill was assessed using the SDT as described previously (Stone & Oliver, 2009). This test has been shown to have good ecological and construct validity, as well as high test–retest reliability ($r = .95$; Reilly & Holmes, 1983). Briefly, the SDT evaluates total body movement, challenging participants to dribble a ball around a set obstacle course as quickly as possible. Timing gates were placed at the start and end lines to measure the time taken to complete the course. Prior to the test, the participants stood with the ball 1 m behind the starting line. On the command go, they dribbled the ball around a series of six cones in a zig-zag fashion. Once they got past the sixth cone, they stopped the ball and sprinted to the finish line. On the experimental day, participants completed the SDT four times with a 1-min rest between trials. The first two were "refamiliarization" trials; the average score of the last two trials was used as the score.

Loughborough Soccer Passing Test

Passing skill was assessed using the LSPT, as described previously (Ali et al., 2007). The LSPT is a skill test that incorporates various technical aspects of soccer, such as passing, ball control, dribbling, and decision making. It also has been shown to be both valid and reliable for soccer-specific technical performance (Ali et al., 2007). Briefly, participants performed 16 passes to four different colored targets, while negotiating a coned area, as quickly as possible. Time to complete the test (test time), accumulated penalties or errors committed during test execution (penalty time), and total time to complete the test after adjustment for penalty time (LSPT total performance) were determined.

Statistical Analysis

Statistical analyses were performed using SigmaPlot for Windows (version 12.0, SYSTAT, San Jose, CA). All data were tested for normality and a nonparametric test (analysis of variance on ranks test) was used if a data set was not normally distributed. Blood metabolite concentrations and expired gases samples were analyzed using a two-way (treatment by time), repeated-measures analysis of variance. Post hoc Tukey's Honest Significant Difference testing was used wherever significant main or interaction effects were found. The SDT was analyzed using analysis of variance on ranks test with post hoc testing (Dunn's test), where necessary. The RSA and LSPT data were analyzed using a paired t test. Significance was set at $p \le .05$. Data are presented as mean $\pm SD$.
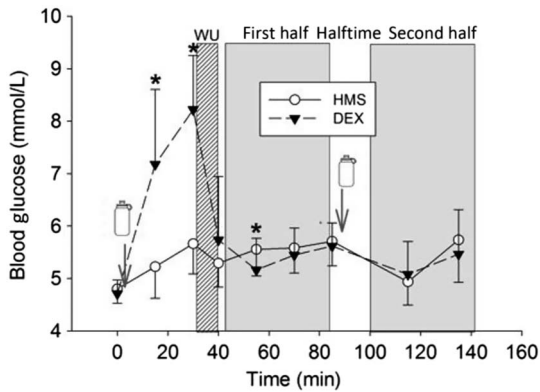
Results

Blood Glucose

There was a significant Treatment $\times$ Time interaction ($p < .001$) for blood glucose (Figure 2). Pairwise comparisons showed that blood
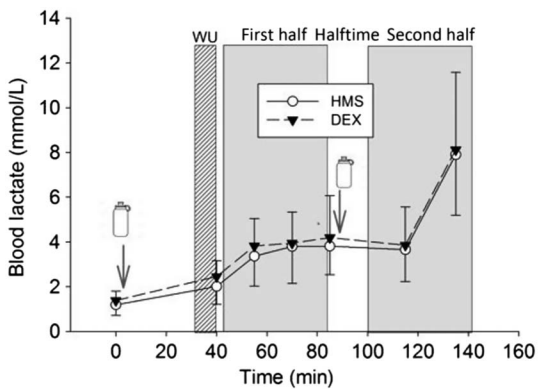
glucose was greater for DEX postdrink 1 ingestion at both 15 min (7.7 ± 1.4 vs. 5.3 ± 0.6 mmol/L, $p < .001$) and 30 min (8.3 ± 1.0 vs. 5.6 ± 0.6 mmol/L, $p < .001$), and lower 15 min after commencing the simulated soccer match (5.1 ± 0.6 vs. 5.8 ± 0.5 mmol/L, $p = .004$) compared with HMS. There was a main effect of time ($p < .001$) for blood glucose concentration. Blood glucose 30 min postdrink 1 was greater compared with any other time. In addition, there was a main ($p = .006$) effect of treatment with DEX being greater.

Blood Lactate

There was a main effect of time ($p < .001$) for blood lactate concentration. Blood lactate was greater after performing the RSA test (8.0 ± 3.0 mmol/L) compared with baseline (1.3 ± 0.4 mmol/L) or any other time during exercise. Furthermore, blood lactate concentration for Block 3 (4.0 ± 1.6 mmol/L) was greater than both baseline (1.3 ± 0.4 mmol/L) and postwarm-up (2.2 ± 0.8 mmol/L) concentrations. However, no treatment ($p = .13$) or interaction ($p = .99$) effects were found; that is, the overall effect of our treatments on blood lactate (measured every 15 min) was similar (Figure 3).

Respiratory Exchange Ratio

A Treatment × Time interaction was detected ($p = .002$) for RER. Pairwise comparisons revealed that RER was lower with HMS during Block 1 (0.84 vs. 0.86, $p = .003$); Block 2 (0.83 vs. 0.85, $p = .004$); and Block 3 (0.83 vs. 0.85, $p = .007$; Figure 4). There were also main effects for both time ($p < .001$) and treatment ($p = .02$) for RER. Specifically, RER was greater for all exercise blocks compared with baseline and greater for DEX compared with HMS.

Measures of Exercise Performance

RSA test.   There were no differences in mean sprint time (4.43 vs. 4.48 s, $p = .35$); best sprint time (4.26 vs. 4.32 s, $p = .26$); or percent sprint decrement (−4.0% vs. −3.6%. $p = .54$) between treatments when comparing HMS to DEX, respectively.

Slalom dribble test.   A main effect of treatment was observed for the dribbling test ($p = .03$). Post hoc comparisons revealed that dribbling time for DEX was slower (15.63 vs. 14.43 s, $p < .05$) than baseline (Figure 5). Furthermore, HMS appeared to attenuate the loss of dribbling test speed observed with DEX, (i.e., HMS

Figure 2 — Blood glucose concentration before and during the simulated soccer match. Values are presented as means ± *SD*s for DEX (filled triangles, $n = 9$) and HMS (open circles, $n = 9$). WU = warm-up; HMS = hydrothermally modified non-GMO corn starch; DEX = dextrose. *Significantly different versus HMS ($p < .001$).

Figure 4 — Respiratory exchange ratio before and during the simulated soccer match. Values are presented as means ± *SD*s for DEX (filled triangles, $n = 11$) and HMS (open circles, $n = 11$). HMS = hydrothermally modified non-GMO corn starch; DEX = dextrose; WU = warm-up. *Significantly greater versus HMS ($p = .002$).
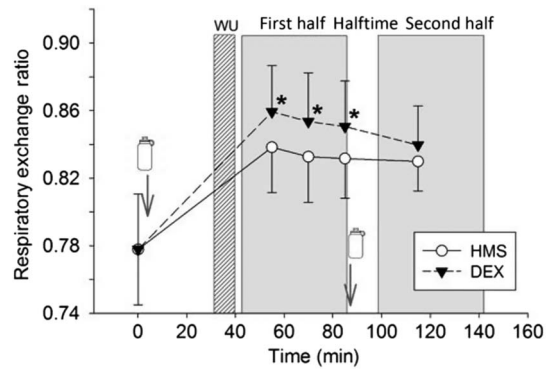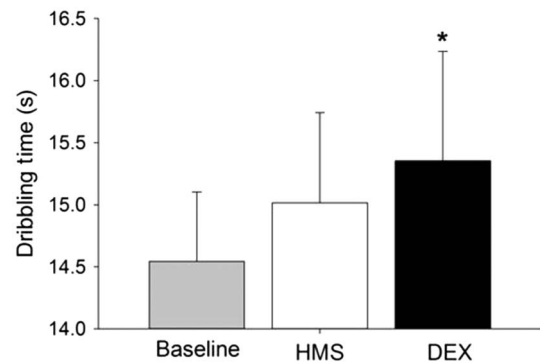
Figure 3 — Blood lactate concentration before and during the simulated soccer match. Values are presented as means ± *SD*s for DEX (filled triangles, $n = 11$) and HMS (open circles, $n = 11$). HMS = hydrothermally modified non-GMO corn starch; DEX = dextrose; WU = warm-up.

Figure 5 — Dribbling time at baseline and after 60 min of a simulated soccer match. Values are presented as mean ± *SD*s for baseline ($n = 11$), DEX ($n = 11$), and HMS ($n = 11$). HMS = hydrothermally modified non-GMO corn starch; DEX = dextrose. *DEX significantly slower versus baseline ($p < .05$). HMS versus baseline ($p > .05$).
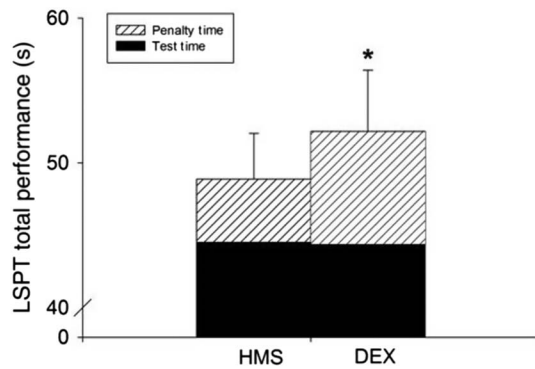
Figure 6 — Passing test performance time (LSPT) after 60 min of a simulated soccer match. Values are presented as mean ± *SD*s for DEX (filled bar, *n* = 11) and HMS (open bar, *n* = 11). HMS = hydrothermally modified non-GMO corn starch; DEX = dextrose; LSPT = Loughborough soccer passing test. *Significantly slower versus HMS (*p* = .006).

and baseline were not significantly different [14.43 vs. 15.04 s, *p* > .05]).

Loughborough soccer passing test. No significant effects were observed for LSPT test time comparing HMS with DEX (44.59 vs. 44.46 s; *p* = .85); however, average penalty time was reduced (4.27 vs. 7.73 s, *p* = .004) with HMS (Figure 6). As a result, LSPT performance (total time) was significantly better with HMS (*p* = .006).

Discussion

With modest dietary CHO (1 g·kg BM^{-1} the evening before and 0.7 g·kg BM^{-1} during a simulated soccer match), HMS in comparison with isoenergetic DEX attenuated the decline in soccer skill performance in the later stages of the second half of our soccer match and lowered RER throughout most of the match suggesting a possible CHO sparing effect. Considering that our study is the first to investigate HMS ingestion efficacy on performance parameters late in an exercise activity consisting of repeated, intense, intermittent exercise (simulated soccer match), it is not possible to compare our findings directly with the literature. In fact, to our knowledge, only one published exercise study has used HMS previously and that investigation examined the HMS effects on a number of physiologic and metabolic parameters during much more prolonged, continuous exercise (150 min) at a lower intensity (~70% V̇O$_2$max; Roberts et al., 2011). Furthermore, in that study, participants ingested 1 g·kg BM^{-1} of either HMS or maltodextrin 30 min before and near the end of the exercise bout. They reported that HMS blunted the initial increase in serum insulin versus maltodextrin (peak 2.5 vs. peak 20.3 mIU·ml^{-1}) resulting in a more uniform serum glucose response as well as an increase in both serum free fatty acid and glycerol concentrations (Roberts et al., 2011). Also, the RER with HMS appeared to be lower (*p* = .07) at both 60 min (0.92 vs. 0.95) and 90 min (0.91 vs. 0.94) of exercise. These observations suggest a greater use of fat for fuel, and the resulting CHO sparing could have important implications on both physical and skill performance during the latter stages of many sporting activities, including soccer (Krustrup et al., 2006).

In the present study, RER values with HMS were lower at 15 min (0.84 vs. 0.86, *p* = .003); 30 min (0.83 vs. 0.85, *p* = .004); and 45 min (0.83 vs. 0.85, *p* = .007) of our simulated soccer match.

These values indicate that there were differences in substrate use between our treatments (greater use of fat and concomitant CHO sparing with HMS). Although the role of fat utilization during high-intensity exercise (>85% of V̇O$_2$max) is often considered negligible (Achten et al., 2002), Romijn et al. (1993) have demonstrated clearly that its use can be substantial even at high exercise intensities. Furthermore, a study by Hetlelid et al. (2015) found that the difference in performance between a group of elite and recreational runners was due mainly to increased fat use. Specifically, the elite runners had nearly a threefold increase in fat oxidation despite similar ratings of perceived exertion, blood lactate concentration, and CHO oxidation rates versus the recreational runners during six 4-min bouts of running just above the second ventilatory threshold. Apparently, fat oxidation can be important even during high-intensity exercise and therefore could be important for soccer performance because significant glycogen depletion occurs in a soccer match (Krustrup et al., 2006).

Of course, one of the most interesting findings in the present study was that HMS ingestion attenuated the decline in soccer skill performance late during our simulated soccer match. Specifically, dribbling speed decreased significantly by 8% with DEX versus baseline (15.63 vs. 14.43 s, *p* < .05), whereas the observed deterioration in dribbling speed with HMS was only 4% and was not significantly different from baseline (15.04 vs. 14.43 s, *p* > .05). Furthermore, with the LSPT (passing test), penalty time was greater with DEX resulting in a significantly improved performance (reduced total time) with HMS (Figure 6). Perhaps differences in fine motor performance are responsible and therefore could be extremely important in elite soccer competition (Ali et al., 2007) because success is often more a result of maintaining skill performance throughout the match than one's ability to exercise intensely (Di Salvo et al., 2009; Hughes & Franks, 2005). Indeed, skill performance is critical to goal scoring (Russell & Kingsley, 2014).

In the present study, despite some differences prior to and during the first 15 min of exercise, blood glucose concentrations were similar between our two conditions. Apparently, at least for some time during prolonged, intermittent activity, it is possible to maintain blood glucose when fuel mix differs. Previously, Coyle et al. (1986) found that during the first hour of exercise blood glucose concentrations in a water-placebo group were similar to a CHO ingestion group, yet significant differences in fuel use and performance were observed much later (especially after 3 hr of cycling). Our simulated soccer match was not long enough to reveal differences in blood glucose concentration.

Somewhat surprisingly, there were no differences in our measures of sprint performance late in the second half of the simulated soccer match. Sprint testing was employed as a standardized assessment of physical performance capacity because this ability has been considered important in elite performance, although perhaps less so than soccer skill performance (Rampinini et al., 2009). In hindsight, the relative energy systems used in these short efforts might have made the test insensitive to detect differences in performance dependent on CHO utilization. Specifically, it is known that anaerobic glycolysis relies on CHO as a substrate and would be expected to supply ~40% of the total energy needed in a 6-s sprint (Gaitanos et al., 1993). However, this contribution has been reported to decrease by approximately 8-fold from the first to the last sprint of ten 6-s maximal sprints interspersed with 30-s recovery periods (Gaitanos et al., 1993). In the present study, participants did 12 × 30-m sprints (~4.5 s) with 35-s recovery periods, which represents a similar effort. Furthermore, it is possible that glycogen availability was adequate to complete these

sprints under both treatments because of the preexperimental treatment control used, even if treatment differences in muscle glycogen stores did exist. A similar exercise intensity test but of longer duration might be better to detect HMS treatment differences, if they exist.

Some might be surprised that the pattern of blood lactate in our study (greater at the end) differs from that observed routinely during soccer matches (greater in the early stages; Krustrup et al., 2006), but this can be explained easily when it is appreciated that our last lactate measure followed the repeated sprint testing. Prior to that post sprinting measure, the values were about 4 mmol/L and similar for both treatments.

Ingestion of HMS, before and at halftime altered substrate use and attenuated the fatigue-related decrements seen in soccer skills during the second half of a simulated soccer match. Similar results would be found for other sporting activities requiring intense, repeated, intermittent exercise bouts, (i.e., many individual and team sports). It is suggested that differences in exercise substrate use are responsible, but future more direct measures are required to confirm this and/or to elucidate any other factors responsible for this apparent ergogenic effect.

Acknowledgments

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