

# Low glycemic CHO ingestion minimizes cognitive function decline during a simulated soccer match

Manuel D Quinones and Peter WR Lemon

International Journal of Sports Science

&amp; Coaching

0(0) 1–7

© The Author(s) 2021



Article reuse guidelines:

sagepub.com/journals-permissions

DOI: 10.1177/17479541211028578

journals.sagepub.com/home/spo



## Abstract

Often cognitive function is affected adversely during prolonged, high intensity exercise. We assessed whether hydrothermally modified corn starch (HMS) ingestion minimizes cognitive decline with soccer play. 11 men ( $177.7 \pm 6.8$  cm,  $77.3 \pm 7.9$  kg,  $22 \pm 3$  y,  $12.8 \pm 4.9\%$  body fat,  $\dot{V}O_{2\max} = 57.1 \pm 3.9$  ml·kg<sup>-1</sup>·min<sup>-1</sup>; mean  $\pm$  SD) completed 60 min simulated soccer matches with HMS (8% CHO;  $0.7$  g·kg<sup>-1</sup>·h<sup>-1</sup>;  $2.8$  kcal·kg<sup>-1</sup>·h<sup>-1</sup>) vs isoenergetic dextrose (DEX) consumed 30 min prior to the match and at half time. Compared to DEX, blood glucose was lower ( $p < 0.001$ ) with HMS at 15 ( $5.3 \pm 0.6$  vs  $7.7 \pm 1.4$  mmol·L<sup>-1</sup>) and 30 min post ingestion ( $5.6 \pm 0.6$  vs  $8.3 \pm 1.0$  mmol·L<sup>-1</sup>), and greater ( $p = 0.004$ ) after 15 min of play ( $5.8 \pm 0.5$  vs  $5.1 \pm 0.6$  mmol·L<sup>-1</sup>). With HMS, perceived exertion ratings were reduced throughout the match ( $p = 0.025$  at 15 min). Flanker test incongruent trial reaction time ( $p = 0.040$ ) and conflict cost ( $p = 0.019$ ) were both better with HMS. **These data suggest that HMS ingestion minimizes cognitive decline during soccer play.** More study is warranted to elucidate fully the cognition benefits of HMS ingestion for sport performance.

## Keywords

Blood glucose, carbohydrate, high intensity intermittent exercise, mental fatigue, perceived exertion, sports drink

## Introduction

Cognitive function declines progressively during high intensity prolonged exercise, with reaction time being one of the most affected cognitive abilities.<sup>1</sup> In many sports, players must exercise intensely for extended time periods while having to make appropriate decisions rapidly. Thus, minimizing cognitive function decline while competing is critical for top performance. Further, carbohydrate (CHO) ingestion before and during exercise is well known to enhance performance<sup>2–4</sup> and part of this may be related to the effects of CHO on brain function<sup>5,6</sup> via a better ability to maintain blood glucose.<sup>7,8</sup> Typically, glucose is the main fuel for the brain and because glucose storage in the brain is limited, a consistent supply from the blood can preserve optimal functioning.<sup>9</sup> Consistent with this are the data showing that hypoglycemia impairs cognitive function<sup>10</sup> and that the delivery rate of dietary CHO also affects cognition.<sup>11</sup> Moreover, fast absorbing (high glycemic index [GI]) CHO can cause transient decreases in blood glucose, if not ingested at regular intervals, and this could potentially impair

cognition. Sport drinks contain high GI CHO and, therefore, must be ingested regularly throughout competition to avoid critical decreases in blood glucose.<sup>12</sup> In some team sports, regular CHO supplementation is more difficult because of the continuous play (e.g., players have more limited fluid ingestion opportunities and may even be restricted to before the match and/or at halftime). Consequently, a drink containing a slowly absorbable CHO (low GI) may be beneficial in such competitions. Hydrothermally modified corn starch (HMS) is a novel product (with modified physical

Reviewer: Mojtaba Kaviani (Acadia University, Canada)

Danny Lum (Singapore Sports Institute, Singapore)

Hunter Paris (Pepperdine University, USA)

Exercise Nutrition Research Laboratory, School of Kinesiology, The University of Western Ontario, London, ON, Canada

## Corresponding author:

Peter WR Lemon, 411 Labatt HSB, Western University, London, ON N6A 3K7, Canada.

Email: plemon@uwo.ca

properties by controlled heat-moisture processing, transforming it into a low GI CHO),<sup>13</sup> developed initially for children with a rare genetic disorder called glycogen storage disease. This condition is characterized by impaired liver glycogen metabolism, resulting in chronic hypoglycaemia and very poor exercise tolerance. HMS use is better than conventional treatments for these children because it helps to maintain more stable blood glucose values.<sup>14</sup> Consequently, HMS might improve cognitive function in long duration sports where liver and muscle glycogen stores are challenged, especially where limited supplementation opportunities are available. The observation that low GI breakfast food (slowly absorbed CHO) promotes better cognitive performance a few hours later in adults,<sup>11</sup> type 2 diabetics,<sup>15</sup> and children,<sup>16</sup> compared to a high GI breakfast food (rapidly absorbed CHO) is consistent with this hypothesis. However, to our knowledge, this possibility has not yet been assessed during repeated, intense, intermittent exercise, like that performed in many sport games. Therefore, the purpose of this study was to assess whether HMS ingestion can attenuate any decline in cognitive performance during a simulated soccer match when CHO is ingested only before and at 45 min of exercise, compared to a rapidly absorbed CHO.

## Methods

### Participants

Eleven healthy, men ( $177.7 \pm 6.8$  cm,  $77.3 \pm 7.9$  kg,  $22 \pm 3$  y,  $12.8 \pm 4.9\%$  BF, and  $\dot{V}O_{2\max} = 57.1 \pm 3.9$  ml·kg body mass<sup>-1</sup>·min<sup>-1</sup>) participated. All were experienced university varsity soccer players from a range of outfield playing positions and had trained for soccer at least three days per week for six months prior to the study. Each individual completed a health information and a physical activity readiness questionnaire (PAR-Q)<sup>17</sup> to minimize any potential contraindications to exercise. The study was approved by our institution's Office of Research Ethics, all potential risks were explained fully, and written, informed consent was provided prior to any data collection.

### Preliminary sessions

Participants visited the laboratory on two separate occasions prior to any experiments for familiarization sessions. During the initial visit, body composition (Bod Pod®, COSMED, Concord, CA),  $\dot{V}O_{2\max}$  (running treadmill test),<sup>18</sup> and maximal sprinting speed (treadmill test) were determined. At least 48 h following the first visit, participants returned and were familiarized with the cognitive tests and the high intensity

intermittent running protocol to be used to simulate the soccer match in order to eliminate potential learning effects during the experimental trials.

### Experimental sessions

A double blind, randomized, crossover research design was implemented involving two experimental treatments, HMS (UCAN Co., Woodbridge, CT, USA; GI = 30)<sup>13</sup> or dextrose monohydrate (DEX; GI = 100). The blinding was successful as only two of the 11 participants (18%) guessed the correct treatment. None of the participants reported any GI distress with any of the drinks. The experimental trials were separated by at least one week and were rotated systematically to prevent order effects. To minimize food intake differences across treatments, the athletes recorded their entire food/drink intake for the two days prior to the first experimental session and replicated this intake the two days preceding their second trial. Further, all were provided a standardized low CHO meal ( $9$  kcal·kg<sup>-1</sup> body mass with a CHO content of  $1$  g·kg body mass<sup>-1</sup> [ $\sim 40\%$  carbohydrate,  $30\%$  fat and  $30\%$  protein]) at  $\sim 1930$  h the night preceding testing to minimize the intra- and inter-variability of nutritional status and to ensure CHO stores would be low during the later stages of the subsequent simulated game.

Participants reported to the laboratory at 0730 h after a 12 h overnight fast having abstained from strenuous exercise, caffeine or alcohol for the 24 h prior to testing. Ad libitum water intake was allowed during the fasting period. Upon arrival, baseline blood glucose (FreeStyle Freedom Lite®; Abbott Diabetes Care Limited, Mississauga, ON, Canada) concentration and resting metabolic rate ( $V_{\max}$  Legacy; Sensor-Medics, Yorba Linda, CA) were assessed. Subsequently, baseline cognitive function was estimated (the Eriksen-Flanker test and the Serial Seven subtraction test – see below for details). Afterwards, participants consumed the corresponding drink treatment, 30 min was provided prior to any exercise to allow for gastric emptying/absorption, and a 10 min pre-match warmup was completed. Both experimental drinks consisted of an 8% CHO solution containing a total of  $0.7$  g·kg body mass<sup>-1</sup>·h<sup>-1</sup> ( $2.8$  kcal·kg body mass<sup>-1</sup>·h<sup>-1</sup>) of the corresponding CHO (HMS or DEX) divided into two intakes (first intake was  $497 \pm 48$  ml containing  $0.5$  g CHO·kg body mass<sup>-1</sup>; second intake was  $199 \pm 18$  ml containing the remaining  $0.2$  g·kg body mass<sup>-1</sup> and was consumed after 45 min of exercise, i.e., at half time of the simulated match). The quantity of CHO ingested and the volume of water used to prepare the beverages were determined based on ACSM guidelines.<sup>19</sup> The

electrolyte concentration in both beverages was controlled using a non-energy flavoured electrolyte replacement powder (UCAN Hydrate®) that contained  $94 \text{ mg} \cdot \text{L}^{-1}$  of magnesium,  $282 \text{ mg} \cdot \text{L}^{-1}$  of chloride,  $563 \text{ mg} \cdot \text{L}^{-1}$  of sodium,  $188 \text{ mg} \cdot \text{L}^{-1}$  of potassium and  $28 \text{ mg} \cdot \text{L}^{-1}$  of calcium. In addition, participants were allowed water ad libitum and the trial one intake was recorded ( $588 \pm 258 \text{ ml}$ ) and reproduced during trial two.

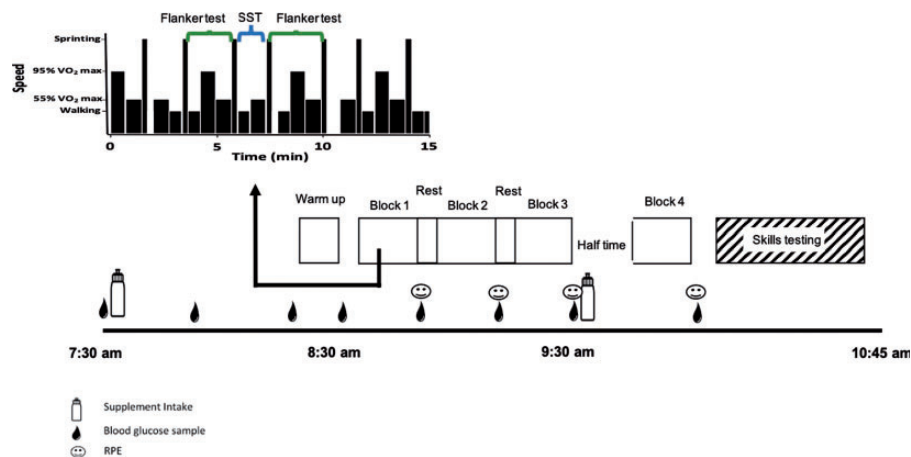
The simulated soccer game was comprised of four x 15-min intermittent running blocks interspersed with three min of passive recovery, followed by some soccer skills testing (Figure 1) as described previously.<sup>4</sup> The intensities and times used during each block were full stopping (15 s), walking (35 s), jogging (46 s at 55%  $\dot{V}\text{O}_2\text{max}$ ), cruising (42 s at 95%  $\dot{V}\text{O}_2\text{max}$ ) and sprinting (17 s at 90% of peak sprint speed). This was adapted from a protocol developed previously by Drust et al.<sup>20</sup> and modified by Clarke et al.;<sup>21</sup> however, the latter investigators used the same absolute speeds for every participant, whereas our participants ran at the same relative intensity (same percentage of their maximum) and at intensities common to soccer matches.<sup>22</sup> The first three blocks corresponded to the first half of the match. Then, a 15-minute half time break was given followed by the second half comprised of the fourth exercise block, and a series of sprints and soccer skill tests. Heart rate was monitored throughout (Cardio 660TM, Sportline), finger prick measures of blood glucose, and rates of perceived exertion (RPE) were collected during the passive recovery period after each exercise block using the 6 – 20 Borg scale. Cognitive testing (Eriksen-Flanker test and the Serial Seven subtraction test) was completed during each 15 min running block (between min 3 and 9) (Figure 1).

### Cognitive testing

**Eriksen-Flanker test.**<sup>23</sup> This is a response inhibition task which measures the ability to suppress responses that

are inappropriate in a particular context. Briefly, this test presented five arrows centered linearly on a computer screen. Athletes were instructed to indicate the direction of the center (target) arrow while ignoring the four flanking it. Each test was comprised of 40 random trials (20 congruent and 20 incongruent). The congruent trials consisted of the target arrow being flanked by arrows that faced the same direction (e.g.,  $\leftarrow \leftarrow \leftarrow \leftarrow \leftarrow$  or  $\rightarrow \rightarrow \rightarrow \rightarrow \rightarrow$ ) while the incongruent trials consisted of the target arrow being flanked by other arrows that faced the opposite direction (e.g.,  $\leftarrow \leftarrow \rightarrow \leftarrow \leftarrow$  or  $\rightarrow \rightarrow \leftarrow \rightarrow \rightarrow$ ). To respond, participants pressed a button on a handheld device interfaced with a computer, while running on the treadmill. The button for each hand also corresponded to the direction of the center arrow on the computer screen, regardless of the trial (congruent or incongruent). This test was performed twice within each exercise block for a total of 320 trials (160 congruent and 160 incongruent) during the soccer match simulation. The task was scored as mean choice reaction time (ms), accuracy (%), and conflict cost (also known as the ‘Flanker effect’) (ms). Eriksen-Flanker conflict cost was quantified as the difference in mean choice-reaction time between congruent and incongruent trials.

**Serial seven subtraction.**<sup>24</sup> Participants completed a one min verbal version of the serial-seven subtraction task once for each of the four exercise blocks throughout the protocol. The starting number for all trials was between 800–999 and chosen by means of a random number generator. Participants were instructed to subtract seven recursively from the starting number as quickly and as accurately as possible within the allotted one min. Time commenced once participants repeated the original number. If a mistake was realized, participants were encouraged to not correct themselves but



**Figure 1.** Study protocol.

to continue subtracting seven from the erroneous value and subsequent responses were scored in relation to the incorrect number. All verbal responses were recorded audibly to ensure answers were quantified accurately. To minimize any potential learning curve, participants completed practice trials during familiarization visits, as mentioned, as well as before each simulated match. Each trial was quantified as the proportion of correct responses over one min.

### Statistical analysis

Statistical analyses were performed using SigmaPlot for Windows (Version 12.0, SYSTAT, San Jose, CA). All data were checked for normality and sphericity. A power test to justify sample size was also performed. Blood glucose concentrations and RPE were analyzed using two-way (condition by time) repeated-measures ANOVA. Post hoc Tukey's Honest Significant Difference (HSD) testing was used, where necessary. The Eriksen-Flanker test and serial seven-subtraction test were analyzed using paired *t* tests. Significance was set at  $p \leq 0.05$ . Data are presented as means  $\pm$  SD.

## Results

### Blood glucose

There was a main effect of time ( $p < 0.001$ ) and treatment ( $p = 0.006$ ), as well as a significant interaction ( $p < 0.001$ ) for blood glucose concentration, as reported previously.<sup>4</sup> Blood glucose concentration

was lower ( $p < 0.001$ ) for HMS at both 15 ( $5.3 \pm 0.6$  vs  $7.7 \pm 1.4 \text{ mmol} \cdot \text{L}^{-1}$ ) and 30 min ( $5.6 \pm 0.6$  vs  $8.3 \pm 1.0 \text{ mmol} \cdot \text{L}^{-1}$ ) post treatment ingestion and greater ( $5.8 \pm 0.5$  vs  $5.1 \pm 0.6 \text{ mmol} \cdot \text{L}^{-1}$ ,  $p = 0.004$ ) after the first exercise block (55 min post ingestion) compared to DEX.

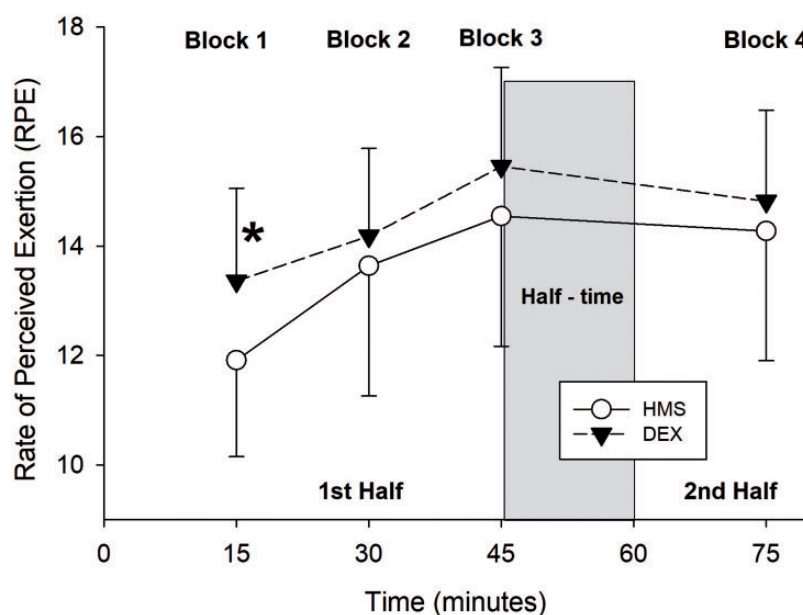
### Ratings of perceived exertion (RPE)

A main effect of time ( $p < 0.001$ ) was detected for RPE (Figure 2). As expected, average RPE for block 1 was lower than both block 3 and block 4. No treatment effect ( $p = 0.24$ ) was observed but there was a treatment  $\times$  time interaction ( $p = 0.013$ ). Pairwise post hoc comparisons indicated that the average RPE for block 1 was lower with HMS ( $p = 0.025$ ) compared to DEX.

### Measures of cognition

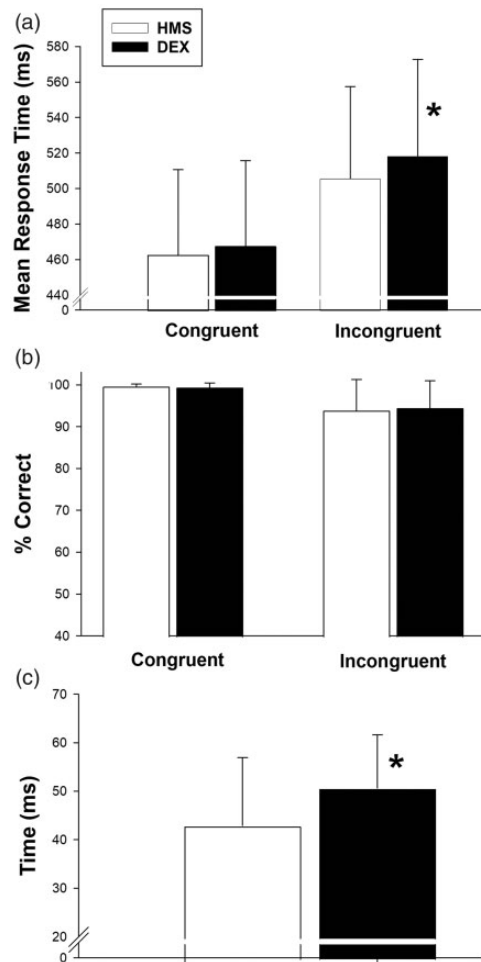
**Eriksen-Flanker task.** There was no significant difference in reaction time ( $p = 0.48$ ) nor accuracy ( $p = 0.81$ ) for the congruent trials. However, the reaction times during the incongruent trials were faster ( $p = 0.04$ ) with HMS supplementation compared to DEX without compromising accuracy ( $p = 0.43$ ) (Figure 3). As a result, better cognitive control or lower conflict cost ( $p = 0.019$ ) was observed with HMS supplementation compared to DEX.

**Serial seven subtraction test.** No significant differences were found for either the number of responses



**Figure 2.** Ratings of perceived exertion during a simulated soccer match. Values are means  $\pm$  SD for DEX (filled triangles,  $n = 11$ ) and HMS (open circles,  $n = 11$ ). \* $p = 0.025$  vs HMS.





**Figure 3.** Cognitive function during a simulated soccer match. Values are means  $\pm$  SD. A) HMS (white bars) improved (\* $p = 0.04$ ) reaction time vs DEX (black bars) during the incongruent trials. B) There were no differences in accuracy between treatments. C) Conflict cost (or interference) was reduced (\* $p = 0.019$ ) with HMS (white bars) vs DEX (black bars).

**Table 1.** Serial seven subtraction test.

Measure	Treatment	Score	p value
Serial subtraction (# Total answers)	HMS	22.7 $\pm$ 10.0	$p = 0.82$
	DEX	22.5 $\pm$ 9.0	
Serial subtraction (% Correct)	HMS	83.2 $\pm$ 14.0	$p = 0.39$
	DEX	86.3 $\pm$ 13.4	

Note: means  $\pm$  SD.

( $p = 0.82$ ) or the accuracy ( $p = 0.39$ ) of those responses during this test (Table 1).

## Discussion

The main finding of this study was that HMS supplementation before and at half-time of a simulated soccer

match reduced Flanker interference significantly and improved reaction time significantly during the incongruent trials while maintaining response accuracy vs isoenergetic DEX. This is important as reaction time, response interference, accuracy, and number of responses were measured using cognitive tasks validated for assessing mental processes related to executive functions such as working memory, selective attention and inhibitory control.<sup>23,25,26</sup> Moreover, HMS displayed more stable blood glucose concentrations and reduced perceived exertion during the simulated match.

To our knowledge, this is the first study to assess cognitive performance during a prolonged, intense, intermittent exercise protocol while consuming a high GI CHO (DEX) vs a low GI CHO (HMS) and suggests the latter can enhance at least some aspects of cognitive function during athletic contests.

Of course, diminishing CHO availability over the course of a soccer match could result in mental fatigue.<sup>27</sup> Although regular (every 15 min) CHO supplementation before and during exercise has been shown to attenuate this decline,<sup>5,6</sup> it is difficult to ingest CHO at regular intervals in some sporting activities due to their nature or the rules. This could lower blood glucose concentration and impair cognitive abilities.<sup>10</sup> The results of our study suggest that supplementing with a slowly absorbable CHO results in better cognitive performance, compared to a more rapidly absorbed CHO, at least when supplementation occurs only before the game and at halftime.

One possible limitation in our study was the unique dietary guidelines our participants followed previous to the evaluations. Although it is true that most soccer players would not follow our pre-match dietary strategy, it is known that soccer match play lowers muscle glycogen by 40–90%.<sup>28</sup> We utilized a reduced and controlled pre-study dietary CHO approach in order to ensure that significant glycogen depletion occurred during our simulated soccer match as well as to control CHO availability under both our experimental treatments.

As expected, reaction time was quicker and accuracy better during the congruent trials of the Eriksen-Flanker test with both treatments, compared to the incongruent trials. Further, as reported by Eriksen & Eriksen,<sup>23</sup> often participants respond more slowly to incongruent trials because of the need to utilize top-down control. Importantly, reaction time during the incongruent trials was improved with HMS supplementation, compared to DEX. Moreover, conflict cost or Flanker interference was improved as well with HMS supplementation. This would likely be beneficial for any athlete competing in activities involving repeated, intense, intermittent exercise, i.e., in activities when glycogen availability is challenged, especially as numerous

split-second decisions are often required.<sup>29,30</sup> But of course, this hypothesis would have to be tested during real play.

In contrast, differences were not observed with the SST, which is considered a measure of working memory.<sup>26</sup> In hindsight, this task requires a reasonable level of arithmetic skill and perhaps that is the critical determinant of performance with this type of test. Alternatively, this test may not be difficult enough to differentiate between conditions, i.e., it may not be the best predictor of decision-making in sports.

It is interesting that these differences in cognitive function were seen despite participants not being in a hypoglycemic state; however, as mentioned, cognitive function is not only affected by hypoglycemia but also by the delivery rate of CHO to the brain.<sup>11</sup> Given the differences in GI of both treatments, it is plausible that DEX resulted in greater insulin release, directing glucose more towards other insulin sensitive tissues and thereby reducing the flow of glucose from the blood to the brain.

During our simulated soccer game, RPE was also lower with HMS (significantly during the first 15 min of exercise,  $p = 0.025$ ), suggesting that the participants found the exercise to be less difficult, particularly at the beginning. Others have also shown that ingesting low GI CHO prior to exercise can result in lower exercise RPE.<sup>31,32</sup> Further, in our study, there were significant differences in blood glucose in the first stages of exercise that correlated with RPE, i.e., the athletes felt the standard exercise bout studied was less rigorous initially with HMS, consistent with the observed more modest changes in blood glucose. This could mean that in an actual soccer game when intensity is not fixed, athletes ingesting HMS would be able to exercise harder and, therefore, perform even better, assuming a comparable skill set.

## Practical application

This study provides insight into what type of CHO ingestion is best during activities that challenge CHO stores and have limited opportunities for supplementation. Based on these data, low GI CHO ingestion before and at halftime may attenuate decrements in decision-making often seen in sporting activities where CHO availability is compromised.

## Conclusion

HMS supplementation vs isoenergetic DEX prior to and at halftime of a simulated soccer match affected blood glucose favourably, reduced perceived exertion, and displayed better cognitive function during the simulated match. These data suggest HMS can improve

some aspects of cognitive function during sports characterized by repeated, intense, intermittent exercise at least when in match CHO supplementation is limited. More study is needed to assess fully the possible cognitive benefits of HMS for athletes.

## Acknowledgements

The authors would like to thank Victor Nguyen and Aaron Rode for their help with the data collection as well as the participants for their dedication and commitment.

## Authors' contribution

The study was designed by Manuel D. Quinones and Peter W.R. Lemon; data was collected and analyzed by MDQ; data interpretation and manuscript preparation were undertaken by MDQ and PWRL. Both authors approved the final version of the paper.

## Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

## Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This project received financial support from Generation UCAN®, but no one from the company was involved in the data collection, interpretation, or study conclusions.

## ORCID iD

Manuel D Quinones  <https://orcid.org/0000-0002-2467-2309>

## References

1. Féry YA, Ferry A, Vom Hofe A, et al. Effect of physical exhaustion on cognitive functioning. *Percept Mot Skills* 1997; 84: 291–298.
2. Ali A, Williams C, Nicholas CW, et al. The influence of carbohydrate-electrolyte ingestion on soccer skill performance. *Med Sci Sport Exerc* 2007; 39: 1969–1976.
3. Cermak NM and Van Loon LJC. The use of carbohydrates during exercise as an ergogenic aid. *Sports Med* 2013; 43: 1139–1155.
4. Quinones MD and Lemon PWR. Hydrothermally modified corn starch ingestion attenuates soccer skill performance decrements in the second half of a simulated soccer match. *Int J Sport Nutr Exerc Metabol* 2019; 29: 498–504.
5. Bottoms LM, Hunter AM and Galloway SDR. Effects of carbohydrate ingestion on skill maintenance in squash players. *Eur J Sport Sci* 2006; 6: 187–195.
6. Collardeau M, Brisswalter J, Vercruyssen F, et al. Single and choice reaction time during prolonged exercise in

- trained subjects: influence of carbohydrate availability. *Eur J Appl Physiol* 2001; 86: 150–156.
7. Coggan R and Coyle EF. Reversal of fatigue during prolonged exercise by carbohydrate infusion or ingestion. *J Appl Physiol* (1985) 1987; 63: 2388–2395.
  8. Roberts MD, Lockwood C, Dalbo VJ, et al. Ingestion of a high-molecular-weight hydrothermally modified waxy maize starch alters metabolic responses to prolonged exercise in trained cyclists. *Nutrition* 2011; 27: 659–665.
  9. Pardridge WM. Brain metabolism: a perspective from the blood-brain barrier. *Physiol Rev* 1983; 63: 1481–1535.
  10. Amiel SA. Cognitive function testing in studies of acute hypoglycaemia: rights and wrongs? *Diabetologia* 1998; 41: 713–719.
  11. Benton D, Ruffin MP, Lassel T, et al. The delivery rate of dietary carbohydrates affects cognitive performance in both rats and humans. *Psychopharmacology (Berl)* 2003; 166: 86–90.
  12. Russell M and Kingsley M. The efficacy of acute nutritional interventions on soccer skill performance. *Sports Med* 2014; 44: 957–970.
  13. Correia CE, Bhattacharya K, Lee PJ, et al. Use of modified cornstarch therapy to extend fasting in glycogen storage disease types Ia and Ib. *Am J Clin Nutr* 2008; 88: 1272–1276.
  14. Bhattacharya K, Orton RC, Qi X, et al. A novel starch for the treatment of glycogen storage diseases. *J Inher Metab Dis* 2007; 30: 350–357.
  15. Papanikolaou Y, Palmer H, Binns MA, et al. Better cognitive performance following a low-glycaemic-index compared with a high-glycaemic-index carbohydrate meal in adults with type 2 diabetes. *Diabetologia* 2006; 49: 855–862.
  16. Ingwersen J, Defeyter MA, Kennedy DO, et al. A low glycaemic index breakfast cereal preferentially prevents children's cognitive performance from declining throughout the morning. *Appetite* 2007; 49: 240–244.
  17. Thomas S, Reading J and Shephard RJ. Revision of the physical activity readiness questionnaire (PAR-Q). *Can J Sport Sci* 1992; 17: 338–345.
  18. Hazell TJ, Hamilton CD, Olver TD, et al. Running sprint interval training induces fat loss in women. *Appl Physiol Nutr Metab* 2014; 39: 944–950.
  19. Thomas DT, Erdman KA and Burke LM. Position of the academy of nutrition and dietetics, dietitians of Canada, and the American College of Sports Medicine: nutrition and athletic performance. *J Acad Nutr Diet* 2016; 116: 501–528.
  20. Drust B, Reilly T and Cable NT. Physiological responses to laboratory-based soccer-specific intermittent and continuous exercise. *J Sport Sci* 2000; 18: 885–892.
  21. Clarke ND, Drust B, Maclaren DP, et al. Fluid provision and metabolic responses to soccer-specific exercise. *Eur J Appl Physiol* 2008; 104: 1069–1077.
  22. Nicholas CW, Nuttall FE and Williams C. The Loughborough intermittent shuttle test: a field test that simulates the activity pattern of soccer. *J Sports Sci* 2000; 18: 97–104.
  23. Eriksen BA and Eriksen CW. Effects of noise letters upon the identification of a target letter in a non-search task. *Percept Psychophys* 1974; 16: 143–149.
  24. Hayman M. Two minute clinical test for measurement of intellectual impairment in psychiatric disorders. *Arch Neuropsych* 1942; 47: 454–464.
  25. Mullane JC, Corkum PV, Klein RM, et al. Interference control in children with and without ADHD: a systematic review of Flanker and Simon task performance. *Child Neuropsychol* 2009; 15: 321–342.
  26. Kase SE, Ritter FE and Schoelles M. Serial subtraction errors revealed. *Proc Annu Conf Cogn Sci* 2009; 31: 1551–1556.
  27. Smith MR, Thompson C, Marcora SM, et al. Mental fatigue and soccer: current knowledge and future directions. *Sports Med* 2018; 48: 1525–1532.
  28. Krstrup P, Mohr M, Steensberg A, et al. Muscle and blood metabolites during a soccer game: implications for sprint performance. *Med Sci Sports Exerc* 2006; 38: 1165–1174.
  29. Anzeneder CP and Bosel R. Modulation of the spatial extent of the attentional focus in high-level volleyball players. *Eur J Cogn Psychol* 1998; 10: 247–267.
  30. Baker LB, Rollo I, Stein KW, et al. Acute effects of carbohydrate supplementation on intermittent sports performance. *Nutrients* 2015; 7: 5733–5763.
  31. Stevenson E, Williams C, McComb G, et al. Improved recovery from prolonged exercise following the consumption of low glycemic index carbohydrate meals. *Int J Sport Nutr Exerc Metabol* 2005; 15: 333–349.
  32. Little JP, Chilibeck PD, Ciona D, et al. Effect of low- and high-glycemic-index meals on metabolism and performance during high-intensity, intermittent exercise. *Int J Sport Nutr Exerc Metabol* 2010; 20: 447–456.