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PHYSIOLOGY AND NUTRITION

Effects of pre-exercise snack bars with low- and high-glycemic index on soccer-specific performance: An application of continuous glucose monitoring

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ABSTRACT

This study aimed to investigate the effects of pre-exercise snack bars with different glycemic indices (GI) on soccer-specific performance. In a randomised crossover study design, 12 recreational soccer players consumed either low- or high-GI snack bars 1 h before 25 min small-sided game (SSG) training. Following the SSG training, the players' passing abilities were assessed using the Loughborough Soccer Passing Test (LSPT), followed by aerobic endurance capacities YOYO Intermittent Recovery Test Level 1 (YYIRT), respectively. Continuous glucose monitors (CGM) were used to track the glycemic response during SSG training and all tests. The result showed that participants' performance was significantly better in the low-GI trial compared with the high-GI trial for the LSPT movement (58.27 ± 10.99 vs. 62.27 ± 7.63 s, $p < 0.05$), LSPT total (74.64 ± 22.66 vs. 83.18 ± 18.29 s, $p < 0.05$), and YYIRT (1196 ± 657 vs. 993 ± 536 m, $p < 0.01$). The CGM data indicated a lower mean (6.2 ± 0.7 vs. 7.1 ± 0.6 mmol/L, $p < 0.01$) and lower glycemic variability in postprandial interstitial glucose levels in the low-GI trial, compared with the high-GI trial. In conclusion, pre-exercise low-GI snacks could result in more stable glycemic responses and enhance soccer-specific performance.

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Carbohydrates; GI; soccer performance; CGM

Introduction

Soccer is a physically demanding sport requiring players to perform high-intensity sprints, endurance, and skilful manoeuvres (D. P. Wong & Wong, 2009). To meet the energy demands and delay fatigue during prolonged exercise, pre-exercise carbohydrate (CHO) intake has been recognised as an important strategy for fuelling the body and optimizing on-field performance (Jeukendrup, 2014). For soccer players, consuming CHO before a game can improve passing and sprinting performance compared to fasting (Currell et al., 2009). Furthermore, a high dose of CHO intake can improve athletic capacity and distance covered during a match compared to a low dose of CHO intake (Souglis et al., 2013).

One aspect of CHO intake that has gained attention in recent decades is glycemic index (GI). GI is used to rank CHO-rich foods based on digestion, absorption and subsequent effect on blood glucose levels (Jenkins et al., 1981). Although there are some debates, a systematic review and meta-analysis concluded that consuming low-GI meals before exercise may yield greater benefits for endurance sports performance than consuming pre-exercise high-GI meals (S. H. Wong et al., 2017). Performance gains following low-GI meals could be attributed to a slower release of glucose into the bloodstream, leading to a sustained and prolonged energy supply (Burdon et al., 2017). This sustained energy supply may also play a crucial role in intermittent sports, such as soccer, where repeated high-intensity sprints are frequently required. Therefore, it would also be interesting to explore the possible benefits of low-GI foods on soccer-specific performance.

Several studies have compared the effects of different GI food intake on performance and physiological responses during soccer matches. Compared to high-GI food, low-GI food intake has been found to improve sprint speed (Goto, 2016), endurance (Burdon et al., 2017), and CHO metabolism (Kaviani et al., 2020) in soccer players. However, inconsistent results have been reported to date. Two previous studies observed that the GI of pre-exercise foods did not affect athletic performance in soccer players (Little et al., 2009; Mizelman et al., 2020). This inconsistency in the findings could be attributed to differences in the type and amount of food intake, nutrition timing, and participants' fitness and health status, all of which could ultimately influence the body's physiological responses. Hence, a more in-depth analysis using state-of-the-art technology may help gain a more comprehensive understanding of pre-exercise nutritional strategies for optimizing soccer performance.

In previous studies, traditional finger-prick capillary blood measurements were often used to assess glycemic responses during exercise. However, technological advancements such as the introduction of continuous glucose monitoring (CGM) may offer several advantages over conventional methods (Bowler et al., 2022). CGM can monitor interstitial glucose concentrations in real-time, enabling a more comprehensive understanding of glycemic responses during physical activities. Recently, CGM has been used to monitor the dynamics of glucose response during marathons (Ishihara et al., 2020), cycling

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(Iscoe et al., 2006), and high-intensity interval training (Bally et al., 2016). Despite the potential benefits of CGM technology in capturing detailed information, to the best of our knowledge, no study has used CGM to assess glycemic responses to different GI food consumption during soccer-specific activities.

To address these research gaps, the present study aimed to investigate the effects of pre-exercise snack bars with low- and high-GI on soccer-specific performance using CGM. Recent surveys have revealed that soccer players often consume convenient food, such as snack bars, up to 1 h before competitions to enhance their performance (Manore et al., 2017). Therefore, the findings of this study contribute to the existing body of literature and improve the understanding of athletes, coaches, and sports nutrition professionals seeking to optimize pre-exercise nutritional strategies in soccer. We hypothesised that soccer players who consumed low-GI snack bars would achieve better soccer-specific performance and more stable glycemic responses than those who consumed high-GI snack bars.

Method

Participants

Twelve male recreational soccer players (age: 20 ± 1 years old; height: 175.6 ± 5.6 cm; body mass: 72.5 ± 18.4 kg) were recruited for this study. None of the participants had previously received professional soccer training. Prior to the experiment, all the participants signed a consent form and were briefed on safety issues to avoid injuries and other hazardous situations. Ethical approval was obtained from the Human Research Ethics Committee of the Education University of Hong Kong and the experiment was conducted in accordance with the ethical standards outlined in the Declaration of Helsinki (Goodyear et al., 2007).

The sample size of this study (12 participants) was determined based on a relevant literature comparing low-GI and high-GI meals (Kaviani et al., 2020) on soccer-related performance profile, with an anticipated effect size of 0.8 (Cohen's d), using paired sample t-test. A significance value of 0.05 and power of 0.8 was adopted in the sample size calculation.

Experimental design

A randomised crossover design was used in this study. The experimental procedure is illustrated in Figure 1. Participants completed two main trials in random order. Three days before the first main trial, the participants were instructed to wear a CGM device (Freestyle Libre YZB/UK 0504–2016, Abbott, U. K). Participants were asked to record their dietary intake 24 h before the first trial and repeat the same diet before the second. Blood glucose levels were continuously recorded, and similar blood glucose levels were ensured before each main trial. During the two main trials, participants were randomly provided with two snack bars with different GI values: a low GI snack bar and a high GI snack bar. A 6 vs. 6 small-sided game (SSG) (Hill-Haas et al., 2011) training was performed on a 40 m × 25 m soccer pitch 1 h later. There were no goalkeepers and goals. A 5 m *25 m pitch area were set in both sides, and participants were scored when they successfully passed the ball into the area. All participants were asked to wear a heart rate (HR) monitor (M430, Polar Electro Oy, Finland) during the main trials. After the SSG, the Loughborough Soccer Passing Test (LSPT) (Ali, Williams, Hulse et al., 2007) and then the YOYO Intermittent Recovery Test Level 1 (YYIRT) (Yang et al., 2025)

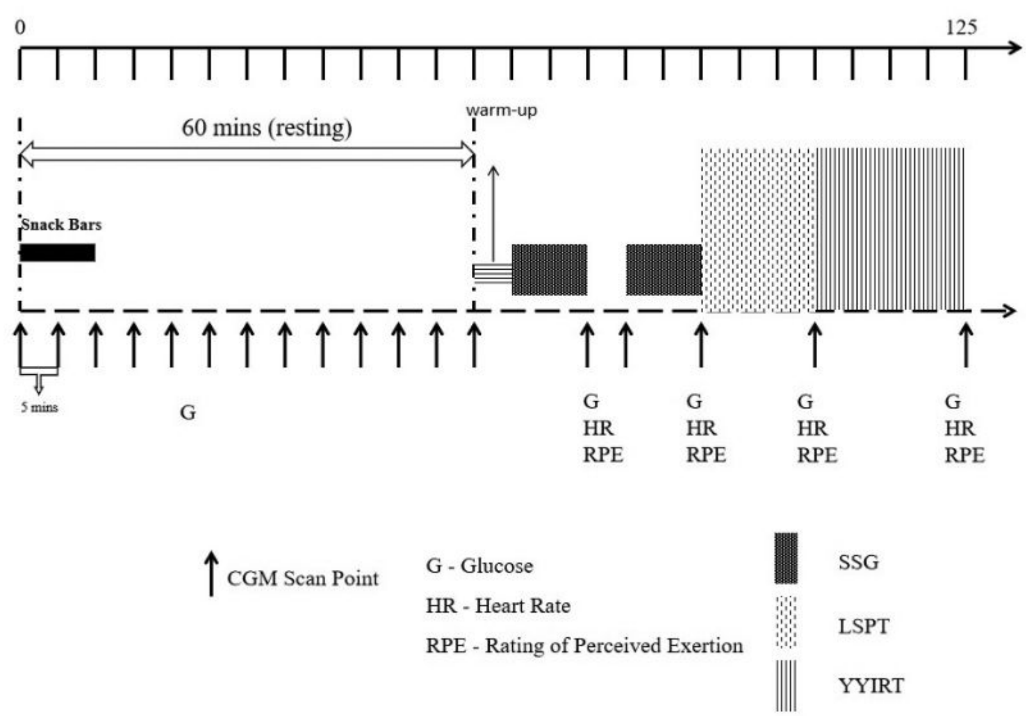


Figure 1. Illustration of procedures in main trial.

test were conducted; interstitial glucose levels, HR, and rating of perceived exertion (RPE) (Impellizzeri et al., 2004) were simultaneously recorded (Figure 1). After a six-day washout period, the second main trial was conducted, with all testing procedures and methods remaining the same, except for the snack bars consumed before the main trial.

Snack bars

Two isocaloric snack bars were used in the present study, with both bars providing 1.0 g CHO per kg of body weight to each participant. This amount of CHO aligns with the current guidelines on pre-exercise meals, which recommend consuming 1–4 g of CHO per kg of body weight 1–4 h prior to exercise (Burke et al., 2013). This quantity of CHO was also used in a previous study (Sun et al., 2013). The fiber content was not included in the calculation of the CHO amounts. The GI values for both snack bars were based on the reference values from the University of Sydney Glycemic Index Research Service (http://www.glycemicindex.com). The estimated GI values for the low- and high-GI bars were 20 and 68, respectively. The key nutrients in both snack bars are listed in Table 1. Before commencing the experiment, the researcher assigned two types of snack bars to each participant based on their weight and placed them into identical packaging. Using the Excel randomisation function, one of the two packets was randomly chosen for each participant and distributed on the day of the first main trial, with the second packet provided in the subsequent trial. To avoid bias, the specific purpose and weight of the snack bars were not disclosed to participants, although the tastes of two commercially available snack bars are different which could not be blinded.

Preliminary trial

One week before the first main trial, the participants were asked to complete a preliminary trial to familiarise themselves with the training and testing procedures in the main trials. In the familiarisation exercise, participants were informed of the basic tactics of the SSG, and the same SSG tactics were used in the following two main trials to achieve the same intensity as much as possible. The participants' HR responses during the SSG training and both tests were monitored to accurately estimate the main trial situation.

Main trials

All participants wore a CGM device three days before the first main trial. The CGM sensor was inserted into each arm of the participants, according to the manufacturer's instructions (Coates et al., 2023). The participants were explicitly instructed to refrain from strenuous exercise and consuming foods high in oil, sugar, caffeine, and alcohol for 24 h before the two main trials. Additionally, they were required to report their food intake during the 24 h preceding the first trial and replicate the same dietary choices the day prior to the second trial. The day before each main trial, the participants were requested not to eat anymore after 9 pm. The two main trials started at the same time, that is, at approximately 9 am. Furthermore, the participants were instructed to sleep for no less than 8 h on the night preceding each main trial to ensure sufficient rest. On each main trial day, all participants self-reported their sleep duration, and none reported sleeping for less than 8 h.

At the beginning of each main trial, the participants arrived at the laboratory in a fasted state. They were randomly given pre-packaged low- or high-GI snack bars according to their body weight, and 500 mL of water was provided (Zhu et al., 2020) to keep the body from being dehydrated. The participants also had their CGM manually scanned before consuming the snack bars to record their fasting interstitial glucose levels. They were also asked to undergo manual scanning every 5 min after intake to record their blood glucose levels.

SSG was conducted 1 h after snack bar intake. The duration of each half of the SSG was 10 min, with a 5-min break in between, for a total of 25 min. Interstitial glucose levels, HR, and RPE were recorded at half and at the end of the SSG.

After 6–8 min of rest, the participants performed the LSPT in the field. All participants were divided into 2 groups and conducted LSPT at the same time. In each group, participants were instructed to complete the test one by one, and each participant needed to complete LSPT twice. The sites setup, testing procedures, and data recoding for the LSPT followed a standardised protocol (Ali, Williams, Hulse et al., 2007). In brief, the test was conducted by two testers. One was responsible for timing, and the other was responsible for calling out the colour of the next target, which was called out before the participant completed the current pass. The same testers were used for all tests to eliminate any discrepancies. The sequence of passes was randomly generated and each trial consisted of eight long passes and eight short passes. In order to achieve the best possible score on the LSPT test, participants were instructed to complete the test as quickly as possible while minimising errors. When the last pass touched the target area, the tester stopped the clock, recorded the data, and calculated the score. Penalty time was awarded in case certain errors were observed such as passing to the wrong bench, missing the target area, and handling the ball. During the data collection period, participants received no feedback on their results from the testers. At the end of the test, all participants manually underwent CGM to record their interstitial glucose levels.

Following another 5 min of rest, all participants participated in the YYIRT. After the completion of the standard dynamic warm-up, the participants sprinted 2 × 20 m at

Table 1. Nutrition composition of the two kinds of food (for a 60 kg participant).

Trial	Low-GI	High-GI
Brand name	SOYJOY Otsuka Ltd. Japan	SNICKERS Mars Inc. USA
Estimated GI Value	20	68
Energy (kcal)	481.0	477.0
CHO (g)	60.0	60.0
Sugar (g)	38.3	43.8
Fat (g)	29.0	23.8
Protein (g)	8.7	15.7
Sodium (g)	235.0	175.0
Calcium (g)	0.0	0.0

GI: Glycemic index; CHO: carbohydrate.

progressively increasing speeds and jogged around a marker placed 5 m behind the finish line for 10 s during every 40 m shuttle (controlled by audio signals). The test ended when the participant chose to terminate or was unable to complete the shuttle run in time on two consecutive occasions. The final running distance was recorded for the analysis (Yang et al., 2025). The test ended when the participant was unable to hold the position or withdrew voluntarily. The total distance run in the YYIRT was the final result. Similarly, HR, glucose level, and RPE scores of all participants were recorded at the end of the YYIRT.

As each CGM device could record glucose for two weeks, the participants did not remove the sensor until the CGM lost its monitoring function. All interstitial glucose data were stored on an app connected to a CGM sensor on the participants' mobile phones.

Measurements

We calculated the average, highest, lowest, and change in interstitial glucose concentration as well as the incremental area under the curve (iAUC) (Liu et al., 2020). The participants' glycemic responses were assessed 24 h before and during each main trial. In addition, the Mean Average Glucose (MAG), standard deviation (SD), mean of glycemic excursions (MAGE), and continuous overall net glycemic action (CONGA) during each main trial were calculated to assess the glycemic variability (GV) (Kovatchev & Cobelli, 2016). These indicators were calculated using EasyGV (version 9.0 R2. Oxford University, UK; https://www.phc.ox.ac.uk/research/resources/easygv) based on the recorded glucose data. Although MAGE is the 'gold standard' for evaluating short-term and daily GV (Service et al., 1970), other indicators such as SD and CONGA are also commonly used in the literature (McDonnell et al., 2005).

Experiment control

To ensure data accuracy, consistent measures were taken regarding the location, time, and testing procedure for both main trials, with the only independent variable being the GI of snack bars intake. Testing days with similar weather conditions, including temperature (20℃–22℃), humidity (70–90%), and site conditions (artificial turf soccer fields), were also selected. During LSPT, a standardised football of the same brand, material, and size was used. The same researcher administered the LSPT and YYIRT in each trial to ensure consistent instructions and scoring standards.

Statistical analysis

Interstitial glucose curves recorded using OriginPro (version 2021, Microsoft Windows) were plotted and read, and the iAUC was calculated. All data were analyzed and reported using GraphPad Prism for Mac (version 9. GraphPad Inc. San Diego, LA, US) software. The results of the YYIRT, LSPT, HR, RPE scores, and GV for both trials were analyzed using paired-sample t-tests. Changes in glucose levels over time were analyzed using repeated-measures ANOVA. All data were presented as means ± SD. The level of significance was set at $p < 0.05$.

Results

The normality test showed that all data were normally distributed. Both the passing test performance in the LSPT and the total running distance in the YYIRT were significantly better in the low-GI trial than in the high-GI trial ($p < 0.05$) (Table 2).

There were no significant differences in HR and RPE after SSG or YYIRT between the two trials (Table 3). Similar HR and RPE values at the end of the SSG indicated that the exercise intensity was moderate during SSG training and was similar in the two main trials. In contrast, at the end of the YYIRT, the participants reached their subjective maximum exercise load tolerance, suggesting a state of exhaustion.

CGM analysis

The 24 h glucose concentration before each main trial between the two trials is shown in Figure 2. The glycemic responses during each main trial are shown in Figure 3. The repeated-measures ANOVA results showed no significant difference in blood glucose changes in the trials under the high-GI ($p = 0.26$) and low-GI conditions ($p = 0.46$). However, there was a significant difference in glucose levels at some time points (25–60 min and 75–90 min) under different GI conditions with paired-sample t-test. All participants' glucose levels before and after exercise were within the normal range (3.9–6.1 mmol/L), and no participants experienced prolonged hyperglycemia. After snack bar consumption, the high-GI trial resulted in a higher postprandial interstitial glucose concentration than the low-GI trial. The peak interstitial glucose level was observed 25 min after starting a meal in the low-GI trial compared to 30 min in the high-GI trial. During the initial 25 min of exercise, the interstitial glucose levels were higher in the low-GI trial than in the high-GI trial. However, after 30 min, no significant differences were observed between the two trials.

Table 2. Passing test performance and aerobic endurance test performance.

Condition	Low-GI (mean ± SD)	High-GI (mean ± SD)	p value
LSPT Movement (s)	58.27 ± 10.99	62.27 ± 7.63	0.027*
LSPT Penalty (s)	16.45 ± 13.17	20.91 ± 11.63	0.182
LSPT Total (s)	74.64 ± 22.66	83.18 ± 18.29	0.047*
YYIRT Distance (m)	1196 ± 657	993 ± 536	0.008*

GI: glycemic index; SD: standard deviation; LSPT: Loughborough soccer passing test; YYIRT: YOYO Intermittent Recovery Test Level 1.
*$p < 0.05$, low-GI vs. high-GI.

Table 3. HR, RPE in SSG and YYIRT.

Test	Time Point	Indicators	Conditions (mean ± SD) High-GI	Low-GI	p value
SSG	Half-time	HR	144 ± 18	152 ± 19	0.054
		RPE	11.4 ± 1.9	11.3 ± 1.4	0.890
	Full-time	HR	149 ± 24	147 ± 17	0.836
		RPE	11.7 ± 1.7	12.0 ± 1.4	0.645
YYIRT		HR	168 ± 21	158 ± 20	0.116
		RPE	16.0 ± 1.5	16.9 ± 1.6	0.117

SD: standard deviation; GI: glycemic index; SSG: small-sided games; YYIRT: YOYO intermittent recovery test level 1; HR: heart rate; RPE: rating of perceived exertion.

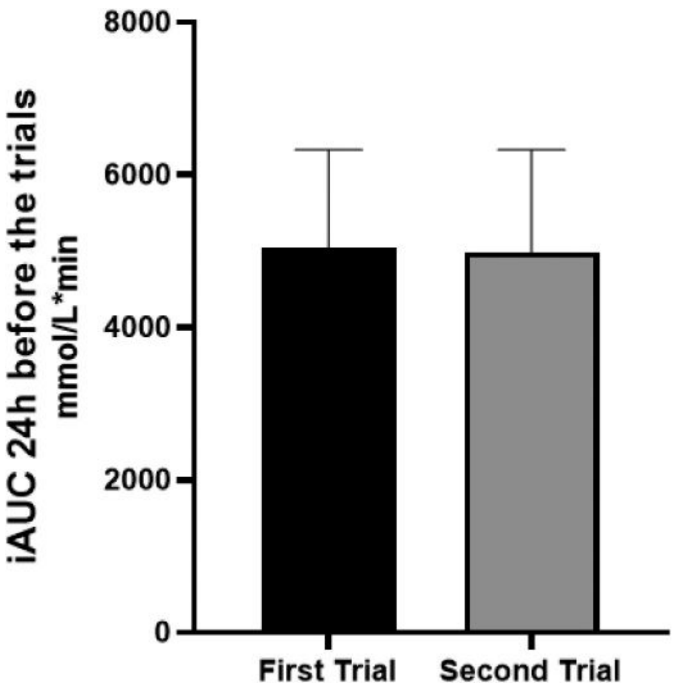


Figure 2. 24-hr iAUC before each main trial.

The mean interstitial glucose level in the high-GI trial was higher than that in the low-GI trial (high-GI vs. low-GI, 7.1 ± 0.6 vs. 6.2 ± 0.7 mmol/L, $p < 0.01$). Similarly, the Δ Glucose value (maximum glucose – minimum glucose) in the high-GI trial was higher than that in the low-GI trial (high-GI vs. low-GI, 5.2 ± 1.5 vs. 3.4 ± 1.5 mmol/L, $p < 0.01$).

The iAUC results are shown in Figure 4. No difference was found in the iAUC between the overall high-GI (198.3 ± 77.2 mmol/L*min) and low-GI (166.1 ± 66.8 mmol/L*min) trials. During the resting period, there was a significant difference in iAUC ($p < 0.05$) between the two trials, with 135.5 ± 57.5 mmol/L*min in the high-GI trial and 92.4 ± 31.8 mmol/L*min in the low-GI trial. During the exercise (SSG and test), the iAUC value in the low-GI trial was higher than that in the high-GI trial (73.8 ± 45.7 vs. 62.8 ± 48.7 mmol/L*min, $p < 0.05$). There was a significant difference in the iAUC between the resting and exercising conditions in the high-GI trials ($p < 0.01$), but no difference in the low-GI trials.

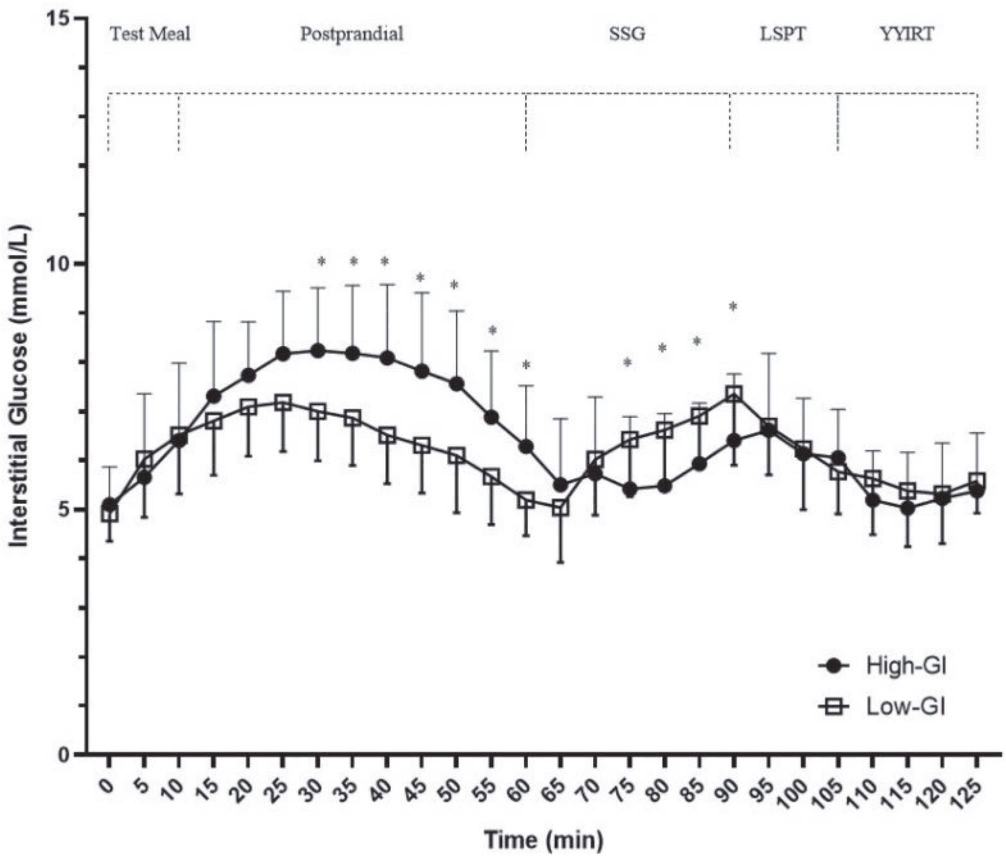
The GV results are listed in Table 4. The mean average glucose level and standard deviation (SD) were lower in the low-GI trial than in the high-GI trial. Although there were no differences in CONGA and MAGE scores, CONGA scores tended to differ between the two trials ($p = 0.06$).

Discussion

The key finding of the present study was that soccer players who consumed low-GI snack bars exhibited improved soccer-specific passing abilities, as measured by the LSPT, and enhanced aerobic endurance capacities, as evaluated by the YYIRT, compared to those who consumed high-GI snack bars. These findings are supported by the more stable glycemic responses captured by emerging CGM technology, revealing the potential performance benefits associated with consuming a low-GI snack bar before soccer-related activities.

Consumption of low-GI snack bars may offer superior benefits for soccer performance, as observed in the present study, for various possible reasons. Low-GI foods release glucose into the bloodstream at a slower and steadier rate, thereby providing a sustained energy supply during exercise (Burdon et al., 2017; S. H. Wong et al., 2017). This notion is consistent with the CGM data collected during the study, which showed less fluctuation and change in the postprandial interstitial glucose levels during the low-GI trial. Glucose levels were significantly higher in the high-GI condition than in the low-GI condition during the initial 60 min after consumption. Furthermore, the low-GI condition demonstrated the ability to sustain higher glucose levels during the subsequent exercise period. The GV results also indicated fewer fluctuations in the low-GI trial (Table 4). This sustained release of glucose may have contributed to improvements in aerobic endurance capacity observed in the YYIRT results. Furthermore, a steady supply of glucose to the brain may help maintain cognitive function and decision-making abilities (McDonnell et al., 2005), leading to more accurate passing performance in the LSPT.

Consistent with a previous meta-analytical study (S. H. Wong et al., 2017), the present study indicated that consuming low-GI snack bars may offer superior benefits for soccer performance. Low-GI foods are digested slower; therefore, glucose is gradually released into the bloodstream. Such steady carbohydrate release may help maintain the energy supply during prolonged exercise (Burdon et al., 2017). More specifically, eating low-GI foods results in a lower response to certain hormones, such as insulin, which promotes fat oxidation as a source of energy and allows the body to utilize stored fat more efficiently during exercise (Moitzi & König, 2023. In contrast, a higher insulin response after consuming high-GI foods results in unstable blood glucose concentrations and increases the risk of

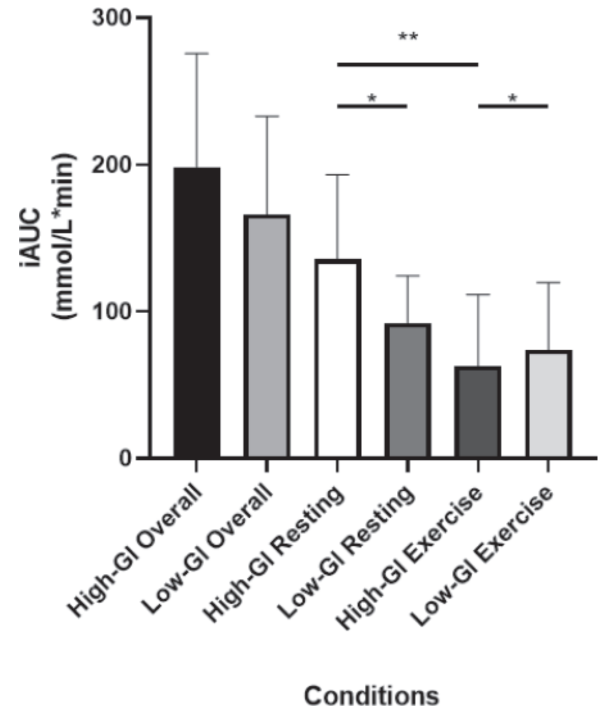


* $p < 0.05$, High-GI vs. Low-GI

Figure 3. Interstitial glucose changes during the main trials.

hypoglycemia, especially at the onset of exercise (O'Reilly & Wong, 2013). These physiological responses are more common when carbohydrates are consumed within 1 h of exercise (Hargreaves et al., 2004). Although hormonal responses and glycogen storage were not directly measured in the present study, the proposed metabolic advantages have been suggested to partially contribute to the enhanced endurance capacity and overall performance during soccer activities (Wee et al., 2005). Additionally, in a more recent study (Kaviani et al., 2020), the consumption of a low-GI lentil-based nutrition bar provided a metabolic benefit, as indicated by a lower carbohydrate oxidation rate and a modest improvement in agility, running, and jumping height late in a simulated soccer match, compared to a high-GI sports nutrition bar. Notably, despite performance differences, there were no significant differences in HR and RPE between the low- and high-GI trials in the present study. This suggests that superior performance in the low GI trial may be primarily attributed to improved efficiency in energy production and cognitive function during exercise (rather than physiological changes), which enables players to perform better without experiencing an increased perception of effort.

The findings of this study align with those of previous research that also reported the performance benefits of pre-exercise low-GI interventions (DeMARCO et al., 1999). In addition to the study mentioned above (Kaviani et al., 2020), another study demonstrated that consuming a pre-exercise low-GI meal 3 h before performing the Loughborough Intermittent Shuttle Test (LIST) resulted in faster sprinting time when compared to consuming an isoenergetic high-GI meal in eight trained adult female soccer players (Goto, 2016). In these two studies, the performance indicators used were agility, jumping height, and sprinting time, which differed from the indicators used in the present study (passing ability and endurance capacity). Therefore, the present study provides new evidence regarding the potential benefits of consuming low-GI foods before soccer training and/or competition. Although the results of these studies are encouraging, contradictory findings have been reported. Little et al. (2009) revealed that low- and high-GI foods consumed 3 h before and halfway through prolonged, high-intensity intermittent exercise resulted in similar repeated sprint performances, although both appeared to be better than fasting in seven male athletes. Similarly, Hulton et al. (2013) found no difference in intermittent high-intensity exercise performance among ten male recreational soccer players after consuming high- or low-GI meals. While these two studies share similarities with the present study in that they both measured the effects of different GI foods on athletic performance, they utilized intermittent exercise to simulate soccer movement patterns instead of conducting actual on-field tests on a soccer pitch, which may have less external validity when compared to our study. Other potential



* p < 0.05, High-GI vs. Low-GI; ** p < 0.01, Resting vs. Exercise.

Figure 4. The iAUC for interstitial glucose in the overall, resting and exercise conditions between high-GI and low-GI trials.

Table 4. Calculation of glycemic variability (GV).

Condition	Low-GI	High-GI	p value
Mean Average Glucose (MAG)	6.41 ± 0.60	6.91 ± 0.65	0.024*
Standard Deviation (SD)	1.00 ± 0.35	1.52 ± 0.50	0.007*
Mean of Glycemic Excursions (MAGE)	1.1 ± 0.48	1.5 ± 1.11	0.335
Continuous overall net glycemic action (CONGA) #	5.54 ± 0.58	4.57 ± 1.47	0.062

*$p < 0.05$, low-GI vs. high-GI #24-hours glucose.

reasons for these inconsistencies may be attributed to variations in the study design, including differences in participant characteristics, timing of snack bar consumption, or variations in the composition of the snack bars used. It is important to consider these factors and explore the potential mechanisms underlying the different outcomes in future research.

One novel aspect of this study was the use of advanced CGM technology to monitor glucose levels during exercise. Compared with the traditional finger-pricked glucose monitoring method, CGM provides real-time data and captures dynamic changes in glucose levels with acceptable accuracy (Thomas et al., 2017). Rapid monitoring and feedback offer valuable insights into metabolic responses during sporting activities, allowing athletes and coaches to adjust their training and nutritional strategies to optimize performance based on glycemic responses (Bowler et al., 2022). Furthermore, CGM is less invasive and does not require frequent finger pricks, which can be uncomfortable and disrupt exercise sessions such as soccer group training, as in the current study. CGM also reduces the risk of infection and other complications associated with frequent finger pricking. Furthermore, it can provide a large amount of continuous data to assess GV and monitor the physical health of participants. In our study, the CGM data supported the observed performance benefits of the low-GI snack bar by demonstrating fewer fluctuations and changes in glucose levels during the low-GI trial. In particular, our results for various indicators, including SD and iAUC, suggested that glycemic control was better and GV was lower in the low-GI trial than in the high-GI trial, although group differences in certain variables, such as MAGE and CONGA, did not reach statistical significance. This lack of significance could be attributed to statistical factors, as our required sample size, which was determined based on performance indicators, may have been underpowered by some GV indicators. It may also be hypothesized that a stable GV leads to better exercise performance. However, this study did not directly assess the effect of GV on performance; therefore, specific conclusions could not be drawn.

Despite the valuable insights gained in this study, some limitations must be acknowledged. First, a limited number of performance outcomes were assessed, focusing primarily on passing ability and aerobic endurance capacity. Exploring a broader range of performance indicators, such as sprinting speed and agility, would provide a more comprehensive evaluation of the effects of GI meals on soccer-specific performance. Second, the sample size was small, and the participants were recreational soccer players with relatively large variations in physical fitness and skill levels. The validity and reliability of performance tests (e.g., LSPT) for recreational players may not be as high as those for professional players. This may limit the generalizability of our findings to elite and professional soccer players. Future studies with more extensive and diverse samples, including athletes with varying skill levels, are encouraged to validate the results and determine the practical implications for different populations. Third, the bars used in this study were commercially available. Although the participants were not informed about the purpose or weight of the bars, they possibly preferred one over the other, potentially influencing their performance. In future studies, it may be worthwhile to consider this aspect when selecting snack bars for participants, such as choosing bars with similar flavours or gathering their preferences. Meanwhile, consumption of snack bars with different dosages of CHO may also affect exercise performance. Furthermore, CHO consumption during exercise is generally recommended which may also affect the benefits of pre-exercise low-GI meal consumption. Therefore, the results of the present study should be elaborated with caution, and more research should be conducted to investigate it with the support of CGM technology. Finally, precautions must be taken when using CGM technology, such as ensuring proper device placement, accuracy of data, and time delay between the blood and interstitial fluid compartments (Castle & Rodbard, 2019). The data from our CGM devices needed to be captured manually and were unavailable for generating minute-by-minute data during the exercise.

Nevertheless, our findings have potential implications for athletes, coaches, and sports nutrition professionals seeking to optimize their pre-exercise nutritional strategies in soccer. From a practical perspective, consuming a low-GI snack bar 1 h before a match can be a convenient and viable dietary option when soccer players have time constraints and/or food restrictions before the start of soccer-related activities. Additionally, some studies have suggested that since soccer games usually last 90 minutes, halftime serves as a good opportunity for players to recover and replenish CHO storage for the second half (Russell et al., 2015). It may be valuable to explore whether low-GI snack bar consumption during halftime could provide certain benefits. As CHO ingestion has been suggested to be effective in maintaining shooting skills (Ali, Williams, Nicholas et al., 2007), players may also consider consuming low-GI snack bars during halftime breaks, as it may offer an advantage in terms of maintaining energy levels and preventing cognitive decline in the late stages of the game (Kaviani et al., 2020; Quinones & Lemon, 2022). The CGM would be very valuable to identify the potential hypoglycemic events during the whole exercise periods and future research should also explore whether potential hypoglycemic events can be assessed at the onset of exercise. This additional perspective enhances the practical implications of this study.

Conclusion

In conclusion, this study demonstrated that consuming low-GI snack bars before soccer activities can improve passing ability and aerobic endurance capacity. The reduced glycemic fluctuation, as captured by our CGM data, suggests that the potential benefits of low-GI foods for soccer performance can be partially attributed to their ability to provide a sustained and stable energy supply.

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Disclosure statement

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Authorship

YZ, ETCP, XZ, BZ, CZ and FS was involved in study design, data collection and management. YZ, ETCP and FS wrote this manuscript. All authors read and approved this manuscript before publication.

References

Ali, A., Williams, C., Hulse, M., Strudwick, A., Reddin, J., Howarth, L., Eldered, J., Hirst, M., & McGregor, S. (2007). Reliability and validity of two tests of soccer skill. *Journal of Sports Sciences*, *25*(13), 1461–1470. https://doi.org/10.1080/02640410601150470

Ali, A., Williams, C., Nicholas, C. W., & Foskett, A. (2007). The influence of carbohydrate-electrolyte ingestion on soccer skill performance. *Medicine and Science in Sports and Exercise*, *39*(11), 1969. https://doi.org/10.1249/mss.0b013e31814fb3e3

Bally, L., Zueger, T., Pasi, N., Carlos, C., Paganini, D., & Stettler, C. (2016). Accuracy of continuous glucose monitoring during differing exercise conditions. *Diabetes Research and Clinical Practice*, *112*, 1–5. https://doi.org/10.1016/j.diabres.2015.11.012

Bowler, A. L. M., Whitfield, J., Marshall, L., Coffey, V. G., Burke, L. M., & Cox, G. R. (2022). The use of continuous glucose monitors in sport: Possible applications and considerations. *International Journal of Sport Nutrition and Exercise Metabolism*, *33*(2), 121–132. https://doi.org/10.1123/ijsnem.2022-0139

Burdon, C. A., Spronk, I., Cheng, H. L., & O'Connor, H. T. (2017). Effect of glycemic index of a pre-exercise meal on endurance exercise performance: A systematic review and meta-analysis. *Sports Medicine*, *47*(6), 1087–1101. https://doi.org/10.1007/s40279-016-0632-8

Burke, L. M., Hawley, J. A., Wong, S. H., & Jeukendrup, A. E. (2013). Carbohydrates for training and competition. *Food, Nutrition and Sports Performance*, *III*, 17–27. https://doi.org/10.1080/02640414.2011.585473

Castle, J. R., & Rodbard, D. (2019). How well do continuous glucose monitoring systems perform during exercise? *Diabetes Technology & Therapeutics*, *21*(6), 305–309. https://doi.org/10.1089/dia.2019.0132

Coates, A. M., Cohen, J. N., & Burr, J. F. (2023). Investigating sensor location on the effectiveness of continuous glucose monitoring during exercise in a non-diabetic population. *European Journal of Sport Science*, *23*(10), 2109–2117. https://doi.org/10.1080/17461391.2023.2174452

Currell, K., Conway, S., & Jeukendrup, A. E. (2009). Carbohydrate ingestion improves performance of a new reliable test of soccer performance. *International Journal of Sport Nutrition and Exercise Metabolism*, *19*(1), 34–46. https://doi.org/10.1123/ijsnem.19.1.34

DeMARCO, H. M., Sucher, K. P., Cisar, C. J., & Butterfield, G. E. (1999). Pre-exercise carbohydrate meals: Application of glycemic index. *Medicine and Science in Sports and Exercise*, *31*(1), 164–170. https://doi.org/10.1097/00005768-199901000-00025

Goodyear, M. D., Krleza-Jeric, K., & Lemmens, T. (2007). The declaration of Helsinki. *Bmj*, *335*(7621), 624–625. https://doi.org/10.1136/bmj.39339.610000.BE

Goto, H. (2016). Ingestion of high carbohydrate meal with low glycaemic index improves repeated sprint performance in elite adult female soccer players. *Football Science*, *13*, 1–8. https://doi.org/10.57547/jssfenfs.13.1_1

Hargreaves, M., Hawley, J. A., & Jeukendrup, A. (2004). Pre-exercise carbohydrate and fat ingestion: Effects on metabolism and performance. *Journal of Sports Sciences*, *22*(1), 31–38. https://doi.org/10.1080/0264041031000140536

Hill-Haas, S. V., Dawson, B., Impellizzeri, F. M., & Coutts, A. J. (2011). Physiology of small-sided games training in football: A systematic review. *Sports Medicine*, *41*(3), 199–220. https://doi.org/10.2165/11539740-000000000-00000

Hulton, A. T., Edwards, J. P., Gregson, W., Maclaren, D., & Doran, D. A. (2013). Effect of fat and CHO meals on intermittent exercise in soccer players. *International Journal of Sports Medicine*, *34*(2), 165–169. https://doi.org/10.1055/s-0032-1321798

Impellizzeri, F. M., Rampinini, E., Coutts, A. J., Sassi, A. L. D. O., & Marcora, S. M. (2004). Use of RPE-based training load in soccer. *Medicine & Science in Sports & Exercise*, *36*(6), 1042–1047. https://doi.org/10.1249/01.MSS.0000128199.23901.2F

Iscoe, K. E., Campbell, J. E., Jamnik, V., Perkins, B. A., & Riddell, M. C. (2006). Efficacy of continuous real-time blood glucose monitoring during and after prolonged high-intensity cycling exercise: Spinning with a continuous glucose monitoring system. *Diabetes Technology & Therapeutics*, *8*(6), 627–635. https://doi.org/10.1089/dia.2006.8.627

Ishihara, K., Uchiyama, N., Kizaki, S., Mori, E., Nonaka, T., & Oneda, H. (2020). Application of continuous glucose monitoring for assessment of individual carbohydrate requirement during ultramarathon race. *Nutrients*, *12*(4), 1121. https://doi.org/10.3390/nu12041121

Jenkins, D. J., Wolever, T. M., Taylor, R. H., Barker, H., Fielden, H., Baldwin, J. M., Bowling, A. C., Newman, H. C., Goff, D. V., & Goff, D. V. (1981). Glycemic index of foods: A physiological basis for carbohydrate exchange. *The American Journal of Clinical Nutrition*, *34*(3), 362–366. https://doi.org/10.1093/ajcn/34.3.362

Jeukendrup, A. (2014). A step towards personalized sports nutrition: Carbohydrate intake during exercise. *Sports Medicine*, *44*(Suppl 1), 25–33. https://doi.org/10.1007/s40279-014-0148-z

Kaviani, M., Chilibeck, P. D., Gall, S., Jochim, J., & Zello, G. A. (2020). The effects of low-and high-glycemic index sport nutrition bars on metabolism and performance in recreational soccer players. *Nutrients*, *12*(4), 982. https://doi.org/10.3390/nu12040982

Kovatchev, B., & Cobelli, C. (2016). Glucose variability: Timing, risk analysis, and relationship to hypoglycemia in diabetes. *Diabetes Care*, *39*(4), 502–510. https://doi.org/10.2337/dc15-2035

Little, J. P., Chilibeck, P. D., Ciona, D., Vandenberg, A., & Zello, G. A. (2009). The effects of low– and high–glycemic index foods on high-intensity intermittent exercise. *International Journal of Sports Physiology and Performance*, *4*(3), 367–380. https://doi.org/10.1123/ijspp.4.3.367

Liu, K. F., Niu, C. S., Tsai, J. C., Yang, C. L., Peng, W. H., & Niu, H. S. (2020). Comparison of area under the curve in various models of diabetic rats receiving chronic medication. *Archives of Medical Science: AMS*, *18*(4), 1078. https://doi.org/10.5114/aoms.2019.91471

Manore, M. M., Patton-Lopez, M. M., Meng, Y., & Wong, S. S. (2017). Sport nutrition knowledge, behaviors and beliefs of high school soccer players. *Nutrients*, *9*(4), 350. https://doi.org/10.3390/nu9040350

McDonnell, C. M., Donath, S. M., Vidmar, S. I., Werther, G. A., & Cameron, F. J. (2005). A novel approach to continuous glucose analysis utilizing glycemic variation. *Diabetes Technology & Therapeutics*, *7*(2), 253–263. https://doi.org/10.1089/dia.2005.7.253

Mizelman, E., Chilibeck, P. D., Hanifi, A., Kaviani, M., Brenna, E., & Zello, G. A. (2020). A low-glycemic index, high-fiber, pulse-based diet improves lipid profile, but does not affect performance in soccer players. *Nutrients*, *12*(5), 1324. https://doi.org/10.3390/nu12051324

Moitzi, A. M., & König, D. (2023). Longer-term effects of the glycaemic index on substrate metabolism and performance in endurance athletes. *Nutrients*, *15*(13), 3028. https://doi.org/10.3390/nu15133028

O'Reilly, J., & Wong, S. H. (2013). Effect of a carbohydrate drink on soccer skill performance following a sport-specific training program. *Journal of Exercise Science & Fitness*, *11*(2), 95–101. https://doi.org/10.1016/j.jesf.2013.11.001

Quinones, M. D., & Lemon, P. W. (2022). Low glycemic CHO ingestion minimizes cognitive function decline during a simulated soccer match. *International Journal of Sports Science & Coaching*, *17*(2), 423–429. https://doi.org/10.1177/17479541211028578

Russell, M., West, D. J., Harper, L. D., Cook, C. J., & Kilduff, L. P. (2015). Half-time strategies to enhance second-half performance in team-sports players: A review and recommendations. *Sports Medicine*, *45*(3), 353–364. https://doi.org/10.1007/s40279-014-0297-0

Service, F. J., Molnar, G. D., Rosevear, J. W., Ackerman, E., Gatewood, L. C., & Taylor, W. F. (1970). Mean amplitude of glycemic excursions, a measure of diabetic instability. *Diabetes*, *19*(9), 644–655. https://doi.org/10.2337/diab.19.9.644

Souglis, A. G., Chryssanthopoulos, C. I., Travlos, A. K., Zorzou, A. E., Gissis, I. T., Papadopoulos, C. N., & Sotiropoulos, A. A. (2013). The effect of high vs. low carbohydrate diets on distances covered in soccer. *The Journal of Strength & Conditioning Research*, *27*(8), 2235–2247. https://doi.org/10.1519/JSC.0b013e3182792147

Sun, F. H., O'Reilly, J., Li, L., & Wong, S. H. S. (2013). Effect of the glycemic index of pre-exercise snack bars on substrate utilization during subsequent exercise. *International Journal of Food Sciences and Nutrition*, *64*(8), 1001–1006. https://doi.org/10.3109/09637486.2013.825701

Thomas, F., Pretty, C. G., Signal, M., Shaw, G., & Chase, J. G. (2017). Accuracy and performance of continuous glucose monitors in athletes. *Biomedical Signal Processing and Control*, *32*, 124–129. https://doi.org/10.1016/j.bspc.2016.08.007

Wee, S. L., Williams, C., Tsintzas, K., & Boobis, L. (2005). Ingestion of a high-glycemic index meal increases muscle glycogen storage at rest but augments its utilization during subsequent exercise. *Journal of Applied Physiology*, *99*(2), 707–714. https://doi.org/10.1152/japplphysiol.01261.2004

Wong, D. P., & Wong, S. H. (2009). Physiological profile of Asian elite youth soccer players. *The Journal of Strength & Conditioning Research*, *23*(5), 1383–1390. https://doi.org/10.1519/JSC.0b013e3181a4f074

Wong, S. H., Sun, F. H., Chen, Y. J., Li, C., Zhang, Y. J., & Huang, W. Y. J. (2017). Effect of pre-exercise carbohydrate diets with high vs low glycemic index on exercise performance: A meta-analysis. *Nutrition Reviews*, *75*(5), 327–338. https://doi.org/10.1093/nutrit/nux003

Yang, W., Yin, L., Poon, E. T. C., Ho, I. M. K., Liu, H., Qi, B., Li, Q., & Li, Y. (2025). Effects of low-volume court-based sprint interval training on aerobic capacity and sport-specific endurance performance in competitive tennis players. *Biology of Sport*, *42*(1), 223–232. https://doi.org/10.5114/biolsport.2025.139088

Zhu, Y., Sun, F., Li, C., Chow, D. H., & Wang, K. (2020). Acute effect of brief mindfulness-based intervention coupled with fluid intake on athletes' cognitive function. *Journal of Sports Science & Medicine*, *19*(4), 753.