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ORIGINAL ARTICLE

Effects of high-carbohydrate versus mixed-macronutrient meals on female soccer physiology and performance

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Abstract

Purpose Athletes are often told to minimize intakes of fiber, fat, and protein in pre-competition meals to avoid gut distress, but this guidance is based on scant direct evidence. This study evaluated the physiological and perceptual effects of pre-competition mixed-macronutrient (MM) and high-carbohydrate (HCHO) meals in collegiate female soccer players.

Methods Fifteen players participated in this randomized, investigator-blinded, crossover study involving two ~ 1000-kcal meals (HCHO and MM) consumed 4 h prior to 70-min scrimmages. Assessments included global positioning system (GPS) tracking, heart rate (HR), perceived exertion (RPE), ratings of fatigue (ROF), gut symptoms, and perceptions of satiety, hunger, and fullness. Differences between conditions for HR, RPE, ROF, and gut symptoms were evaluated with Wilcoxon signed-rank tests. GPS data and hunger, satiety, and fullness scores were compared using within-subjects repeated measures ANOVAs.

Results No statistically significant differences were found between the conditions at any time point for HR, RPE, ROF, or gut symptoms. Significant time effects were found for two GPS variables (total distance covered and high-speed running), indicating that participants covered less distance during the second half of the scrimmages in comparison to the first half. However, there were no significant condition or condition × time interactions for GPS data. Finally, there were no condition or condition × time interactions for hunger, fullness, and satiety, though significant time effects were observed.

Conclusion A MM meal consumed 4 h prior to 70 min of soccer competition does not increase gut symptoms and can be similarly ergogenic as a HCHO meal.

Keywords Athlete · Carbohydrate · Exercise performance · Fiber · Protein · Satiety

Abbreviations

CHO	Carbohydrate
HCHO	High-carbohydrate
HR	Heart rate
HSR	High-speed running
IQR	Interquartile range
GPS	Global positioning system
MM	Mixed-macronutrient
ROF	Rating of fatigue
RPE	Rating of perceived exertion
SD	Standard deviation
TDC	Total distance covered

Introduction

Soccer requires athletes to perform recurring high-intensity efforts (i.e., sprints of 3–4 s) interspersed with lower-intensity efforts such as jogging or walking (Spencer et al. 2005). During periods of the season associated with high training and competition volumes, muscle glycogen degradation can outpace muscle glycogen resynthesis, resulting in accumulated physical and mental fatigue if proper nutritional protocols are not followed (Williams and Rollo 2015). In order to mitigate the effects of fatigue, both the acute and chronic consumption of dietary nutrients, particularly carbohydrate (CHO), is imperative. In 2013, for example, an experimental study revealed that when professional male footballers were assigned to a 3.5-day diet containing 8 g of CHO per kg of

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body mass per day, they covered greater jogging and sprint distances during matches than when they were assigned to a low-CHO diet containing 3 g of CHO per kg of body mass per day (Souglis et al. 2013). In the acute context, six out of eight studies identified in a systematic review looking at CHO feeding before and/or during soccer skills tests showed an enhancement in at least one aspect of performance (shooting, passing, dribbling) (Russell and Kingsley 2014). Additionally, acute CHO ingestion before and during 15-min blocks of high-intensity intermittent running and sprinting can aid in preserving muscle glycogen when compared to placebo ingestion (Nicholas et al. 1999).

Although there is evidence that supplying moderate-to-high amounts of dietary CHO can maintain glycogen levels, reduce fatigue, and enhance exercise performance, much of this evidence comes from studies of male athletes that used endurance exercise protocols (e.g., Achten et al. 2004; Stellingwerff et al. 2006). The lack of inclusion of female participants also extends to many other areas of sports nutrition research. For example, a 2014 systematic review of nutritional interventions for improving soccer skill performance found that none of the eight studies that examined the effects of CHO included women (Russell and Kingsley 2014). Currently, it appears as though many dietary recommendations for sport performance and recovery are primarily constructed based on research with male participants, then extrapolated to females without consideration for potential sex differences with respect to physiology, behaviors, and dietary needs (Costello et al. 2014).

In its most recent position statement on nutrition and athletic performance, the American College of Sports Medicine recommends a high-carbohydrate (HCHO) meal prior to exercise lasting more than 60 min (Thomas et al. 2016). In addition, it is stated that foods high in fat, fiber, and protein may need to be avoided to prevent gastrointestinal issues. Although it makes sense to avoid large quantities of fat, fiber, and protein within an hour of exercise due to their slowing effects on gastric emptying, an athlete who avoids these nutrients in a meal eaten 3–4 h before competition could, in theory, experience greater hunger at the onset of exercise. This suggestion is most strongly supported by evidence indicating that protein and fiber have greater satiety-inducing effects in comparison to carbohydrate and fat (Gerstein et al. 2004). The effects of dietary fat on satiety and hunger are more variable and dependent upon the nutrients which are consumed alongside it (Warrilow et al. 2019). One experimental study, for example, found that the satiety response to a high-fat meal was improved with the addition of fiber (Olli et al. 2015). Moreover, even when substantial quantities of protein, fat, and fiber are included in a feeding (~20–30 g each), the majority of such a meal empties from the stomach within 3 h (Benini et al. 1995). Thus, when a meal is eaten 3–4 h before exercise, the risk of gastrointestinal upset may be low regardless of the meal's macronutrient content, though this requires verification.

Beyond the potential drawback of inducing greater hunger, another theoretical issue with restricting pre-competition protein intake is suboptimal muscle protein synthesis. Consuming 20–40 g of protein every 3–4 h is now recognized as an important strategy for optimizing muscle protein synthesis in athletes throughout the day (Stokes et al. 2018). As such, avoiding protein in a pre-exercise meal (especially when it is eaten 3–4 h before exercise) could, over time, contribute to suboptimal skeletal muscle adaptations.

The theoretical disadvantages of restricting dietary fat in a pre-exercise meal are less clear than for protein, but it is possible that severely limiting dietary fat could contribute to less optimal blood glucose levels and substrate use at the onset of exercise, especially when a meal is eaten 3–4 h prior to exercise. When fat is consumed with carbohydrate, the postprandial rise and subsequent fall in blood glucose are decidedly delayed (Gentilcore et al. 2006), which could be beneficial with respect to blood glucose availability during exercise. Further, the addition of fat to a pre-exercise meal increases free fatty acid levels in the blood and can reduce reliance on endogenous CHO (Ormsbee et al. 2014).

Overall, there is a paucity of research on the effects of different pre-exercise feedings on performance, perceptions, and physiological responses in female athletes. Furthermore, the research to date, even in men, has largely neglected to recognize some of the theoretical disadvantages to restricting fat, fiber, and protein in meals eaten 3–4 h before the onset of exercise. Thus, the aim of this randomized crossover trial was to compare the effects of pre-exercise meals with different macronutrient contents on performance, perceptual changes, and physiological responses in female soccer players. It was hypothesized that, in comparison to a HCHO meal, a mixed-macronutrient (MM) meal (with moderate amounts of CHO, protein, fat, and fiber) eaten 4 h before competition would result in less hunger and more satiety while maintaining performance. Furthermore, a MM meal would result in no greater levels of gastrointestinal distress during competition in comparison to a HCHO meal that has lower amounts of fat, fiber, and protein.

Materials and methods

Research design

This study used a randomized, investigator-blinded, crossover design involving two meals (HCHO and MM) consumed 4 h prior to intra-squad soccer scrimmages. Specifically, the coaching staff divided players into two equally matched squads of ten players (9 field players plus 1 goalie). Prior to the first scrimmage, participants who volunteered for the study were randomly assigned to one of the two meals. Both soccer scrimmages occurred at roughly the same time of day (~3:30 p.m.). The following week, a second scrimmage took place, and participants received the opposite meal. Given the type of intervention (i.e., dietary), players remained unblinded to the treatments but the investigators collecting the data were blinded to treatment assignments until data collection was finished. Investigators packaged meals in sealed, opaque bags before randomization, while a third party not involved with data collection completed the randomization and labeling before distribution.

Participants

The sample was comprised of National Collegiate Athletic Association soccer players from a division I team who were greater than 18 years of age. Players who had an injury precluding them from participation in soccer practice did not contribute. The study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards, and players interested in volunteering went through an informed consent process and signed a consent document approved by Old Dominion University's Institutional Review Board. Once players were enrolled, they were given a background questionnaire on demographics and food allergies, at which time height and weight were collected. They were also familiarized to the subjective questionnaires that were to be used for data collection.

Twenty-one players consented to participate in the study. Two participants were goalkeepers, and given the differences in positional demands between goalkeepers and field players, they were dropped from the analyses. Four additional participants were not included in the analyses due to injuries preventing them from playing in the scrimmages. Thus, 15 participants remained for the analyses (19.6 ± 1.3 years; 165.9 ± 9.1 cm; 67.5 ± 12.9 kg). Any additional soccer players that were involved in the 10-on-10 scrimmages besides the 15 field players did not partake in the dietary intervention study.

Pre-scrimmage dietary procedures

Throughout the spring, this soccer team periodically used 70-min intra-squad scrimmages to mimic match play, and two of these scrimmages were utilized for this study. Participants were randomly assigned to consume one of the two meals (HCHO or MM) 4 h prior to one of these scrimmages, and the opposite meal was assigned for the second scrimmage. Due to logistical constraints of working with college players who had class and other obligations, the participants consumed the meals on an unsupervised individual basis instead of under direct supervision of the researchers. The participants were sent email and text reminders to consume the meals 4 h before the scrimmages.

For convenience and food safety purposes, the meals consisted of packaged foods that were ready-to-eat or that only required microwaving. The nutrient composition of the meals is presented in Table 1. Food substitutions were used for two participants with food allergies, but the macronutrient and energy intakes were the same for these two participants. The ~1000-kcal energy content of the meals was a byproduct of creating a meal for the HCHO condition that roughly followed the ACSM guidelines (i.e., to consume 3–4 g of CHO per kg of body mass) for a typical-sized female soccer player. Energy content was not based upon our participants' individual body masses because pre-packaged food items were utilized, making the logistics of individuating intakes impractical.

Several strategies were employed to minimize the impact of other nutritional choices on the study's outcomes. Participants were told to refrain from eating any energy-containing foods for 3 h prior to consuming their pre-scrimmage meal. Although this approach may have somewhat reduced the ecological validity of the study, we felt it was necessary to maintain control over extraneous nutritional choices. From the time of pre-scrimmage meal consumption up until the scrimmage was completed, participants were only permitted to drink water. Again, this may have impacted ecological validity, but the size of the pre-scrimmage meal (~1000 kcal) made it largely unnecessary for athletes to

Table 1 Nutrient composition of the two meals

High-carbohydrate meal	Mixed-macronutrient meal
30 g of Craisins (100 kcal, 25 g CHO, 2 g fiber, 0 g protein, 0 g fat)	60 g of Craisins (200 kcal, 50 g CHO, 4 g fiber, 0 g protein, 0 g fat)
12 oz of apple juice (210 kcal, 52 g CHO, 0 g fiber, 0 g protein, 0 g fat)	1 Muscle Milk (160 kcal, 7 g CHO, 4 g fiber, 25 g protein, 4.5 g fat)
1 Chocolate Chip Clif Bar (250 kcal, 45 g CHO, 4 g fiber, 9 g protein, 5 g fat)	1 packet of Nutella (80 kcal, 9 g CHO, 1 g fiber, 1 g protein, 5 g fat)
2 microwavable Kraft Mac and Cheese cups (440 kcal, 81 g CHO, 0 g fiber, 12 g protein, 7 g fat)	2 oz of roasted peanuts (320 kcal, 12 g CHO, 4.5 g fiber, 12 g protein, 28 g fat)
	1 Whey Protein Clif Bar (250 kcal, 25 g CHO, 3 g fiber, 14 g protein, 11 g fat)
1000 kcal, 203 g CHO, 6 g fiber, 21 g protein, 12 g fat	1010 kcal, 103 g CHO, 16.5 g fiber, 52 g protein, 48.5 g fat

consume energy in proximity (e.g., within 60 min) to the scrimmage. They also recorded their food intake on the morning of the first scrimmage using records, and these food records were returned to participants before the second scrimmage so that they could match their food choices to the previous pre-scrimmage period (other than the HCHO and MM meals). If participants did not finish the pre-scrimmage meal, they were asked to make a note in their personal food record stating what food was left over. The participants were given 16 oz of water to consume with the HCHO and MM meals to ensure they were adequately hydrated. In addition, food records were analyzed to examine whether there were differences between conditions in pre-meal nutritional intakes (i.e. intakes on mornings of the scrimmages).

Scrimmage protocol

Participants competed in 10-on-10 intra-squad scrimmages consisting of two, 35-min halves. Halftime was five minutes. Participants drank water as desired at half-time, but no energy-containing liquids or foods were permissible. This was not markedly different than normal, as this group of athletes does not consume meaningful amounts of exogenous CHO during these types of scrimmages. Given the scrimmages were conducted during the team's official practices, the precise protocol for each scrimmage was at the discretion of the coaching staff. The field size was reduced from 120 × 75 m to 102 × 67 m.

After completion of the first scrimmage, the same procedures were implemented during a second scrimmage that was held five days later. The difference was that the participants who initially received HCHO received MM, and vice versa for the participants who originally received MM. The protocols were chosen to limit any interruptions in the normal routine of the individual participants and team, resulting in higher ecological validity.

Outcome variables

Twelve players wore Titan 1+GPS units (Integrated Bionics; Houston, TX, USA) for the measurement of total distance covered (TDC), high-speed running (HSR; ≥ 14.4 km/h), and sprint count (number of bouts > 17.1 km/h, sustained for at least 1 s). The sample size for GPS variables was limited to 12 because of equipment availability. HR during scrimmages was collected via Firstbeat monitors (Firstbeat Technologies, Finland). Borg's rating of perceived exertion (RPE; Borg 1982) was collected at the end of each half, while rating of fatigue (ROF) on a 0–10 scale (Micklewright et al. 2017) was collected pre-scrimmage and at the end of each half.

Gastrointestinal symptoms (nausea, fullness, reflux, abdominal cramps, flatulence, and urges to have a bowel movement) were evaluated with a validated scale (0 = no discomfort, 5 = moderate discomfort, 10 = unbearable discomfort; Wilson 2017). These symptoms were collected within 10 min of scrimmage start and at the end of each half. For the analyses, ratings were summed into upper (nausea, fullness, reflux) and lower (cramps, flatulence, urges to have a bowel movement) categories, with possible scores ranging from 0 to 30.

Ratings of hunger, fullness, and satiety were assessed via visual analog scales (Flint et al. 2000) and were collected before the pre-scrimmage meals, within 10 min of the scrimmage start, and at the end of each half.

Statistical analysis

Normality of the data was evaluated via the Shapiro–Wilk test and visual inspection of histograms. Descriptive statistics are presented as means and standard deviations (SDs) for normally distributed data and medians with interquartile ranges (IQRs) for non-normal data.

The GPS data showed generally normal distributions, so within-subjects repeated measures ANOVAs were used to evaluate if there were any condition effects, time effects (half one vs. half two), or condition × time interactions. Similarly, data from the hunger, satiety, and fullness scales demonstrated normal distributions and were compared using within-subjects repeated measures ANOVAs with Bonferroni post-tests. Sphericity was evaluated with the Mauchly test, and Greenhouse–Geisser statistics were used when the assumption of sphericity was violated.

Due to the data being non-normally distributed, differences in HR between HCHO and MM were evaluated with Wilcoxon signed-rank tests, as were differences in RPE, ROF, and gastrointestinal ratings.

To test for period effects (i.e., differences in variables between the two scrimmages irrespective of treatment assignment), paired samples t-tests and Wilcoxon signed-rank tests were used. These evaluations were carried out for selected variables (GPS, HR, ROF, and RPE) that were most likely to be impacted by cumulative fatigue over the roughly 1-week period over which the scrimmages were held.

Analyses were carried out using SPSS software (version 26) from the IBM corporation (Armonk, NY), and the significance level was set at a two-sided $p < 0.05$.

Results

GPS data

TDC, HSR, and sprint count data are shown in Fig. 1. During the first half, TDC was 3.44 ± 0.30 km for HCHO while it was 3.43 ± 0.22 km for MM. During the second

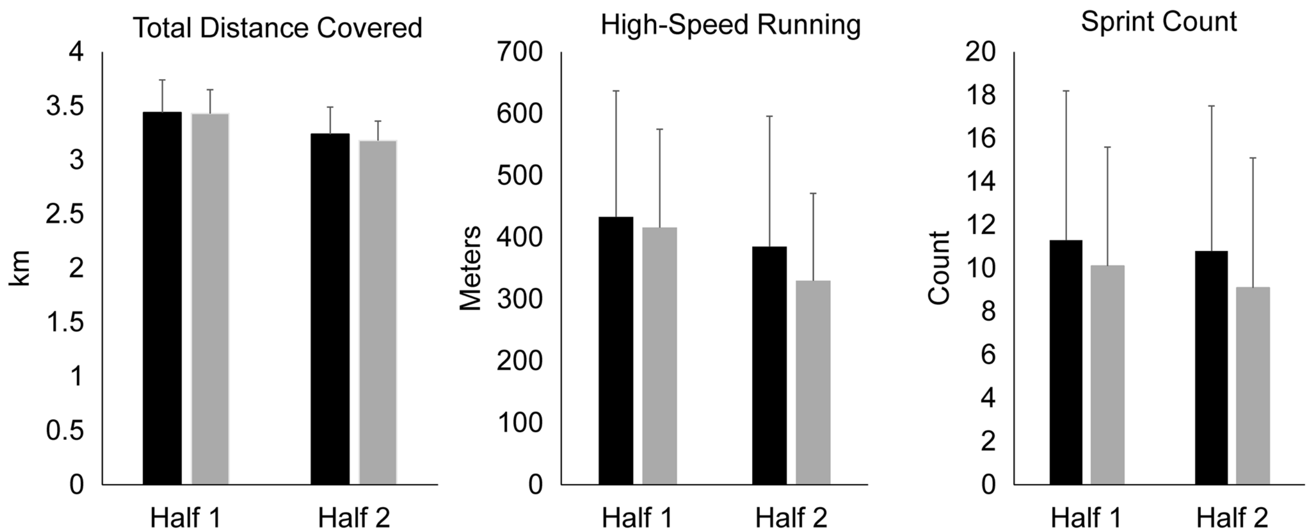

Fig. 1 GPS data by half and condition. Black bars represent the HCHO condition while grey bars represent the MM condition

half, TDC decreased and was 3.24 ± 0.25 km for HCHO and 3.18 ± 0.18 km for MM. The within-subjects ANOVA revealed a significant time effect ($F = 27.3$, $p < 0.001$) but no significant condition effect ($F = 0.18$; $p = 0.684$) or condition × time interaction ($F = 0.34$; $p = 0.571$).

Participants did 433 ± 204 m of HSR during the first half while on HCHO in comparison to 416 ± 159 m while on MM. The corresponding values for the second half decreased and were 385 ± 211 and 330 ± 141 m, respectively. The within-subjects ANOVA showed a significant time effect ($F = 6.93$, $p = 0.023$) but no significant condition effect ($F = 0.59$; $p = 0.459$) or condition × time interaction ($F = 1.47$; $p = 0.251$).

For sprint count, the first half averages were 11.3 ± 6.9 and 10.1 ± 5.5 for HCHO and MM, respectively. For the second half, the averages were 10.8 ± 6.7 and 9.1 ± 6.0 for the HCHO and MM conditions. There were no significant time ($F = 0.67$; $p = 0.431$), condition ($F = 0.92$; $p = 0.357$), or condition × time ($F = 0.10$; $p = 0.763$) effects.

Heart rate

Median HRs during the scrimmages were 180 (171–186) and 182 (173–189) bpm for HCHO and MM, respectively ($Z = -1.036$, $p = 0.30$). Time spent above 90% of max HR was 28 (14–47) and 41 (9–55) min for HCHO and MM, which was not significantly different ($Z = -0.284$, $p = 0.776$).

Ratings of fatigue and exertion

ROF and RPE ratings by timepoint and condition are presented in Table 2. There were not any statistically significant between-condition differences.

Gastrointestinal ratings

Upper and lower gastrointestinal symptoms at pre-scrimmage, half-time, and end-scrimmage are shown in Table 3. Most participants reported relatively low ratings, and none of the time points were associated with significant differences between conditions.

Table 2 Ratings of fatigue and perceived exertion at various time points

	High-carbohydrate	Mixed-macronutrient	*z*-Statistic	*p*-Value
Pre-scrimmage ROF (0–10)	3 (0–3)	2 (0–3)	−1.149	0.250
Halftime ROF (0–10)	5 (4–6)	5 (4–7)	− 0.000	1.000
End-scrimmage ROF (0–10)	6 (5–8)	7 (6–7)	− 0.224	0.823
Halftime RPE (6–20)	14 (13–15)	14 (13–15)	− 0.052	0.959
End scrimmage RPE (6–20)	15 (14–16)	15 (14–16)	− 0.209	0.834

Values are shown as median (IQR)

ROF rating of fatigue, *RPE* rating of perceived exertion

Table 3 Gastrointestinal ratings at various time points

	High-carbohydrate	Mixed-macronutrient	z-Statistic	p-Value
Pre-scrimmage upper (0–30)	3 (0–4)	2 (1–3)	− 0.874	0.382
Pre-scrimmage lower (0–30)	0 (0–0)	0 (0–0)	− 0.135	0.893
Halftime upper (0–30)	3 (1–3)	1 (0–2)	− 1.658	0.097
Halftime lower (0–30)	0 (0–0)	2 (0–4)	− 1.719	0.086
End-scrimmage upper (0–30)	1 (0–2)	0 (0–1)	− 1.853	0.064
End-scrimmage lower (0–30)	0 (0–3)	1 (0–3)	− 0.762	0.446

Values are shown as median (IQR)

Ratings of hunger, fullness, and satiety

Figure 2 displays data from the hunger, satiety, and fullness visual analog scales. The within-subjects ANOVAs revealed significant time effects for hunger ($F=7.69$; $p=0.003$), satiety ($F=3.49$; $p=0.037$), and fullness ($F=8.02$; $p=0.002$) but no significant condition or condition × time interactions (all $p>0.10$). For fullness, ratings were significantly lower pre-meal relative to pre-scrimmage ($p=0.032$). Also, fullness was rated higher pre-scrimmage relative to halftime ($p=0.002$) and end-scrimmage ($p=0.001$). When examining the pairwise comparisons for satiety, ratings were not significantly different when comparing individual time points (all $p>0.05$). For hunger, ratings were significantly lower pre-scrimmage relative to pre-meal ($p=0.001$). In addition, hunger was rated lower pre-scrimmage relative to end-scrimmage ($p=0.03$) and at half-time relative to end-scrimmage ($p=0.001$).

Pre-meal nutritional intake

There were no differences between conditions for pre-meal nutritional intakes (all $p>0.10$). Median (IRQ) intakes were as follows: energy, 267 (0–331) kcal for HCHO and 200 (0–410) kcal for MM; CHO, 31 (0–44) g for HCHO and 31 (0–44) g for MM; protein, 11 (0–17) g for HCHO and 11 (0–15) g for MM; fat, 6 (0–12) g for HCHO and 5 (0–12) g for MM; and fiber, 3 (0–6) g for HCHO and 3 (0–5) g for MM.

Period effects

Based on paired samples t-tests, TDC was not different between scrimmage one and scrimmage two for either half. However, HSR during the first half was lower for scrimmage one than scrimmage two (364 vs. 486 m, $p=0.004$). Likewise, HSR during the second half was lower for scrimmage one than scrimmage two (309 vs. 405 m, $p=0.048$). In addition, first-half sprint count was lower for scrimmage one than scrimmage two (9.2 vs. 12.2, $p=0.020$). HR data also supported the fact that players did less high-intensity work during scrimmage one, as median HR was lower (179 vs. 181 bpm, $Z=-2.10$, $p=0.035$). Lastly, pre-scrimmage ROF values were higher for scrimmage one than scrimmage two (median: 3 vs. 0, $Z=-2.14$, $p=0.032$). No period differences in ROF or RPE were found for half-time or end-scrimmage values.

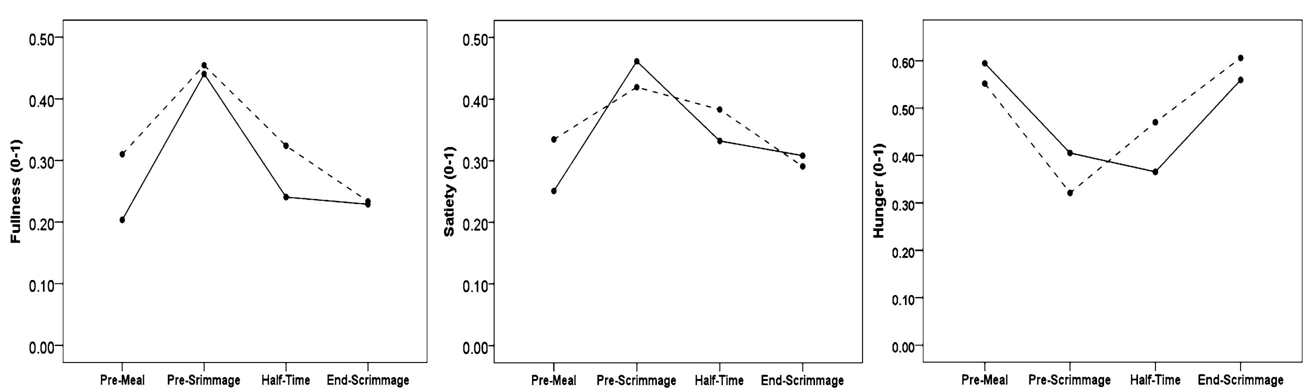

Fig. 2 Fullness, hunger, and satiety ratings over time and by condition. Solid lines represent the HCHO condition while dashed lines represent the MM condition

Discussion

In general, the present study provides evidence that pre-exercise MM and HCHO meals elicit similar physiological and perceptual responses when compared over 70-min soccer scrimmages in female collegiate athletes. When eaten 4 h before competition, a MM meal that is relatively high in fat, fiber, and protein can be consumed with limited gastrointestinal distress during subsequent high-intensity intermittent exercise. In addition, a modest amount of CHO supplied (1.5 g per kg of body mass) in a ~1000-kcal MM meal appears to be sufficient to maintain physical performance, at least for a match lasting 70 min.

It is commonly recommended to consume a pre-competition meal that is rich in CHO but relatively low in fat, fiber, and protein in order to provide CHO for sustained high-intensity work while minimizing gastrointestinal issues (Thomas et al. 2016). As such, this study evaluated whether these recommendations are truly justified when athletes eat several hours before competition. In addition, females were a focus of this investigation because much of the previous literature on pre-exercise fueling has used males. For this study, on-field performance was measured through GPS and related physiological (HR) and perceptual (RPE, ROF) responses, and there were two main hypotheses. First, in comparison to a HCHO meal, a MM meal eaten 4 h before competition would result in no greater level of gastrointestinal distress while maintaining performance. Second, in comparison to HCHO, MM would increase satiety and reduce hunger. The following sections address each of the dependent variables specifically and whether the hypotheses were supported.

GPS and heart rate

The players in this study covered roughly 6.6 km in 70 min, which equates to 0.94 km every 10 min, meaning the distance covered was similar, though slightly less, than real competition. Previous research has found that elite female players cover an average of 9.5–11 km over 90-min matches (Andersson et al. 2010; Vescovi and Favero 2014), equating to 1.05–1.2 km every 10 min. The reduced distance covered may be due, in part, to the simulated nature of the scrimmages and the reduced pitch size.

Regarding the meals' effects on GPS parameters, there were no significant condition or condition × time interactions. These results generally support the hypothesis that a meal with balanced amounts of CHO, protein, fat, and fiber eaten 4 h before competition can maintain performance to a similar level as a HCHO meal, though it must be acknowledged that a sample size of 12 may not have been sufficient for detecting small but meaningful differences. In addition, the scrimmages were 70 min and may not have been long enough to deplete glycogen stores. However, according to a recent meta-analysis from Areta and Hopkins (2018), individuals show substantial reductions in muscle glycogen (e.g., 50%) following 70 min of continuous exercise at 70% VO_2max, an intensity that is comparable to the average VO_2max across a soccer match. Further, athletes who have low-to-moderate levels of glycogen at baseline may be more likely to experience near-complete glycogen depletion after 70 min of exercise (Areta and Hopkins 2018). Another point to consider is that females have a reduced rate of glycogen usage as compared to men (Areta and Hopkins 2018). These points, among others, are difficult to decipher in the context of the present study given that invasive physiological measures were not available.

Mean HRs and time spent above 90% of max HR were relatively similar between the conditions. Thus, the combined GPS and HR results seemingly confirm that exercise intensity was analogous between conditions. When comparing our data to studies that have monitored HR during match-play in elite female players, the average HR is somewhat higher (Andersson et al. 2010; Stølen et al. 2005). The higher mean HRs observed are likely due to several factors, including that the halves were 10 min shorter than real matches and there were few, if any, stoppages of play. Mean HRs of 180+ bpm have been observed in other female team-sport athletes during competition (Rodriguez-Alonso et al. 2003; Sell and Ledesma 2016).

Ratings of fatigue and perceived exertion

Based on these subjective questionnaires, there were no significant differences in ROF and RPE between the conditions, though ratings did appear to increase over time during the scrimmages, as would be expected. The lack of between-condition differences parallels the objective HR and GPS data, providing additional support for the equivalence of HCHO and MM.

Of note, ROF was higher before the first scrimmage than the second scrimmage. The higher ROF before the first scrimmage suggests that the players were, on average, in a more heightened state of fatigue. This is also supported by the GPS data, which showed that players did less HSR during the first scrimmage. Unfortunately, this is the reality of conducting research with a competitive soccer team during their season when it is impossible to control all extraneous factors such as sleep, psychological stress, and training load.

Gastrointestinal symptoms

There were no statistically significant differences seen in upper or lower gastrointestinal symptoms between conditions. This is despite the fact that MM contained roughly 2.5 times the amount of fiber and protein and four times the amount of fat as HCHO. It is worth pointing out that gastrointestinal symptoms were relatively low in severity in this sample of athletes, which may be because the meals were eaten 4 h before the scrimmages. A high incidence of gastrointestinal symptoms has been observed during and after exercise and competition in other sports, though most of this research has been done in endurance athletes (Wilson 2019; Wright et al. 2009). The American College of Sports Medicine states that fat, protein, and fiber may need to be kept to a minimum in pre-exercise meals to avoid gastrointestinal symptoms (Thomas et al. 2016). Yet, this recommendation is largely based on theoretical grounds instead of direct data from athletes, and assuming an athlete eats several hours before competition, there should be enough time for most of the ingested food to empty from the stomach.

In total, our results suggest that recommendations to restrict fat, fiber, and protein in pre-competition meals are not necessary in all cases, especially when a meal is eaten 4 h before competition. In addition, a few studies have found that endurance exercise capacity is actually increased when high-fiber foods are included in a pre-exercise meal, perhaps because of their impact on glycemic responses and subsequent effects on substrate use (Kirwan et al. 1998; Thomas et al. 1991; Wu and Williams 2006). Still, more research is required to determine how these findings translate to different sports and athletes.

Hunger, fullness, and satiety

In comparison to HCHO, MM contained larger amounts of protein, fiber, and fat and was designed to increase satiety and fullness while reducing hunger. A modest increase in protein, when limiting other macronutrients, has been shown to enhance satiety in some situations (Blom et al. 2006; Lejeune et al. 2006). Mechanistically speaking, the hormone ghrelin, which induces hunger, is decreased after the ingestion of both protein and CHO (Wang et al. 2001). By adding protein to the pre-scrimmage MM meal, we hypothesized that greater satiety and less hunger would be observed. Increased fiber intake has also been linked to decreased hunger and increased satiety (Clark and Slavin 2013). When a food contains a substantial amount of fiber, especially viscous fiber, it forms a gel-like substance in the stomach that delays gastric emptying. Furthermore, due to fiber's low energy density, it provides greater bulk for a set amount of energy (Slavin and Green 2007).

Despite these theoretical advantages, we did not find lower hunger or enhanced satiety with MM. One potential reason for this is the type of protein that was prevalent in MM. Most of the protein was in the form of whey, which is faster-digesting than other sources such as casein and beef (Detzel et al. 2016; Gorissen and Witard 2018), though there is evidence that whey is more effective at promoting satiety than carbohydrate (Luhovyy et al. 2007). In addition, the foods were primarily pre-packaged, highly processed, and energy-dense, which could have resulted in different perceptual responses than if we had used foods such as beef, chicken, whole fruit, whole grains, etc. The timing of the meal could have also affected perceptions of satiety, fullness, and hunger, as some of the participants may have been accustomed to consuming a snack close to match time or grazing throughout the pre-competition period.

Limitations

In the current study, there are several notable limitations to consider. First, mainly owing to temporal real-time constraints, participants were not supervised during consumption of pre-scrimmage meals, and therefore the authors recognize the possibility that some participants may have neglected to completely finish their designated meals, even though all participants self-reported finishing their meals. Secondly, habitual energy intake is understood to be commonly under-reported among athletes (Magkos and Yannakoulia 2003). The veracity of the dietary food records which participants were asked to keep remains to be unknown. Thirdly, dietary intakes over the days leading to the scrimmages were not controlled, although, to some effect, this problem may have been mitigated by the crossover design of the experiment. Lastly, participants' physical activity, sleep, and stress levels were not measured or controlled for leading into the scrimmages. Regarding the training environment, it was controlled by the coaching staff, which brought a higher ecological validity to our study.

It is also essential to recognize the demographics of the participants are narrow in scope (members of a division I women's soccer team). It should be noted that the menstrual cycle was not accounted for, as it does not seem to influence performance of female soccer players at the group level (Julian et al. 2020). However, it is important to consider there could have been individual differences among the participants of this study. Finally, the authors conclude it important to appreciate that, given this study was conducted in the field, invasive physiological measurements—muscle biopsies, blood glucose, and substrate oxidation—were not possible. As a result, practitioners must be judicious when making specific conjectures about the effects of these types of meals on endogenous CHO stores and metabolism.

Conclusion

In summary, MM and HCHO meals appear to elicit similar effects on performance and perceptual responses during 70-min simulated soccer scrimmages. Therefore, this study provides evidence that, if given an adequate amount of time before a match for digestion to occur, female soccer players can eat a MM meal and sustain performance with a low incidence of gastrointestinal distress. Additional studies with larger samples sizes and longer match durations would help to confirm these initial findings.

Author contributions JW and PW conceived and designed the study. JW, AE, and PW collected the data. JW and PW analyzed and interpreted the data. JW, AE, and PW wrote and/or revised the manuscript. All authors have read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethics approval This study was performed in line with the principles of the Declaration of Helsinki. The protocol for this study was reviewed and approved by the Old Dominion University Institutional Review Board.

Consent to participate Informed consent was obtained from all individual participants included in the study.

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