# Low FODMAP: A Preliminary Strategy to Reduce Gastrointestinal Distress in Athletes

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**ABSTRACT**

LIS, D. M., T. STELLINGWERFF, C. M. KITIC, J. W. FELL, and K. D. K. AHUJA. Low FODMAP: A Preliminary Strategy to Reduce Gastrointestinal Distress in Athletes. *Med. Sci. Sports Exerc.*, Vol. 50, No. 1, pp. 116–123, 2018. **Introduction**: Gastrointestinal (GI) distress in endurance athletes is prevalent and detrimental to performance. Adverse GI symptomatology can be analogous with irritable bowel syndrome, where fermentable oligosaccharide, disaccharide, monosaccharide, and polyols (FODMAP) reduction has demonstrated efficacy. This study investigated the effects of low FODMAP (LFOD) diet on GI distress parameters in runners with a history of nonclinical exercise-associated GI symptoms. **Methods**: Eleven recreationally competitive runners (five men, six women; 5-km personal best 23:00 ± 4:02 min:s) participated in the study. Runners were allocated to a randomized 6-d LFOD or high FODMAP (HFOD) diet separated by a 1-d wash-out in a controlled, single-blinded cross-over study. In each period participants completed two strenuous running sessions consisting of 5 × 1000 m and a 7-km threshold run. GI symptoms (during-exercise and daily) and the Daily Analysis of Life Demand for Athletes questionnaires were completed. Area under the curve was calculated for daily GI symptoms across each dietary period and analysis was conducted using multilevel mixed-effects linear regression for comparison between the two diets. **Results**: A significantly smaller area under the curve for daily GI symptoms 6 d during the LFOD compared with HFOD (mean difference, −13.4; 95% confidence interval, −22 to −4.60; $P = 0.003$) was observed. The daily GI symptoms that were significantly lower during LFOD were flatulence ($P < 0.001$), urge to defecate ($P = 0.04$), loose stool ($P = 0.03$), and diarrhea ($P = 0.004$). No significant differences in during exercise symptoms or Daily Analysis of Life Demand for Athletes responses were observed between diets ($P > 0.05$). **Conclusions**: Preliminary findings suggest that short-term FODMAP reduction may be a beneficial intervention to minimize daily GI symptoms in runners with exercise-related GI distress. **Key Words:** GASTROINTESTINAL DISTRESS, EXERCISE, DIET, SHORT-CHAIN CARBOHYDRATES, ATHLETE, RUNNER'S TROTS

Optimal athletic performance can be directly compromised by gastrointestinal (GI) dysfunction (1). High rates of GI distress are reported to occur in 30% to 50% of endurance athletes (2,3). Although most symptoms occurring are mild to moderate, severe symptoms may impair training capacity and performance (2). During strenuous exercise GI symptoms are triggered in part by significant splanchnic hypoperfusion, as blood is shunted away from the GI tract toward the working muscles, which instigates acute enterocyte injury, increased intestinal permeability and altered motility (4). Symptoms associated with exercise-induced GI distress are numerous, but many are analogous with clinical indications associated with irritable bowel syndrome (IBS) (4,5). In particular, lower abdominal symptoms, such as diarrhea, bloating, abdominal pain, and flatulence, share remarkable similarities in both conditions. Interestingly, fermentable oligosaccharides, disaccharides, monosaccharides, and polyols (FODMAP) restriction has been emerging as an efficacious treatment for IBS symptoms (5–8). Therefore, it is plausible that FODMAP manipulation may also positively affect exercise-associated GI symptoms (9,10).

Nutritionists and athletes employ various dietary strategies to reduce exercise-associated GI distress, including limiting dietary fiber and lactose, eating low-residue foods around competition, training the gut to tolerate larger carbohydrate loads or removing gluten (11,12). A gluten-free diet has become a popular regimen to supposedly alleviate exercise-associated in nonceliac athletes (13) and IBS-related GI symptoms (14) although negligible peer-reviewed evidence exists supporting these anecdotal claims (13). Conversely, data in nonathlete clinical populations propose that GI symptom improvement associated with gluten elimination may actually be modulated by the subsequent reduction in FODMAP content that generally accompanies a gluten-free diet, and not necessarily gluten elimination itself (3,15). A low FODMAP (LFOD) diet is predicted to be the next popular equivalent to the gluten-free diet (16).

FODMAP are poorly absorbed short chain carbohydrates that have been shown to increase osmotic load in the small

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intestine and colonic gas volume, which instigates adverse symptoms in hypersensitive individuals (10). Examples of foods restricted with a LFOD diet include lactose-containing products, such as cow's milk, a range of fruit high in fructose, wheat-based products, onions and garlic encompassing fructans and galactooligosaccharides, and fruits with stones (pits) or confectionary with naturally occurring or added polyols. In Western diets, up to 40 g of undigested carbohydrates reach the colon daily (17) including an average of 1 to 10 $g \cdot d^{-1}$ of inulin and oligofructans (18). In sensitive individuals, FODMAP can cause adverse GI symptoms. FODMAP are also important dietary constituents offering favorable prebiotic effects, such as acting as a substrate for beneficial microbial populations, increasing stool bulk, enhancing micronutrient absorption, and immune function (19), so unnecessary restriction is not advocated. To date, studies suggest that healthy individuals without IBS would not benefit from restricting FODMAP intake (9,20) and a prolonged strict LFOD diet does not appear to be a common practice among athletes (21). However, in athletes looking to reduce GI symptoms, self-reported data indicate that over half eliminate high FODMAP (HFOD) foods, without necessarily realizing that these foods were considered part of the FODMAP family (21). Eighty-six percent of these athletes report subsequent symptom improvement (21). Therefore, it is plausible that the physiological mechanisms and symptoms associated with exercise-associated GI injury increase sensitivity to all, or some FODMAP and it is relevant to consider if symptoms could be reduced with FODMAP restriction in endurance athletes.

We have recently published a case study showing positive outcomes of a LFOD dietary intervention in a multisport athlete (22). Based on these results, and encouraging clinical research on LFOD diets (10), it is imperative that the manipulation of short-chain carbohydrate be investigated as a novel tool for individualized dietary management aimed at attenuating GI distress in a group of healthy athletes. Hence, the purpose of this preliminary study was to examine the effect of a LFOD versus a HFOD diet on symptoms of self-reported GI distress and perceived well-being in clinically healthy recreationally competitive runners with a history of GI symptoms. Our *a priori* hypothesis was that a short-term LFOD diet would reduce the severity of GI symptoms appearing daily and during strenuous running sessions.

## METHODS

**Participants.** Eleven recreational competitive runners (>25 km running per week) age 18 to 50 yr with self-reported persistent exercise-associated GI symptoms were invited to participate in this study. Inclusion criteria included: a minimum of three chronic exercise-associated GI symptoms (e.g., nausea, bloating, diarrhea) with score greater than 4 (quite often) on the background GI questionnaire (23), a habitual HFOD intake of ≥20 g FODMAP per day (24) as assessed with the Complete Nutrition Assessment Questionnaire (http://www.cnaq.com.au/) (25) and the capacity to complete two consecutive days of prescribed strenuous running training during the study. Exclusion criteria included a history of food intolerance (e.g., diagnosed lactose intolerance), known celiac disease or known familial history of celiac disease, clinically diagnosed nonceliac gluten sensitivity or IBS, current adherence to any special diet, or any preexisting medical condition that could be affected by dietary intervention. The dietary intervention periods were purposefully scheduled to avoid the potential influence of hormone changes over the menstrual cycle for the female runners. Ethics approval was obtained from the Tasmanian Health and Medical Human Research Ethics Committee (H0015151). All participants provided signed informed consent.

**Experimental design.** Using a single-blind, crossover design, participants were randomized to receive either a HFOD or a LFOD diet for 6 d, separated by a 1-d washout, followed by the alternative diet (Fig. 1). Randomization was generated using GraphPad QuickCals software. Participants were informed that they would be assigned "Specific Carbohydrate Diet A or B" for the first dietary period then the alternate diet for the subsequent dietary period, with no specific reference to FODMAP or gluten. Participants self-selected their training schedule based on study guidelines (see details below). All trainings were replicated during the subsequent dietary period. Participants were asked to record their daily exercise, food intake, and complete a postexercise GI questionnaire, daily GI questionnaire and Daily Analysis of Life Demands (DALDA) questionnaire each day throughout the two dietary periods.

**Food preparation and provision.** Participants were provided with premade frozen lunch and dinner meals (prepared, weighed, and frozen in a commercial kitchen; Matson's Catering, Launceston, Australia), breakfast (cereals, breads, milk, yoghurt), and snack foods (muesli bars, crackers). Because the study participants were blinded, all food was packaged in the same opaque containers and labeled according to each dietary period (e.g., week 1, muesli bars; day 2, lunch). Alongside the controlled study food provisions, the participants were able to self-select from a suggested list (of *choose* and *avoid*) and supplement the study food with fresh fruits, vegetables, and nuts with the stipulation that a counterpart substitution be exchanged in the second dietary period. A registered dietitian (lead researcher) provided dietary education to the participants on nutrition intake recording and appropriate food selections. The LFOD and HFOD meals were established based on previous research (20), Monash University's LFOD diet resources (http://www.med.monash.edu/cecs/gastro/fodmap/) and typical athlete diets (26). Recipes for LFOD and HFOD were similar, but ingredients were modified to alter the FODMAP content (Table 1). Meals were matched for content of total energy, protein, carbohydrate, fat, and fiber; however, resistant starch information was not available due to the absence of comprehensive resistant starch food composition tables. Each meal was analyzed for FODMAP

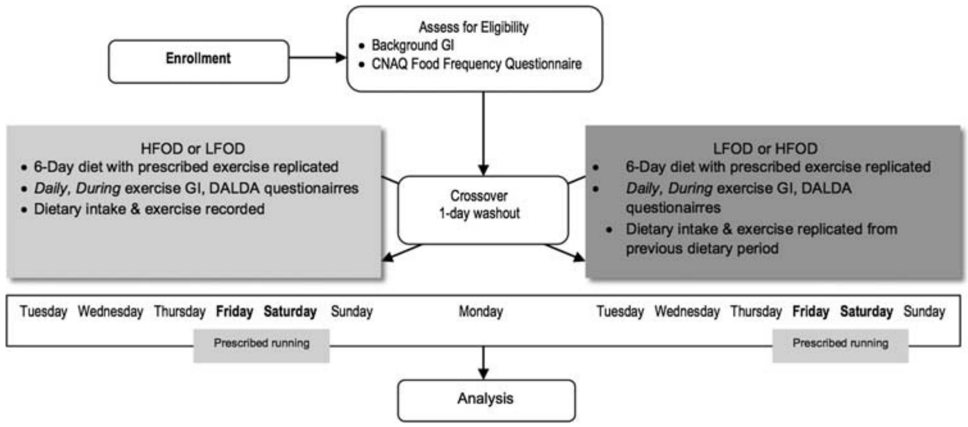


**FIGURE 1—Schematic showing participant selection and study design.**

content using a FODMAP-specific database (Monash University, FoodWorks Professional 7, Xyris, Brisbane, Australia) to ensure that LFOD meals contained less <0.5 g FODMAP per meal (27). An example of the study meals for each diet is provided in Table 1. The prototype study menu presented a macronutrient profile containing 5 to 7 $g \cdot kg^{-1}$ carbohydrate, 1.2 to 1.7 $g \cdot kg^{-1}$ protein, and 0.8 to 1.2 $g \cdot kg^{-1}$ fat (26) (FoodWorks Professional 7).

**Exercise and prescribed running.** Participants self-selected their training schedule based on study guidelines which indicated: days 1 and 2 to be light- to moderate-intensity training, day 3 to be rest or very light nonrunning exercise (e.g., yoga, swimming). Days 4 and 5 were prescribed very intense running sessions, and day 6 was entirely self-selected exercise or rest. Day 4 (interval session) consisted of a 10-min self-prescribed warm-up with increasing intensity, 5 × 1000 m interval pace (100% of predicted $v\dot{V}O_{2max}$) with 3-min brisk walk or light jog between intervals followed by a 10-min self-selected cooldown. Day 5 (threshold session) consisted of a 7- to 10-min self-selected warm-up with increasing intensity, 7 km at threshold pace (~90% of predicted $v\dot{V}O_{2max}$) followed by a 10-min self-selected cooldown. Prescribed running sessions were individually monitored using participants' personal Garmin GPS running watches (Forerunner® 735XT, 630XT, 235, or 910XT), and all trainings were replicated in the second intervention period. Interval and threshold paces were individually prescribed based on calculations from a recent race performance using VDOT (velocity at $vV0_{2max}$) tables (28). Running sessions were completed on flat terrain, at the same time of day (±30 min) over the period of data collection (December 2015 to February 2016).

TABLE 1. Example of high and low FODMAP diets.

| Meal | LFOD Diet | HFOD Diet |
|---|---|---|
| Breakfast | LFOD muesli[a] | Muesli with dried fruit and nuts |
| | Lactose-free milk | Milk |
| | Blueberries | Apple |
| | Coffee/tea with lactose-free milk | Coffee/tea with milk |
| Snack | Corn Cruskits | Rye Cruskits |
| | Lactose-free yogurt | Yogurt |
| | Grapes | Nectarine |
| Lunch | Maple glazed salmon on quinoa/rice pesto pasta[b] | Honey-glazed salmon on durum wheat pesto pasta[c] |
| Snack | Gluten-free biscuits | Wheat biscuits |
| | Cheddar cheese | Cheddar cheese |
| | Tomato, cucumber | Snap peas, cucumber |
| Dinner | Grilled chicken and vegetables on quinoa[d] | Grilled chicken and vegetables on couscous[e] |
| Snack | Lactose-free yogurt | Yogurt |
| | Strawberries | Cantaloupe |
| | Coffee/tea with lactose-free milk | Coffee/tea with milk |

[a]LFOD muesli made with rice crispies, corn flakes, quinoa flakes, shredded coconut, and pumpkin seeds.
[b]LFOD pesto pasta made with: cherry tomatoes, eggplant, garlic infused oil, pine nuts, basil, parsley.
[c]HFOD pesto pasta made with: cauliflower, asparagus, pistachios nuts, basil, parsley, garlic.
[d]LFOD vegetables included: small portion sweet potato, red bell pepper, spinach.
[e]HFOD vegetables included: larger portion of sweet potato, beetroot, garlic, red onion.

**GI symptom monitoring.** During-exercise GI questionnaires and daily GI questionnaires were used to assess the occurrence and severity of upper and lower abdominal symptoms determined using a 10-point scale ranging from 0 "no problem at all" to 9 "the worst it has ever been" (23). Section 1 of the questionnaire addresses upper abdominal symptoms: reflux, heartburn, burping, bloating, stomach pain/cramps, vomiting, and nausea. Section 2 addresses lower abdominal symptoms: flatulence, urge to defecate, left abdominal pain (side stitch), right abdominal pain (side stitch), loose stool, diarrhea, and intestinal bleeding (23). Diarrhea criterion was defined as an increase in the number of bowel movements per day compared with the participants usual bowel habit. Participants completed the during-exercise GI questionnaire immediately after their training session and the daily GI questionnaire at the end of each day at the same time. The GI symptom scores were tabulated for each day and exercise session (23). Mean scores for daily GI symptoms, during-exercise GI symptoms, and incremental area under the curve (AUC) for daily GI symptoms across all 6 d of each dietary period were compared between the diets.

**Perceptual well-being monitoring.** Participants completed the DALDA questionnaire at the end of each day. This questionnaire is used to assess general stress levels (part A)

TABLE 2. Composition of dietary intake during the HFOD and LFOD dietary periods.

| Dietary Component | HFOD | LFOD | P |
|---|---|---|---|
| Total energy (kcal) | 3181 ± 403 | 3198 ± 429 | 0.724 |
| Total carbohydrate (g) | 323 ± 63 | 327 ± 67 | 0.569 |
| Total protein (g) | 158 ± 16 | 153 ± 20 | 0.030* |
| Fat (g) | 130 ± 12 | 137 ± 15 | 0.003* |
| Fiber (g) | 32 ± 5 | 30 ± 5 | 0.318 |
| **Total FODMAP** (g) | 41.4 ± 7.9 | 8.1 ± 3.5 | <0.0001* |
| **Excess fructose** (g) | 1.9 ± 0.54 | 0.5 ± 0.4 | <0.0001* |
| **Lactose** (g) | 28.0 ± 8.6 | 0.9 ± 0.3 | <0.0001* |
| **Total oligosaccharides** (g) | 8.7 ± 1.9 | 5.5 ± 3.2 | 0.001* |
| Fructooligosaccarides (g) | 7.3 ± 1.8 | 4.5 ± 2.7 | <0.001* |
| Galactooligosaccarides (g) | 1.4 ± 0.3 | 1.0 ± 0.5 | 0.006* |
| **Total Polyols** (g) | 2.9 ± 0.9 | 1.3 ± 0.7 | <0.0001* |
| Sorbitol (g) | 1.8 ± 0.9 | 0.9 ± 0.4 | 0.001* |
| Mannitol (g) | 1.1 ± 0.3 | 0.4 ± 0.5 | <0.0001* |

*Significance between HFOD and LFOD ($P < 0.05$).
Energy, macronutrients and fiber were calculated using FoodWorks dietary software, which is based on the Australian Food Composition tables. Total FODMAP = excess fructose + lactose + sorbitol + mannitol + fructans + galactooligosaccharides. Bold text indicates additive constituents for total FODMAP. Data are presented as group ($n$ = 11) mean ±SD for HFOD and LFOD.

and to determine stress-reaction symptoms (part B) using a rating scheme of "worse than normal," "normal," or "better than normal" for variables. Scores were tabulated and the "worse than normal" and "better than normal" scores compared between the two dietary periods.

**Statistical analysis.** All GI symptoms and DALDA scores and dietary variables were treated as continuous data (29) and compared between the two diets using multilevel mixed-effects repeated measure linear regression adjusted for order and period effects (Stata 13.0, StataCorp LP, College Station, TX). Regression residuals were tested for assumptions of linear regression (heteroscedasticity, skewness, kurtosis or linearity). Where regression residuals did not meet the assumptions of linear regression the analyses were repeated with multilevel mixed-effects ordered logistic regression. For consistency, all comparison results are presented as mean difference (95% confidence interval [CI]). For each dietary intake variable, the mean ± SD was calculated and compared between the diets using mixed-effects ordered logistic regression. $P$ values ($P < 0.05$) are from the relevant analyses (linear regression or ordered logistics regression in case of violation of linear regression assumptions). Incremental AUC, above zero, for daily GI symptoms was calculated from total daily GI symptom scores over each 6-d diet (GraphPad Prism, version 6.0, San Diego, CA) and compared between the two diets.

## RESULTS

**Participants details and compliance.** Dietary intake (Table 2), GI symptom assessment (Fig. 2), and DALDA results were available for 11 of 12 participants (five men, six women; 41 ± 10 yr; weight, 69.0 ± 12.0 kg; height, 171.1 ± 10.0 cm; 5 km personal best 23:00 ± 04:02 min:s). One participant was removed due to incomplete data. Background GI symptoms, primarily boating, flatulence, urge to defecate, and loose stool were predominant and were reported to occur *quite often* to *always* (score of ≥4 to 9). Total HFOD daily FODMAP intake was 43.8 ± 16.9 g FODMAP per day. The prescribed running sessions were completed as assigned, and exercise volume matched in each period (HFOD total exercise volume 50:12:43 h:min:s, 0:56:51 ± 0:25:33 daily mean ± SD; LFOD 50:36:42, 0:57:18 ± 0:23:55) with no significant differences in temperature (16.2°C ± 5.2°C vs 15.7°C ± 4.9°C) or humidity (64.0% ± 14.9% vs 55.3% ± 19.6%) for the LFOD or HFOD dietary periods, respectively.

All participants consumed the prescribed diets, and dietary intake was analyzed from food intake records for HFOD and LFOD. The composition of the diets is shown in Table 2. The two test diets were similarly matched for total energy, carbohydrate, and fiber. Protein and fat were statistically different between the diets ($P$ = 0.03 and $P$ = 0.003, respectively). These differences are of negligible clinical significance given the 5-g protein and 7-g fat daily variances. As designed, FODMAP intake differed significantly between the two diets being 41.4 ± 7.9 g·d$^{-1}$ HFOD and 8.1 ± 3.5 g·d$^{-1}$ LFOD ($P$ < 0.0001).

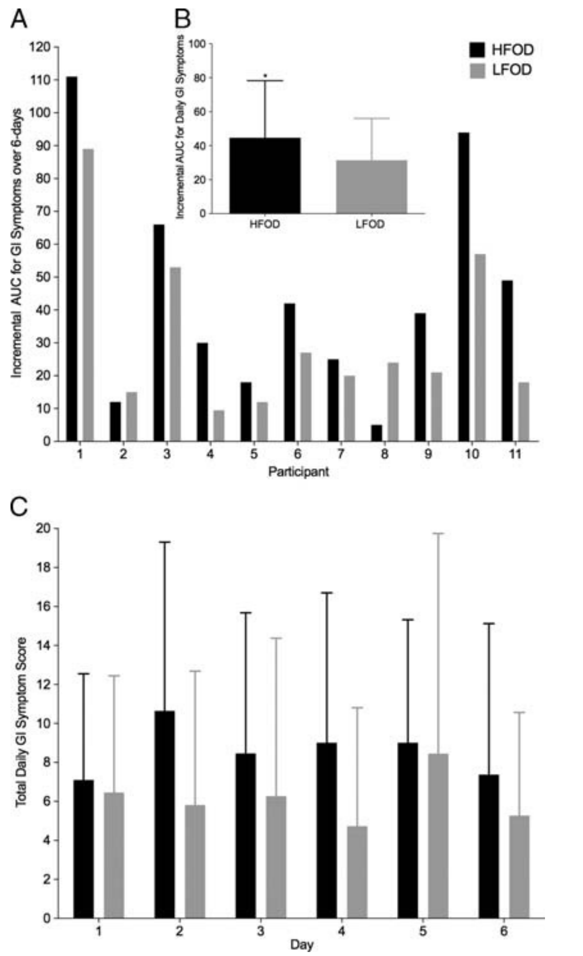


**FIGURE 2—(A) Individual AUC for daily GI symptom scores over 6 d for LFOD vs HFOD ($n$ = 11). (B) Mean group AUC during LFOD compared with HFOD for daily GI symptom scores. (C) Mean total daily GI symptom scores for each day (days 1–6) of the dietary period for all participants (error bars represent SD) on LFOD and HFOD ($P$ = 0.006). *Significance ($P$ = 0.003).**

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**GI symptoms: daily and during exercise.** Daily GI symptoms scores were collected each day of the study and tabulated. Individual AUC responses show that 82.0% (9 of 11) of participants had a smaller AUC for daily GI symptom scores for 6 d during the LFOD compared with HFOD (mean difference, −13.4; 95% CI, −22 to −4.60; $P = 0.003$; Fig. 2A). The group AUC (Fig. 2B) was lower in LFOD (mean ± SD, 31.4 ± 24.6) compared with HFOD (44.6 ± 33.6). Specific daily GI symptoms that were reduced during LFOD included flatulence (mean difference, −1.12; 95% CI, −1.55 to −0.75; $P < 0.001$), urge to defecate (mean difference, −0.41; 95% CI, −0.81 to −0.02; $P = 0.04$), loose stool (mean difference, −0.38; 95% CI, −0.73 to −0.04; $P = 0.03$), and diarrhea (mean difference, −0.45; 95% CI, −0.75 to −0.14; $P = 0.004$). The mean GI symptoms scores for day 1 to day 6 were higher during HFOD compared with LFOD (mean difference, −2.45; 95% CI, −4.21 to −0.69; $P = 0.006$; Fig. 2C). No order or period effects were observed for total daily GI symptoms, during-exercise GI symptoms on any of analyzed variables except for loose stool (mean difference, −0.35; 95% CI, −0.79 to −0.01; $P = 0.03$).

During-exercise GI symptoms scores for the HFOD and LFOD dietary periods for days 4 and 5, when prescribed strenuous running sessions, were compared. Half of the participants rated GI symptoms during the prescribed running sessions to be moderate to severe (≥3). Burping was the one symptom that was significantly higher (mean difference, 0.30; 95% CI, 0.01–0.58; $P = 0.04$) during LFOD compared with HFOD. No significant differences in any other GI symptoms were found during the prescribed running sessions between HFOD and LFOD.

**Perceptual well-being.** Overall well-being was measured using DALDA and the worse and better than normal scores were compared for each dietary period, as well as the scores on the prescribed training days (days 4 and 5). Total worse than normal scores for stress (part A) and stress response (part B) combined were not different (mean difference, −0.45; 95% CI, −1.30 to 0.40; $P = 0.30$) during HFOD (3.71 ± 3.18) compared with LFOD (3.30 ± 3.31). Similarly, total better than normal scores for the HFOD (2.59 ± 2.80) and LFOD (2.97 ± 3.66) were not significantly different across each dietary period (mean difference, 0.43; 95% CI, −0.52 to 1.37], $P = 0.38$). Total worse than normal scores on day 4 or day 5 were not different (mean difference, −0.82; 95% CI, −2.26 to 0.63; $P = 0.30$; mean difference, −0.91; 95% CI, −2.35 to 0.53; $P = 0.25$, respectively). Total better than normal scores on day 4 or day 5 were not different (mean difference, 0.5; 95% CI, −1.11 to 2.11; $P = 0.55$; mean difference, 1.23; 95% CI, −0.39 to 2.84; $P = 0.10$, respectively). No order or period effects were observed for DALDA scores.

## DISCUSSION

Dietary intake, and its interactions with strenuous exercise, is of particular importance to athletes because resulting GI distress is a common problem potentially impairing training capacity and performance (12). This is the first study to examine the effects of a short-term LFOD diet on GI symptoms and perceptual well-being in athletes with a history of exercise-associated GI distress. The aim of this preliminary study was to investigate if self-reported and case-study outcomes, demonstrating beneficial effects of FODMAP reduction on exercise-associated GI symptoms (21,22), could be substantiated in a larger cohort. Results from this preliminary study indicate that a LFOD diet had a positive effect on daily GI symptoms in 82% of the participants.

**Effect of LFOD on daily GI symptoms.** In participants with persistent exercise-associated GI symptoms, 9 of the 11 reported a reduction in daily GI symptoms on a short-term LFOD diet (Fig. 2). To date, LFOD diet research has predominantly focused on clinical populations, specifically individuals with IBS. Discernible symptomatic improvements in approximately 70% of IBS patients encourage the use of this diet as first line treatment (10). A limited number of investigations have included healthy controls (9,20,30), and results suggest that although healthy individuals demonstrate functional changes with FODMAP ingestion, GI symptoms remain very minor or nonexistent (20,30). Low-level GI symptoms likely have a negligible impact on athletic performance, but more moderate to severe symptoms may be detrimental (1). Although healthy populations, including healthy athletes, would be assumed to not benefit from FODMAP reduction with reduced GI symptoms, it is interesting to consider if the unique physiological, mechanical, and nutritional stress encountered by endurance athletes could increase susceptibility to any dietary triggers, such as FODMAP, for some of these athletes. GI symptoms are largely variable but our preliminary data suggest that a short-term LFOD diet may be efficacious in the management of daily GI symptoms (Fig. 2), particularly lower abdominal GI symptoms, in healthy athletes. Although changes in GI symptoms during exercise were not found, the ability to reduce daily GI symptoms would be very advantageous in extended events like the Tour de France, rigorous training camps, or multievent athletics, which feature sequential days of intensive and extensive exercise.

**Effect of LFOD on exercise-specific GI symptoms.** The GI symptoms during prescribed running sessions were similar for the HFOD and LFOD dietary periods. In race conditions, 4% to 32% of athletes report GI distress, and some symptoms are so severe that there is withdrawal from competition results (23). Numerous factors exacerbate GI symptoms during exercise including dietary intake/timing, mechanical impact, and physiological stress. Significantly greater GI issues are reported during prolonged events (e.g., Ironman), as compared with relatively shorter events, such as the marathon (23). Ingestion of carbohydrates as consumed in endurance sport, particularly solutions with a high osmolality, is associated with the development of GI symptoms during exercise (31). Exercise duration in the current study did not warrant carbohydrate ingestion; however, it is interesting to consider if ingestion of short-chain carbohydrates during exercise or preexisting FODMAP in the GI tract would have additive osmotic actions

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and consequent symptoms (2). It is possible that the chosen exercise duration (45–60 $min \cdot d^{-1}$), coupled with no CHO ingestion during exercise, curtailed any measurable difference in during-exercise GI symptoms between the diets. Timing of FODMAP intake may also influencing symptoms. In the present study, runners replicated their usual dietary patterns (e.g., timing) before exercise, which was fundamental in this research design to avoid altering habitual food intake timing and adding a confounding variable to the primary measure. Although this study did not investigate mechanistic hypotheses, it may also be conceivable that GI symptoms during exercise could be exacerbated with the presence of short-chain carbohydrates in the gut or during exercise FODMAP ingestion. In overall GI symptom reduction, our preliminary findings support further research of the hypothesis that FODMAP reduction would positively affect the severity or occurrence of exercise-associated GI symptoms.

**Effects of altering FODMAP on perceptual well-being.** Extreme and persistently high chronic training loads are associated with greater psychosomatic stress. Psychological well-being, personality traits and psychosocial factors, such as stress, also have the potential to influence perceptions of GI symptom presence and severity (32). The reverse may also occur, in that GI symptoms caused by exercise may be reflected by reductions in overall perceptual well-being. In the current study, DALDA evaluation was conducted alongside each dietary intervention with the aim to capture the relationship between perceptual well-being and GI symptoms influenced by diet and exercise stress. In athletes, the multifactorial nature of GI distress is well known, and the influence of psychological well-being or stress on alterations of the autonomic nervous system has been recognized (33,34). These changes in homeostatic balance have been characterized by slowing of gastric emptying, increased distal colonic motility, and acceleration of intestinal transit, further contributing to adverse GI symptoms (35). In the present study, it is possible that DALDA was not a sensitive enough tool to detect any FODMAP-related changes. A more chronic fatigue state over several days or weeks or longer is likely required to capture changes in DALDA responses (36).

**Reflections for future studies.** Dietary control was achieved, however, three reasons are suggested as to why no difference in GI symptoms were observed during the prescribed strenuous running sessions. First, daily GI symptoms on the LFOD diet were lower compared with HFOD. Lower preexercise symptomology during the LFOD may have skewed perceptions of the during-exercise GI symptoms toward being more exaggerated (greater net difference), resulting in reporting of higher during exercise symptom scores for LFOD. Second, although residual FODMAP are suggested to transit through the GI tract in less than 3 d (11), a longer period of LFOD may be necessary to augment further symptom reduction. Changes in the gut microbiome occur over time as the biomass evolves, and it is possible that the full benefits of the diet are not realized until 7 d (24) or a few weeks (10). Most importantly, exercise duration and climatic factors have been correlated with GI distress (23). Longer running sessions may be required to distinguish differences in GI symptoms between the diets. Although, the outdoor running climate throughout the current study was moderate with nominal variance between intervention periods, differences in climate and hydration status should be considered as influencers of GI symptoms. A greater effect may be observed under more extreme exercise conditions, and future research should consider this element in the methodology.

**FODMAP manipulation considerations for the practitioner.** Our developing work proposes that FODMAP manipulation may be an innovative addition to the sport nutrition practitioners' toolbox for management of exercise-associated GI distress. Certain considerations must be taken into account when trialing short-chain carbohydrate restriction with athletes because dietary requirements are individual and unnecessary food restriction may compromise optimal fueling (37). When appropriately planned, under the guidance of a dietetic professional, a LFOD diet can be matched for energy, macronutrients, and fiber (Table 2). Although differences in protein and fat intake were statistically significant between LFOD and HFOD, 7 and 5 g, respectively, these findings are not clinically significant. As a source of high-quality protein, cow-based dairy is often consumed by athletes at or above the general population recommendation of two to four servings per day. Coinciding high lactose intakes are likely (Table 2) and should be investigated as a primary trigger for GI symptoms with appropriate high-protein substitutes made, such as lactose-free milk if required. A LFOD diet should be considered once typical GI symptom triggers have first been assessed, such as lactose (11,12).

Intakes of prebiotic fructooligosaccharides and galacto-oligosaccharides, found in high amounts in wheat and legumes, are restricted with a LFOD diet, which is concerning. These prebiotics stimulate healthy colonic bifidobacterium. After 4 wk of a restricted fermentable carbohydrate diet, bifidobacteria populations were decreased in IBS patients (38). Immune health may be compromised with lower bifidobacterium count, which is an important consideration for overall athlete immunity and health (39). In athletes, it is unclear if risk associated with decreased healthy bacterial populations due to diet may be more or less apparent because exercise further alters diet–microbe–host metabolic interactions and may support higher gut microorganisms diversity (40). Exercise and an athletes' diet could offer a protective element against a decrease in healthy gut bacterial populations associated with FODMAP restriction. Given the restrictive nature and novelty of this dietary approach, a systematic and individualized approach will be obligatory for successful and efficacious implementation of a LFOD diet in an athletic setting.

## CONCLUSIONS

Results from this study have shown that a short-term LFOD results in significantly lower daily GI symptoms over the intervention period compared with an HFOD diet in athletes with a self-reported history of persistent exercise-associated GI distress. Exercise-associated GI distress and pathophysiology of IBS are multifactorial, but both conditions feature similar symptomatology. Although, more work is needed to determine the effectiveness of a LFOD diet, our preliminary findings suggest that this dietary approach may be applicable beyond the clinical realm and offer a novel strategy to reduce GI symptoms in some symptomatic but otherwise clinically healthy athletes.

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## REFERENCES

1. Gisolfi CV. Is the GI system built for exercise? *News Physiol Sci*. 2000;15:114–9.
2. de Oliveira EP, Burini RC, Jeukendrup A. Gastrointestinal complaints during exercise: prevalence, etiology, and nutritional recommendations. *Sports Med*. 2014;44(1 Suppl):S79–85.
3. Gibson PR, Muir J. Not all effects of a gluten-free diet are due to removal of gluten. *Gastroenterology*. 2013;145(3):693.
4. van Wijck K, Lenaerts K, Grootjans J, et al. Physiology and pathophysiology of splanchnic hypoperfusion and intestinal injury during exercise: strategies for evaluation and prevention. *Am J Physiol Gastrointest Liver Physiol*. 2012;303(2):G155–68.
5. Shepherd SJ, Lomer MC, Gibson PR. Short-chain carbohydrates and functional gastrointestinal disorders. *Am J Gastroenterol*. 2013;108(5):707–17.
6. De Giorgio R, Volta U, Gibson PR. Sensitivity to wheat, gluten and FODMAPs in IBS: facts or fiction? *Gut*. 2016;65(1):169–78.
7. Gibson PR, Shepherd SJ. Evidence-based dietary management of functional gastrointestinal symptoms: the FODMAP approach. *J Gastroenterol Hepatol*. 2010;25(2):252–8.
8. Zhan YL, Zhan YA, Dai SX. Is a low FODMAP diet beneficial for patients with inflammatory bowel disease? A meta-analysis and systematic review. *Clin Nutr*. 2017; Epub ahead of print. 10.1016/j.clnu.2017.05.019.
9. Halmos EP, Power VA, Shepherd SJ, Gibson PR, Muir JG. A diet low in FODMAPs reduces symptoms of irritable bowel syndrome. *Gastroenterology*. 2014;146(1):67–75.e5.
10. Staudacher HM, Irving PM, Lomer MC, Whelan K. Mechanisms and efficacy of dietary FODMAP restriction in IBS. *Nat Rev Gastroenterol Hepatol*. 2014;11(4):256–66.
11. de Oliveira EP. Runner's diarrhea: what is it, what causes it, and how can it be prevented? *Curr Opin Gastroenterol*. 2017;33(1):41–6.
12. de Oliveira EP, Burini RC. Food-dependent, exercise-induced gastrointestinal distress. *J Int Soc Sports Nutr*. 2011;8:12.
13. Lis DM, Fell JW, Ahuja KD, Kitic CM, Stellingwerff T. Commercial hype versus reality: our current scientific understanding of gluten and athletic performance. *Curr Sports Med Rep*. 2016;15(4):262–8.
14. Biesiekierski JR, Peters SL, Newnham ED, Rosella O, Muir JG, Gibson PR. No effects of gluten in patients with self-reported non-celiac gluten sensitivity after dietary reduction of fermentable, poorly absorbed, short-chain carbohydrates. *Gastroenterology*. 2013;145(2):320–8.
15. Gibson PR, Muir JG, Newnham ED. Other dietary confounders: FODMAPS et al. *Dig Dis*. 2015;33(2):269–76.
16. Despain D. The surprising reason gluten-free diets actually work. [Internet]. Available from: http://www.outsideonline.com/1923951/surprising-reason-gluten-free-diets-actually-work.
17. Scott KP, Gratz SW, Sheridan PO, Flint HJ, Duncan SH. The influence of diet on the gut microbiota. *Pharmacol Res*. 2013;69(1):52–60.
18. van Loo J, Coussement P, de Leenheer L, Hoebregs H, Smits G. On the presence of inulin and oligofructose as natural ingredients in the western diet. *Crit Rev Food Sci Nutr*. 1995;35(6):525–52.
19. Martinez RC, Bedani R, Saad SM. Scientific evidence for health effects attributed to the consumption of probiotics and prebiotics: an update for current perspectives and future challenges. *Br J Nutr*. 2015;114(12):1993–2015.
20. Ong DK, Mitchell SB, Barrett JS, et al. Manipulation of dietary short chain carbohydrates alters the pattern of gas production and genesis of symptoms in irritable bowel syndrome. *J Gastroenterol Hepatol*. 2010;25(8):1366–73.
21. Lis D, Ahuja KD, Stellingwerff T, Kitic CM, Fell J. Food avoidance in athletes: FODMAP foods on the list. *Appl Physiol Nutr Metab*. 2016;41(9):1002–4.
22. Lis D, Ahuja KD, Stellingwerff T, Kitic CM, Fell J. Case study: utilizing a low FODMAP diet to combat exercise-induced gastrointestinal symptoms. *Int J Sport Nutr Exerc Metab*. 2016;26(5):481–7.
23. Pfeiffer B, Stellingwerff T, Hodgson AB, et al. Nutritional intake and gastrointestinal problems during competitive endurance events. *Med Sci Sports Exerc*. 2012;44(2):344–51.
24. Halmos EP, Christophersen CT, Bird AR, Shepherd SJ, Gibson PR, Muir JG. Diets that differ in their FODMAP content alter the colonic luminal microenvironment. *Gut*. 2015;64(1):93–100.
25. Barrett JS, Gibson PR. Development and validation of a comprehensive semi-quantitative food frequency questionnaire that includes FODMAP intake and glycemic index. *J Am Diet Assoc*. 2010;110(10):1469–76.
26. Maughan RJ, Shirreffs SM. IOC Consensus Conference on Nutrition in Sport, 25-27 October 2010, International Olympic Committee, Lausanne, Switzerland. *J Sports Sci*. 2011;29(1 Suppl):S1.
27. Shepherd SJ, Parker FC, Muir JG, Gibson PR. Dietary triggers of abdominal symptoms in patients with irritable bowel syndrome: randomized placebo-controlled evidence. *Clin Gastroenterol Hepatol*. 2008;6(7):765–71.
28. Daniels J. *Daniels' Running Formula*. Champaign, IL: Human Kinetics; 2013. 320 pp.
29. Peters HP, van Schelven FW, Verstappen PA, et al. Gastrointestinal problems as a function of carbohydrate supplements and mode of exercise. *Med Sci Sports Exerc*. 1993;25(11):1211–24.
30. Murray K, Wilkinson-Smith V, Hoad C, et al. Differential effects of FODMAPs (fermentable oligo-, di-, mono-saccharides and polyols) on small and large intestinal contents in healthy subjects shown by MRI. *Am J Gastroenterol*. 2014;109(1):110–9.
31. Pfeiffer B, Cotterill A, Grathwohl D, Stellingwerff T, Jeukendrup AE. The effect of carbohydrate gels on gastrointestinal tolerance during a 16-km run. *Int J Sport Nutr Exerc Metab*. 2009;19(5):485–503.
32. Mayer EA, Tillisch K. The brain-gut axis in abdominal pain syndromes. *Annu Rev Med*. 2011;62:381–96.

33. Killer SC SI, Carter JM, Randell RK, Jeukendrup AE, Gleeson M. The physical, mental and hormonal responses to short-term intensified training in well-trained cyclists with a high carbohydrate nutritional intervention. In: *Proceedings of the 2nd World Congress of Cycling Science*. Leeds, UK: 2014. 78.
34. Tache Y, Martinez V, Million M, Wang L. Stress and the gastrointestinal tract III. Stress-related alterations of gut motor function: role of brain corticotropin-releasing factor receptors. *Am J Physiol Gastrointest Liver Physiol*. 2001;280(2):G173–7.
35. Brouns F, Beckers E. Is the gut an athletic organ? Digestion, absorption and exercise. *Sports Med*. 1993;15(4):242–57.
36. Achten J, Halson SL, Moseley L, Rayson MP, Casey A, Jeukendrup AE. Higher dietary carbohydrate content during intensified running training results in better maintenance of performance and mood state. *J Appl Physiol (1985)*. 2004;96(4):1331–40.
37. Mountjoy M, Sundgot-Borgen J, Burke L, et al. The IOC consensus statement: beyond the female athlete triad—relative energy deficiency in sport (RED-S). *Br J Sports Med*. 2014;48(7):491–7.
38. Staudacher HM, Lomer MC, Anderson JL, et al. Fermentable carbohydrate restriction reduces luminal bifidobacteria and gastrointestinal symptoms in patients with irritable bowel syndrome. *J Nutr*. 2012;142(8):1510–8.
39. Gleeson M. Immunological aspects of sport nutrition. *Immunol Cell Biol*. 2016;94(2):117–23.
40. O'Sullivan O, Cronin O, Clarke SF, et al. Exercise and the microbiota. *Gut Microbes*. 2015;6(2):131–6.