Commercial Hype Versus Reality: Our Current Scientific Understanding of Gluten and Athletic Performance

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Abstract

Recent explosion in the prevalence of gluten-free athletes, exacerbated by unsubstantiated commercial health claims, has led to some professional athletes touting gluten-free diet as the secret to their success. Forty-one percent of athletes report adhering to a gluten-free diet (GFD), which is four-fold higher than the population-based clinical requirements. Many nonceliac athletes believe that gluten avoidance improves gastrointestinal well-being, reduces inflammation, and provides an ergogenic edge, despite the fact that limited data yet exist to support any of these benefits. There are several plausible associations between endurance-based exercise and gastrointestinal permeability whereby a GFD may be beneficial. However, the implications of confounding factors, including the risks of unnecessary dietary restriction, financial burden, food availability, psychosocial implications, alterations in short-chain carbohydrates (fermentable oligosaccharides, disaccharides, monosaccharides, and polyols), and other wheat constituents emphasize the need for further evaluation.

Introduction

The concept of performance extends beyond the actual physical wins or losses in sport. It also encompasses aspects of individual well-being performance that are influenced by dietary intakes and beliefs that ultimately may provide a competitive edge (Fig. 1). Nonceliac, non–gluten-sensitive gluten-free athletes (NCA) have rapidly become a prevalent group adopting a gluten-free diet (GFD) as a means to optimize health and gain a performance edge. Athletes who follow a GFD, fully or partially, for nonclinical reasons are already four times higher than the 5% to 10% of the general population requiring gluten avoidance for clinical reasons (29,42), which include celiac disease (CD), wheat allergy, and nonceliac gluten sensitivity (NCGS). The rapid uptake of GFDs with high adherence rates is further exacerbated by illustrious commercial claims equating GFDs with enhanced health, as well as some high profile athletes touting this diet as the secret to their athletic success (23).

This explosion of gluten-free products and NCA adopting this diet raises the following question: Is there anything unique about a GFD that may benefit the athlete in competitive performance and/or performance-related parameters including gastrointestinal (GI) health, inflammation, dietary healthiness, and perceptual well-being? It continues to be debatable whether the unique physiological stress of athletic training creates an increased susceptibility (11) to gluten or if rates of NCGS are higher in endurance athletes who already have increased GI issues (38). In this review, we examine GFD research conducted on athletes, as well as clinical and population-based dietary investigations with findings potentially applicable to an athletic population. Although the contemporary nature of this area provides limited NCA-specific evidence, this review further explores theoretical connections associated with gluten and gut injury, inflammation, dietary choices, and the belief effect to increase understanding of the gluten-free movement among NCA and how these elements require further research or may ultimately impact health and performance.

Gluten-Related Clinical Conditions

Gluten is a storage protein composite, with the alcohol-soluble gliadins defined as *prolamins* and the alcohol-insoluble glutenins as *glutelins* (1). Although all grain products, even those considered gluten free, contain prolamins,

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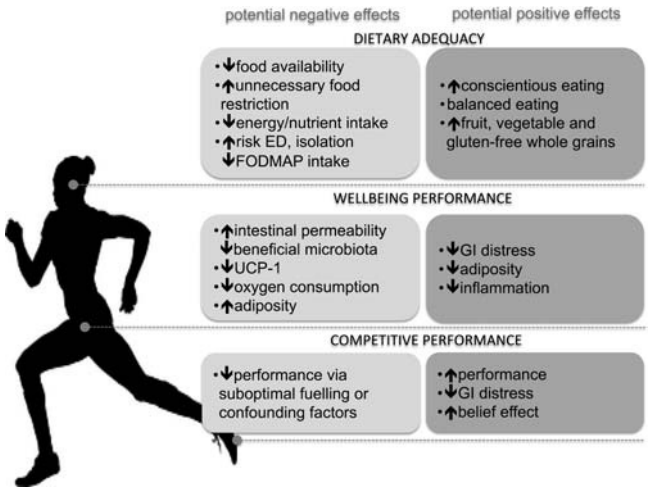

Figure 1: Schematic overview of the potential negative or positive effects/interactions of gluten on athletic performance or health performance. ED, eating disorder; UCP-1, uncoupling protein.

only the prolamins found in wheat (gliadin), rye (secalin), and barley (hordein) are the primary peptides associated with immunological reactions in CD. Gluten is also present in other food products through the addition of grain-based foodstuffs, present as gluten itself (*e.g.*, soy sauce) or via cross-contamination, such as is common in oats (43). Average intakes of gluten vary (42) geographically and individually. In Western diets, gluten intake ranges from 10 to 20 $g \cdot d^{-1}$ with some individuals consuming up to 50 g of gluten per day (42). Grain-containing foods and sports foods are a common source of carbohydrate-dense nourishment, and it is plausible that many athletes ingest above average gluten-containing food quantities to meet elevated energy and carbohydrate requirements.

Athletes with clinical gluten-related conditions generally experience improvements or complete resolution of a spectrum of intraintestinal and extraintestinal symptoms with strict gluten elimination (30). For example, in clinical case reports, athletes presenting with symptoms representative of ill health, including GI issues and poor nutrient status, exhibited improvements in health status, training, and competition capacities subsequent to CD diagnosis and the implementation of a GFD (13,25). However, the vast majority of NCAs are self-diagnosing clinical conditions (Fig. 2), NCGS in particular, and subsequently self-prescribing gluten avoidance. GI symptoms commonly reported in endurance athletes also are believed to be caused by gluten, and self-selection of a GFD is readily implemented as a perceived treatment (29). One of the primary reasons for self-diagnosis is likely the arduous double-blind gluten elimination and rechallenge currently employed as the "best practice" diagnostic tool to determine true NCGS (9), after CD and wheat allergy have been ruled out. Recent research appears to be developing biomarkers (2) to assess NCGS; however, contrary to popular belief, no scientifically validated diagnostic biomarker is readily available to confirm NCGS. It is risky for athletes to self-diagnose medical conditions and subsequently adopt a GFD as underlying medical or physiological conditions could be overlooked. Further, nonscholarly advice potentially influencing athletes' GFD decisions often lack the individualization required to optimize dietary intake supporting peak athletic performance and may risk injudicious outcomes.

Gluten-Related Beliefs on Athletic Performance

Among the 41% of athletes (n = 910) that adhere to a GFD, over half believe gluten avoidance improves competitive performance (29). Even in athletes not adhering to a GFD, approximately a quarter believe gluten avoidance has an ergogenic effect (7,29). Regardless of the prevalent belief in the performance benefits of a GFD, our research group has conducted the only study that has investigated the effects of this diet in NCA on exercise performance (28). This double-blind placebo-controlled crossover trial examined the effects of the effects of a 7-d GFD or gluten-containing diet on 15-min time trial (TT) performance (29). All food was provided, except for fresh fruit and vegetables, and habitual exercise was replicated between trials, with 16 $g \cdot d^{-1}$ of either gluten or placebo (whey protein) provided in an indistinguishable study food bar. There was no statistical difference between treatments for cycling performance (Fig. 3). Some questions remain whether a longer intervention may account for differential gut flora habituation and thus potentially influence immune parameters or GI symptoms. However, this is not supported by a 4-wk GFD in healthy subjects, which demonstrated a reduction in healthy gut bacterial populations (41). Performance is influenced by a plethora of factors and is difficult to accurately measure; however, in our study, performance improvement was 100% negligible using magnitude-based inference statistics as well as classic statistical approaches (P = 0.37). More research is required to definitively elicit whether gluten has any effect on

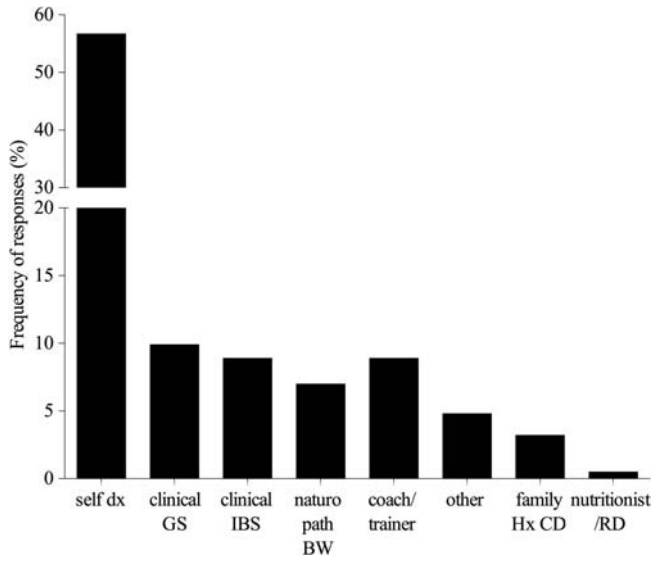

Figure 2: For athletes adhering to a GFD at least half of the time the basis for prescription of a GFD. GS, gluten sensitivity; BW, bloodwork; dx, diagnosis; hx, history; RD, registered dietitian. Modified, with permission, from Lis D, Stellingwerff T, Shing C, Ahuja KDK, Fell JW. Exploring the popularity, experiences, and beliefs surrounding gluten-free diets in non-celiac athletes. *Int. J. Sport Nutr. Exerc. Metab.*, 2015; 25:37–45. http://dx.doi.org/10.1123/ijsnem.2013-0247. © Human Kinetics, Inc.

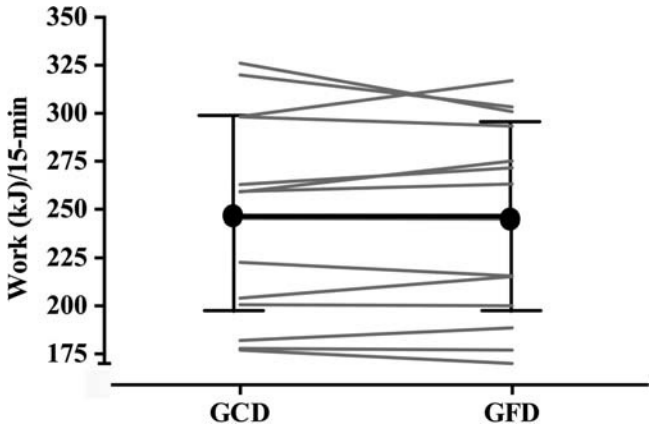

Figure 3: Overall 15-min TT performance (kJ) in response to gluten-containing diet and GFD. Solid gray lines — individual performance, means (SD); n = 13. GCD, gluten-containing diet. Reprinted with permission, from Lis D, Stellingwerff T, Kitic CM, Ahuja KD, Fell J. No effects of short-term gluten-free diet on performance in non-celiac athletes. *Med. Sci. Sports Exerc.* 2015; 47:2563-70. http://www.ncbi.nlm.nih.gov/pubmed/25970665. © *Medicine & Science in Sports & Exercise*.

competitive or well-being performance. Regardless, this seminal study does not support the popular belief that a short-term GFD has a performance-enhancing effect.

Although no direct performance effect has been shown with a GFD when athletes are blinded to the intervention, in reality, athletes are not blinded to dietary changes. Psychological influences and the "belief" in the effects of a GFD on performance and related parameters, such as pain, have the potential to influence outcomes (5). Beedie et al. (5) and Halson and Martin (21) have discussed the "belief effect" in sport showing a 1% to 3% improvement in performance. A dietary placebo effect may result in a positive (placebo) effect on performance, experienced both objectively (*e.g.*, improved performance) and/or subjectively (*e.g.*, reduced pain or exertion) (5,21). Although no research yet supports any benefits of a GFD for NCA, in actuality, the belief in the ergogenic benefits of a GFD may positively influence performance in the field. It is also noteworthy to deliberate situationally appropriate circumstances where a GFD can be used to "tap into" an athlete's belief in a dietary intervention to their advantage (5,49). However, one needs to appreciate that the complications potentially accompanying a GFD for NCA could be unfavorable to health and performance due to issues in dietary adequacy and other complications, as outlined below.

Gluten and Well-being Performance

Athletes place their bodies under unique and repetitive stress. Perhaps there are unique aspects to the physical stress of elite training and competition that does provide an underpinning mechanism, which may cause athletes to be more clinically susceptible to gluten.

Exercise GI Distress

GI distress is reported to occur in 30% to 50% of endurance athletes (11), and numerous elements can initiate or intensify GI symptoms in an individualized manner during primarily endurance exercise, including mechanical (splanchnic hypoperfusion), physiological (dehydration), psychological (stress), and climatic (heat [11]) factors. Dietary factors such as fiber quantity, carbohydrate type and load (10,38), and wheat constituents in sensitive individuals also may contribute to GI symptoms (8). Hypothetically, and similarly to NCGS and CD (53), injury to the intestinal barrier endured by athletes also could create a GI environment more sensitive to gluten, or similar multisystemic GI side effects of clinical gluten conditions.

Although the gut is partially trainable and does increase splanchnic blood flow after training (18), elite endurance athletes commonly undergo multiple training sessions per day, which is far less than the 4 to 5 d required for epithelial cell repair. Investigative research suggests a possible role of increased intestinal permeability leading to excessive absorption of gluten-derived peptides in NCGS (8), which could further potentiate immune-related responses. Dehydration and heat further compromise intestinal integrity, and athletes training or competing in these conditions may experience exacerbated GI injury (52). Altered digestion of short-chain carbohydrates also may augment GI symptoms triggered during exercise. Reductions in GI symptoms are the most popular rationale for eliminating gluten (29), although our study, described previously, did not show any effect of gluten on GI symptoms (28).

Immune Health

Illness can have a negative impact on health and performance. For athletes that engage in prolonged, strenuous exercise, a "J-shaped curve" model has been used to show the relationship between excessive exercise and increased illness rates (36). Numerous dietary strategies are recommended to maintain a robust immune system in athletes (19), but to date, a GFD is not one of them for NCA. Many NCAs, however, believe gluten elicits undesirable inflammatory responses (29) and in combination with excessive exercise could have an additive toll on the immune system. Our controlled intervention study, discussed previously, does not support this conviction. Inflammatory markers (interleukin (IL)-1β, IL-6, IL-8, IL-10, IL-15, and tumor necrosis factor (TNF)-α assessed in response to exercise (pre-TT, during TT, and post-TT) on the last day of each intervention period showed no significant difference between the gluten-containing diet or GFD (28). Similarly, in irritable bowel syndrome (IBS) patients with conviction that gluten triggers symptoms, no difference in C-reactive protein was found after a high gluten, low gluten, or a control diet for 1 wk in a crossover design (6).

In contrast to short-term human studies, rodent-based research in nonceliac C57B/6 male mice has shown increased IL-6 expression and a trend toward higher TNF levels with an 8-wk gluten-containing diet compared with a GFD, suggesting a proinflammatory profile (14). Aside from the obvious disparities in rodent versus human metabolism and disassociation to exercise, the dissimilar observations between studies could be owing to a longer intervention length in the rodent study, unconnected to exercise and cytokines measurements taken from adipose tissue. Nonetheless, gluten or wheat constituents are central to the inflammatory response in sensitive individuals (53),

and this can be associated to the abovementioned exercise-induced intestinal permeability (10,52). Therefore, the substantial and repeated stresses placed on an athlete's immune status and the subsequent effects on the inflammatory state highlight the need for a greater understanding on the effects of gluten or wheat constituents as a component of immunonutrition strategies.

Body Composition

Athletes eliminate gluten to promote weight loss or improve body composition for sport (29), although evidence to support this is lacking (15). Most research has analyzed weight changes pre- and post-GFD adherence in CD (50), but the dietary control is inconsistent and the complexity of confounding factors (*e.g.*, type 1 diabetes, chronic inflammation) limits its applicability to NCA. Surprisingly, in CD populations, there is an increased risk of obesity with GFD adherence suggested to be linked to increased nutrient absorption and intakes of high-fat/sugar gluten-free products (50). While there are no studies in nonceliac humans investigating the effect of gluten on body composition, studies in male C57B/6 mice suggest that a gluten-containing diet compared with an isocaloric GFD increases fat deposits, regardless of whether the diet is high fat or of normal fat content (14,46). The increased body weight and adipose tissue in gluten-fed mice also was associated with impaired glucose homeostasis, a decrease in fasting and nonfasted oxygen uptake, and lowered energy expenditure and increased adipocyte content of proinflammatory cytokines (14). These data have limited transferability to NCA as the macronutrient breakdown of the diets was not representative of typical athlete diet recommendations (51). In general, athletes aim to optimize power-to-weight ratio by achieving low body fat levels, and if a gluten-containing diet promoted adiposity, it would obviously be counterproductive.

Gluten and Nutritional Adequacy

Our recent questionnaire-based publication showed that the majority of NCAs adopting a GFD (at least 50% of the time) are recreationally competitive endurance athletes (~70% of 910 respondents) with the conviction that it is healthier, improves conscientiousness of food choices, and promotes overall more balanced eating (29). It is debatable whether a GFD equates to dietary changes resulting in a healthier or less healthy diet, or if other dietary habits are subsequently modified resulting in improved or worsened eating behaviors. Hype about this diet brings in the question of dietary and nutritional adequacy and the issue of suboptimal fuelling risk as described in other elimination-type diets (48).

NCAs adhering to a GFD do so in varying degrees, ranging from periodic gluten elimination, elimination 1 to 2 wk before competition, or up to 100% of the time (29). Although adherence rates vary, enhanced dietary mindfulness is suggested as an outcome to avoidance of gluten-containing products (16,29). Converting to a GFD plausibly results in some athletes increasing their conscientiousness of healthy balanced eating, increasing fruit and vegetable and whole grain intake and decreasing processed food selections (16); food choices all underpinning good sport nutrition practices. The variable nature of dietary choice highlights the fact that individual food selection may be an instrumental predictor of the overall healthfulness and nutritional adequacy of a GFD for NCA (44). Historically, a GFD has been associated with suboptimal intake of protein, fiber, B vitamins, and iron alongside increased fat and sugar intake (50). However, the proliferation of the gluten-free food products market results in both an increase of unhealthy gluten-free products as well as the production of more nutrient-rich pseudocereals, such as amaranth, buckwheat, and quinoa, replacing corn and rice flour (37). These substitutions could potentially reduce the risk of omitted dietary sources of B vitamins and iron that are critical for metabolism and athletic adaptations.

An athletes' dietary intake is unique in that it must be optimized to maintain sufficient energy intake and to augment training adaptation and health. Nutrition interventions may purposefully integrate periodized energy deficits to augment sport-specific body composition. However, elimination diets have been linked to nonstrategic suboptimal energy intakes and could potentiate low energy availability and associated risks, especially in endurance athletes (48). Analysis of the capacity of a GFD to support athletic energy demands has not been conducted so it is unknown if the dietary restriction associated with this diet compromises energy availability. Clinical investigation in this area is dated and fails to account for newer gluten-free food alternatives now accessible. The only recent study investigating energy intakes in GFD compared the nutritional status of patients with CD adhering to a strict long-term (2-year) GFD to healthy controls and found energy intake to be similar in both groups (3). However, the multifactorial nature of fuelling athletes also encompasses unique and complex eating behaviors that may overlap with avoidance of gluten-containing grains. Some behaviors may include restriction of grain-based foods completely, consumption of a limited low energy density diet, or orthorexia nervosa behaviors under the blanket of a GFD, particularly in weight-dependent sports (34). Additive factors such as limited accessibility to gluten-free foods when travelling or competing abroad further complicate the ability of a GFD to reliably support athlete energy requirements (22).

Macronutrient and some micronutrient requirements for athletes are often higher compared with the general population (51). For athletes, there is the additional concern of insufficient carbohydrate associated with the exclusion of gluten-containing foods (29). Contemporary studies, conducted in different countries with varying methodologies, have presented conflicting evidence concerning the macronutrient and micronutrient adequacy of gluten-free foods for the general population (50). Three studies have profiled the nutritional quality of 63 to 3213 gluten-free food products (*e.g.*, staple items: pasta, breads, and ready-to-eat breakfast cereals) compared with gluten-containing equivalents and also compared the Health Star Rating (an algorithm based on energy, total sugar, sodium, saturated fat, fiber, and protein) (54) or macro- and micronutrient composition (24,33). For athletes choosing gluten-free products, there is no obvious nutrient shortfall in most of these products compared with gluten-containing equivalents, but no health benefit either.

Quantification of the healthfulness of gluten-free foods is important to discuss as there exists a belief among athletes that eating gluten free equates to healthier food choices (29). Aside from being an effective treatment for the spectrum of gluten-related disorders, evidence-based research supporting a GFD as a "healthier" option for NCA is lacking (15). Several studies have analyzed a GFD for nutritional appropriateness compared with a gluten-containing diet using diverse methodologies in CD populations. Approaches used include prospective dietary analysis (40), virtual comparative analysis (32), and GFD compared against controls (3). Some statistical differences were found with lower protein or lower fiber, but there were no consistent findings across all studies that clearly indicate a difference in this nonathletic population. The slightly lower protein content indicated across gluten-free products and a GFD is negligible and of little practical significant as athletes are recommended to rely upon meat/alternatives and dairy as sources of protein, not grains (51). Overall, these studies indicate that the distribution of macronutrients was similar between a GFD and gluten-containing diet (3,32,40); however, there have been no studies published examining nutritional adequacy of GFDs in varying elite athlete populations. Due to the scarce evidence in this area and inherent error associated with diet record collection, it is not possible to conclude whether a GFD provides an optimal macro- or micronutrient profile for athletes; thus, GFD adequacy should be assessed individually.

Some athletes are so focused on eating gluten free that they overlook the importance of eating a balanced diet to support training and recovery. Complications possibly arising from unnecessary food restriction may include increased anxiety around food (orthorexia nervosa), time commitment, expense, social concerns, and interference with appropriate medical intervention (16,45). An enormous amount of time and money is spent by individuals with CD on label and food checking, at an estimated 10 to 20 h per month (39), plus an estimated 206% to 267% increase in food expenses (16,33). Social consequences also present, such as difficulty eating outside of the home, with friends, family, or team (16), or in various training/competition locations where gluten-free foods may be less available or inaccessible, may compromise optimal fueling. For some athletes, the lifestyle complications and challenges in supporting optimal fueling or nutrient intake on a GFD may be an unnecessary burden if a GFD is not a clinical necessity. See et al. (43) summarize the key dietary planning strategies that may reduce the nutritional risks historically associated with a GFD; however, athletes' unique nutritional requirements may be elevated, and capability of a GFD to reliably meet these has not been evaluated. It is therefore prudent to acknowledge that dietary restriction, or an elimination diet, may pose a risk for optimal fueling for sport performance, particularly for athletes already under fueling.

Are Fermentable Oligosaccharides, Disaccharides, Monosaccharides, and Polyols a Major Gluten Symptom Confounder?

Gluten-free markets are predicted to experience continued growth, but emerging market reports also predict low fermentable oligosaccharides, disaccharides, monosaccharides, and polyols (FODMAP) diets to eventually become the "new" GFD (31). FODMAPs are a family of short-chain carbohydrates (including fructans), are found naturally in foods, and are particularly prevalent in wheat, some fruits/vegetables, and legumes (4). Coincidently, a GFD also reduces fructan and galactooligosaccharide intake, and some researchers suggest that the change in dietary fructan load, rather than gluten itself, is the primary GI symptom modulator (17,35). For some individuals, fructans and other FODMAPs are poorly absorbed in the small intestine where they increase luminal fluid content and possibly affect gastric motility (47). Poorly absorbed, they subsequently transit to the colon as products for fermentation by colonic bacteria, resulting in GI symptoms such as diarrhea and flatulence (47). Although no data are published yet in athletes without IBS, it is conceivable that residual FODMAPs in the small intestine (ileum) and colon or intake of FODMAPs during training potentiates GI distress during and after strenuous exercise.

A low FODMAP diet is a strategy efficaciously not only applied in the treatment of IBS (47), but also practiced by some athletes to decrease GI symptoms (12). Investigation of the role of FODMAPs in athletes with persistent exercise-induced GI symptoms is in its infancy. However, preliminary work has been conducted by our group quantifying high FODMAP food/category elimination in athletes (27). Self-reported data indicate that 51% of athletes (n = 465 of 910) eliminate at least one high FODMAP food or food category with the aim to reduce GI symptoms. After elimination, reported symptom improvement ranged from 68.2% (polyols) to 83.7% (lactose) (27). In this study, athletes self-selected FODMAP categories that were queried alongside a short list of high FODMAP food examples (*e.g.*, fructose: apples, mango, and honey), and they may have been familiar with FODMAPs and/or only the high FODMAP foods listed. Lactose (86.8%, n = 402 of 465) was the most commonly eliminated followed by galactooligosaccharides, fructose, fructans, and polyols to a much lesser extent. Lactose elimination also was the most commonly reported to occur alongside gluten avoidance, which parallels population-based and clinical findings (20,27). From an intervention perspective, one case study report (26) of a multisport athlete with persistent running-specific exercise-induced GI symptoms reported measurable symptom improvement with a 3-d low FODMAP diet prior to and throughout 3 d of strenuous running training (26). Although there are limitations associated with self-report data, these initial findings from our group suggest that perceived gluten-triggered GI symptoms in athletes might be due to FODMAPs, particularly fructans and lactose as potential symptom modulators, although much more placebo-controlled double-blind studies are required to confirm this.

Conclusions

Widespread media validation continues to drive the popularity of GFDs forward, yet this diet has not been shown to affect either positive or negative competitive performance or symptoms of GI health and inflammation and/or nutritional status in NCA. Sport nutrition practitioners are faced with a unique challenge when advising on the appropriateness of GFDs for NCA, as most are

self-prescribing this diet based on non–peer-reviewed evidence. Theoretically, mechanisms unique to athletes may increase susceptibility to gluten locally and systemically with exercise-induced GI injury, but these have not been directly explored. Direct confounding factors of concern with gluten avoidance in athletes include caloric fuelling challenges, unnecessary restrictive eating practices, or the risk of overlooking appropriate medical diagnosis. While this "belief effect" may be responsible for NCA-perceived benefits of going gluten free, practitioners determining the appropriateness of a GFD for a NCA should first consider possible underlying GI disorders or other food intolerance, as well as potential risks associated with unnecessary food restrictions, psychosocial implications, and cost. Current limited evidence does not support the performance or health benefits of a GFD for NCA. Adoption of this diet should be carefully deliberated and prescribed under appropriate medical and/or dietetic guidance.

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