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Under Consumed and Overestimated: Discrepancies in Race-Day Carbohydrate Intake Among Endurance Athletes

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ABSTRACT

Despite well-established guidelines for carbohydrate (CHO) intake to support endurance performance, many athletes fail to meet these targets, and in-race intake is often estimated based on planned consumption rather than measured intake. We aimed to quantify actual CHO intake during endurance races and explore behavioral and psychological predictors. Sixty Tier 2 endurance athletes (38 marathoners and 22 cyclists) participated in two official races. Athletes' planned, perceived, and actual CHO intake 24 h before and during the race were assessed using food diary analysis, and pre- and post-race weighing of sports products containing CHO. Sleep behavior (ASBQ), pre-race anxiety (CSAI-2R), and gastrointestinal symptoms were also evaluated using validated questionnaires. Across the cohort, actual CHO intake (31.7 ± 23.5 g/hr) was lower than planned (38.0 ± 27.3 g/hr; $p < 0.001$). The absolute planned-actual gap was larger in cyclists (58.9 → 49.1 g/hr; $\Delta = 10.3$ g/hr) than in marathoners (25.9 → 21.7 g/hr; $\Delta = 4.2$ g/hr); proportionally, the shortfall was similar (~16%–17%) in both groups. Cyclists planned substantially higher CHO intakes and achieved higher actual intakes than marathoners. Regression analysis showed that race type, better sleep behavior, and lower cognitive anxiety predicted higher actual intake ($R^2 = 0.41$, $p < 0.05$). Despite similar intentions, marathoners consumed less CHO than cyclists and overestimated their CHO intake, highlighting behavioral gaps. Sleep and psychological readiness played key roles in fueling success. Findings support the importance of measuring actual intake and considering individual behavioral factors to optimize endurance nutrition strategies.

1 | Introduction

Endurance sports such as marathons and long-distance cycling are widely regarded as extreme disciplines, characterized by prolonged physiological stress, substantial energy demands, and the need for precise pacing and nutrition strategies. As participation in these events has steadily increased beyond elite circles to include vast numbers of recreational and subelite athletes, scientific attention has turned toward understanding the underlying physiology and identifying ways to make these sports more sustainable, particularly from a nutritional standpoint, to support both performance and long-term health (Braschler et al. 2025). Guidelines for both prerace and in-race nutrition predominantly emphasize carbohydrate (CHO) intake, as it is critical for sustaining endurance performance, maintaining blood glucose levels, and preserving key fuel sources such as muscle and liver glycogen (Podlogar and Wallis 2022; Tiller et al. 2019; Tiller and Millet 2025). Several

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Highlights

- Despite well-established guidelines, nonelite endurance cyclists and marathoners under-consumed CHO on race day with 49.1 and 21.7 g of carbohydrates consumed per hour of exercise in cyclists and marathoners, respectively.
- Both cyclists and marathoners overestimated their CHO intake in race, especially when relying on gels, which had the highest leftover rate.
- Cyclists demonstrated better fueling strategies and stronger adherence to planned intake, influenced by better sleep behaviors and lower cognitive anxiety.
- The occurrence of GI symptoms was similar between cyclists and marathoners, suggesting that GI distress did not account for the observed differences in fueling strategies between the groups.

studies have consistently shown that endurance athletes, whether professional, amateur, or recreational, fail to meet the recommended CHO intake guidelines. For instance, CHO intake on hard training days has been reported to reach only up to 7.3 g/kg/day in distance runners (Heikura et al. 2017). In a mixed cohort of professional and amateur athletes, average CHO intake the day before the race ranged from 5.6 ± 2.0 to 7.2 ± 2.0 g/kg, with only 10% achieving the target of 10–12 g/kg/day (Sampson et al. 2024). Similarly, in another study, only 19% of amateur runners met even the minimum 5 g/kg/day threshold, with average intake as low as 3.3 g/kg/day (McLeman et al. 2019). These findings reflect a clear trend across different athlete populations, with actual CHO consumption before races generally ranging between 3.3 and 7.3 g/kg/day, well below evidence-based recommendations. Beyond prerace strategies, field studies quantifying during-exercise CHO intake show substantial between-sport differences and wide interindividual ranges. In large cohorts across marathon running, road cycling, and triathlon, mean race-day CHO intake is typically highest in triathlons (~62–71 g/h), intermediate in amateur cycling (~53 g/h), and lowest in marathons (~35 g/h), with individual values spanning 6–136 g/h (Pfeiffer et al. 2012). Higher CHO intake has been associated with faster finishing times in Ironman events, although higher intake may coincide with minor GI symptoms such as nausea and flatulence. Most field reports infer intake from planned products or counts carried, which can overestimate actual consumption because leftovers are rarely quantified (McLeman et al. 2019; Sampson et al. 2024); this underscores the value of weighed-product methods to capture what athletes truly consume in competition.

There is increasing interest in how personal and behavioral factors might influence CHO consumption during endurance races. Variables such as sleep quality (Matos et al. 2025), precompetition anxiety (Cooke et al. 2011), and gastrointestinal (GI) disturbances (Arribalzaga et al. 2021) are believed to affect an athlete's capacity to follow their intended nutrition strategy. A large-scale study using hierarchical clustering further revealed that ultra-endurance athletes had a higher prevalence of poor sleep quality compared to endurance runners, highlighting the greater physical and psychological load in longer events (Matos et al. 2025). Poor sleep can also disrupt cognitive function and appetite cues (Greer et al. 2013), making it harder to consume and tolerate fuel mid-race. Endurance and ultra-endurance runners were found to have low sleep quality prior to competition, with endurance runners showing greater alterations in sleep patterns and both groups reporting inadequate CHO intake during the race, factors that can hinder physiological recovery and performance (Santos et al. 2023). In addition, elevated anxiety may exacerbate GI issues during endurance events, making it more difficult for athletes to consume and tolerate fuel mid-race, particularly at high CHO intake levels, which are often linked to GI discomfort. This is especially relevant in ultra-endurance settings, where despite the performance and recovery benefits of high CHO intake (e.g., typically from 90 to 120 g/h), GI symptoms remain highly prevalent and are influenced by factors such as environmental stress, altitude, and exercise intensity (Arribalzaga et al. 2021). Although these factors are widely acknowledged, limited research has explored how they collectively influence actual CHO intake during endurance events, particularly among nonelite athletes, who often contend with unpredictable routines and limited access to tailored nutrition planning.

Marathoners and cyclists face unique challenges during endurance events, including longer race durations, less structured nutrition plans, elevated prerace anxiety, and disrupted sleep, factors that can collectively impair fueling strategies and performance (Jiménez-Alfageme et al. 2025). The mode of exercise introduces additional complexity: runners are more prone to lower GI symptoms such as diarrhea and urgency due to repetitive high-impact forces, whereas cyclists may experience upper GI discomfort linked to posture and increased abdominal pressure, especially in the aero position (de Oliveira et al. 2014; Parnell et al. 2020). These physiological and mechanical differences, alongside individual variability in prerace routines and psychological readiness, may influence both the amount and tolerance of CHO intake, justifying the inclusion of both runners and cyclists in studies exploring real-world race nutrition.

Given the critical role of CHO availability in endurance performance and the widespread reliance on prepackaged sports nutrition products, this study aimed to evaluate the accuracy of self-planned and perceived CHO intake versus actual intake measured by pre- and postrace product weights. Additionally, we explored the relationship between actual CHO intake and potential factors of influence such as race-related anxiety, prerace CHO loading, GI symptoms, and sleep quality. We hypothesized that actual CHO intake would fall below planned amounts due to leftover products or mid-race consumption challenges, and that higher anxiety, insufficient CHO loading, and poorer sleep quality would be associated with lower CHO intake.

2 | Methods

2.1 | Study Design & Participants

A total of 60 Tier 2 endurance athletes (57 males and 3 females), including 30 marathon runners (mean age: 44.8 ± 7.7 years,

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body weight: 73.3 ± 6.4 kg, height: 1.75 ± 0.07 m, 11.1 ± 9.2 years of endurance training experience) and 30 cyclists (mean age: 36.9 ± 10.1 years, body weight: 72.8 ± 8.5 kg, height: 1.77 ± 0.07 m, 8.7 ± 7.2 years of endurance training experience), were recruited from the International Mersin Marathon (Mersin, Turkey, December 15th, 2024) and a 101-km Gran Fondo cycling race (Antalya, Turkey, November 17th, 2024). Eligible participants were aged between 18 and 65 years, with no reported health conditions that could impact performance or nutritional intake. The participant cohort was classified as Tier 2 (trained/developmental), reflecting their regular training habits, competitive intent, and local-level race participation, in line with the criteria outlined by McKay et al. (McKay et al. 2021).

This observational study complied with the principles of the Declaration of Helsinki. Ethical approval for the study was obtained from the University Ethical Committee (Approval No: 2024/9; Date: October 30, 2024). All participants provided informed consent before data collection.

2.2 | Study Procedure

On race days, data collection was conducted by experienced sport dietitians and sport scientists. Participants completed a comprehensive questionnaire capturing general demographics, weekly training habits, personal best performance, diet-related behavior (including prerace CHO loading strategies), race-day nutrition plans, and gastrointestinal symptoms. Prerace assessments included the Athlete Sleep Behavior Questionnaire (ASBQ) (Darendelİ et al. 2019; Driller et al. 2018) and the Competitive State Anxiety Inventory-2 Revised (CSAI-2R) (Akgönül et al. 2021; Cox et al. 2003) to evaluate sleep patterns and race-related anxiety, respectively. Validated culturally adapted versions of all scales were used in the study.

To quantify actual CHO intake during races, athletes' sports products (e.g., gels, bars) were weighed before and after the event. This allowed precise determination of CHO intake based on the weight difference of consumed versus leftover portions. Participants were asked to report both their planned and perceived CHO intake during the race. In this study, *planned* refers to the amount of CHO the athlete intended to consume based on their strategy, *perceived* is the amount they believed they had consumed, and *actual* intake was objectively determined by weighing all sports nutrition products (e.g., gels, drink powders, bars) before and after the race. This approach allowed for a detailed comparison between intended, perceived, and true intake. To quantify actual CHO intake during the races, all CHO-containing sports products (e.g., gels, CHO drink powders, bars) were weighed on-site before and after the event using a calibrated digital laboratory scale (Kern EMB 200-2, precision ± 0.01 g). Prior to the race, each product was individually weighed, labeled with a participant ID, and documented along with its manufacturer-declared CHO content per gram. Participants were instructed to store all wrappers and any partially consumed items in their race kit or pockets during the event and to return all remaining packaging postrace. In the cycling race, due to adverse weather conditions, all leftover products were collected immediately upon arrival at the finish line. For the marathon, leftover items were retrieved at two collection points: the 20-km aid station and the finish line. At both events, unconsumed or partially consumed products were placed in individually labeled zip-lock bags (participant ID + product type) to avoid cross-contamination or misidentification, and reweighed using the same digital scale under consistent conditions. Actual CHO intake was calculated by subtracting the postrace weight of each product from its prerace weight and multiplying the difference by the product's known CHO content per gram.

The Gastrointestinal Symptom Rating Scale (GSRS) was administered both before and after the race to evaluate GI distress (Dimenäs et al. 1995; Turan et al. 2017).

2.2.1 | Races

Data were collected from two endurance events in southern Turkiye: the International Mersin Marathon (42.195 km, December 15th, 2024) (n = 38) held in mild weather (12°C–17°C) and a 101-km cycling race (UCI Nirvana Gran Fondo World Series Antalya) (November 17th, 2024) (n = 22) marked by windy and rainy conditions, with temperatures between 14°C and 20°C.

2.2.2 | Questionnaires

2.2.2.1 | Athlete Sleep Behavior Questionnaire (ASBQ). Sleep behavior was assessed using the ASBQ, an 18-item validated tool developed for athletes (Darendelİ et al. 2019; Driller et al. 2018). The ASBQ also includes subdomains for sport-related (stimulant/caffeine use around training/competition; late-evening/early-morning sessions; sleeping in unfamiliar environments; pre-bed planning/worry), sleep-quality (long naps; sore muscles at bedtime; screens before bed; waking during the night; travel disrupting routine), habitual efficiency (alcohol close to bedtime; variable bed/wake times; going to bed thirsty), and sleep disturbance (sleep medication use; snoring; muscle twitching). Responses are recorded on a five-point Likert scale (1 = 'never' to 5 = 'always'). Total scores range from 18 to 90, with higher scores indicating poorer sleep behaviors. Categories include good (≤ 36), moderate (37–42), and poor (> 42) sleep behavior. The ASBQ also includes subdomains for sports-related, behavioral, and environmental factors. In this study, ASBQ was completed prerace.

2.2.2.2 | Competitive State Anxiety Inventory-2 Revised (CSAI-2R). Race-related anxiety was measured using the CSAI-2R, a 17-item validated instrument divided into three subscales: cognitive anxiety, somatic anxiety, and self-confidence (Akgönül et al. 2021; Cox et al. 2003). Each item is rated on a four-point Likert scale (1 = 'not at all' to 4 = 'very much so'). Higher scores on cognitive and somatic anxiety reflect increased anxiety, whereas higher self-confidence scores suggest stronger performance confidence. Scores were calculated separately for each subscale and used to evaluate psychological readiness.

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2.2.2.3 | Gastrointestinal Symptom Rating Scale (GSRS).

The GSRS was used to assess GI symptoms pre- and postrace. This 15-item tool measures five symptom clusters: reflux, abdominal pain, indigestion, diarrhea, and constipation. Each item is rated on a seven-point Likert scale, where higher scores indicate more severe GI distress (Dimenäs et al. 1995; Turan et al. 2017). This scale was used to explore possible associations between GI symptoms and CHO intake or anxiety.

2.2.2.4 | Food Diary (Pre-Race Day and Race Morning).

Participants completed a structured food diary for the 24 h before the race *(prerace day dietary intake)* and race-morning breakfast *(race-day breakfast).* Diaries included time of consumption, portion estimates, preparation, and brand. Actual in-race CHO intake was derived from pre- and postrace weighing of all CHO-containing products on a calibrated laboratory scale; these values did not rely on recall or diary entries. The day before the race, participants completed a structured 'Race-day Nutrition Plan' questionnaire listing the specific CHO products (brand/type) they intended to use and the planned number of units/servings and, where relevant, bottle volumes. Immediately postrace, they completed the parallel 'perceived intake' section reporting the number of each item believed consumed *(in-race dietary intake).* Participants were provided with detailed instructions by a sports dietitian on how to accurately record their intake, including estimated times of consumption, portion sizes, preparation methods, and brand names where applicable. The completed food diaries were analyzed by the sports dietitian using Nutritics software (Nutritics Research Edition, Dublin, Ireland). Dietary intake was then summarized to quantify the macronutrient and energy content for each of the specified time periods.

2.3 | Statistical Analysis

All statistical analyses were conducted using SPSS (Version 26.0, IBM Corp., Armonk, NY, USA). Descriptive statistics (mean ± SD) were calculated to summarize participant characteristics, including demographic, anthropometric, and training data, as well as nutritional intake variables. Normality tests (e.g., Shapiro–Wilk) were conducted to determine the appropriate use of parametric (paired *t*-tests, independent *t*-tests) or nonparametric (Wilcoxon signed-rank, Mann–Whitney U) tests. Group comparisons between marathoners and cyclists were assessed for variables such as energy intake, CHO intake (g, g/kg, g/hr), fluid and electrolyte intake, and psychological and sleep behavior scores. To evaluate differences between planned, perceived, and actual CHO intake, repeated measure analyses were performed. Paired *t*-tests were used to compare planned versus actual intake within each group, whereas violin plots were used to visualize intake distributions. The proportion of athletes meeting established nutritional guidelines was calculated and compared to reference cutoffs (e.g., 60–90 g/hr CHO during race), with adequacy percentages. Multiple linear regression analyses were conducted in three hierarchical models to explore predictors of actual CHO intake. Regression diagnostics were checked to confirm model assumptions (e.g., linearity, multicollinearity). Standardized beta coefficients (β), unstandardized coefficients (B), R^2 values, and F statistics are reported to interpret the predictive power of each model. Linear regression plots were used to assess the association between race duration (min) and actual CHO intake (g/hr) within each group. Statistical significance was set at $p < 0.05$.

3 | Results

3.1 | Participants Characteristics

Table 1 compares general demographic characteristics, training profiles, race performance, anxiety levels, and sleep behaviors between marathoners ($n = 38$) and cyclists ($n = 22$). Although body weight, height, BMI, and training experience were similar between groups, cyclists were significantly younger ($p = 0.001$, $d = 0.87$) and reported substantially longer weekly training durations ($p < 0.001$, $d = 1.31$).

3.2 | Pre-Race Anxiety and Sleep Behavior

Pre-race cognitive and somatic anxiety, as well as self-confidence, did not differ significantly between athletes. However, cyclists scored higher on sleep-related behaviors, including sports-related factors ($p = 0.035$, $d = 0.54$), habitual sleep efficiency ($p = 0.012$, $d = 0.76$), and showed a trend toward better sleep quality ($p = 0.055$, $d = 0.51$) and greater total sleep behavior scores (ASBQ-Total, $p = 0.004$, $d = 0.82$).

3.3 | Dietary Intake Before and During Races

Tables 2 and 3 show macronutrient and fluid intake 24 h before, prerace on race day, and during races. Cyclists had significantly higher total energy and CHO intake both 24 h before the race ($p < 0.001$, $d = 0.99$ and $p = 0.002$, $d = 0.87$, respectively) and prerace ($p = 0.011$, $d = 0.73$ and $p = 0.043$, $d = 0.56$, respectively), including higher protein and fat intakes. Notably, the relative CHO intake (in g/kg of body weight) was significantly greater in cyclists across all time points, with a particularly large effect during races (planned CHO intake in g/hr: $p < 0.001$, $d = 1.39$). Cyclists also consumed more caffeine prerace ($p = 0.045$, $d = 0.53$) and during the race ($p = 0.076$, $d = 0.45$), though not all differences reached significance. During the race, cyclists ingested significantly more energy, protein, and fat, but less fluid in both absolute and relative terms compared to marathoners. Specifically, fluid intake was significantly lower in cyclists compared to marathoners both in absolute volume (1015 ± 330 mL vs. 1266 ± 339 mL; $p = 0.007$, Cohen's $d = 0.75$) and relative to body weight (14.0 ± 4.8 mL/kg vs. 17.3 ± 4.6 mL/kg; $p = 0.010$, $d = 0.70$).

Table 4 highlights the inadequacy of CHO intake across all periods for both athlete groups when compared to established guidelines. Marathoners showed particularly low compliance with CHO recommendations, with only 5.3% meeting the 24-h and during-race CHO targets and 42.1% achieving the prerace minimum. Cyclists demonstrated better compliance, with 72.7% meeting prerace and 50% during-race CHO goals, though none met the 24-h recommendation. Despite statistically significant

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TABLE 1 | Participants' characteristics.

Variable	Combined (n = 60)	Marathoners (n = 38)	Cyclists (n = 22)	p, Cohen's d
Athletes (male/Female)	57/3	37/1	20/2	
Age (year)	41.8 ± 9.4	44.8 ± 7.7	36.9 ± 10.1*	**0.001, 0.87**
Body weight (kg)	73.1 ± 7.2	73.3 ± 6.4	72.8 ± 8.5	0.809, 0.07
Height (m)	1.76 ± 0.06	1.75 ± 0.07	1.77 ± 0.07	0.347, 0.28
Endurance training experience (year)	10.1 ± 8.5	11.1 ± 9.2	8.7 ± 7.2	0.299, 0.29
Weekly training duration (hours)	10.3 ± 4.6	8.4 ± 3.6	13.7 ± 4.4*	**< 0.001, 1.31**
Personal best (hh:mm)	3:19 ± 0:36	3:23 ± 0:34	3:05 ± 0:43	0.168, 0.47
Expected race finish time (hh:mm)	3:17 ± 0:35	3:30 ± 0:32	2:44 ± 0:22*	**< 0.001, 1.67**
Actual race finish time (hh:mm)	3:16 ± 0:40	3:34 ± 0:36	2:54 ± 0:26*	**< 0.001, 1.27**
Pre-Race anxiety				
Cognitive anxiety	15.3 ± 5.8	15.2 ± 6.3	15.3 ± 4.9	0.984, 0.02
Somatic anxiety	12.0 ± 3.4	12.1 ± 3.8	12.0 ± 2.8	0.955, 0.03
Self-confidence	29.4 ± 8.1	28.4 ± 8.3	31.0 ± 7.7	0.238, 0.32
Sleep behavior				
Sports-related factors	11.3 ± 3.4	10.7 ± 3.6	12.4 ± 2.6*	**0.035, 0.54**
Sleep quality factors	10.1 ± 2.9	9.6 ± 2.9	11.0 ± 2.5	0.055, 0.51
Habitual sleep efficiency factors	6.8 ± 1.9	6.3 ± 1.9	7.6 ± 1.5*	**0.012, 0.76**
Sleep disturbance factors	4.1 ± 1.6	3.8 ± 1.2	4.6 ± 2.1	0.082, 0.47
ASBQ-total score	32.4 ± 7.3	30.4 ± 7.4	35.8 ± 5.6*	**0.004, 0.82**

Note: Bold values indicate statistical significance, $p < 0.05$.
Abbreviations: ASBQ, Athlete Sleep Behavior Questionnaire; BMI, Body Mass Index.
*$p < 0.05$; marathoners versus cyclists.

TABLE 2 | Macronutrient and fluid intake in the 24 h before race day and the pre-race period on race morning.

Variable	Combined (n = 60)	Marathoners (n = 38)	Cyclists (n = 22)	p, Cohen's d
24-h before RACE				
Energy (kcal)	2635 ± 981	2299 ± 756	3216 ± 1067*	**< 0.001**, 0.99
CHO (g)	289 ± 132	250 ± 120	357 ± 127*	**0.002**, 0.87
CHO (g/kg)	3.97 ± 1.81	3.40 ± 1.62	4.95 ± 1.73*	**0.001**, 0.91
Fiber (g)	24.5 ± 10.9	23.1 ± 11.7	26.9 ± 9.1	0.191, 0.36
Protein (g)	103.6 ± 51.2	91.2 ± 36.9	125 ± 64*	**0.012**, 0.65
Protein (g/kg)	1.41 ± 0.63	1.24 ± 0.49	1.68 ± 0.74*	**0.008**, 0.88
Fat (% energy)	38.8 ± 10.3	39.4 ± 9.9	37.7 ± 11.0	0.549, 0.16
Fat (g/kg)	1.55 ± 0.67	1.4 ± 0.6	1.9 ± 0.7*	**0.007**, 0.77
Fluid (mL)	2336 ± 743	2263 ± 794	2463 ± 644	0.318, 0.28
Fluid (mL/kg)	32.2 ± 10.8	31.0 ± 11.3	34.3 ± 9.9	0.274, 0.31
Caffeine (mg)	73.2 ± 99.9	58.5 ± 108.1	98.7 ± 80.0	0.134, 0.42
PreRACE				
Energy (kcal)	638 ± 401	539 ± 414	810 ± 320*	**0.011**, 0.73
CHO (g)	81.6 ± 51.1	71.5 ± 51.4	99.1 ± 46.7*	**0.043**, 0.56
CHO (g/kg)	1.12 ± 0.71	1.0 ± 0.7	1.4 ± 0.7*	**0.029**, 0.57
Fiber (g)	7.16 ± 5.32	6.2 ± 5.4	8.8 ± 4.9	0.066, 0.50
Protein (g)	19.5 ± 14.7	14.6 ± 12.6	28.0 ± 14.5*	**< 0.001**, 0.99

(Continues)

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TABLE 2 | (Continued)

Variable	Combined (n = 60)	Marathoners (n = 38)	Cyclists (n = 22)	p, Cohen's d
Protein (g/kg)	0.27 ± 0.19	0.2 ± 0.2	0.4 ± 0.2*	**< 0.001**, 1.00
Fat (g)	25.0 ± 22.9	20.8 ± 23.7	32.4 ± 19.6	0.058, 0.53
Fat (g/kg)	0.34 ± 0.30	0.3 ± 0.3	0.4 ± 0.3*	**0.042**, 0.33
Caffeine (mg)	54.9 ± 71.2	40.9 ± 61.4	79.1 ± 81.5*	**0.045**, 0.53

Note: Bold values indicate statistical significance, $p < 0.05$.
*p< 0.05; marathoners versus cyclists.

TABLE 3 | During-race macronutrient and fluid intake.

Variable	Combined (n = 60)	Marathoners (n = 38)	Cyclists (n = 22)	p, Cohen's d
During RACE				
Energy (kcal)	471 ± 281	362 ± 236	657 ± 259	**< 0.001**, 1.19
CHO (g), planned	113 ± 68	89.1 ± 58.4	154.3 ± 65.0	< **0.001**, 1.06
CHO (g/hr), planned	38.0 ± 27.3	25.9 ± 18.2	58.9 ± 28.2	< **0.001**, 1.39
CHO (g), actual	94.4 ± 58.9	74.8 ± 49.7	128.2 ± 59.2*	< **0.001**, 0.97
CHO (g/hr), actual	31.7 ± 23.5	21.7 ± 15.4	49.1 ± 25.2*	< **0.001**, 1.31
Fiber (g)	0.49 ± 1.58	0.21 ± 0.68	0.96 ± 2.41	0.077, 0.42
Protein (g)	1.30 ± 4.20	0.11 ± 0.31	3.35 ± 6.52*	**0.003**, 0.70
Fat (g)	0.91 ± 3.72	0.06 ± 0.22	2.37 ± 5.93*	**0.019**, 0.55
Fluid (mL)	1174 ± 354	1266 ± 339	1015 ± 330*	**0.007**, 0.75
Fluid (mL/kg)	16.1 ± 4.87	17.3 ± 4.6	14.0 ± 4.8*	**0.010**, 0.70
Caffeine (mg)	67.3 ± 117.1	46.9 ± 89.9	102.6 ± 149.0	0.076, 0.45
Caffeine (mg/kg)	0.91 ± 1.60	0.65 ± 1.27	1.37 ± 2.01	0.093, 0.43
Sodium (mg)	365 ± 482	298 ± 483	482 ± 469	0.156, 0.39
Magnesium (mg)	66.8 ± 96.7	76.1 ± 103.8	50.8 ± 83.1	0.333, 0.27
Potassium (mg)	177 ± 243	122 ± 127	273 ± 351*	**0.019**, 0.57

Note: Planned (prerace plan) and actual (derived from pre-/postrace weighing) in-race carbohydrate intake, normalized to finishing time (g/hr); values are mean ± SD by sport and overall. Bold values indicate statistical significance, $p < 0.05$.
*$p < 0.05$; marathoners versus cyclists.

TABLE 4 | Adequacy, compliance, and effect size analysis of nutritional intake among marathoners versus cyclists.

Category	24-h CHO intake (g/kg)	Pre-race CHO intake (g/kg)	During race CHO intake (g/hr)
Guidelines	10–12	1–4	60–90
Mean (SD) marathoners	3.40 ± 1.62	1.12 ± 0.71	25.9 ± 18.2
p-value (suggested vs. actual intake) (lower end, upper end)	0.001, 0.001	0.805, < 0.001	< 0.001, < 0.001
Mean (SD) cyclists	4.95 ± 1.73	1.4 ± 0.7	58.9 ± 28.2
p-value (suggested vs. actual intake) (lower end, upper end)	< 0.001, < 0.001	0.021, < 0.001	0.859, < 0.001
% adequate intake marathoners[a]	5.3	42.1	5.3
% adequate intake cyclists[a]	0.0	72.7	50.0

[a]% of athletes meeting the minimum recommended intake for CHO intake.

group differences in actual intake (e.g., $p < 0.001$ for 24-h and during-race CHO), both groups consistently fell short of optimal carbohydrate loading and fueling targets, emphasizing a need for improved race nutrition strategies.

The types of foods and drinks consumed during races by marathoners and cyclists are presented in Table 5. It highlights a strong reliance on gels in both groups. Nearly all athletes consumed gels (97.4% marathoners, 90.9% cyclists), whereas

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TABLE 5 | Foods and drinks consumed during races.

	Category	Marathoners (*n*, %)	Cyclists (*n*, %)
1	CHO gels	37, 97.4%	20, 90.9%
2	CHO gels with caffeine	9, 23.7%	9, 40.9%
3	CHO gummies	1, 2.6%	0, 0.0%
4	CHO drink powders	2, 5.3%	6, 27.3%
5	Energy bars	1, 2.6%	0, 0.0%
6	Cereal bars	0, 0.0%	1, 4.5%
7	Sports drinks	1, 2.6%	0, 0.0%
8	Banana	0, 0.0%	2, 9.0%

Note: Full item names and CHO content per unit: *(1) CHO Gels*: SIS Beta Fuel (60 mL per serving, 40 g CHO, Science in Sport, UK); SIS Isotonic Energy Gel (60 mL per serving, 22 g CHO, Science in Sport, UK); GU Energy Gel (32 g per serving, 23 g CHO, GU Energy Labs, California, USA); Maurten 100 (40 g per serving, 25 g CHO, Maurten AB, Gothenburg, Sweden); Maurten 160 (65 g per serving, 40 g CHO, Maurten AB, Gothenburg, Sweden); Ingobio Energy Gel (50 g per serving, 26.5 g CHO, Ingobio, Istanbul, Turkey); On the Go Gel (60 mL per serving, 24 g CHO, BIGJOY, Istanbul, Turkey); Z Konsept Pro Energy Gel (40 mL per serving, 30 g CHO, Germany); WUP Boost Neo3 Energy Gel (45 g per serving, 26 g CHO, WUP, Istanbul, Turkey); WUP Boost Iso Gel (45 g per serving, 25 g CHO, WUP, Istanbul, Turkey); WUP Podium Energy Gel (42 per serving, 25 g CHO, WUP, Istanbul, Turkey); NDuranz Gel 45 (75 g per serving, 45 g CHO, NDuranz, Ljubljana, Slovenia). *(2) CHO Gels with Caffeine*: GU Energy Gel with caffeine (32 g per serving, 23 g CHO, 20 mg caffeine, GU Energy Labs, California, USA); Ingobio Energy Gel with caffeine ((50 g per serving, 26.5 g CHO, 50 mg caffeine, Ingobio, Istanbul, Turkey); On the Go Gel with caffeine (60 mL per serving, 24 g CHO, 150 mg caffeine, BIGJOY, Istanbul, Turkey); WUP Podium Energy Gel with caffeine ((40 g per serving, 24 g CHO, 50 mg caffeine, WUP, Istanbul, Turkey); *(3) CHO Gummies*: On the Go Energy Gummy (30 g per serving, 25 g CHO, BIGJOY, Turkey); *(4) CHO Drink Powders*: Maurten Mix 320 (83 g per serving, 80 g CHO, Maurten AB, Gothenburg, Sweden); Ingobio Isocarbo (30 g per serving, 24.9 g CHO, Ingobio, Istanbul, Turkey); NDuranz Drink 90 (96 g per serving, 90 g CHO, NDuranz, Ljubljana, Slovenia); WUP Carb3+ (30 g per serving, 26 g CHO, WUP, Istanbul, Turkey); Hardline Carbopure (46 g per serving, 46 g CHO, Hardline Nutrition, Istanbul, Turkey); *(5) Energy Bars*: SIS (40 g per serving, 27 g CHO, Science in Sport, UK); *(6) Cereal Bars*: Tadım Sportive Bar (30 g, 12 g CHO, Tadım, Istanbul, Turkey); *(7) Sports Drink*: Powerade (500 mL bottle, 19.5 g CHO, Coca-Cola Company, Atlanta, USA); *(8) Banana:* ~27 g CHO per 120 g average fruit.

caffeine-containing gels were used more frequently by cyclists (40.9%) than marathoners (23.7%). CHO drink powders were also more common among cyclists (27.3% vs. 5.3%), reflecting a broader fueling strategy. Minimal use of other sources such as gummies, bars, or bananas was reported, with cyclists alone consuming cereal bars (4.5%) and bananas (9.0%). These findings suggest that athletes prioritized easily digestible, high-CHO options like gels, particularly cyclists who displayed more variety and higher usage of CHO-rich products. Among leftover products, gels accounted for the largest portion of unconsumed items, whereas CHO drink powders, gummies, and sports drinks contributed minimally.

The violin plots (Figure 1) highlight significant discrepancies between planned, perceived, and actual CHO intake during races, particularly among marathoners. In marathoners, actual CHO intake (21.7 ± 15.4 g/hr) was significantly lower than both their planned (25.9 ± 18.3 g/hr) and perceived intake, with mean differences of 4.2 g/hr ($p < 0.001$, $d = 0.25$). This is visually represented by narrower distributions and downward shift in the actual intake plot, confirming that marathoners not only consumed less than intended but also overestimated their intake ($p < 0.01$ and $p < 0.001$, respectively). In contrast, cyclists planned substantially higher CHO intakes (~59 g/h) and, although they also under-consumed (actual: 49.1 ± 25.2 g/h), their absolute planned-actual gap was larger than in marathoners (~10.3 vs. ~4.2 g/h), whereas the proportional shortfall was similar to slightly larger (~17% vs. ~16%). Perceived intake in cyclists closely matched the actual intake, whereas marathoners over-estimated their intake (perceived > actual).

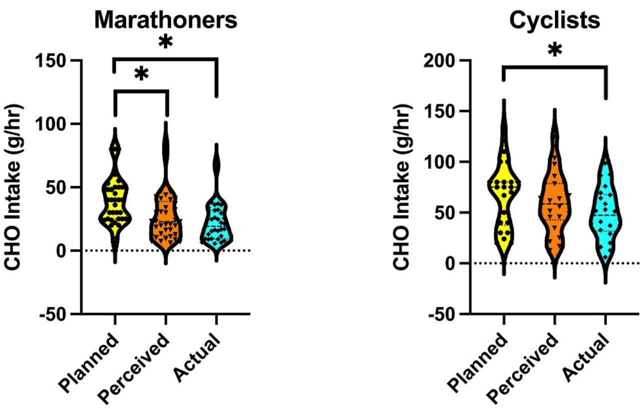

FIGURE 1 | Comparison of planned, perceived, and actual carbohydrate (CHO) intake during races among marathoners and cyclists. 'Planned' refers to the amount of carbohydrate (CHO) the athlete intended to consume during the race, 'perceived' is the amount they believed they had consumed, and 'actual' represents the objectively measured intake based on pre- and post-race product weighing. *: $p < 0.005$.

3.4 | Factors Influencing CHO Intake in Race

Multiple linear regression models were computed to identify predictors of actual CHO intake during the race (Table 6). In Model 1, race type alone explained 31% of the variance in CHO intake ($R^2 = 0.31$), but the overall model was not statistically significant ($F(1,58) = 2.01$, $p = 0.12$), despite race type being a significant individual predictor ($B = 27.361$, $p < 0.001$), with cyclists consuming more CHO than marathoners. In Model 2, the inclusion of sleep behavior (ASBQ total score) significantly improved model fit ($R^2 = 0.37$, $F(2,57) = 16.49$, $p < 0.001$), and both predictors were significant: race type ($B = 23.303$, $p < 0.001$) and better sleep behavior ($B = 0.745$, $p = 0.047$). This model emerged as the best-fitting and only statistically significant model. Model 3, which added cognitive anxiety, explained 41% of the variance ($R^2 = 0.41$), and all predictors were individually significant, race type ($B = 22.741$, $p < 0.001$), sleep

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TABLE 6 | Multiple linear regression models predicting actual CHO intake.

Variables	B	SE	β	t	p	R^2	F
Model 1	−5.656	7.578	—	−0.746	0.458	0.31	27.377
Race type	27.361	5.229	0.566	5.232	< 0.001*		
Model 2	−24.215	11.748	—	−2.061	0.044*	0.37	16.488
Race type	23.303	5.472	0.482	4.259	< 0.001*		
Sleep behaviors (ASBQ total score)	0.745	0.367	0.230	2.031	0.047*		
Model 3	−13.786	12.500	—	−1.103	0.275	0.41	13.030
Race type	22.741	5.330	0.471	4.267	< 0.001*		
Sleep behaviors (ASBQ total score)	0.853	0.361	0.263	2.365	0.021*		
Cognitive anxiety (CSAI-2R score)	−0.862	0.419	−0.213	−2.059	0.044*		

Note: This table presents the results of three hierarchical multiple linear regression models assessing predictors of actual carbohydrate (CHO) intake during the race. The predictors included race type (coded as marathoners = 1, cyclists = 0), total sleep behavior assessed by the Athlete Sleep Behavior Questionnaire (ASBQ), and cognitive anxiety measured by the Competitive State Anxiety Inventory-2 Revised (CSAI-2R). B refers to the unstandardized regression coefficient, SE is the standard error of B, β (beta) represents the standardized regression coefficient (effect size), *t* is the t-statistic, and *p* indicates the significance level ($p < 0.05$ considered statistically significant; denoted by *). R^2 represents the proportion of variance in CHO intake explained by the model, and *F* indicates overall model fit.

behavior ($B = 0.853$, $p = 0.021$), and cognitive anxiety ($B = -0.862$, $p = 0.044$). However, the overall model again failed to reach statistical significance ($F(3,56) = 2.01$, $p = 0.12$), suggesting that although these factors are independently associated with CHO intake, their combined predictive capacity was not robust in this sample.

Figure 2 illustrates the relationship between actual CHO intake (g/hr) and race duration (min) for marathoners and cyclists using linear regression. In marathoners (left panel), there is a weak negative relationship ($R^2 = 0.09$), indicating that race duration accounts for only 9% of the variance in CHO intake. In contrast, cyclists (right panel) exhibit a moderate negative association ($R^2 = 0.52$), meaning that 52% of the variability in CHO intake is explained by race duration.

4 | Discussion

The present study investigated actual CHO intake during endurance races by comparing pre- and postrace weights of nutrition products and explored how behavioral and physiological factors such as sleep, anxiety, gastrointestinal symptoms, and CHO loading the day before may influence in-race intake. Our key findings are (1) across the cohort, actual in-race CHO intake was lower than planned; (2) cyclists consumed more CHO overall and used a wider variety of products than marathoners, and their absolute planned-actual gap was larger, whereas the proportional shortfall was similar between groups; (3) both groups consumed less than planned, but only marathoners significantly overestimated their intake (perceived > actual); (4) among leftover products, CHO gels accounted for the largest portion of unconsumed items, whereas CHO drink powders, gummies, and sports drinks contributed minimally; and (5) multiple regression analyses showed that better sleep behavior (ASBQ) and lower cognitive anxiety (CSAI-2R) were significant predictors of higher actual CHO intake. These findings underscore the complexity of in-race fueling behavior and the need to consider psychological and behavioral factors when developing individualized nutrition strategies for endurance athletes.

Despite guidance recommending ~60–90 g/h for exercise lasting > 2.5 h (Burke et al. 2011; Jeukendrup 2014; Thomas et al. 2016), both marathoners and cyclists fell below this range: marathoners averaged 21.7 ± 15.4 g/h and cyclists 49.1 ± 25.2 g/h. These findings align with previous literature, which reports CHO intake during competition ranging from 35.4 to 52 g/h in marathon runners (Sampson et al. 2024; Jiménez-Alfageme et al. 2025; Hoogervorst et al. 2019) and 63–90.8 g/h in cyclists (Havemann and Goedecke 2008; Muros et al. 2019), suggesting generally higher intake among cyclists. Notably, although cyclists in our study had a larger absolute gap between planned and actual intake (10.3 g/h, $p < 0.001$), the proportional shortfall was comparable (~17% vs. ~16%). Additionally, marathoners significantly overestimated their intake, with actual CHO intake falling below both their planned (25.9 ± 18.3 g/h) and perceived amounts ($p < 0.01$ and $p < 0.001$), indicating a disconnect between perceived and actual fueling. The discrepancy between planned and actual CHO intake suggests not just a planning-execution mismatch but potentially leftover products (e.g., unused gels/gummies). Future analysis should integrate leftover tracking (e.g., unused gels) and qualitative data (e.g., reasons for nonconsumption) to better understand adherence behaviors and refine personalized fueling strategies.

Contrary to our hypothesis, prerace CHO intake did not significantly predict in-race CHO intake in either marathoners or cyclists. This finding suggests that insufficient CHO loading in the 24 h prior to competition may not necessarily influence actual CHO intake during the race, at least among nonelite endurance athletes. One possible explanation is that athletes may treat prerace and in-race fueling as separate strategies, with race-day intake determined more by real-time factors such as gastrointestinal tolerance, perceived effort, and logistical accessibility of products rather than prior nutrition.

Consistent with controlled trials comparing drink, gel, jelly-chew, and mixed formats at ~120 $g \cdot h^{-1}$ glucose + fructose and solid bar versus drink, exogenous CHO oxidation and tolerance are broadly comparable across forms, suggesting that format per se is not limiting when the intake rate and CHO type

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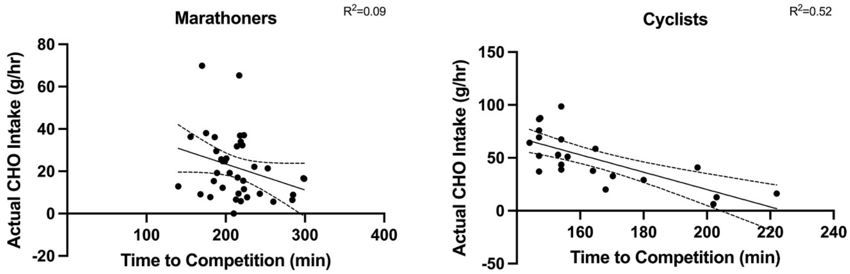

FIGURE 2 | Interaction between race duration and actual carbohydrate intake in marathoners and cyclists. Each dot represents an individual participant. Solid lines indicate linear regression fit; dashed lines represent 95% confidence intervals. The R^2 value (coefficient of determination) is shown in the top right corner of each graph.

are optimized (Hearris et al. 2022; Pfeiffer et al. 2010). However, our findings suggest that the delivery form may influence consumption behavior: CHO gels accounted for the largest proportion of leftover products, whereas CHO drink powder, gummies, and sports drinks were largely consumed. Notably, cyclists used a wider range of CHO products, with CHO drink powder being more common, reflecting a more diverse fueling strategy. These findings suggest that although gels are popular for their practicality, they may be more prone to partial consumption, which can lead to overestimation of actual CHO intake. This result highlights the importance of product design and environmental factors in fueling behavior.

Our findings support the hypothesis that higher cognitive anxiety is associated with lower actual CHO intake during endurance events. Regression analysis showed that being a cyclist, having better sleep behaviors, and experiencing lower cognitive anxiety predicted higher CHO intake. This aligns with earlier research showing that runners with improved performance often exhibit moderate cognitive anxiety, low somatic anxiety, and high self-confidence, an adaptive psychological profile (Jaenes Sanchez and Caracuel 2016). Although moderate anxiety may be motivating, excessive anxiety can impair appetite, digestion, and focus, hindering mid-race fueling. Self-confidence may help temper these effects and support better execution of nutrition strategies (Houltberg et al. 2018; Tracey and Elcombe 2004). These findings highlight the importance of managing anxiety to optimize fueling behavior and performance in endurance athletes.

In addition to its role in recovery, sleep quality emerged as a significant predictor of race-day CHO intake in our study, reinforcing the broader importance of sleep in endurance sports. Among marathon runners, research has shown that poor sleep behavior, particularly longer sleep onset latency and pre-bedtime screen use, is associated with longer marathon completion times, potentially due to impaired recovery, increased fatigue, and disrupted fueling behaviors (Cook et al. 2023). Notably, 23.5% of marathoners in a large cohort reported sleep difficulties severe enough to warrant professional support. Similarly, sleep deprivation is a well-documented and often necessary feature of ultra-endurance cycling, with narrative reviews highlighting its negative impact not only on performance but also on psychological well-being (Smith et al. 2022). Despite the growing popularity of long-distance cycling and running events, sleep behavior remains under investigated in both populations. Taken together, these findings suggest that addressing sleep disturbances—whether behavioral or race-induced—may support better fueling execution and endurance performance across disciplines.

Analysis of macronutrient and fluid intake revealed clear differences in fueling strategies between marathoners and cyclists across the 24-h, prerace, and in-race periods. Cyclists consumed significantly more energy, CHO, protein, and fat during the race, but less fluid than marathoners. These patterns suggest more aggressive fueling strategies among cyclists especially considering the shorter race duration compared to marathoners. Although GI distress is often cited as a limiting factor for CHO intake (Pfeiffer et al. 2012), our data showed no significant difference between groups in upper or lower GI symptoms either pre- or postrace ($p > 0.20$ for all comparisons). Serious symptoms (rated > 4) were reported by only a small proportion of athletes (prerace GI symptoms: 7.9% marathoners, 13.6% cyclists; postrace GI symptoms: 10.5% marathoners, 4.5% cyclists), with no statistically significant difference between participants. Therefore, the discrepancies in CHO intake are unlikely to be explained by GI complaints alone and may instead reflect other factors such as fueling logistics, accessibility of products, better sleep behaviors, lower race anxiety, or different nutrition strategies.

Another key finding was that cyclists' perceived that CHO intake closely matched their planned intake, yet their actual intake was significantly lower than what they had planned. This suggests that although cyclists believed they consumed what they had intended for the race, they unknowingly underconsumed. This reinforces the importance of accounting for leftover product to accurately assess true CHO consumption.

This study has several strengths that enhance its relevance and applicability. Most notably, to the best of our knowledge, it is the first attempt at weighing sport nutrition products to accurately measure actual CHO intake during the race, moving beyond traditional self-reported estimates. It was also focused on a nonelite population, a group often underrepresented in sports nutrition research, and was conducted in a real-life race setting, adding ecological validity. The inclusion of multiple validated tools, such as the CSAI-2R and the ASBQ, allowed for comprehensive assessment of psychological and sleep-related variables. Additionally, the diverse sample, including both marathoners and cyclists, provides valuable insights into discipline-specific fueling behaviors. However, some limitations should be acknowledged. The sample size (n = 60) limits the generalizability of findings, and objective sleep data via

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actigraphy were not collected, relying instead on self-reported ASBQ scores. Although pre/post weighing enhances accuracy, the requirement to carry products and leftovers may alter behavior; for example, runners might avoid picking up or finishing a bottle to prevent carrying it, or conversely consume more than intended to avoid leftovers. In marathons, participants could offload at the 20-km aid station or the finish; cyclists kept bottles in standard cages with immediate post-finish collection. Only self-selected, planned products were carried (no investigator-supplied items). Nevertheless, any behavior modification could bias intakes upward or downward and cannot be quantified in this study. Notably, actual intake remained lower than planned overall, suggesting this limitation did not mask a general pattern of under-consumption. Because we did not measure sleep on the night preceding the race (e.g., actigraphy or sleep diary), associations between sleep and race-day intake should be interpreted with caution. Furthermore, potential recall bias in reporting CHO loading strategies prior to the race may have influenced data accuracy.

These findings highlight the need to educate endurance athletes, particularly marathon runners, on the importance of adequate CHO fueling before and during races, as many fall short of evidence-based guidelines. Practitioners should recommend structured CHO strategies that align with current recommendations (e.g., 10–12 g/kg/day prerace and 60–90 g/h during competition) and emphasize the role of real-time monitoring (e.g., weighing leftovers) to assess actual intake. In addition, athletes and coaches should be encouraged to evaluate psychological and sleep-related factors in the days leading up to competition, as these can influence race-day fueling behaviors. Expanding this line of research to include ultra-endurance and elite-level populations will help determine whether similar behavioral patterns and barriers to optimal intake exist in more experienced or high-performance groups.

5 | Conclusion

This study reveals a significant discrepancy between planned, perceived, and actual CHO intake during endurance events, particularly among nonelite marathoners. Through a multi-method approach combining weighed food records, validated psychological and sleep behavior questionnaires, and postrace assessments, this study contributes to a more nuanced understanding of how behavioral and physiological factors influence race-day nutrition practices in endurance athletes. Despite well-established guidelines, most athletes under-consumed CHO on race day, often overestimating their intake, especially when relying on gels, which had the highest leftover rate. Cyclists demonstrated better fueling strategies and stronger adherence to planned intake, influenced by better sleep behaviors and lower cognitive anxiety. The occurrence of GI symptoms was similar between cyclists and marathoners, suggesting that GI distress did not account for the observed differences in fueling strategies between the groups. These findings emphasize the importance of integrating behavioral, psychological, and practical considerations into individualized race nutrition strategies.

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We are grateful to all participants for their time, commitment, and valuable contributions to this research.

Ethics Statement

This study received ethical approval from the university's research ethics committee (Approval No: 2024/9; Date: October 30, 2024) and was conducted in accordance with the Declaration of Helsinki. As a cross-sectional study, it was not subject to clinical trial registration.

Consent

All participants were provided with comprehensive written and verbal information about the study's purpose, procedures, and potential risks and benefits. Written informed consent was obtained from all participants before enrolment.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data generated and analyzed during this study can be obtained from the corresponding author upon reasonable request.

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