Nutritional Intake and Gastrointestinal Problems during Competitive Endurance Events

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ABSTRACT

PFEIFFER, B., T. STELLINGWERFF, A. B. HODGSON, R. RANDELL, K. PÖTTGEN, P. RES, and A. E. JEUKENDRUP. Nutritional Intake and Gastrointestinal Problems during Competitive Endurance Events. *Med. Sci. Sports Exerc.*, Vol. 44, No. 2, pp. 344–351, 2012. There is little information about the actual nutrition and fluid intake habits and gastrointestinal (GI) symptoms of athletes during endurance events. **Purpose**: This study aimed to quantify and characterize energy, nutrient, and fluid intakes during endurance competitions and investigate associations with GI symptoms. **Method**: A total of 221 endurance athletes (male and female) were recruited from two Ironman triathlons (IM Hawaii and IM GER), a half-Ironman (IM 70.3), a MARATHON, a 100/150-km CYCLE race. Professional cyclists (PRO) were investigated during stage racing. A standardized postrace questionnaire quantified nutrient intake and assessed 12 GI symptoms on a scale from 0 (no problem) to 9 (worst it has ever been) in each competition. **Results**: Mean CHO intake rates were not significantly different between IM Hawaii, IM GER, and IM 70.3 (62 ± 26, 71 ± 25, and 65 ± 25 $g \cdot h^{-1}$, respectively), but lower mean CHO intake rates were reported during CYCLE (53 ± 22 $g \cdot h^{-1}$, $P = 0.044$) and MARATHON (35 ± 26 $g \cdot h^{-1}$, $P < 0.01$). Prevalence of serious GI symptoms was highest during the IM races (~31%, $P = 0.001$) compared with IM 70.3 (14%), CYCLE (4%), MARATHON (4%), and PRO (7%) and correlated to a history of GI problems. In all data sets, scores for upper and lower GI symptoms correlated with a reported history of GI distress ($r = 0.37$ and $r = 0.51$, respectively, $P < 0.001$). Total CHO intake rates were positively correlated with nausea and flatulence but were negatively correlated with finishing time during both IM ($r = -0.55$ and $r = -0.48$, $P < 0.001$). **Conclusions**: The present study demonstrates that CHO intake rates vary greatly between events and individual athletes (6–136 $g \cdot h^{-1}$). High CHO intake during exercise was related not only to increased scores for nausea and flatulence but also to better performance during IM races. **Key Words:** CHO INGESTION, GASTROINTESTINAL DISTRESS, RUNNING, CYCLING, TRIATHLON, FIELD STUDY

The popularity of mass participation in endurance and ultraendurance events is ever increasing. Athletes participating in these events are required to sustain relatively high work rates for a prolonged period, which results in high sweat rates and energy expenditure. Fatigue during endurance events is generally not caused by a single factor but is the result of a multifaceted phenomenon that often coincides with dehydration, hyperthermia, CHO depletion, central fatigue, and hypoglycemia (1,22). To delay the onset of fatigue and optimize prolonged endurance performance, it is recommended to compensate fluid and electrolyte losses as well as to fuel the body with energy from CHOs (for review, see position stand [2]). Because CHO intake has been shown to improve endurance capacity and performance (for review, see Jeukendrup [21]), the current position stand of the American College of Sports Medicine (ACSM) and the American Dietetics Association (ADA) advises athletes to consume CHO at rates of 0.7 $g \cdot kg^{-1}$ body weight per hour (30–60 $g \cdot h^{-1}$) during endurance events (2). An alternative contemporary recommendation (21) suggests higher CHO intake rates of up to 90 $g \cdot h^{-1}$ for athletes competing in intense (ultra)endurance events longer than 2 h. The rationale to recommend higher CHO intake rates is based on recent research that revealed higher exogenous CHO oxidation rates (19,23) and superior performance (7) with the ingestion of much glucose + fructose blends compared with isoenergetic amounts of glucose. However, whether athletes actually manage to meet these recommendations remains to be established.

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There are only limited and partly contradicting data available about nutritional intake strategies of athletes during endurance events. Several studies have investigated CHO and fluid intake of athletes during events longer than 2 h (Table 1). However, excluding retrospective studies, to the best of our knowledge, all previous studies have focused on a single event, and most studies were conducted with fewer than 20 subjects. For example, reported CHO intake rates in professional cyclists range from as little as 25 $g \cdot h^{-1}$ (9) up to 94 $g \cdot h^{-1}$ (37). The difference among studies could be because of difficulties measuring nutrient intake during competitions, variation in the methodology, environmental conditions, or changing nutritional practices during the years between the studies. Furthermore, a large interindividual difference in nutritional intake habits has been reported in numerous studies investigating athletes during various events (8,9,13,17,26,37), and it is therefore difficult to draw conclusions from small sets of data. It may also be inappropriate to extrapolate findings from one sporting event to another. A retrospective questionnaire–based study by Peters et al. (27) compared food and fluid intakes among different endurance sports in 422 athletes. Higher liquid and food intakes were reported by triathletes compared with runners. Hence, although current recommendations do not differentiate between runners, cyclists, and triathletes (2), it is possible that the nutritional intake strategies used are very different.

Furthermore, a limitation of nutritional recommendations during exercise is the limited consideration of the negative effect that gastrointestinal (GI) distress might have on exercise performance. The intake of several nutrients, such as fat, fiber, and protein, has previously been linked to GI distress during exercise (29). In several studies, ingestion of CHO, and in particular hypertonic drinks, has been related to GI distress (27,29,34). In contrast, a recent series of studies has suggested that the intake of high rates of CHO ($\sim$1.4 $g \cdot min^{-1}$) in the form of gels is well tolerated from most athletes during simulated 10-mile (16-km) running races under mild environmental conditions (30). However, it has to be kept in mind that the incidence of GI problems increases with exercise time (28) and might be increased under hotter and more humid weather and competition conditions. Therefore, the effect of nutrient intake on GI symptoms during more extreme events with longer duration remains unclear.

The purposes of the present study were 1) to quantify and characterize the food and fluid intake of athletes during marathon running, road cycling, and long-distance triathlon using a large subject pool with the same GI questionnaire–based methodology and 2) to investigate whether nutrient (especially CHO) intake, fluid consumption, training status, and race distance is correlated with the incidence of GI distress and/or performance outcomes. According to previous research, we speculated that fat and fiber intake and hot and humid weather conditions would be positively correlated with GI distress. We also hypothesized that high CHO

TABLE 1. Reported nutritional intake of (ultra-)endurance athletes during events in previous studies (mean ± SD).

Reference	Sport	Event/Distance	Survey Method	Subjects	Exercise Time (h:min)	Ambient Temperature (°C)	CHO Intake	Fluid Intake
Saris et al. (37)	Cycling	Tour de France (3 wk)[a]	Food diary questionnaires	5 M	5:14	NA	94 $g \cdot h^{-1}$	$\sim$1250 $mL \cdot h^{-1}$
García-Roves et al. (9)	Cycling	Tour de France (three stages)[a]	Food diary questionnaires	10 M	NA	NA	25 $g \cdot h^{-1}$ (10–43 $g \cdot h^{-1}$)	6700 ± 200 $mL \cdot d^{-1}$
Havemann and Goedecke (17)	Cycling	Road race (210 km)	Food diary questionnaires	45 M	7:18 ± 1:03	28–30	63 ± 23 $g \cdot h^{-1}$ (28–145 $g \cdot h^{-1}$)	600 ± 178 $mL \cdot h^{-1}$ (282–167 $mL \cdot h^{-1}$)
Kimber et al. (26)	Triathlon	Ironman	Seven interviews during race	18 (10 M and 8 F)	M: 12:00 ± 0:36 F: 12:36 ± 0:54	21	M: 82 $g \cdot h^{-1}$[b] F: 62 $g \cdot h^{-1}$[b]	M: $\sim$763 $mL \cdot h^{-1}$[b] F: $\sim$628 $mL \cdot h^{-1}$[b]
Colombani et al. (4a)	Multisport	Gigathlon (244 km)	Questionnaires before/after; interview at transition/finish	12	18:36 (17:00–19:48)[c]	NA	60 $g \cdot h^{-1}$ (36–90 $g \cdot h^{-1}$)[c]	560 $mL \cdot h^{-1}$ (310–790 $mL \cdot h^{-1}$)[c]
Glace et al. (13)	Running	Ultramarathon (160 km)	Interview during race (every 13 km)	19 (18 M and 1 F)	24:18	NA	50 $g \cdot h^{-1}$	765 $mL \cdot h^{-1}$
Glace et al. (14)	Running	Ultramarathon (160 km)	Interview during race (every 13 km)	26 (21 M and 5 F)	26:12 ± 3:36	up to 38	54 $g \cdot h^{-1}$[d]	740 $mL \cdot h^{-1}$[d]
Fallon et al. (8)	Running	Ultramarathon (100 km)	Dietary record by investigators during event	7 M	10:29	2–17	43 ± 16 $g \cdot h^{-1}$	540 ± 210 $mL \cdot h^{-1}$
Zimberg et al. (40a)	Adventure race	Laboratory simulation (477 km)	Dietary record by investigators during event	10 M	67:00	NA	$\sim$36 $g \cdot h^{-1}$	NA

When no SD or raw data were published, only means are reported.
[a] PRO athletes.
[b] Calculated from relative fluid intake per kilogram of body weight.
[c] Values are median (range).
[d] Calculated for 16 finishers.
M, male participants; F, female participants.

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intake rates during prolonged exercise would be correlated with increased performance.

METHODS

Subjects. For this study, different levels of athletes were recruited: amateur and pro triathletes, amateur cyclists, professional cyclists from two different pro cycling teams (both in the top 10 of the International Cycling Union ranking), and amateur runners. Athletes were recruited via e-mail or were personally approached on the event exhibition. All participants of the study were informed about the purpose of the study, the practical details, and the risks associated with the procedure before giving their written consent. The study was approved by the School of Sport and Exercise Sciences ethics subcommittee, University of Birmingham, Birmingham, United Kingdom.

Events. Table 2 highlights the different events, including subject characteristics and race conditions. All competitions occurred between June and October 2009.

Triathlon. Three different triathlons were investigated, featuring two different race distances: two full-distance Ironman (IM) races, each covering a 3.8-km swim, 180-km bike, and a 42.2-km run, and an Ironman 70.3 (IM 70.3) race, which covers half of the IM distances (1.9-km swim, 90-km bike, and 21.1-km run). Data were collected during the IM European Championships in Frankfurt, Germany (IM GER), the IM World Championships in Hawaii (IM Hawaii), and during the IM Germany 70.3 in Wiesbaden, Germany (IM 70.3).

Road cycling. Professional cyclists (PRO) from two different teams were investigated. One professional cycling team was investigated during two flat stages (228 and 182 km) of the Dauphine Liberé, France. The other professional cycling team was studied during the Vuelta a España (Tour of Spain). Two mountain stages (204.7 and 188.8 km) and a flat stage (171.2 km) were investigated. Amateur cyclists were investigated at the Vattenfall Cyclassics cycling race, Hamburg, Germany (CYCLE). Half of the subjects participated in a shorter 100-km event, whereas the other half completed 155 km on a slightly hilly course.

Running. A city marathon (42.2 km) with a relatively flat course profile was investigated in Munich, Germany (MARATHON).

Experimental design. Subjects were recruited via e-mail or at the event exhibition and had at least one personal contact with the investigators before the event where they were carefully instructed and briefed about the importance of the accuracy in their responses. During the briefing, athletes were also given strategies to remember food and fluid consumption during the race, such as for participants with a nutrition plan to remember any deviations from the plan. The participants then filled in one questionnaire before the event to assess training history, nutritional habits, and history of GI discomfort and one after the event to accurately quantify their fluid and food intake and rate their GI discomfort during the event. To ensure the accuracy of data, replies were followed up via e-mail or in personal communications whenever possible. Professional cyclists were individually interviewed immediately after the race days rather than asked to fill in the questionnaires themselves.

Prerace questionnaire. One or two days before the events, subjects were asked to complete a first questionnaire to assess personal characteristics, training history, nutritional habits, and history of GI problems.

Race-day questionnaire. In the evening after the races, all participants received an e-mail with the second questionnaire, reminding them to fill it in as soon as possible, but no longer than 2 d after the race. Race environmental conditions were collected from local weather stations, and these are expressed as heat index. The heat index takes increased humidity into account, which can lead to increased heat stress and is described elsewhere (15). The questionnaire after the race asked the participants to accurately write down what they ingested in the morning, before the race, and during the entire race.

The food and fluid intake was assessed by mentioning the available food and fluid options from the event organizer and giving examples on precision of amounts (e.g., water in milliliters or cups or bottles). For the triathlon races, all food and fluid intake at the start (up to 30 min before the race) was counted into the swim section of the event, the first and second transition were counted into the cycle and

TABLE 2. Subjects characteristics and ambient conditions for all endurance events (mean ± SD).

	Heat Index (°C)	Participants (Male/ Female)	Age (yr)	Height (m)	Body Weight (kg)	Finish Time (h:min)	Endurance Training Experience (yr)	Running Training ($h \cdot wk^{-1}$)	Cycling Training ($h \cdot wk^{-1}$)	Total Training ($h \cdot wk^{-1}$)
IM Hawaii[a]	29 (26–36)	53 (34/19)	41 ± 13	171 ± 26	67 ± 16	11:40 ± 2:05	13 ± 9	6 ± 3	11 ± 4	19 ± 8
IM GER[b]	25 (15–33)	54 (45/9)	38 ± 7	176 ± 26	73 ± 11	11:09 ± 1:23	12 ± 8	5 ± 1	12 ± 1	17 ± 6
IM 70.3[c]	24 (15–34)	43 (36/7)	38 ± 7	178 ± 13	75 ± 13	6:05 ± 0:44	11 ± 10	4 ± 2	7 ± 3	13 ± 5
MARATHON	12 (7–14)	28 (22/6)	45 ± 12	177 ± 10	71 ± 13	3:46 ± 0:34	13 ± 9	6 ± 3	NA	NA
CYCLE	20 (15–24)	28 (28/0)	41 ± 7	185 ± 8	81 ± 13	3:32 ± 0:42	14 ± 11	NA	7 ± 4	NA
PRO team Dauphine Liberé	17 (10–23)	7 (7/0)	31 ± 5	181 ± 5	70 ± 5	5:04 ± 0:32	17 ± 5	NA	23 ± 2	NA
PRO team VUELTA	25 (19–31)	8 (8/0)	29 ± 3	181 ± 5	71 ± 7	5:22 ± 1:01	16 ± 5	NA	23 ± 2	NA

[a] Amateurs and two PRO athletes.
[b] Amateur and three PRO athletes.
[c] Amateurs and one PRO athlete.
NA question was not assessed.

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run section, respectively. Afterward, data on food and fluid intake were evaluated by a trained nutritionist using NutritionistPro™ (Axxya Systems, Stafford, TX), following up estimated energy, nutrient, and fluid intakes in personal or e-mail conversations if there were doubts. Furthermore, participants were asked to answer questions on GI problems, adapted from a previous research (30). The questions about GI symptoms were similar in the prerace questionnaire, which assessed race occurrence and history of GI symptoms. The questionnaires were organized in three sections, and each section included between four and seven questions. Section 1 addressed upper abdominal problems (reflux/heartburn, belching, bloating, stomach cramps/pain, nausea, vomiting); section 2 addressed lower abdominal problems (intestinal/lower abdominal cramps, flatulence, urge to defecate, side ache/stitch, loose stool, diarrhea, intestinal bleeding); and section 3 addressed systemic problems (dizziness, headache, muscle cramp, urge to urinate). Each question was assessed on a 10-point scale, ranging from 0 or "no problem at all" to 9 or "the worst it has ever been."

Statistical analysis. Nutrient intake data, training details, and performance data were normally distributed and evaluated with a parametric statistical approach. Mean values from different events were compared using one-way ANOVA. A Tukey *post hoc* test was applied where a significant F-ratio was detected. For comparison of mean values between modes of exercise within one triathlon, a repeated-measures one-way ANOVA was used and followed up with a Tukey *post hoc* test if a significant F-ratio. Possible correlations between race performance (finish time) and nutrient intake during the races were analyzed using the Pearson correlation coefficient.

To evaluate data on GI symptoms, a nonparametric statistical approach was chosen, as scores on GI symptoms were mainly recorded on the low end of the scale and not normally distributed. Mean values were compared with the use of Mann–Whitney tests. Factors that have previously been linked to GI distress, such as environmental conditions and history of GI distress, were analyzed using the Spearman rank correlation coefficient. Because the overall 12 GI symptoms were answered after 6 different events, the false-positive rate of 5% could be inflated owing to the multiple tests. To reduce multiplicity, analysis was restricted to data from triathlon events, which revealed highest frequency for GI symptoms and took place under similar conditions. First, analyses were performed on averages over a section of symptoms (upper and lower abdominal problems). Second, correlations were performed for individual questions during each triathlon. The P values of those tests were not adjusted for multiple tests. Therefore, the P values serve as a flag to indicate interesting results. Furthermore, GI symptoms that were scored > 4 were classified as "serious." For all tests, P values < 0.05 were considered significant. All data are reported as means ± SD. In addition, minimum and maximum scores are reported for nutrient intake data. Statistics were performed using SPSS version 15 for Windows (SPSS, Inc., Chicago, IL).

RESULTS

Race Conditions and Participants' Characteristics

Race conditions (ambient temperature, expressed as heat index), participant characteristics, including finishing times of the events, and details about training experience are shown in Table 2.

Nutrient Intake (CHO, Fluid, Sodium, and Caffeine)

An overview of energy, nutrient, and fluid intakes during the different races is shown in Table 3.

CHO intake rates. Mean CHO intake rates were not significantly different between IM Hawaii, IM GER, and IM 70.3 (62 ± 26, 71 ± 25, and 65 ± 25 g·h^{-1}, respectively, $F_{2,145}$ = 1.6, P = 0.2). Comparison of mean CHO intake rates between triathlons, marathon, and cycling races showed a significant effect of the event on CHO intake rates ($F_{3,216}$ = 13.9, P < 0.001). In contrast to the triathlons, the average CHO intake rate during CYCLE was significantly lower (53 ± 22 g·h^{-1}, P = 0.044). The lowest mean CHO intake rates were reported during MARATHON (35 ± 26 g·h^{-1}), which were significantly lower than intake rates during CYCLE (P = 0.034) and all triathlon events (P < 0.001). Regardless of the event, individual CHO intakes among athletes varied greatly (range = 6–136 g·h^{-1}).

Within all triathlon events, CHO intake rates depended significantly on the mode of exercise, with significantly higher intakes during the cycling section compared with the run (P < 0.05; Fig. 1).

Form of CHO intake. Carbohydrate was ingested in solid, liquid, and gel form during all events. CHO-containing drinks supplied between 29% (MARATHON) and 49% (IM Hawaii) of the total CHO intake. CHO gels accounted for 28% (CYCLE) to 45% (MARATHON) of the race's CHO intake. Only 15% of CHO was ingested in solid form during IM Hawaii, whereas solid CHO intake made up 37% of the CHO intake during the PRO races.

TABLE 3. Nutrient intakes during endurance events (mean ± SD).

	Fluid (mL·h^{-1})	kcal·h^{-1}	CHO (g·h^{-1})	Protein (g·h^{-1})	Fat (g·h^{-1})	Fiber (g·h^{-1})	Sodium (mg·h^{-1})	Caffeine (mg·h^{-1})
IM Hawaii	794 ± 309 (146–1617)	258 ± 96 (117–472)	62 ± 26 (22–124)	2 ± 2 (0–6)	1 ± 1 (0–7)	1 ± 1 (0–3)	422 ± 213 (127–1116)	26 ± 22 (0–78)
IM GER	703 ± 238 (352–1656)	292 ± 104 (114–564)	71 ± 25 (33–126)	2 ± 2 (0–10)	1 ± 1 (0–4)	1 ± 1 (0–2)	444 ± 216 (69–975)	33 ± 29 (0–100)
IM 70.3	700 ± 254 (318–1385)	265 ± 105 (96–494)	65 ± 25 (31–122)	3 ± 3 (0–12)	1 ± 1 (0–5)	1 ± 1 (0–4)	403 ± 193 (91–936)	28 ± 24 (0–107)
MARATHON	354 ± 187 (81–918)	146 ± 102 (18–527)	35 ± 26 (6–136)	3 ± 5 (0–16)	1 ± 1 (0–13)	2 ± 3 (0–12)	118 ± 87 (9–321)	23 ± 32 (0–125)
CYCLE	643 ± 599 (69–1012)	233 ± 103 (53–557)	53 ± 22 (13–114)	3 ± 3 (0–13)	1 ± 1 (0–5)	1 ± 1 (0–4)	208 ± 183 (15–857)	21 ± 29 (0–108)
PRO	711 ± 270 (333–1268)	284 ± 76 (167–431)	64 ± 20 (29–107)	4 ± 2 (0–8)	2 ± 2 (0–6)	1 ± 1 (0–2)	311 ± 156 (164–768)	12 ± 14 (0–45)

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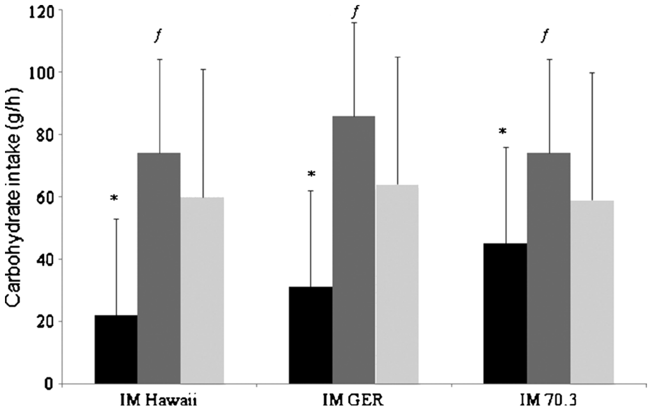

FIGURE 1—CHO intake during IM Hawaii, IM GER, and IM 70.3 split into swim (*black*), cycle (*dark gray*), and run (*light gray*) sections of the event (means ± SD). Intake up to 30 min before race start is included into the swim section. *Significantly different from cycle and run section. *f* Significantly different from run section. $P < 0.05$.

When analyzing CHO (from solid, gel, and liquid) together with fluid intake rate, an estimate of percent CHO solution consumed was calculated. On average, the percent CHO solution across all six events was 10.6% ± 6.2%. The consumed percent CHO solution was significantly more diluted during IM Hawaii (8.8% ± 4.4%, $P < 0.05$) compared with all other events. The ingested CHO expressed as percent solution ranged from 3.5% to 27%.

Fluid intake. Fluid intake rates were not significantly different between all triathlon races ($F_{2,145} = 1.6$, $P = 0.20$; Table 3). However, ANOVAs showed that fluid intake rates were different between triathlons and the other races ($F_{3,216} = 20.9$, $P < 0.001$). During CYCLE, significantly lower fluid volumes were ingested compared with those ingested during triathlon (643 ± 599 $mL \cdot h^{-1}$, $P < 0.001$). Compared with all other events, the lowest fluid intake rates were reported during MARATHON (354 ± 187 $mL \cdot h^{-1}$; $P < 0.001$).

Fluid intake was higher during the cycle compared with the run section within all three triathlon events (849 ± 339 and 729 ± 377 $mL \cdot h^{-1}$, respectively, $P < 0.001$). Heat index highly correlated with fluid intake rates ($r = 0.9$, $P < 0.01$).

Within IM Hawaii and IM GER, fluid intake tended to be higher within males compared with females (IM Hawaii: 849 ± 280 and 675 ± 289 $mL \cdot h^{-1}$, respectively, $P = 0.03$; IM GER: 729 ± 245 and 575 ± 216 $mL \cdot h^{-1}$, respectively, $P = 0.08$). However, corrected for body weight, the differences were not significant.

GI Symptoms during the Races

Frequency of serious GI problems and ratings of upper and lower abdominal problems during events are displayed in Table 4. Significantly more participants reported serious GI problems (GI scores > 4) during IM Hawaii and IM GER compared with those during IM 70.3 (Table 4; $P = 0.001$). Only 4% of the athletes during CYCLE and MARATHON and 7% of all PRO cyclists reported serious GI problems.

History of GI symptoms. During all events, scores for upper and lower abdominal symptoms were positively correlated with the reported history of upper and lower abdominal symptoms ($r = 0.37$ and $r = 0.51$, respectively, $P < 0.001$).

CHO intake. Mean scores for upper and lower abdominal problems were not correlated with CHO intake rates in any of the triathlon events.

When scores for single GI symptoms were evaluated, some significant low to moderate correlations were detected. However, none of these individual GI symptoms were corrected for multiple tests. Nausea and flatulence were correlated with CHO intake rate in two data sets ($r = 0.33$ and $r = 0.34$ for nausea and $r = 0.34$ and $r = 0.35$ for flatulence during IM Hawaii and IM 70.3, respectively, $P < 0.05$). When triathletes were divided into subjects experiencing serious GI problems and subjects with mild or without GI problems, CHO intake rates were not significantly different between both groups (65 ± 25 and 69 ± 27 $g \cdot h^{-1}$, respectively, $P = 0.49$).

Race performance. During both IM events and MARATHON, faster finish times were correlated ($r = -0.55$, $r = -0.45$, and $r = -0.49$, $P < 0.01$) with high CHO intake rates (Fig. 2).

DISCUSSION

The present study featured food and fluid intake habits of athletes that were quantified with the use of the same standardized GI questionnaire methodology and a large subject pool ($n = 221$) during different endurance events. A major finding of the present study was that CHO intake rates varied greatly among running, cycling, and triathlon events but also among individual athletes. Previously recommended high CHO intake rates (up to 90 $g \cdot h^{-1}$) (21) were achieved by ~50% of the triathletes, 30% of the cyclists, and 15% of the marathon runners. High CHO intake rates were significantly correlated with faster finishing times, and although they were not associated with higher average scores for upper or lower GI symptoms, they did seem to be a risk factor for nausea and flatulence. However, it seems reasonable to advise athletes to aim for a relatively high CHO intake as tolerated by the individual.

TABLE 4. GI symptoms during endurance events: any of the 12 GI symptoms rated > 4 were considered as serious.

	% Serious Symptoms	Upper Abdominal Symptoms	Lower Abdominal Symptoms
IM Hawaii	32	0.89 ± 1.00	0.72 ± 0.80
IM GER	31	1.12 ± 1.18	0.70 ± 1.02
IM 70.3	14	0.84 ± 0.90	0.41 ± 0.54
MARATHON	4	0.33 ± 0.48	0.19 ± 0.27
CYCLE	4	0.20 ± 0.31	0.18 ± 0.27
PRO	7	0.20 ± 0.41	0.25 ± 0.23

Values for upper and lower GI symptoms are means ± SD.

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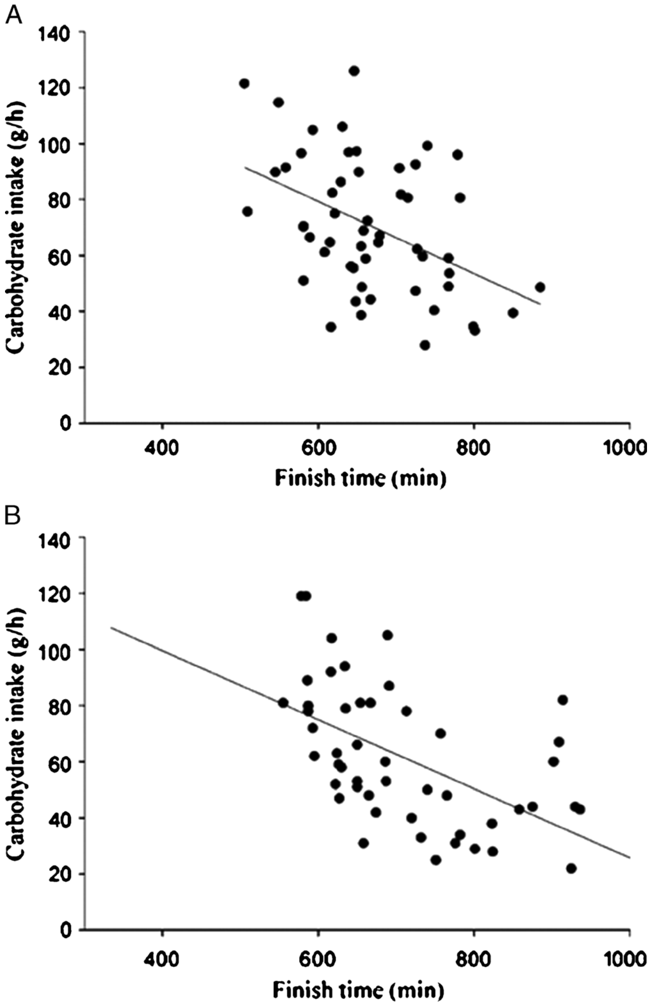

FIGURE 2—Correlation between finishing time and CHO intake rate during IM Hawaii (A; $r = -0.55$, $P < 0.001$) and IM GER (B; $r = -0.45$, $P < 0.001$).

CHO and fluid intakes during endurance events. The highest CHO intake rates within the present study have been reported in ultraendurance triathlon events. In agreement with a previous study by Kimber et al. (26), average CHO intake rates during IM and IM 70.3 (67 $g \cdot h^{-1}$) exceeded ACSM recommendations (2). During the amateur cycling event (CYCLE), significantly lower average CHO intake rates (53 $g \cdot h^{-1}$) were reported. However, the lowest average CHO intake rates (35 $g \cdot h^{-1}$) were found during MARATHON. Consequently, 73% of marathon runners failed to meet the comparatively low ACSM recommendations. Altogether, it has to be recognized that the intraindividual differences in intake rates are large (6–136 $g \cdot h^{-1}$) and a substantial number of athletes ingested less or more CHO than recommended. The average fluid intakes during the events were between 354 (MARATHON) and 794 $mL \cdot h^{-1}$ (IM Hawaii). Interestingly, the average resulting CHO solution was 10.6%, with individual percent CHO solution ranging from 3.5% to 27%. The lowest average CHO concentration (8.8% during IM Hawaii) still exceeds the general recommendations for the composition of sports drinks of 4%–8% (2,12). Strategies to achieve CHO and fluid intake rates generally consisted of a mixed intake of CHO forms (solid, semisolid, and liquid), and only 1% of athletes ingested CHO solely from solutions. In support of the strategy to ingest different CHO forms, recent studies have shown similar exogenous CHO oxidation rates between fluids, semisolid gels (32), and solid bars (31).

Factors influencing CHO and fluid intakes. Several factors varied among the different events that might have influenced food and fluid intakes. For example, ambient conditions were different among events with hot conditions (24°C–29°C), namely, during the triathlon events compared with moderate temperatures during MARATHON (12°C). Previous studies have shown that hot conditions lead to high voluntary fluid intake rates (13), and our data support this. The highest proportion of CHO ingested in the form of liquid (49%) was found during the hottest event (IM Hawaii), whereas the lowest percentage CHO intake (29%) in the form of liquid was reported during the coolest event (MARATHON). In addition, the investigated events varied in average race duration between 3.5 and 11.7 h. Furthermore, in this study and in previous studies, CHO intake rates have been correlated to faster finishing times (26), indicating that a higher CHO intake potentially improved endurance performance. Although there is still debate about a dose–response effect with CHO ingestion on performance, recent intervention-based laboratory studies seem to substantiate this effect (38,39). However, it is also possible that faster athletes tend to ingest more CHO compared with slower athletes (17). Alternatively, it could be speculated that faster athletes have a greater ability to ingest and absorb larger quantities of CHO. Furthermore, during this study, it was not possible to assess or control prerace nutrition. Hence, we cannot exclude the possibility that prerace nutrient intake was different between athletes and had an influence on race performance.

Previous research has clearly demonstrated varying nutrient intakes during different endurance sports (26,27), which is supported by the current study. For example, a retrospective questionnaire–based study by Peters et al. (27) reported a higher intake of both liquids and food by triathletes during competition than runners. In the present study, CHO intake rates during all triathlons were considerably higher compared with MARATHON and CYCLE. Furthermore, CHO and fluid intake rates during MARATHON were substantially lower compared with CYCLE and triathlon. Part of this difference might be explained by the considerably colder weather during MARATHON compared with all other events. However, the difference in CHO and fluid intake rates between running and cycling also persists within the triathlon events (Fig. 1). A similar nutrition pattern has been reported in a study by Kimber et al. (26), and the authors suggested that the lower nutrient intakes during running are due to practical difficulties ingesting large fluid volumes or solid foods.

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Prevalence of GI symptoms. A further aspect of our study was to investigate GI distress, which is common during ultraendurance events (25,27,36). In the present study, a high prevalence for serious GI distress (~30%) was reported during the IM races. Significantly lower frequencies of serious complaints were reported during IM 70.3 (14%), MARATHON (4%), and CYCLE (4%). It is known that prevalence for GI distress is augmented with increasing exercise duration (28), possibly caused by increasing dehydration and decreased blood supply to the GI tract (11). Furthermore, hot conditions have previously been linked to a higher prevalence of GI symptoms (4,10), most likely due to increased cutaneous blood flow and associated restricted blood flow to the GI tract (11). In the present study, environmental conditions were more extreme (hot and humid) during all triathlons compared with MARATHON and CYCLE and, accordingly, heat index correlated with scores of upper and lower GI symptoms. Therefore, the combined effects of exercise duration and hot environmental conditions are most likely the causes for significantly increased GI distress during both IM races compared with IM 70.3 and for higher levels of GI distress during IM 70.3 compared with MARATHON and CYCLE.

However, the most important factor that influenced GI problems within our study was an individual predisposition and history of GI distress among athletes. Independent of the event, we detected a positive correlation between GI symptoms during the races and reported history of GI distress. This finding is consistent with our previously published data (30) and suggests an individual predisposition for GI distress during exercise.

CHO intake and GI symptoms. The ingestion of CHO, especially the excessive consumption of hypertonic drinks, has previously been linked to altered GI distress (34). It has been speculated that hypertonic drinks cause GI distress via water retention to the human intestines (34). Furthermore, much CHO can lead to incomplete absorption (35), and residual CHO in the intestine has been linked to GI problems in studies about rest (5,33). In contrast to previously reported links between CHO intake and GI distress, a recent series of studies has suggested that the intake of high rates of CHO ($\sim$1.4 $g \cdot min^{-1}$) in the form of glucose + fructose gels is well tolerated from most athletes during ~70 min of endurance running under mild environmental conditions (30). However, it has to be kept in mind that the incidence of GI problems increases with exercise time (28) and might be increased under more extreme weather and race conditions. In the present study, we detected no clear relationship between CHO intake rates and GI distress. Mean upper and lower abdominal symptoms were not associated with CHO intake rates. Furthermore, mean CHO intake rates were not different between athletes with and without serious GI symptoms. However, we detected correlations between scores for nausea and flatulence with high CHO intake rates in more than one data set (IM Hawaii and IM 70.3). This confirms the finding of a previous study where we reported higher scores for nausea with high (90 $g \cdot h^{-1}$) compared with lower CHO intake rates (60 $g \cdot h^{-1}$) during a 16-km outdoor run (30). Similarly, in a study by van Nieuwenhoven et al. (40), flatulence was previously linked to CHO consumption when the ingestion of a CHO sports drink was compared with water intake. Altogether, these data suggest that CHO intake can indeed be a risk factor for nausea and flatulence during exercise. However, those more minor symptoms are less likely to impair performance compared with symptoms such as diarrhea or stomach cramps (24), and it should be kept in mind that high CHO ingestion rates were correlated with faster finishing times.

Benefits and limitations of measurements. One aspect that has to be recognized with all dietary measurements is the difficulty to estimate food and fluid intakes, even more so when subjects are exercising. Direct measurement of food and fluid intake on the race course is not possible with the large number of investigated subjects. Hence, the measures rely on the memory of athletes, which is a challenge especially regarding correct estimates of fluid intake during prolonged races. However, all athletes received detailed instructions before the event and were supplied with strategies to remember their race intake such as to recall from where the actual intake deviated relative to a prerace nutrition plan. Furthermore, any answers that caused doubt, such as very low or high fluid intakes, were directly followed up with individual athlete interviews after the race. Consequently, this is the only study using strict subject and dietary control that features more than 200 subjects and six different competitive situations.

CONCLUSIONS

In summary, the present study showed that CHO intake rates vary greatly not only between events but also between individual athletes (6–136 $g \cdot h^{-1}$). The incidence of serious GI distress was quite variable in the present study (4%–32%). High CHO intakes rates were significantly positively correlated with finishing times during IM events but, at the same time, were linked to higher scores of nausea and flatulence. Moreover, a correlation between reported GI symptoms and history of GI distress was reported in this and previous research (32), suggesting an individual predisposition for GI distress. Altogether, the findings of the present study suggest a need for more individualized nutritional advice for endurance athletes, where each athlete finds his/her unique balance between the ergogenic effects of optimal CHO and fluid intake and the potential ergolytic effects of substantial CHO intakes causing GI distress.

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