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Energy Balance During an Ironman Triathlon in Male and Female Triathletes

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Energy balance of 10 male and 8 female triathletes participating in an Ironman event (3.8-km swim, 180-km cycle, 42.2-km run) was investigated. Energy intake (EI) was monitored at 7 designated points by dietary recall of food and fluid consumption. Energy expenditure (EE) during cycling and running was calculated using heart rate-$\dot{V}O_2$ regression equations and during swimming by the multiple regression equation: $Y = 3.65\upsilon + 0.02W - 2.545$ where Y is $\dot{V}O_2$ in $L \cdot min^{-1}$, υ is the velocity in $m \cdot s^{-1}$, W is the body weight in kilograms. Total EE (10,036 ± 931 and 8570 ± 1014 kcal) was significantly greater than total EI (3940 ± 868 and 3115 ± 914 kcal, $p < .001$) for males and females, respectively, although energy balance was not different between genders. Finishing time was inversely related to carbohydrate (CHO) intake ($g \cdot kg^{-1} \cdot h^{-1}$) during the marathon run for males ($r = -.75$, $p < .05$), and not females, suggesting that increasing CHO ingestion during the run may have been a useful strategy for improving Ironman performance in male triathletes.

Key Words: carbohydrate intake, energy expenditure, gender, ultradistance, performance

The popularity of ultradistance events has greatly increased since the first Ironman triathlon was held in 1978. Ironman ultradistance triathlons involve a 3.8-km swim, 180-km cycle, and 42.2-km marathon run. To be successful athletes must have the ability to sustain a high rate of energy expenditure (EE) for prolonged periods of time (23). They must also maintain their fluid balance and energy supply to meet the considerable physiological demands of this event (1, 16).

Currently, few studies have described energy balance during an ultradistance triathlon. The methodological difficulties of measuring EE and energy intake (EI) in a field setting may explain the paucity of research in this area. Studies have attempted to simulate under controlled laboratory conditions the physiological demands

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of performing ultradistance triathlons (18, 24). In one study, highly trained triathletes were reported to maintain a power output eliciting an average of approximately 50% of their peak oxygen consumption during 8 hours of continuous cycling and running (24). Extrapolation of this data to an Ironman triathlon yields a large EE of between 8,500 kcal and 11,500 kcals (16).

Evaluation of EI during approximately 5 hours of cycling revealed that cyclists consumed 25% of total EE (18), while EI approximated 54% of the energy expended during a 24-hour cycling time-trial (35). Nutrient intakes in 16 male and 11 female Ironman triathletes were reported by Applegate et al. (2). Mean total EI during the race was 4000 ± 380 kcal (390 kcal $\cdot$ h^{-1}) and 2400 ± 300 kcal (230 kcal $\cdot$ h^{-1}) for men and women, respectively. Carbohydrate (CHO) ingestion rates of 1.3 $g \cdot kg^{-1} \cdot h^{-1}$ for men and 0.9 $g \cdot kg^{-1} \cdot h^{-1}$ for women were similar to the maximal CHO oxidation rate of 1.0 $g \cdot kg^{-1} \cdot h^{-1}$ reported during prolonged endurance exercise (14). Furthermore, these high rates of CHO ingestion appeared sufficient to contribute to the energy demands of exercise without interfering with fluid absorption.

The current study is novel in that we examined the EI and EE in both male and female athletes during an Ironman ultradistance triathlon. Specifically, the aims of this study were to examine gender differences in (a) total energy, food and fluid, macronutrient, and sodium intake during the Ironman, (b) EE for each stage of the Ironman, (c) energy balance (EB) for an Ironman event, and (d) relationships between energy and CHO intake, EB, and finishing time in the Ironman triathlon. There are no published studies describing EB during an Ironman triathlon reported in the literature. However, Maruyama et al. (20) reported that the mean ratio of EI to EE during the entire day of an Ironman event was 0.55 ± 0.27 for 18 male triathletes. Determining EB during an Ironman triathlon will assist athletes in optimizing their nutrient intake for such an event. Furthermore, this investigation provides valuable information on ultradistance events and competitors, which may be useful for developing guidelines for health professionals and organizers of such events. We hypothesized that athletes would be in substantial negative EB (EI:EE ratio < 0.5) after completing the Ironman and that CHO ingestion would be related to improved performance in both male and female triathletes.

Method

Subjects

Eight female and 10 male athletes volunteered to participate in this study. Subjects were recruited from entries submitted for the 1997 New Zealand Ironman triathlon. Athletes living in Auckland city, where the race was held, and whose estimated race times were between 10.5 and 14 hours, were invited to participate in this study. Subjects gave written informed consent, and the study was approved by the North Health Ethics Committee. All subjects were healthy, with no significant medical illnesses and no consumption of medication. Subject characteristics are presented in Table 1.

Laboratory Testing

Three to 4 weeks prior to the Ironman, all subjects reported to a laboratory (mean barometric pressure of 760 mmHg, relative humidity of 54.6%, and temperature of

Table 1 Subject Characteristics

	Females			Males		
Variable	*M*	*SD*	Range	*M*	*SD*	Range
Age (years)	34.3	7.0	23–46	36.2	9.6	23–49
Height (cm)	166.4	4.1	160–171	177.7*	8.2	165–193
Pre-race weight (kg)	62.3	3.9	57–67	74.4*	9.1	65–94
% body fat	22.2*	3.6	18–29	15.1	3.6	10–21
Fat mass (kg)	13.9	2.7	11–19	11.3	3.2	7–16
Fat-free mass (kg)	48.4	3.0	46–55	63.1*	7.9	54–82
BMI ($kg \cdot m^{-2}$)	22.5	1.4	20–25	23.5	1.7	21–25
Cycle $\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	51.2	2.5	48–54	54.5	3.7	48–60
Run $\dot{V}O_{2peak}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	53.6	5.8	47–65	58.3	3.9	52–65

Note. Values are means ± *SD* for 8 females and 10 males except for cycle $\dot{V}O_{2max}$ ($n = 5$ females) and run $\dot{V}O_{2peak}$ ($n = 7$ females). BMI = body mass index.
*Significantly higher compared to the opposite gender ($p < .01$).

27.3 °C) on two occasions for the determination of body composition and peak oxygen consumption ($\dot{V}O_{2peak}$). All subjects were familiarized with the equipment and procedures prior to testing.

During the first visit, the method of Durnin and Womersley (12) was used to estimate percentage body fat from skinfold thickness using Harpenden calipers (British Indicators Ltd., UK). Body mass (accurate to 0.2 kg, GEC Avery Ltd., Invercargill, New Zealand) and height (accurate to 0.1 cm) were also measured. Subjects then completed a maximal test to volitional exhaustion on a motorized treadmill (Powerjog, Sports Engineering Ltd., Birmingham, UK).

On a subsequent visit at least 24 hours after the first, each subject performed a cycle ergometer test to exhaustion (Cateye Cyclosimulator CS-1000). Oxygen consumption ($\dot{V}O_2$) was measured during each test using a pre-calibrated on-line system (Oxygen Analyser S-3A/l, Carbon Dioxide Analyser CD-3A, Ametec, Pittsburgh, U.S.), and heart rate (HR) was monitored using a Sports Tester PE 3000 (Polar Electro, Kempele, Finland).

The treadmill test began after a 3-min warm up at 8 $km \cdot h^{-1}$. Following the warm up, a discontinuous incremental protocol was used, starting at a treadmill speed of 10 $km \cdot h^{-1}$ and 0% gradient. The workload was increased by 1 $km \cdot h^{-1}$ to a maximum speed of 15 $km \cdot h^{-1}$, followed by 1.5% gradient increments. Each workload was of 3-min duration, with a 1-min rest interval. Peak oxygen uptake ($\dot{V}O_{2peak}$) was taken as the highest value obtained, since in many cases, work rate increments towards the end of exercise were too large to elicit a true plateau in oxygen uptake. A $\dot{V}O_{2peak}$ protocol was utilized to enable the concomitant measurement of blood lactate during treadmill running. The cycling tests were performed with the athletes' bicycles (thereby allowing for self-selection of body position, gear ratios, and pedal cadence) using a continuous incremental protocol involving a 3-min warm up at the initial workload of 100 W followed by 40-W increments every 1.5 min. Maximal oxygen uptake ($\dot{V}O_{2max}$) was determined from a plateau in $\dot{V}O_2$ (increase <2 ml · kg^{-1} · min^{-1}) with a further increase in work load.

Energy Expenditure

Environmental conditions recorded at noon on race day indicated ambient air temperature was 21 °C, water temperature 20.7 °C, relative humidity 91%, barometric pressure 754 mmHg, and wind velocity 19.2 km · h^{-1}. Oxygen consumption for all athletes during the swim section was estimated from the following multiple regression equation developed by Montpetit et al. (21) from a population of male and female swimmers with a minimum of 3 years swimming experience: $Y = 3.65\text{y} + 0.02W - 2.545$ where Y is $\dot{V}O_2$ in L · min^{-1}; y is the velocity in m · s^{-1}, W is the body weight in kilograms. The contribution of speed and body weight in this regression equation was able to account for about 74% of the variance in predicted oxygen consumption. The remaining variance was most likely explained by technical proficiency and other factors (21). At speeds ranging from 1.0 to 1.2 m · s^{-1}, the calculations for the general multiple regression equation fall within 10% of the observed values from previously published studies (21). Equating an EE of 20.5 kJ for each liter of oxygen consumed per minute (34) allowed the estimation of total swimming EE for each athlete.

Energy expenditure during the cycle and run stages was determined for each subject using a Sports Tester PE 3000 to record their heart rate at 60-s intervals. Total oxygen consumption during the cycle and run was estimated by a comparison of recorded HR data with the regression line of $\dot{V}O_2$ on HR obtained during the maximal treadmill running and cycle ergometer tests. Total cycling and running EE was calculated from the predicted oxygen consumption at each heart rate recorded (34).

Energy Intake

Food and drink were freely available at support stations every 12 km on the cycle course and every 1.8 km on the run. Foods available included Moro bars^{TM}, Power Bars^{TM}, bananas, oranges, and Griffin's chocolate chip cookies. Fluids available included water, Coca Cola^{TM}, and a sports drink (Powerade^{TM},) containing 8% carbohydrate and 10 mmol · L^{-1} of sodium. The measurement of fluid intake in all subjects was completed as part of a separate study (29), and the data from that investigation were used by permission to analyze nutrient intake and gender differences in this investigation. Methodology was identical to that outlined previously (29). Athletes were instructed before the start of the race to monitor the type and quantity of food and fluid they consumed. These were expressed as the number of drink bottles on the cycle, cups of fluid on the run, and number of food items for each discipline. Interviewers ran or cycled with the athletes for a short distance to obtain this information and interviewed athletes at transitions. Specifically, interviews took place at the swim-cycle transition, at 100 km on the cycle course, the cycle-run transition, at three points on the run course (6.2 km, 19.9 km, and 34.7 km), and immediately after finishing the race. All subjects verified their nutrient intake data during a telephone interview 2–3 days after the Ironman.

Drink cups at the run support stations were predominantly 355 ml in volume, although a few 250-ml cups were also used. It was estimated that the drink cups were filled to contain approximately 175 ml of fluid. During the cycle, 750-ml drink bottles were used, and it was estimated that these were filled to contain approximately 700 ml of fluid. Dietary data was analyzed for nutrient composition using the nutrition calculation software package Diet/1 version 3.1 (Xyris Software, Australia, 1991).

Statistics

Gender differences for physical characteristics, EI (cycling and running), and EE (swimming, cycling and running) variables were tested using a one-way ANOVA. Within-group differences between food and fluid intake for females were also tested using a one-way ANOVA. Relationships between variables are reported as Pearson Product-Moment Correlation Coefficients. Significance was set at $p < .05$. Data are represented as means ± *SD*.

Results

Subject Characteristics

The subject characteristics presented in Table 1 illustrate that the female and male athletes were a homogenous group in respect to age, BMI, and maximal aerobic capacities obtained from the cycling and running tests. Females were significantly shorter and lighter, and had significantly higher levels of body fat than males.

Energy Intake

Mean total EI for males exceeded that for females, although this difference was not statistically significant (Table 2). In addition, cycling, running, and total EI relative to body weight was similar between genders. All subjects consumed significantly more energy during the cycle section (2233 ± 627 kcal and 2896 ± 836 kcal) compared to the run (883 ± 627 kcal and 1049 ± 267 kcal, $p < .001$) for females and males, respectively. Energy consumption while cycling accounted for an average 73% of total EI.

Female athletes obtained significantly more energy from food during the cycle (1386 ± 271 kcal vs. 847 ± 495 kcal) and run (570 ± 265 kcal vs. 313 ± 127 kcal, $p < .05$) compared to fluid intake. No difference between food and fluid intake was found for males, although the greater EI from food compared to fluids during the cycle approached significance ($p = .069$). Average EI from food was 63% and 43% of total energy for females and males, respectively. Furthermore, females consumed significantly more water (73 ± 23 ml $\cdot$ kg^{-1} vs. 42 ± 23 ml $\cdot$ kg^{-1}, $p < .05$) than males (Figure 1). Total fluid intake relative to body weight was comparable between genders (123 ± 18 ml $\cdot$ kg^{-1} vs. 127 ± 29 ml $\cdot$ kg^{-1}) for males and females, respectively (Figure 1). Interestingly, total EI and energy consumed during the cycle showed a significant positive relationship ($r = .74$ and $r = .80$, $p < .05$ for total EI and cycling EI, respectively) with finishing time for female triathletes only (Table 3).

Table 2 Energy Intake During the 180-km Cycle and 42.2-km Run for Female (n = 8) and Male (n = 10) Ironman Triathletes

	Females			Males		
Variable	*M*	*SD*	Range	*M*	*SD*	Range
Cycle						
Total (kcal)	2233*	627	1856–4524	2896*	836	1856–4524
Total (kcal · kg^{-1})	36*	11	22–54	39*	10	22–54
Fluid (kcal)	847*	495	1008–3046	1693*	720	1008–3046
Food (kcal)	1386*#	271	814–1570	1203*	270	814–1570
Run						
Total (kcal)	883	347	693–1439	1049	267	693–1439
Total (kcal · kg^{-1})	14	5.6	8–22	14	3.8	8–22
Fluid (kcal)	313	127	253–874	585	187	253–874
Food (kcal)	570#	265	23–770	485	208	23–770
Total (kcal)	3115	914	1298–4235	3940	868	2843–5269
Total (kcal · kg^{-1})	50	16	36–71	53	11	36–71

*Significant difference between the cycle and run ($p < .001$). #Significant difference between food and fluid intake ($p < .05$).

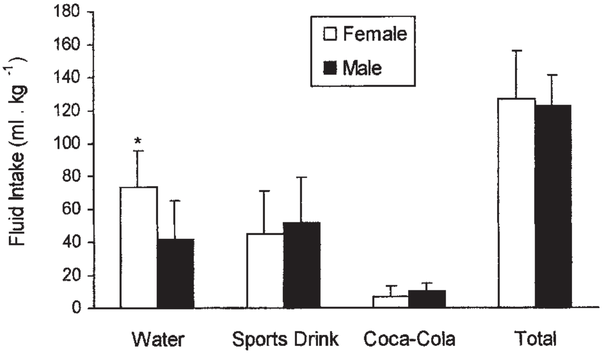

Figure 1 — Fluid intake relative to body weight during the 180-km cycle and 42.2-km run for female (n = 8) and male (n = 10) Ironman triathletes. *Significant gender difference ($p < .05$).

Macronutrient and Sodium Intake

Mean CHO consumption was high for all athletes, averaging 94.0% of total energy (Table 4). Relative ingestion rates of CHO per hour during the Ironman were similar between genders and were sufficient to support the proposed maximum rate of CHO utilization of 1.0 g · kg^{-1} · h^{-1} in skeletal muscle (14). Both genders consumed significantly more CHO during the cycle (686 ± 213 g and 531 ± 156 g) compared to

Table 3 Relationships Between Energy and Carbohydrate Intake, Energy Balance, and Finishing Time in the Ironman Triathlon

Variable	Females (*n* = 8)	Males (*n* = 10)
Kilocalories		
Total	.74*	.01
Cycle	.80*	.20
Run	.51	–.55
Carbohydrates (g)		
Total	.72*	–.03
Cycle	.77*	.16
Run	.46	–.59
Carbohydrates ($g \cdot kg^{-1} \cdot h^{-1}$)		
Total	.48	–.12
Cycle	.59	.32
Run	.30	–.75*
Energy balance	–.31	.15

Note. Values are correlation coefficients for 8 females and 10 males except for energy balance (*n* = 5 females, *n* = 8 males).
*Significant correlation ($p < .05$).

the run (255 ± 64 g and 221 ± 86 g, $p < .001$), for males and females, respectively (Figure 2). Similarly, CHO intake relative to body weight and discipline time was significantly greater for the cycle ($1.5 \pm 0.6\ g \cdot kg^{-1} \cdot h^{-1}$ and $1.2 \pm 0.3\ g \cdot kg^{-1} \cdot h^{-1}$) than the run ($0.6 \pm 0.2\ g \cdot kg^{-1} \cdot h^{-1}$, $p < .001$ and $0.8 \pm 0.3\ g \cdot kg^{-1} \cdot h^{-1}$ $p < .05$) for males and females, respectively (Figure 2). Protein and fat contributed small amounts to total energy intake (~4% and 2%, respectively). Surprisingly, a significant positive relationship was obtained for total CHO intake ($r = .72$, $p < .05$) and cycle CHO intake in grams ($r = .77$, $p < .05$) with finishing time for female triathletes (Table 3). Furthermore, run CHO intake relative to body weight and time showed a significant negative relationship ($r = –.75$, $p < .05$) with finishing time for males (Table 3). Mean sodium intake was within the range of the Recommended Dietary Intake (RDI) for sodium (19), and tended to be higher for males than females (Table 4).

Energy Expenditure

Table 5 illustrates that total EE was significantly higher for males (10,036 ± 931 kcal) than females (8570 ± 1014 kcal, $p < .05$). Significant gender differences were revealed for cycling (5384 ± 553 kcal vs. 4683 ± 551 kcal, $p < .05$) and running (3875 ± 585 kcal vs. 3097 ± 657 kcal, $p < .05$) in males and females, respectively. Relative to fat-free mass, total EE was similar between genders for cycling and running. However, swimming EE per kilogram of fat-free mass was significantly greater for females ($14.8 \pm 0.6\ W \cdot kg^{-1}$) than for males ($12.7 \pm 0.7\ W \cdot kg^{-1}$, $p < .01$).

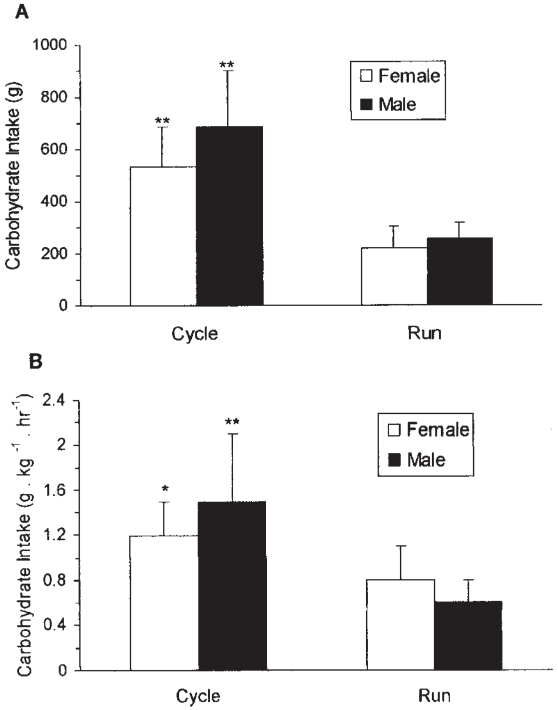

Figure 2 — Absolute (A) and relative (B) carbohydrate intake during the 180-km cycle and 42.2-km run for female ($n = 8$) and male ($n = 10$) Ironman triathletes. *Significant difference between cycle and run ($p < .05$) and **($p < .001$).

Energy Balance

Mean EE was significantly greater than mean EI ($p < .001$), as indicated by the substantial energy deficit (EI – EE = –5123 ± 1193 kcal EB) for females and (EI – EE = –5973 ± 1274 kcal EB) males (Table 5). These results reveal that subjects obtained a high proportion (59%) of their energy from endogenous fuel stores.

Discussion

Energy Balance

The first important finding of this study is the relatively high rate of EE in relation to EI in both female (EB = –5123 kcal) and male (EB = –5973 kcal) ultradistance triathletes. Since EI was calculated to provide approximately 40% of total EE, endogenous fuel stores were estimated to supply over half of the energy expended during the Ironman. This finding illustrates the importance of consuming a high CHO diet prior to ultradistance events to maximize endogenous fuel stores. Energy balance was similar between genders, indicating that males and females were able to replace energy at similar rates in relation to their exercise intensity. Maruyama et al. (20) reported an EI:EE ratio of 0.55 on the day of an Ironman triathlon; however, a

Table 4 Macronutrient and Sodium Intake for Female (n = 8) and Male (n = 10) Triathletes During the Ironman

	Females				Males			
Variable	*M*	*SD*	RDI	Range	*M*	*SD*	RDI	Range
Energy								
% CHO	93.9	3.9	—	86–99	94.0	3.7	—	88–98
% protein	3.3	2.8	—	0–5	3.8	2.3	—	1–6
% fat	2.8	1.8	—	1–9	2.2	1.5	—	1–7
CHO (g)	753	226	—	287–990	939	222	—	692–1311
CHO ($g \cdot kg^{-1} \cdot h^{-1}$)	1.0	0.3	—	0.4–1.3	1.1	0.2	—	0.8–1.5
Protein (g)	20	13	55	6–43	32	19	45	13–64
Total fat (g)	9.7	6.6	—	2–22	11	8.2	—	3–24
Sodium (mg)	1453	655	920–2330	435–2261	1929	265	920–2330	1598–2467

Note. RDI, Recommended Dietary Intake—the levels of intake of essential nutrients considered on the basis of available scientific knowledge to meet the known nutritional needs of practically all healthy people.

Table 5 Energy Expenditure for Swimming (3.8 km), Cycling (180 km), and Running (42.2 km), Energy Balance, and Finishing Time in Male and Female Ironman Triathletes

	Females			Males		
Variable	*M*	*SD*	Range	*M*	*SD*	Range
Swim						
kcal	737	148	551–1016	768	97	639–940
W · kg^{-1}	14.8**	0.6	13.6–15.9	12.7	0.7	11.3–13.5
Cycle						
kcal	4683	551	4141–5479	5384*	553	4442–6107
W · kg^{-1}	16.2	0.8	15.2–17.3	15.0	2.2	10.9–17.3
Run						
kcal	3097	657	2022–3924	3875*	585	2701–4486
W · kg^{-1}	16.4	4.3	9.2–23.7	16.0	1.8	13.8–19.3
Total						
kcal	8570	1014	7646–10136	10,036*	931	8359–10,957
W · kg^{-1}	16.2	0.7	15.2–17.2	15.1	1.5	12.7–17.1
Energy balance						
(EI – EE, kcal)	–5123	–1193	–3683 to –7878	–5973	–1274	–1267 to –6941
Finishing time						
(hours)	12.6	0.9	11.6–14.4	12.0	0.6	10.9–13.0

Note. Values are means ± *SD* for 8 females and 10 males except for Cycle EE, Total EE, and Energy balance ($n = 5$ females and $n = 8$ males) and run ($n = 7$ females and $n = 8$ males). Values in W · kg^{-1} are expressed as kilograms of fat-free mass (FFM).
*Significant difference between males and females ($p < .05$). **Significant difference between males and females ($p < .01$).

comparison of EI to EE during actual Ironman competition has not previously been reported.

Estimates based on assumptions of endogenous fat and CHO contribution to EE may assist in validating the energy deficit results reported in this study. Assuming an average respiratory exchange ratio of 0.82 during the Ironman (17, 24), approximately 60% of energy would be derived from fat and 40% from CHO. If each gram of fat yields 9 kcal of energy and each gram of CHO 4 kcal of energy, then to meet the mean 5646 kcal energy deficit, 3384 kcal (376g) of fat and 2260 kcal (565g) of CHO would be oxidized. Approximately 7200 kcal (8000 g) of total body fat, 1500 kcal (375 g) of glycogen in active muscle (25 g of glycogen · kg muscle mass wet weight), and 100 g of liver glycogen is potentially available during endurance running (22). Differences between the estimated 565 g of CHO oxidized in this study and the predicted (about 475 g) glycogen content of the liver and active muscle may result from a progressive redistribution of CHO, in the form of lactate, from inactive to adjacent active muscle fibers via the interstitial fluid (3, 22, 26).

Energy Expenditure

From the results obtained, it is evident that an Ironman triathlon is a physiologically demanding event, requiring athletes to produce high rates of EE for a prolonged period. The total energy cost of an Ironman triathlon was greater for male subjects in all three disciplines because of their significantly heavier body mass. When adjusted for fat-free mass, total EE was similar between genders, illustrating that females were exercising at a comparable intensity to males throughout the Ironman.

It is plausible that the degree of negative EB in this study resulted from an overestimation of EE. Studies have found that HR recording overestimates energy expenditure by 9.8% compared with the doubly labeled water technique (26), although estimation of energy expended in activity by HR was significantly correlated ($r = .80$) to indirect calorimetry (32). The average HR-$\dot{V}O_2$ correlation coefficient was highly significant for all subjects ($r = .990 \pm .008$ and $r = .983 \pm .013$, $p < .001$) for ergometer cycling and treadmill running, respectively. It must be taken into account, however, that even in a single individual, the calibration curve may change from one day to another (6) and more so under field conditions. Indeed, HR may drift upwards during prolonged activity to compensate for reduced stroke volume (8), causing an overestimation of EE when using the HR-$\dot{V}O_2$ regression equation. Despite this possibility, HR profiles obtained during this study did not indicate cardiovascular drift.

Maruyama et al. (20) found male triathletes expended 9847 kcal during the entire day of an Ironman race, which is comparable with the total energy cost of completing an Ironman for males in this study (10,036 kcal). Simulated ultradistance triathlon studies in a laboratory setting (17, 24) show comparable results to the present data, suggesting that the estimated EE rates reported in this study are realistic indicators of the actual physiological demands of an Ironman event.

Energy Intake

The second important finding of this study is the description of energy, food and fluid, macronutrient, and sodium intake during an Ironman triathlon. Previous reports describing energy and macronutrient intake during Ironman competition are limited (2, 20).

Mean total EI during the Ironman for males (3940 ± 868 kcal) was comparable with the previous finding of 4000 ± 868 kcal by Applegate et al. (2) and substantially higher than the value of 2779 kcal reported by Maruyama et al. (20). For the female group, mean total energy intake of 3115 ± 914 kcal was considerably higher than the 2400 ± 300 kcal found by Applegate et al. (2). The variability in EI between these studies may relate to the course topography, environmental conditions, training status, EE rates, availability of nutrients at support stations, body size, body image, culture of the individual, and errors associated with collecting nutrient data during an Ironman competition.

The finding that all subjects consumed a large percentage of their total EI during the cycle stage is similar to other Ironman studies (2, 20). Since cycling comprised approximately 54% of total race time for all subjects, and food and fluids are easier to ingest while cycling, this section of an Ironman provides an important opportunity for obtaining energy and fluid in preparation for the marathon run.

Interestingly, females consumed significantly more food and water during the Ironman. Consequently, females consumed a lower quantity of sports drink (Figure 1) and obtained less energy from fluid in comparison to males (Table 2). An important consequence of this finding is the association between the intake of fluids low in sodium (water and Coca Cola) and the development of exercise-associated hyponatremia (31). Indeed, Speedy et al. (30) have recently described 2 female athletes who were found to have low serum sodium levels (<135 mmol · L^{-1}) after completing an Ironman triathlon.

Carbohydrate ingestion rates were significantly higher during cycling compared to running (Figure 2). These high rates of CHO ingestion during the cycle enabled male and female athletes to obtain an average of 1.0 – 1.1 g · kg^{-1} · h^{-1} of CHO during the entire Ironman. Consequently, athletes appeared to consume sufficient quantities of CHO during the Ironman to support a maximal CHO oxidation rate of 1.0 g · kg^{-1} · h^{-1} reported during endurance exercise (14). Carbohydrate supplementation during prolonged exercise is essential for maintaining plasma glucose levels, thereby “sparing” the conversion of liver glycogen to plasma glucose (4) and maintaining adequate rates of glucose oxidation at a low (55% $\dot{V}O_{2peak}$) exercise intensity during prolonged exercise (25). However, ingesting CHO is not reported to slow the rates of glycogen utilization by working muscle (4, 9) until muscle glycogen content has fallen below 70 mmol · kg^{-1} (5). Furthermore, Kang et al. (15) suggest that enhanced endurance performance following a combination of CHO ingestion and CHO supercompensation may be due to the maintenance of plasma glucose concentrations and a greater availability of exogenous CHO energy substrates during the later stages of exercise. Hence, to prevent premature fatigue during an Ironman, triathletes should ingest CHO even if they have “CHO-loaded” before exercise (11).

Subjects’ fat and protein intake during the Ironman was obtained exclusively from food. Quantities of fat and protein ingested were small, a finding consistent with previous data (18). Since CHO ingestion is essential for enhancing endurance capacity (7, 9, 36), compromising CHO intake with protein and fat during exercise may be detrimental to performance.

Sodium replacement is recommended for ultradistance athletes to enhance the absorption of glucose, and to partially correct any sodium losses in sweat and urine (28). Mean sodium intakes during the Ironman were adequate in relation to the RDI, although the requirements for sodium in an Ironman may be higher than the RDI. Further research is needed in this area. Ultradistance athletes are at risk of developing exercise-associated hyponatremia, a condition principally caused by fluid overload (31). While there are no published data on the role of sodium supplementation in preventing hyponatremia during an Ironman, a recent article has suggested that replacing sweat losses with sodium-free fluid can lower the plasma sodium concentration and thereby precipitate the development of hyponatremia during endurance exercise (33).

The degree of negative EB reported in this study may also result from an underestimation of EI. The validity of nutrient intake data depended on how accurately subjects were able to recall their food and fluid consumption and the ability of the interviewer to correctly interpret and record information. Validation of food and fluid intake after the post-race interview primarily involved the clarification of drink volumes consumed during the run, since there was some variability in how much fluid was contained in the drink cups. After these follow-up interviews, nutrient data from this group of triathletes were considered a valid representation of actual food and fluid intake during the Ironman.

Relationship Between Nutrient Intake and Performance

The significant positive correlation between total ($r = .74$) and cycle ($r = .80$, $p < .05$) EI and finishing time for female triathletes was an unexpected finding in this study. Furthermore, the significant positive correlation between total ($r = .72$) and cycle ($r = .77$, $p < .05$) CHO intake (g) and finishing time for females is difficult to explain, and indicates that factors other than energy and CHO intake are related to improved performance for females. A possible rationale for why higher intakes of energy and CHO were related to longer finishing times in females is the significant shift in lipid utilization seen after training at the same relative workload, suggesting females decrease their reliance on CHO oxidation after endurance training in comparison to their male counterparts (13). In addition, the longer average finishing time for females in this study may have provided more opportunity for energy consumption from CHO during the Ironman. Difficulties associated with digesting and absorbing large amounts of energy and CHO intake, particularly in the form of solid food, may have also contributed to longer finishing times in the female group. It should also be noted that if females are indeed able to utilize endogenous lipid stores to a greater extent, this may attenuate fatigue from glycogen depletion and offer a competitive advantage over their male counterparts during ultradistance events.

Ingestion of CHO during prolonged exercise can improve performance by delaying the onset of fatigue (10); therefore, increasing CHO intake would be expected to decrease finishing time. Indeed, a novel finding in this study was the significant inverse relationship between relative CHO intake ($g \cdot kg^{-1} \cdot h^{-1}$) during the run and finishing time for male athletes ($r = -.75$, $p < .05$). It can be speculated that a higher CHO consumption during the marathon run was in part related to increased performance for male triathletes. Thus, increasing CHO and total EI during the run may have been a useful strategy for preventing fatigue associated with glycogen depletion and improving Ironman performance for males in this study. Whether female athletes with faster finishing times would have benefited from increasing CHO and total EI towards the latter stages of the Ironman remains elusive, and requires further investigation. It must also be noted that generalizing these results to other ultradistance events is not possible because of the small sample size in this study. Clearly, further research is required in this area to elucidate whether the amount of CHO, fluid, and energy consumed can affect performance during ultradistance competition.

Conclusion

The major finding of this study is that despite the large negative EB, mean EI appeared sufficient for all subjects in this study to finish the Ironman before reaching exhaustion from substrate depletion. In support of this finding, rates of CHO intake were adequate to meet maximal rates of plasma glucose oxidation by skeletal muscle. Carbohydrate intake may have been a factor contributing to improved performance during the latter stages of an Ironman for male athletes. Indeed, increasing EI primarily in the marathon run may have improved performance for males. In contrast, increasing CHO and total EI during the Ironman did not relate to faster finishing times in female triathletes, suggesting other factors were important for improving performance. It remains to be determined if ultradistance triathletes can optimize their EI in relation to EE to maximize performance during an Ironman triathlon.

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