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CASE STUDY

Case Study: Nutrition and Training Periodization in Three Elite Marathon Runners

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Laboratory-based studies demonstrate that fueling (carbohydrate; CHO) and fluid strategies can enhance training adaptations and race-day performance in endurance athletes. Thus, the aim of this case study was to characterize several periodized training and nutrition approaches leading to individualized race-day fluid and fueling plans for 3 elite male marathoners. The athletes kept detailed training logs on training volume, pace, and subjective ratings of perceived exertion (RPE) for each training session over 16 wk before race day. Training impulse/load calculations (TRIMP; min × RPE = load [arbitrary units; AU]) and 2 central nutritional techniques were implemented: periodic low-CHO-availability training and individualized CHO- and fluid-intake assessments. Athletes averaged ~13 training sessions per week for a total average training volume of 182 km/wk and peak volume of 231 km/wk. Weekly TRIMP peaked at 4,437 AU (Wk 9), with a low of 1,887 AU (Wk 16) and an average of 3,082 ± 646 AU. Of the 606 total training sessions, ~74%, 11%, and 15% were completed at an intensity in Zone 1 (*very easy to somewhat hard*), Zone 2 (*at lactate threshold*) and Zone 3 (*very hard to maximal*), respectively. There were 2.5 ± 2.3 low-CHO-availability training bouts per week. On race day athletes consumed 61 ± 15 g CHO in 604 ± 156 ml/hr (10.1% ± 0.3% CHO solution) in the following format: ~15 g CHO in ~150 ml every ~15 min of racing. Their resultant marathon times were 2:11:23, 2:12:39 (both personal bests), and 2:16:17 (a marathon debut). Taken together, these periodized training and nutrition approaches were successfully applied to elite marathoners in training and competition.

Keywords: TRIMP, carbohydrate and fluid, caffeine, endurance, performance

Since the legendary run of Pheidippides in the Battle of Marathon (490 B.C.) no event has captured the human imagination quite like the marathon, as evidenced by the long interest in marathon-associated physiology and performance (“Proceedings of the 2006 World Congress,” 2007). However, only a few published studies have examined physiological, anthropometric, nutritional, or training characteristics of truly world-class marathoners (Billat, Demarle, Slawinski, Paiva, & Koralsztein, 2001; Billat et al., 2003; Lucia et al., 2006; Onywera, Kiplamai, Boit, & Pitsiladis, 2004). Traditionally, most elite marathon training expertise is tackled anecdotally through word of mouth and practical experience and not systematically documented through validated methodologies in peer-reviewed scientific journals.

Scientific interest in the marathon, and what causes fatigue and ultimately limits performance, continues to be highly relevant as evidenced by the recent viewpoint article by Joyner, Ruiz, and Lucia (2011) titled “The Two-Hour Marathon: Who and When?” and the 38 unique published countercommentaries (Stellingwerff & Jeukendrup, 2011). What has become clear is that there are a myriad of potential physiological, psychological, environmental, and sociological determinants of marathon performance. One distinctive facet to the marathon is that carbohydrate (CHO) metabolism, primarily muscle glycogen, is the dominate fuel at exercise intensities greater than 75% VO_{2max} and can start to become limiting after ~90 min. So despite the fact that endurance running played a significant role in the evolution of man (Bramble & Lieberman, 2004), given the high exercise intensities of marathon racing dictating a high muscle glycogen use (>80% VO_{2max}; O’Brien, Viguie, Mazzeo, & Brooks, 1993), it could be argued that humans are not adapted to racing marathon distances at high exercise intensities. Thus, perhaps underappreciated is the vital role that fueling and hydration status plays on marathon success, which is not necessarily a prerequisite for success over shorter distances (<90 min).

Contemporary scientific studies have started to examine the interactions that altered nutrition approaches may have on endurance-training adaptations. For example, a periodic lack of CHO availability may further enhance training adaptations (Burke, 2010), the gastrointestinal (GI) tract may also be adapted to handling increased fluid and CHO, and an individualized approach to race-day CHO type and fluid intake may contribute to optimal competitive success (Jeukendrup, 2011). However, there have been no studies published that characterize these training and nutrition approaches in elite marathon

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runners. Therefore, the primary aim of the current case study was to use field data to characterize several training and nutrition techniques, leading to an individualized race-day fluid and fuel plan in a periodized approach with three elite male marathon runners.

Interventions and Methods

Background and Athletes

Each marathoner (Table 1) undertook an individualized 16-week training plan and competed in different marathons at Week 16 but implemented the same nutrition approaches with the same physiology/nutrition practitioner. Each athlete/coach has read, approved, and provided written permission for this publication, which conforms to the principle approval for case studies in the *International Journal of Sports Nutrition and Exercise Metabolism* by the ethics committee of the Australian Institute of Sport.

Training Assessment

All athletes kept detailed training logs, including information on duration and volume (min and km), body weight (BW), subjective training feedback (ratings of perceived exertion; RPE), and weather conditions. All the data collected were exclusively used to characterize training, not to affect training decisions. Each training session's "load" was calculated by multiplying the training duration (minutes) by intensity (RPE scale of 1–10, *easy* to *maximal*) into a single arbitrary unit (AU) called training impulse (TRIMP), as previously validated and described by Foster et al. (Foster, 1998; Foster et al., 2001). Session RPE was further divided into three separate intensity zones: Zone 1 = RPE of 0–4 (*very easy to somewhat hard*); Zone 2 = RPE of 5–7 (*hard*); and Zone 3 = RPE of >7 (*very hard to maximal*). These three TRIMP RPE training-zone breakpoints, corresponding to first ventilatory and second ventilatory threshold, respectively, have previously been validated and shown not to differ from TRIMP analysis using either heart rate or blood lactate data (Seiler & Kjerland, 2006).

Dietary Approaches

There were two main nutrition approaches, which were periodized across three training mesocycles: general preparation phase (Weeks 1–6), specific preparation phase (Weeks 7–12), and competition taper phase (Weeks 13–16), with the target marathon being at the end of Week 16. Each dietary approach was described in writing and verbally to each athlete and coach and individually implemented and continuously monitored.

Low-CHO-Availability Training. Athletes were instructed to periodically undertake and develop their ability to tolerate training with low CHO availability (~1–5 times per week as individually tolerated, with emphasis during the general preparation phase). This was done either by limiting exogenous skeletal-muscle CHO availability (by undertaking morning-fasted training) or by limiting endogenous skeletal-muscle CHO availability (by undertaking reduced-muscle-glycogen training). For periodic overnight-fasted training, athletes were instructed to undertake aerobic training (at or below lactate/ventilatory threshold) first thing on waking, with just prerun water and/or coffee consumption. Conversely, low-glycogen training featured doing two training sessions within a single day, but limiting dietary CHO intake after the first training session so that the second training session was undertaken with reduced muscle glycogen stores. Immediately after this second training

Table 1 Anthropometric, Training, and Performance-History Characteristics of the Three Marathon Runners

	Marathoner			
Parameter	**1**	**2**	**3**	***M* ± *SD***
Age	31	27	27	28.3 ± 2.3
Body weight (kg)	61.5	68.0	68.0	65.8 ± 3.8
Height (cm)	175	191	188	184.7 ± 8.5
Body-mass index (kg/m^2)	20.1	18.6	19.2	19.3 ± 0.7
Resting morning heart rate	33	39	43	38 ± 5
Years of elite training	10	9	8	9.0 ± 1.0
Years with current coach	12	4	0.5	5.5 ± 5.9
3,000-m track personal best	7:53.51	7:59.49	7:58.70	7:57 ± 3
5,000-m track personal best	13:21.53	13:40.33	13:57.80	13:39 ± 18
10,000-m track personal best	27:56.92	N/A	28:58.45	28:27 ± 44
1/2-marathon road personal best	1:03:46	N/A	1:03:53	63:50 ± 5

bout, athletes consumed optimal CHO and protein to maximize glycogen and protein synthesis. The few times reduced-glycogen training was implemented, a demanding interval-based training session was undertaken in the morning commencing with higher muscle glycogen to ensure high training quality. This type of training would also cause a large reduction in muscle glycogen, which was maintained with low CHO intakes, before the second daily training session (>4 hr), which was prolonged but aerobic in nature (at or below lactate/ventilatory threshold). These low-CHO-availability training sessions are not to be mistaken for a low-CHO diet. Instead, athletes were instructed to merely alter the timing and availability of CHO in their diet around specific training situations. They were taught the amount and timing of CHO to maximize postexercise glycogen synthesis, as well as the dietary choices required to limit CHO availability when required.

Individualized Targeted CHO Fueling and Hydration During Training and Competition. Athletes were taught to measure CHO- and fluid-intake rates, measure sweat rate via BW changes, and record GI tolerance during key training bouts (1–3 times per week with emphasis during the specific preparation phase and competition taper phase) in a worksheet (Table 2). They were instructed to adjust fluid intake, aiming for ~2–3% BW losses during training sessions. On runs >2 hr, athletes were encouraged to consume at least ~30–60 g CHO/hr and ~400–600 ml/hr, but then urged to further increase intakes to maximize their individual upper tolerance. During the competition taper phase, athletes were encouraged to consume fluids and CHO in every session >75 min. Within 48 hr postrace, athletes reported their race-day fluids, carbohydrate, and caffeine consumption (Table 3). Since each marathoner was a recognized elite athlete, each got to prepare his own fuel/fluid bottles, which were placed at elite-athlete-only aid stations to facilitate more accurate reporting. Unfortunately, due to the complexities postrace for these elite marathoners (e.g., interviews, doping controls, etc.), pre- to postrace BW tracking for the competitions resulted in either uncertain data or was not possible.

Observations and Outcomes

Marathoner Characteristics and Performance Outcomes

The characteristics of each marathoner at the time of his race are outlined in Table 1, with data reported as *M* ± *SD*. To date, these athletes have won a combined 12 Canadian Championships and competed in 16 global championships (World or Olympic Games). Average training weight was 67.3 ± 3.3 kg, which decreased 2.2% for racing. Marathon times were 2:11:23 and 2:12:39 for Marathoners 1 and 3, respectively (previous personal bests were 2:16:53 and 2:15:15, respectively). Marathoner 2 debuted at 2:16:17.

Training Data

Training data are based on 606 training sessions over 12.6 ± 2.1 training sessions per week per athlete, featuring average weekly training volumes of 173.6 ± 32.5, 213.3 ± 41.2 and 159.6 ± 27.0 km/week for Marathoners 1, 2, and 3, respectively (Figure 1). Each marathoner had his highest training volume during the specific preparation phase, with highs of 228, 266, and 199 km/week, respectively. Lowest weekly training volumes were on race week (114.5 ± 14.1 km), with ~35% of that week's running volume coming on race day. Due to the highly subjective nature of RPE TRIMP assessment, it can only be compared within a given athlete (Figure 2; Marathoner 1). This athlete had a weekly high TRIMP of 4,437 AU (Week 9) and low of 1,887 AU (Week 16), with a 16-week average of 3,082 ± 646 AU. For all athletes combined, of the 606 total training sessions, 74.3% ± 3.5%, 11.0% ± 1.7%, and 14.7% ± 3.5% of the sessions were completed in Zone 1 (*very easy to somewhat hard*), Zone 2 (*hard*), and Zone 3 (*very hard to maximal*), respectively (Figure 3).

Periodized Dietary Approaches During Marathon Preparation

Figure 4 provides an overview of the two nutrition techniques, which were periodized across each training phase. On average, there were 2.5 ± 2.3, 2.6 ± 2.3, and 1.3 ± 2.3 low-CHO-availability training bouts per week across the general preparation phase, specific preparation phase, and competition taper phase, respectively. There were 107 low-CHO-availability training sessions for all 3 marathoners, of which 11 were reduced-glycogen training and 96 were morning-fasted training. CHO-fueling practice sessions increased during each phase, with an average of 19.0 ± 6.1 CHO-fueling sessions throughout the 16 weeks, with most during the specific preparation phase and the competition taper phase. A wide range of individual sweat rates was recorded by Marathoner 2 during training: ~750–1,000 ml/hr (Table 2). This marathoner practiced with a wide range of CHO- and fluid-consumption rates and demonstrated great individual GI tolerance to fluid and CHO intake during running (Table 2).

Race-Day Intakes

On average, athletes consumed 61 ± 15 g CHO in 604 ± 156 ml/hr of racing, resulting in a CHO solution of 10.1% ± 0.3% (Table 3). All marathoners used commercial products featuring CHO blends of maltodextrin (glucose) and fructose in the form of sports drinks and CHO gels. On average, marathoners consumed ~15 g CHO in ~150 ml every ~15 min of racing. Two of the marathon runners used caffeine (Table 3). They took ~60% of their total caffeine dose 1 hr before the start as caffeine pills and then consumed ~40% of their remaining dose throughout the race via CHO gels containing caffeine, which resulted in 3.7 ± 1.4 mg caffeine per kg BW throughout the race. Variability of caffeine intake between athletes was mostly due to previous individual experience.

Table 2 Individualized Sweat and Fluid and Carbohydrate (CHO) Intake for Marathoner 2

Date	Temperature (°C)	Humidity (%)	Prerun weight (kg)	Postrun weight (kg)	Fluids ingested (L/hr)	Total run time (hr)	Sweat rate[a] (L/hr)	% body-weight loss	CHO ingested (g/hr)	% CHO solution	Comments
12-10	–4	100	69.5	66.7	0.350	2.50	1.260	4.0	48.0	13.7	Stomach felt great, harder to drink when tired and cold.
12-17	–5	100	69.0	67.0	0.100	2.00	1.050	2.9	26.0	26.0	Only 2 gels—bottles on course were stolen during session.
1-6	5	51	68.9	68.1	0.000	1.13	0.708	1.2	0.0	0.0	Easy evening run, no fueling—just sweat testing.
1-9	–1	46	69.1	67.7	0.300	2.25	0.756	2.0	35.0	10.0	Tried apple gel flavor, liked it. Great fueling on the long run.
1-12	2	52	68.9	67.5	0.100	1.75	0.857	2.0	20.0	10.0	Fueled during 4 × 10 min, stomach a bit off, some discomfort.
1-13	4	48	69.4	68.7	0.000	1.30	0.538	1.0	0.0	0.0	Easy evening run, no fueling—just sweat testing.
1-15	7	34	68.7	67.5	0.375	2.00	0.788	1.7	38.0	10.0	Longer tempo workout, fueling went well. Great workout.

[a] Sweat rate calculated as [(prerun weight – postrun weight) + ingested fluids (L)]/total run time (hr).

Table 3 Actual Race-Day Carbohydrate (CHO), Fluid, and Caffeine (CAFF) Intakes

Athlete	Total CHO intake (g)	CHO g/hr	Total fluid intake (ml)	Fluid ml/hr	% CHO solution	Total CAFF (mg)	CAFF/kg body weight	# of aid stations	CHO/aid station	Fluid/aid station
Marathoner 1	106.5	48.8	1,020	467.2	10.4	290	4.7	8	13.3	127.5
Marathoner 2	128.0	56.4	1,300	572.4	9.8	184	2.7	9	14.2	144.4
Marathoner 3	171.0	77.3	1,710	773.4	10.0	0	0.0	10	17.1	171.0
M	135.2	60.8	1,343	604.3	10.1	158	2.5	9	14.9	147.6
SD	32.8	14.8	347	155.6	0.3	147	2.4	1	2.0	21.9

Note. Marathoner 1 race: Toronto, September 26, 2010; 12 °C, 77% humidity. Marathoner 2 race: Houston, January 30, 2011; 17 °C, 90% humidity. Marathoner 3 race: Sacramento, December 5, 2010; 10 °C, 91% humidity.

Discussion

The aim of this case study was to characterize several training and nutrition techniques, leading to an individualized race-day fluid and fuel plan. Although there are many variables to consider in marathon performance, together these unique periodized training and nutrition techniques were successfully implemented with three elite marathoners.

Training Load, Distribution, and Tapering Analysis

There are few publications on training characteristics of elite marathoners, and the athletes in the current study averaged ~13 hr/week or ~182 km/week of running (Figure 1), which is comparable to the volume range reported in elite French/Portuguese (Billat et al., 2001) and Kenyan runners (Billat et al., 2003; Onywera et al., 2004). However, their average volume and peak volume (231 km/week) are substantially higher than what was recorded by elite Spaniard (129 km/week) or Eritrean runners (105 km/week; Lucia et al., 2006). Training intensity also needs to be considered when assessing total training load. This case study contains the first published RPE-based TRIMP scores for an elite marathoner (Figure 2). Most contemporary training programs feature cycles of increasing load, followed by consolidation and recovery weeks, which are captured in the week-to-week TRIMP variability. Throughout the first 12 weeks, there was an average TRIMP of 3,350 ± 561 AU/wk, which is comparable to the ~4,000-AU/week threshold that Foster (1998) identified as what is routinely performed by elite endurance athletes.

A polarized pattern of training features ~70–75% of training performed below lactate threshold and >15% well above that intensity (Fiskerstrand & Seiler, 2004). This polarized training distribution has previously been used by successful (e.g., Olympic and World medalists) rowers, cross-country skiers, and track cyclists (Seiler & Tonnessen, 2009). Despite each marathoner having an individualized training program, with no training-plan interventions, a polarized distribution resulted (Figure 3). The 3-week premarathon taper featured a 52% reduction in volume with no appreciable change in training frequency (Figure 1). This taper is congruent with the recommendations from a recent meta-analysis on the effects of tapering on performance, which found the ideal length of taper to be ~2–3 weeks, where training volume was decreased 41–60%, without any modification of training intensity or frequency (Bosquet, Montpetit, Arvisais, & Mujika, 2007). Thus, it appears that all three athletes implemented a scientifically supported approach to training volume, distribution, and tapering.

Altering Carbohydrate Availability During Endurance Training

Conventional nutrition recommendations dictate that endurance athletes endeavor to replenish muscle glycogen stores postexercise to ensure that subsequent training bouts are conducted in a glycogen-compensated state. However, reports from professional cyclists and East African runners indicate that some of those athletes purposely undertake some training in a glycogen-depleted/reduced and/or fasted/water-only state, in an attempt to force muscle adaptation (personal communication). In support of this, recent scientific hypotheses have suggested that periodically decreasing CHO availability may further enhance endurance-training adaptations and possibly performance (for review, see Burke, 2010). Nevertheless, it is difficult to extrapolate the results of laboratory training studies to the real world, where athletes are looking for only marginal improvements in performance over years of training. Despite the fact that low-CHO-availability training is both physiologically and psychologically challenging, these scientific and anecdotal reports suggest

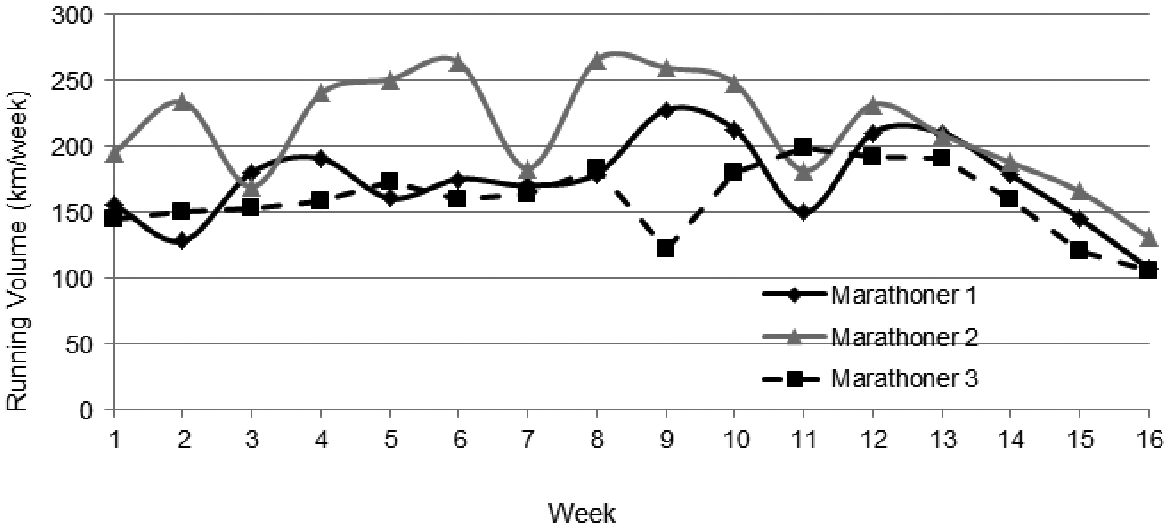

Figure 1 — Comparison of weekly training volume over 16 weeks until the target marathon (race included).

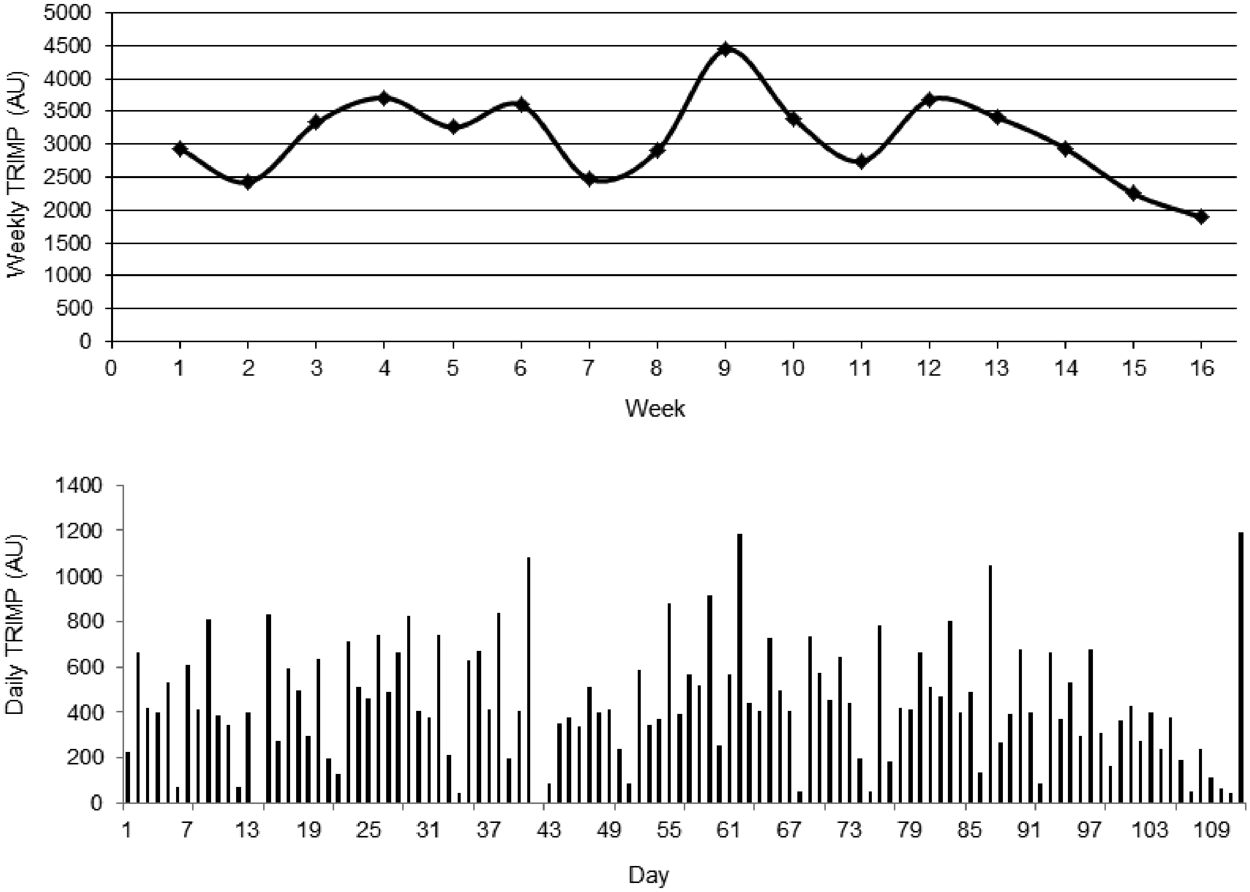

Figure 2 — Average weekly and daily training impulse (TRIMP) for Marathoner 1 throughout 16 weeks. AU = arbitrary units.

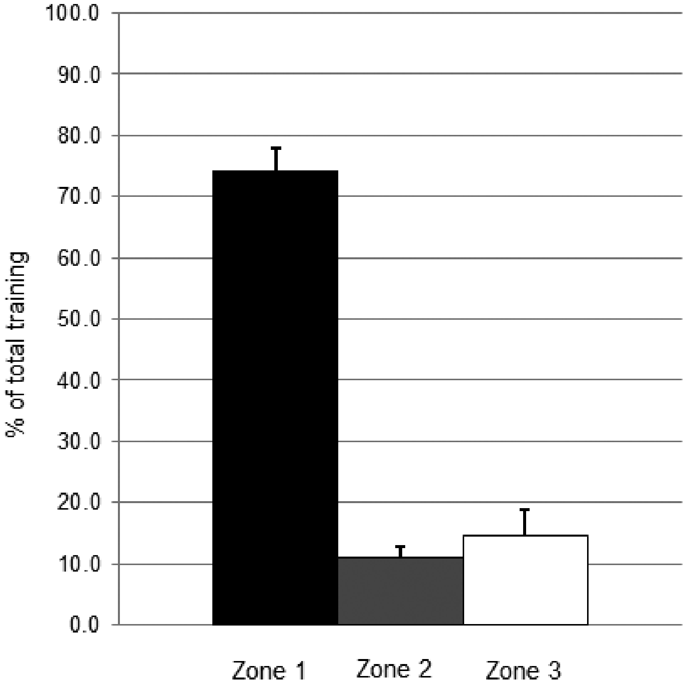

Figure 3 — Average training-intensity distribution during the 16-week marathon-preparation period as assessed by training impulse based on rating of perceived exertion.

that maximally adapted athletes may need to periodically undertake low-CHO-availability training to fully exploit endurance-training responses. Accordingly, these interventions were individualized at different rates into each marathoner's training program, and each was encouraged to increase the frequency, duration, and quality of these sessions throughout the general preparation phase and specific preparation phase as they better tolerated and adapted. There was a purposeful decline in these training sessions during the competition taper phase (Figure 4). Low-CHO-availability training had a large degree of individual variability according to personal acclimatization/tolerance, as Marathoner 2 conducted ~35% of his training sessions with low CHO availability, compared with ~10% of training sessions for Marathoners 1 and 3. Marathoner 2 already had a lot of experience in doing fasted and low-glycogen training and thus was much more willing to undertake these types of training sessions. Furthermore, feedback from the athletes indicated that morning-fasted training was physiologically much easier to integrate than the more strenuous reduced-glycogen training, as evidenced by the fact that only 10% of the low-CHO training was reduced-glycogen training.

Individualizing CHO and Fluid Intake During Training

Most studies demonstrate improved endurance performance when subjects consume CHO drinks compared with water, with CHO delivery and oxidation being a central mechanism (for review, see Jeukendrup, 2011). Accordingly, a recent CHO dose-response study showed a step-wise improvement in endurance performance in combination with increased CHO oxidation, with 60 g CHO/hr resulting in better performance than either 30 or 15 g CHO/hr (Smith et al., 2010). This suggests that the more CHO that can be feasibly consumed, the better the potential endurance-performance benefits. Recent evidence suggests that high intake rates (>90 g/hr) of glucose + fructose produce 20–50% greater exogenous CHO-oxidation rates, potentially decreased negative GI side effects (Jeukendrup, 2011), and an 8% increase in time-trial performance versus isocaloric glucose alone (Currell & Jeukendrup, 2008). Accordingly, marathoners used glucose + fructose mixtures at ~60 g/hr in an attempt to minimize adverse GI issues and to enhance performance.

The most recent position stand on fluid intake (Sawka et al., 2007) highlights the need for individualized recommendations according to sweat rates (Table 2). Marathoners experimented with a wide range of CHO- and fluid-consumption rates to ascertain individual GI tolerance in varying training intensities, especially in weather conditions that athletes were likely to face on race day. This allowed for an individual intake profile of tolerance for fluids and CHO to be made for each athlete. A recent study examining CHO- and fluid-intake rates (Pfeiffer et al., 2012) showed that 73% of marathon runners did not reach the relatively low recommendation of 30–60 g CHO/hr during racing (Sawka et al., 2007). Thus, during this CHO-fueling period (specific preparation phase and competition taper phase; Figure 4), athletes were strongly encouraged to slowly increase intakes in an attempt to

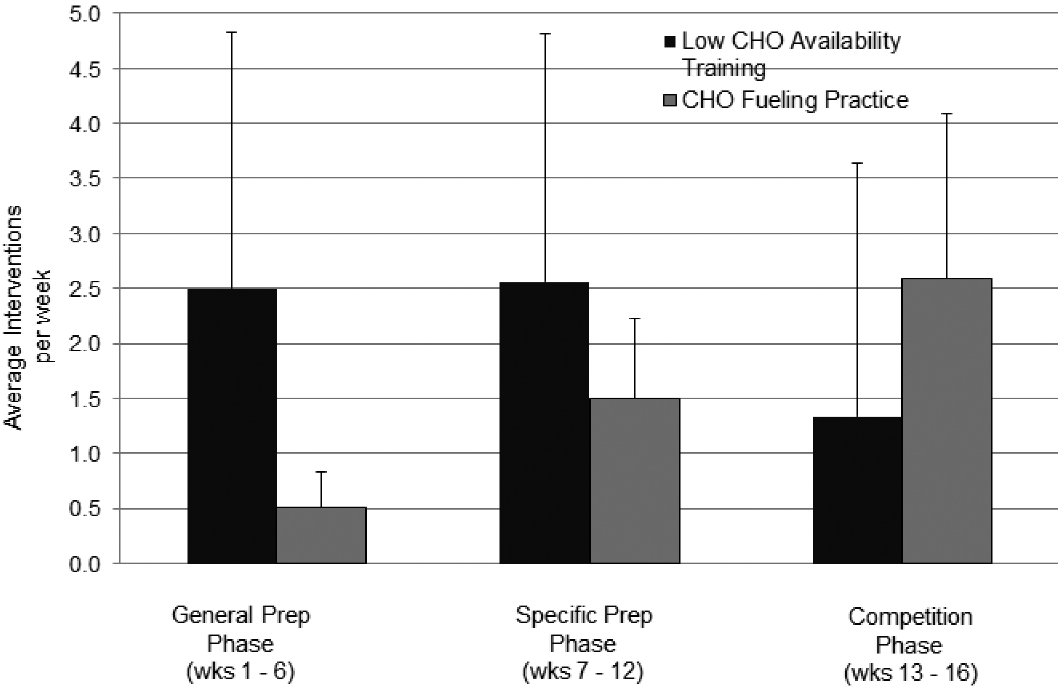

Figure 4 — Frequency of nutrition approaches throughout the 16-week marathon preparation. CHO = carbohydrate.

at least reach the threshold of ~60 g CHO/hr, with even higher intakes if tolerated.

However, excessive consumption of fluids and CHO during prolonged exercise can also result in adverse GI problems, as we have previously shown through significant correlation between endurance athletes who have a history of GI problems and subsequent measured GI problems during competition (Pfeiffer et al., 2012). It has been suggested that the GI tract can adapt and be optimized to large fluid and CHO intakes (Jeukendrup, 2011), as GI comfort was shown to improve in just five training bouts with fluid consumption (Lambert et al., 2008). Furthermore, 1 month of endurance training with 100 g CHO/hr increased steady-state exercise CHO oxidation by 14%, which the authors hypothesized was due to increased intestinal CHO transporters (Cox et al., 2010). Therefore, in the last 4 weeks before our athletes' target marathons, there was a continual emphasis on CHO fueling and fluid intake (Figure 4). This process of fluid and CHO individualization, and gut adaptation, resulted in each athlete finding his individual balance between the ergogenic effect of maximal CHO and fluid intake on race day and the potential ergolytic effect of GI distress.

Race-Day Nutrition and Hydration Intakes

A recent large (*N* = 221) CHO- and fluid-intake field study showed a significant positive correlation between higher CHO intake rates and faster finishing times in Ironman and marathon races (Pfeiffer et al., 2012). Thus, all our marathoners attempted to maximize their fueling and hydration plan that was individually optimized from the many prerace nutrition/hydration-monitoring sessions (Table 2) by consuming ~15 g CHO in ~150 ml of fluids every ~15 min during the race, along with a total of ~3 mg caffeine/kg BW (Table 3). This fluid intake of 604 ± 156 ml/hr is very similar to the 550 ± 34 ml/hr recently reported in elite marathon runners (Beis, Wright-Whyte, Fudge, Noakes, & Pitsiladis, 2012). Haile Gebrselassie "only" ran 2:06:35 in his first serious marathon, consuming only water. Conversely, Gebrselassie consumed ~60–70 g CHO/hr (personal communication) in ~900–1,000 ml/hr (Beis et al., 2012) during his 2008 2:03:59 marathon world record. World-class marathon performance is influenced by incredible genetics, physiological and psychological aptitude, and dedication to handle enormous training loads in an intelligent program. However, a periodized and individualized marathon nutrition and training approach can certainly facilitate the quest for marathon success.

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