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Nutrition Concepts for Elite Distance Runners Based on Macronutrient and Energy Expenditure

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Context: Elite distance runners (EDR) must optimize their nutrition to maintain their demanding training schedules.

Objective: To develop a nutrition concept for EDR based on energy and macronutrient expenditures.

Design: This theoretical study provides calculations for macronutrient and energy expenditures of EDR. Anthropometric and metabolic characteristics of EDR were assumed based on average real EDR.

Setting: University of Kiel.

Patients or Other Participants: Three prototypic types of male EDR described in the literature as type I (TI; body mass = 72 kg, respiratory quotient = 0.9 at rest, fast-twitch muscle fibers = 60% to 70%), type II (TII; body mass = 67 kg, respiratory quotient = 0.82 at rest, fast-twitch muscle fibers = 50%), and type III (TIII; body mass = 60 kg, respiratory quotient = 0.75 at rest, fast-twitch muscle fibers = 30% to 40%).

Main Outcome Measure(s): We calculated the macronutrient and energy expenditures of the 3 types of EDR according to body mass, respiratory quotient, and percentage of fast-twitch muscle fibers.

Results: We found that the average energy expenditure was 3750 kcal · d^{-1} for TI runners, 3463 kcal · d^{-1} for TII runners, and 3079 kcal · d^{-1} for TIII runners. The carbohydrate (CHO) expenditure reached an average value of 10.0 g · kg^{-1} · d^{-1} for TI runners, 8.0 g · kg^{-1} · d^{-1} for TII runners, and 4.7 g · kg^{-1} · d^{-1} for TIII runners. When the EDR accomplished running sessions at a pace $\geq$100% of maximum oxygen consumption, all types of runners had a CHO demand of about 10 g · kg^{-1} · d^{-1}. The TI and TII runners need a CHO intake of 8 to 10 g · kg^{-1} · d^{-1}. For the TIII runners, a CHO intake >6 g · kg^{-1} · d^{-1} is necessary during anaerobic training sessions.

Conclusions: Nutrition concepts must be differentiated for EDR according to metabolic and anthropometric characteristics of the runners and their special training emphases.

Key Words: diet, endurance, sports

Key Points

- Carbohydrate and energy expenditures differed among types of runners and were very high for all runners during training sessions with a pace $\geq$100% of maximum oxygen consumption.
- During all training phases, type I runners should consume at least 70% of total energy from carbohydrates; type II runners, 60% to 65%; and type III runners, 50%.
- Type I runners, who have large carbohydrate expenditures, are at risk for not taking in enough energy from carbohydrates.
- Type II and III runners have larger carbohydrate needs during training in mesocycles III through V.
- Nutrition education during out-of-season periods can teach elite distance runners how to apply dietary recommendations to their training.

When elite distance runners (EDR) compete, the margin between winning and losing can be extremely small. For example, during the Games of the XXVIII Olympiad in 2004, the winner of the men's 5000-m competition finished with a running time of 13:14:39 minutes; the runner-up, 13:14:59 minutes; and the last runner, 14:02:01 minutes.[1] Because the margin is small, EDR whose competition distances range from 800 m to marathon have to exhaust their maximal physiologic and psychological potential. The use of regeneration measures (eg, sauna), medical care, and adequate rest sessions are also crucial for EDR. In addition, EDR must follow an optimized nutrition program to maintain their training schedules, which are characterized by a running load between 100 and 250 km · wk^{-1} and 2 to 3 running sessions per day.[2] General nutrition recommendations in competitive sports[3–10] are not sufficient for athletes with this type of training schedule. Therefore, the purpose of our study was to develop nutrition concepts for EDR based on energy and macronutrient expenditures. Our concept was based on biochemical principles.[11,12]

METHODS

Approach

Findings in the literature[2,11,13–16] and our knowledge of typical metabolic characteristics (eg, respiratory quotient [RQ]; Tables 1–3) enabled us, through 11 equations, to calculate the macronutrient and energy expenditures of 3 prototypic types of runners during 4 running intensity zones. The obtained values were applied to a typical annual training schedule (Table 4 and Appendices) to identify training

Table 1. Values Employed for Calculations

No.	Characteristic	Unit	Value Assumed	Rationale
1	$\dot{V}O_{2max}$	mL $O_2 \cdot min^{-1} \cdot kg^{-1}$	80	Average values of elite distance runners[16]
2	Body mass	kg	72 (type I runner), 67 (type II runner), 60 (type III runner)	Typical values of different types of elite distance runners
3	Respiratory quotient	Nondimensional	low (type I runner), medium (type II runner), high (type III runner)[a]	Based on muscle fiber composition and according to Goedecke et al[13]
4	Percentage of energy expenditure in form of carbohydrate and fat	Carbohydrate %, fat %	100, 0 (RQ = 1); 84, 16 (RQ = 0.95); 67, 33 (RQ = 0.90); 50, 50 (RQ = 0.85); 44, 56 (RQ = 0.82); 16, 84 (RQ = 0.75)	According to McArdle et al[15]
5	Energetic equivalent at a given respiratory quotient	kcal $\cdot$ L $O_2{}^{-1}$	5.05 (RQ = 1); 4.94 (RQ = 0.95); 4.86 (RQ = 0.85)	According to McArdle et al[15]
6	Protein expenditure	Energy %	5 (zone I); 8 (zone II); negligible quantities (zones III and IV)	According to McArdle et al[14]
7	Glycogen content in working muscles	g	300	Adapted from Newsholme et al[17]
8	Percentage of aerobic and anaerobic energy expenditures	Aerobic %, anaerobic %	13, 87 (zone III); 7, 93 (zone IV)	Adapted from Newsholme et al[17]
9	$\dot{V}O_{2max}$ pace (100%)	s $\cdot$ km^{-1}	150	$\dot{V}O_{2max}$ pace cannot be maintained longer than 10 min. This pace is during 3 to 5 km races[11]
10	Physical activity level beyond training	Nondimensional	1.3	Low physical activity
11	Time beyond training	h $\cdot$ 24 h^{-1}	22.5	Average training time per day is 1.5 h
12	Energy expenditure beyond training	kcal $\cdot min^{-1} \cdot kg^{-1}$	0.0217	According to McArdle et al[15]
13	Protein expenditure beyond training	mg $\cdot min^{-1} \cdot kg^{-1}$	0.5556	Assumes a protein intake of 0.8 g $\cdot kg^{-1} \cdot d^{-1}$

Abbreviations: RQ, respiratory quotient; $\dot{V}O_{2max}$, maximum oxygen consumption.
[a] Details are provided in Table 3.

situations during which athletes have specific nutrition requirements and need nutrition recommendations.

Types of Elite Distance Runners

The classifications of EDR correspond with different physiques, body masses, RQs,[13] and muscle fiber contents[16] of typical EDR.[18] The type I (TI) runner has large proportions (60%–70%) of fast-twitch glycolytic fibers and fast-twitch oxidative (FTO) fibers in the leg muscles. The type II (TII) runner tends to have equal proportions of slow-twitch (ST) and fast-twitch (FT) fibers. The type III (TIII) runner typically has a large proportion (60%–70%) of fatigue-resistant ST fibers. Compared with FT fibers, ST fibers exhibit larger mitochondria and myoglobin content, less myosin adenosine triphosphatase activity, more capillary density, and more glycogenolytic activity, and they express the M-isoform of lactate dehydrogenase. Among others, these metabolic differences result in high RQs for TI runners, medium RQs for TII runners, and low RQs for TIII runners during rest and running training (Tables 2 and 3).

Training Zones

The definitions of training zones (Tables 1–3) are based on the training concepts developed by Martin and Coe[11] and the German Track and Field Athlete Association (Deutscher Leichtathletik Verband).[12] Zone I (ZI) involves aerobic conditioning, basic endurance training I, base work, and distance running; zone II (ZII), anaerobic conditioning, basic endurance training II, and pace training; zone III (ZIII), aerobic capacity, high-intensity, long speed, and long interval training; and zone IV (ZIV), anaerobic capacity, speed, short speed, and short interval training. The running pace in ZI through ZIV is expressed in percentage of maximum oxygen consumption ($\dot{V}O_{2max}$) pace (Tables 2 and 3).[11]

Table 2. Characteristics of Rest and Running Zones I through IV

	Rest	Running Zone I	II	III	IV
Pace (%$\dot{V}O_{2max}$)	Not applicable	55–80	80–90	90–100	100–130
Average pace (%$\dot{V}O_{2max}$)	Not applicable	70	85	100	120
Heart rate (% maximum)	Not applicable	60–80	80–90	90–100	100
Blood lactate (mm)	Not applicable	1–3.5	3.5–5	5–8	>8
Single training session (km)	Not applicable	10–20	8–15	4–6	2–4
Training volume per year (%)	Not applicable	50–70	10–30	5–15	1–5

Abbreviation: $\dot{V}O_{2max}$, maximum oxygen consumption.

Table 3. Expenditure of Energy and Macronutrients in Different Types of Elite Distance Runners During Rest and Running Zones

Elite Distance Runners	Rest	Running Zone I	II	III	IV
Type I					
Respiratory quotient	0.90	1.0	1.0	≥1.0	>>1.0[a]
kcal (min · kg^{-1})	0.0217	0.28	0.34	0.40	0.49
Carbohydrate (mg · min^{-1} · kg^{-1})	3.2569	67.12	79.05	337.34	1024
Fat (mg ·min^{-1} · kg^{-1})	0.7130	Negligible quantities	Negligible quantities	Negligible quantities	Negligible quantities
Protein (mg · min^{-1} · kg^{-1})	0.5556	3.53	6.87	Negligible quantities	Negligible quantities
Type II					
Respiratory quotient	0.82	0.95	1.0	≥1.0	>>1.0
kcal (min · kg^{-1})	0.0217	0.28	0.34	0.40	0.49
Carbohydrate (mg · min^{-1} · kg^{-1})	2.1392	55.32	79.05	337.34	1024
Fat (mg · min^{-1}· kg^{-1})	1.2101	4.61	Negligible quantities	Negligible quantities	Negligible quantities
Protein (mg · min^{-1} · kg^{-1})	0.5556	3.46	6.87	Negligible quantities	Negligible quantities
Type III					
Respiratory quotient	0.75	0.85	0.95	≥1.0	>>1.0
kcal (min · kg^{-1})	0.0217	0.27	0.34	0.40	0.49
Carbohydrate (mg · min^{-1} · kg^{-1})	0.7778	32.32	64.68	337.34	1024
Fat (mg · min^{-1} · kg^{-1})	1.8148	14.37	5.60	Negligible quantities	Negligible quantities
Protein (mg · min^{-1} · kg^{-1})	0.5556	3.40	6.72	Negligible quantities	Negligible quantities

[a] >> indicates much, much greater than.

Mesocycles

Mesocycles are training periods over 4 to 12 weeks with special training emphasis (eg, 8 weeks with focus on anaerobic training sessions). The M0 serves as a recovery period; MI through MIV, as the main cycles; and MV, as the final adaptation period before competition.

Calculations

We used 11 equations to calculate energy (Equations 2 and 7), protein (Equations 3 and 9), carbohydrate (CHO) (Equations 4, 6, 8, and 10), and fat (Equations 5 and 11) expenditures during and after the training. Calculations were based on oxygen expenditure (Equation 1); percentage of CHO and fat expenditure (RQ); and standard energy values of protein (4 kcal · g^{-1}), CHO (4 kcal · g^{-1}), and fat (9 kcal · g^{-1}).

Oxygen expenditure during ZI through ZIII training was calculated using the following formula:

$$\text{mL } O_2 \cdot \text{min}^{-1} \cdot \text{kg}^{-1} = \dot{V}o_{2max}\left(\text{mL} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}\right) \cdot \%\dot{V}o_{2max} \text{ pace.} \quad (1)$$

Energy expenditure during ZI through ZIII training was calculated using the following formula:

$$\text{kcal} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} = \text{mL } O_2 \cdot \text{kcal} \cdot \text{L } O_2^{-1} \text{ at a given RQ,} \quad (2)$$

where mL O_2 is the value calculated with Equation 1 and the RQ equals an assumed value given in Table 1, No. 4.

Protein expenditure during ZI and ZII training was calculated using the following formulas:

Table 4. Running Load as Mean in Kilometers per Week (%) During Each Training Zone and Mesocycle of Elite Distance Runners Based on an Annual Training Schedule[a]

Zone	Mesocycle I	II	III	IV	Total[b]
I	194 (100%)	100 (69.0%)	97 (70.9%)	120 (83.9%)	128 (82.0%)
II	0 (0%)	45 (31.0%)	36 (26.2%)	7 (4.9%)	22 (14.1%)
III	0 (0%)	0 (0%)	0 (0%)	12 (8.4%)	4 (2.6%)
IV	0 (0%)	0 (0%)	4 (2.9%)	4 (2.8%)	2 (1.3)
I–IV	194 (100%)	145 (100%)	137 (100%)	143 (100%)	156 (100%)

[a] The annual training schedule is described in the Appendices.
[b] The total is the average value of mesocycles I through IV.

$$\text{kcal protein} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} = \text{kcal} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} \cdot \text{protein expenditure (energy \%)}, \tag{3a}$$

where kcal · min^{-1} · kg^{-1} is the value calculated with Equation 2 and protein expenditure is expressed as energy percentage.

$$\text{mg} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} = \text{kcal protein} \cdot 4^{-1} \left(\text{kcal} \cdot \text{g protein}^{-1}\right) \cdot 1000, \tag{3b}$$

where kcal protein is the value calculated with Equation 3a.

Carbohydrate expenditure during ZI and ZII training was calculated using the following formula:

$$\text{mg} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} = \left(\text{kcal} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} - \text{kcal protein}\right) \cdot \text{CHO expenditure} \cdot 4^{-1} \left(\text{kcal} \cdot \text{g CHO}^{-1}\right) \cdot 1000, \tag{4}$$

where kcal · min^{-1} · kg^{-1} is the value calculated with Equation 2, kcal protein is the value calculated with Equation 3a, and CHO expenditure is expressed as energy percentage.

Fat expenditure during ZI and ZII training was calculated using the following formula:

$$\text{mg} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} = \left(\text{kcal} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} - \text{kcal protein}\right) \cdot \text{fat expenditure} \cdot 9^{-1} \left(\text{kcal} \cdot \text{g fat}^{-1}\right) \cdot 1000, \tag{5}$$

where kcal · min^{-1} · kg^{-1} is the value calculated with Equation 2, kcal protein is the value calculated with Equation 3a, and fat expenditure is expressed as energy percentage.

Carbohydrate expenditure during ZIII training was calculated using the following formulas:

$$\text{CHO aerobic} : \text{mg} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} = \text{kcal} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} \cdot \text{aerobic CHO expenditure} \cdot 4^{-1} \left(\text{kcal} \cdot \text{g CHO}^{-1}\right) \cdot 1000, \tag{6a}$$

where kcal · min^{-1} · kg^{-1} is the value calculated with Equation 2 and aerobic CHO expenditure is an assumed value given in Table 1, No. 8, and is expressed as aerobic percentage.

$$\text{CHO anaerobic} : \text{mg} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} = \text{kcal} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} \cdot \text{aerobic CHO expenditure} \cdot 4^{-1} \left(\text{kcal} \cdot \text{g CHO}^{-1}\right) \cdot 19 \cdot 1000, \tag{6b}$$

where kcal · min^{-1} · kg^{-1} is the value calculated with Equation 2 and aerobic CHO expenditure is an assumed value given in Table 1, No. 8, and is expressed as anaerobic percentage. Note that the CHO expenditure is 19 times higher for the anaerobic energy production than for the aerobic energy production.

$$\text{CHO total} : \text{mg} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} = \text{mg aerobic} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} + \text{mg anaerobic} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}, \tag{6c}$$

where mg aerobic · min^{-1} · kg^{-1} is the value calculated with Equation 6a and mg anaerobic · min^{-1} · kg^{-1} is the value calculated with Equation 6b.

Energy expenditure during ZIV training (120% of $\dot{V}O_{2max}$ pace) was calculated using the following formula:

$$\text{kcal} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} = \text{kcal} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} \text{ at } \dot{V}O_{2max} \text{ pace} \cdot 1.2. \tag{7}$$

CHO expenditure during ZIV training was calculated using the following formulas:

$$\text{CHO aerobic} : \text{mg} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} = \text{kcal} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} \cdot \text{aerobic CHO expenditure} \cdot 4^{-1} \left(\text{kcal} \cdot \text{g CHO}^{-1}\right) \cdot 1000, \tag{8a}$$

where kcal · min^{-1} · kg^{-1} is the value calculated with formula 7 and aerobic CHO expenditure is an assumed value given in Table 1, No. 8, and is expressed as aerobic percentage.

$$\text{CHO anaerobic} : \text{mg} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} = \text{kcal} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} \cdot \text{aerobic CHO expenditure} \cdot 4^{-1} \left(\text{kcal} \cdot \text{g CHO}^{-1}\right) \cdot 19 \cdot 1000, \tag{8b}$$

where kcal · min^{-1} · kg^{-1} is the value calculated with formula 7, and aerobic CHO expenditure is an assumed value given in Table 1, No. 8, and is expressed as anaerobic percentage. Note that the CHO expenditure is 19 times higher for the anaerobic energy production than for the aerobic energy production.

$$\text{CHO total} : \text{mg} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} = \text{mg aerobic} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} + \text{mg anaerobic} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}, \tag{8c}$$

where mg aerobic · min^{-1} · kg^{-1} is the value calculated with formula 8a and mg anaerobic · min^{-1} · kg^{-1} is the value calculated with formula 8b.

Protein expenditure after the training was calculated using the following formula:

$$\text{kcal} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} = 0.5556\ \text{mg} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} \cdot 4\left(\text{kcal} \cdot \text{g protein}^{-1}\right) \cdot 1000^{-1}, \tag{9}$$

where 0.5556 $\text{mg} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ is an assumed value given in Table 1, number 13.

Carbohydrate expenditure after the training was calculated using the following formula:

$$\text{mg} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} = \left(\text{kcal} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} - \text{kcal protein}\right) \cdot \text{CHO expenditure} \cdot 4^{-1}\left(\text{kcal} \cdot \text{g CHO}^{-1}\right) \cdot 1000, \tag{10}$$

where $\text{kcal} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ is an assumed value given in Table 1, number 12; kcal protein is the value calculated with formula 9; and CHO expenditure is expressed as energy percentage.

Fat expenditure after the training was calculated using the following formula:

$$\text{mg} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} = \left(\text{kcal} \cdot \text{min}^{-1} \cdot \text{kg}^{-1} - \text{kcal protein}\right) \cdot \text{fat expenditure} \cdot 9^{-1}\left(\text{kcal} \cdot \text{g CHO}^{-1}\right) \cdot 1000, \tag{11}$$

where $\text{kcal} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ is an assumed value given in Table 1, No. 12; kcal protein is the value calculated with formula 9; and fat expenditures is expressed as energy percentage.

RESULTS

Carbohydrate Expenditure During Zone I Training

Virtually all EDR divide their running training into ZI through ZIV (Tables 2 and 3).[2] The ZI training is accomplished at about 70% of $\dot{V}O_{2max}$ pace and improves the development and recruitment of ST fibers, the oxidative metabolic capabilities of cardiac and skeletal muscles, the gene expression and the activity of oxidative enzymes, the mitochondrial content of skeletal muscles, and the capillary density of the heart and skeletal muscles. The resulting increase in the arteriovenous oxygen difference in ST and FTO fibers augments the use of intramuscular triacylglycerols and decreases RQ during ZI and ZII training, especially in TII and TIII runners. The calculation of CHO expenditure during ZI training (Table 3) revealed oxidation rates of 67.12 mg CHO $\cdot$ $\text{min}^{-1} \cdot \text{kg}^{-1}$ in TI runners, 55.32 mg CHO $\cdot$ $\text{min}^{-1} \cdot \text{kg}^{-1}$ in TII runners, and 32.32 mg CHO $\cdot$ $\text{min}^{-1} \cdot \text{kg}^{-1}$ in TIII runners.

Carbohydrate Expenditure During Zone II Training

The ZII training[2] is intensity oriented and involves the lactate-ventilatory threshold (Table 2). It stimulates the development of ST and FTO fibers, promotes upregulation of glycolytic and oxidative enzymes in the working muscles, augments the $\dot{V}O_{2max}$ by increasing the maximal cardiac output, and improves the lactate threshold. As a result, the EDR sustain a pace of about 85% of $\dot{V}O_{2max}$ up to 60 minutes in a single training session. This is accompanied by hypoxia and acidity within the working muscles, which leads to a preferential use of glycogen and to a higher RQ during ZII training than during ZI training. For ZII training, we found that CHO expenditures reached 79.05 $\text{mg} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ in TI and TII runners and 64.68 $\text{mg} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ in TIII runners (Table 3).

Carbohydrate Expenditure During Zone III and IV Training

Training in ZIII and ZIV consists of shorter distance intervals, with a total load of 2 to 6 km per session (Table 2). Based on $\dot{V}O_{2max}$ pace, the intensity is about 100% in ZIII and 120% in ZIV training. The physiologic adaptations resulting from these training loads include the development and activation of FT and, particularly, of FTO fibers; increase in aerobic and anaerobic capacity of FT and FTO fibers; increase in cardiac stroke volume; and increase in blood-buffering capacity. Because 87% (ZIII training) and 93% (ZIV training) of the used adenosine triphosphate during these training sessions is generated by anaerobic metabolism, CHO becomes the primary contributor for energy supply.[14,17] The resynthesis of glycogen from lactate is not significant in humans,[19–21] so the use of CHO in ZIII and ZIV training is extremely high. For all types of runners, we calculated CHO expenditures of 337.34 $\text{mg} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ during ZIII training and 1024 $\text{mg} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ during ZIV training (Table 3).

Energy Expenditure During Zone I Through Zone IV Training

During ZI training, the calculated energy needs were 0.28 $\text{kcal} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ for TI and TII runners and 0.27 $\text{kcal} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ for TIII runners. For all types of runners, energy expenditures were 0.34 $\text{kcal} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ for ZII training, 0.40 $\text{kcal} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ for ZIII training, and 0.49 $\text{kcal} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ for ZIV training (Table 3).

Carbohydrate and Energy Expenditures Within Mesocycles of an Annual Training Schedule

The goals for the main mesocycles (MI through MIV) are the long-term maximization of physiologic responses that ZI through ZIV training induce. To calculate CHO and energy expenditure within these cycles, we applied a typical annual training schedule of EDR,[12] which was characterized by 2 training sessions per day, an average running load of 155 $\text{km} \cdot \text{wk}^{-1}$, and high percentages of ZI (82.0%) and ZII (14.1%) training (Table 4 and Appendices). During all mesocycles, the average CHO energy expenditure during 2 training sessions per day reached 405 g (range, 381–464 g) for TI runners, 343 g (range, 295–373 g) for TII runners, and 219 g (range, 176–276 g) for TIII runners (Table 5). The average corresponding energy expenditures were 1644 $\text{kcal} \cdot \text{d}^{-1}$ (range, 1456–2066 kcal $\cdot$

Table 5. Average Energy, Carbohydrate, and Protein Expenditures of Different Types of Elite Distance Runners With 2 Training Sessions per Day Within Mesocycles Based on an Annual Training Schedule[a]

Runner Type	Mesocycle[b] I	II	III	IV	Total[c]
I					
Energy (kcal)	2066	1539	1456	1515	1644
Carbohydrate (g)	464	354	381	419	405
Protein (g)	25.7	22.9	20.7	17.4	21.7
II					
Energy (kcal)	1882	1411	1335	1385	1503
Carbohydrate (g)	372	295	333	373	343
Protein (g)	23.7	21.1	19.0	15.7	19.9
III					
Energy (kcal)	1658	1241	1175	1222	1324
Carbohydrate (g)	197	176	228	276	219
Protein (g)	20.4	18.0	16.3	13.6	17.1

[a] The annual training schedule is described in the Appendices.
[b] Calculations are based on Tables 2 and 3.
[c] The total is the average value of mesocycles I through IV.

d^{-1}), 1503 kcal · d^{-1} (range, 1335–1882 kcal · d^{-1}), and 1324 kcal · d^{-1} (range, 1175–1658 kcal · d^{-1}), respectively. As a next step, energy and CHO expenditures beyond the training sessions were calculated. The average 24-hour CHO expenditure for all mesocycles was 722 g (range, 671–781 g) for TI runners, 537 g (range, 489–567 g) for TII runners, and 282 g (range, 239–339 g) for TIII runners (Table 6). The daily energy expenditures were 3750 kcal (range, 3621–4172 kcal), 3463 kcal (range, 3295–3842 kcal), and 3079 kcal (range, 2930–3413 kcal), respectively. Based on daily CHO and energy expenditures, we found that TI runners spent 77.0% energy in the form of CHO (range, 73.6%–81.3%), which corresponded with an average expenditure of 10.0 g CHO · kg^{-1} (range, 9.3–10.8 g CHO · kg^{-1}). The TII runners spent an average of 62.0% energy in the form of CHO (range, 58.0%–67.8%), which corresponded with an average expenditure of 8.0 g CHO · kg^{-1} (range, 7.3–8.5 g CHO · kg^{-1}). The TIII runners spent an average of 36.6% energy in the form of CHO (range, 30.5%–45.5%), which corresponded with an average expenditure of 4.7 g CHO · kg^{-1} (range, 4.0–5.7 g CHO · kg^{-1}).

Protein and Fat Expenditure During All Training Zones and Within Mesocycles of an Annual Training Schedule

Protein oxidation rates were similar among the different types of runners.[14] For the 3 types of runners, calculated values ranged from 3.40 mg · min^{-1} · kg^{-1} to 3.53 mg · min^{-1} · kg^{-1} during ZI training and from 6.72 mg · min^{-1} · kg^{-1} to 6.87 mg · min^{-1} · kg^{-1} during ZII training (Table 3). Protein oxidation during ZIII and ZIV training is less than 2% of the energy expenditure,[14] so we did not calculate it. The amount of protein used daily for energy production ranged from an average of 13.6 g to an average of 25.7 g, depending on the mesocycle and the type of runners (Table 5). Fat use was negligible during ZIII and ZIV training for all type of runners, because the RQ reached values of more than 1.0. Fat exhaustion in TI runners also was negligible. The TII runners oxidized fat at a rate of 4.61 mg · min^{-1} · kg^{-1} during ZI training (Table 3). In this type of runner, the average daily fat expenditure ranged from 15.7 g to 31.7 g, depending on the mesocycle (Appendices). For the TIII runner, we found fat oxidation rates of 14.37 mg · min^{-1} · kg^{-1} during ZI

Table 6. Average Energy and Carbohydrate Expenditures per 24 h of Different Types of Elite Distance Runners Within Mesocycles Based on an Annual Training Schedule[a]

Runner Type	24 h^{-1}	Mesocycle I	II	III	IV	Total[b]
I	Energy (kcal)	4172	3645	3562	3621	3750
	Carbohydrate (g)	781	671	698	736	722
	Carbohydrate · kg^{-1} (g)	10.8	9.3	9.7	10.2	10.0
	Carbohydrate (energy %)	74.9	73.6	78.4	81.3	77.0
II	Energy (kcal)	3842	3371	3295	3345	3463
	Carbohydrate (g)	566	489	527	567	537
	Carbohydrate · kg^{-1} (g)	8.4	7.3	7.9	8.5	8.0
	Carbohydrate (energy %)	58.9	58.0	64.0	67.8	62.0
III	Energy (kcal)	3413	2996	2930	2977	3079
	Carbohydrate (g)	260	239	291	339	282
	Carbohydrate · kg^{-1} (g)	4.3	4.0	4.9	5.7	4.7
	Carbohydrate (energy %)	30.5	31.9	39.7	45.5	36.6

[a] The annual training schedule is described in the Appendices.
[b] Calculations are based on Tables 2 and 3. The total is the average value of mesocycles I through IV.

training and 5.60 mg · min^{-1} · kg^{-1} during ZII training (Table 3). The average daily fat use of TIII runners ranged from 48.9 g to 87.4 g, depending on the mesocycle (Appendices).

DISCUSSION

Nutrition recommendations for intense endurance training and competition often are formulated as general guidelines,[3–10] or they focus on nutrition supplements.[22–24] Because these recommendations are not formulated with the extreme training load and metabolic and anthropometric characteristics of EDR in mind, different nutrition recommendations for this group of athletes are needed. To formulate an appropriate nutrition concept for EDR, the investigator must have detailed knowledge of the exact energy and macronutrient expenditure. However, no one has followed this approach. In our study, we developed a nutrition concept for EDR based on calculated macronutrient and energy expenditures during and beyond the training that occurs with an intense annual schedule. The calculations revealed major differences in expenditures, depending on the type of distance runner and the intensity of the training (Table 3). For example, we found that a TI runner spends an average of 77.0% of energy in the form of CHO each day. We calculated an average value of 62.0% of energy expenditure as CHO for a TII runner and an average value of only 36.6% of energy expenditure as CHO for a TIII runner. These findings suggest that a TI runner, who competes at high speeds and short distances, needs larger CHO intakes than a TIII runner, who competes at long distances. In addition, the macronutrient and energy expenditures depend strongly on the training zone. During ZI and ZII training, all EDR use CHO and a small portion of their protein for their energy supplies; TII and TIII runners also oxidize fat. In contrast, the energy supply of all EDR during ZIII and ZIV solely comes from the metabolism of CHO. In these training zones, the oxidation of fat and protein as fuel is very small. Therefore, the recommendations should differ according to special training emphasis during the various mesocycles.

Recommendations for Energy Intake

Because EDR are barely active outside of their training loads, the average energy expenditures of the different types of runners within MI through MIV were relatively low and were between 2930 kcal · d^{-1} for TIII in MIII and 4172 kcal · d^{-1} for TI in MI. We found that the TI runner, followed by TII and TIII runners, had the highest energy demand in all mesocycles. We found the highest average energy expenditure in MI for all types of runners, with 4172 kcal · d^{-1} in TI runners, 3842 kcal · d^{-1} in TII runners, and 3413 kcal · d^{-1} in TIII runners, due to the large number of ZI training sessions. Compared with the average energy expenditure in MI, the average energy expenditure in MII through MIV was at least 527 kcal · d^{-1} lower in TI runners, 471 kcal · d^{-1} lower in TII runners, and 417 kcal · d^{-1} lower in TIII runners. This means that MII through MIV needs for TI runners were more than 3500 kcal · d^{-1}, for TII runners were between 3000 and 3500 kcal · d^{-1}, and for TIII runners were less than 3000 kcal · d^{-1}. If an average person needs an energy intake of 2500 kcal · d^{-1}, then EDR need an additional intake of 500 to 1500 kcal · d^{-1}. These intakes easily can be reached by following a normal diet according to the common dietary guidelines.[25,26]

Recommendations for Fat Intake

Although the difference in fat expenditures among the 3 types of runners is large and expenditures of 250 g · d^{-1} are possible, specific quantitative recommendations regarding fat intake are not necessary. Fat needs that ensure an adequate energy supply are easily met through a normal diet. Furthermore, the replacement of fat oxidized during exercise is not considered to be a key process during recovery and training adaptation.[27,28]

Recommendations for Protein Intake

With the highest training load, protein expenditures in M1 were 25.7 g protein · d^{-1} in TI runners, 23.7 g protein · d^{-1} in TII runners, and 20.4 g protein · d^{-1} in TIII runners (Table 5). These values correspond roughly with a protein expenditure of 0.35 g protein · kg body mass^{-1} · d^{-1} in all types of runners. Considering that the protein quality of a mixed diet is 70%, individual differences in protein metabolism of 1 SD (30%) and a safety margin of 30% of additional protein intake, the recommended protein intake should be about 2 times higher than the actual requirement. Regarding the recommended intake of 0.8 g protein · kg body mass^{-1} · d^{-1} of protein for healthy people who are not EDR,[25,26] a protein intake of 1.5 (0.8 + 0.7) g · kg body mass^{-1} · d^{-1} would be enough for almost all physiologic situations and should be adequate for EDR. This value meets common recommendations for endurance athletes.[6,14,29–31] When expressing this value as the percentage of dietary energy intake, EDR need only 11% of their energy from proteins. During MI, the energy exhaustion of the TI runner is relatively high. Under this condition, negative energy and CHO balances are possible and would cause a significantly higher oxidation of amino acids,[29,31] which donate their carbon skeletons for the synthesis of glucose by the liver. Thus, protein can contribute more than 10% of the total energy production during training sessions. We recommend that diet provide 15% of energy from protein. This can be achieved easily by a mixed Western diet.[25] Therefore, from a quantitative point of view, EDR do not need special recommendations regarding the amount of protein in their diet. In addition, the recommendations for the daily protein intake are the same for all types of EDR regardless of the daily training loads (ZI–ZIV). The EDR should ensure that one–third of their protein intake consists of animal food (meat, fish, and dairy products) and that two–thirds of the protein intake consists of plant food (whole grain products, vegetables, potatoes, and legumes). For example, the daily protein intake of animal food could include 100 g meat or fish, 1 egg, and 200 mL of milk or yogurt. The protein intake from plant food could include 100 g of cereal, 200 g of whole grain bread, and 200 g of legumes and vegetables.

One point of interest is the timing of protein ingestion. Researchers[32–34] have shown that ingesting protein with CHO immediately after endurance exercise can promote glycogen storage. This storage could contribute to a faster recovery and better adaptation, especially in athletes who participate in many training sessions each day and week and subsequently have short recovery periods. Ingesting 0.4 g · kg^{-1} of protein immediately after training and 2 hours later is a common schedule that has been beneficial. Due to the decreased cellular amino acid availability and hyperinsulinemia, a well-directed protein intake can lead to a net muscle-protein accumulation[35–37] and can positively affect glycogen resynthesis.

Recommendations for Carbohydrate Intake

Glycogen deficiency leads to reduced training intensity and response,[38] low achievements in competitions,[38] overtraining syndromes,[14] low concentrations of lactate in the blood,[39] high concentrations of ammonia in the blood,[40–42] and higher protein expenditure for energy supply.[29,31] To avoid these problems, large CHO intake for endurance athletes generally is accepted. However, our calculations revealed that the CHO expenditure during and beyond training is highly dependent on the type of distance runner and that runner's respective training zones. Therefore, recommendations regarding CHO intake must be differentiated by these important factors. Authors[34,43–51] of many guidelines for CHO intake have described the beneficial effects of CHO feeding strategies, alone or in combination with protein, on the performance of 1 exercise session. In those guidelines, the authors hinted at the described differentiations; the recommendations distinguished between the CHO needs for recovery and for fuel in athletes undertaking exercise programs of moderate, high, or extreme intensity. They also referred to the body mass of an athlete in terms of grams of CHO per kilogram of body mass per day. However, no authors differentiated their recommendations regarding important factors, such as $\dot{V}O_{2max}$ pace and RQ of EDR. With respect to ZIII and ZIV training during which EDR have a $\dot{V}O_{2max}$ pace of 100% or more, our concept shows the importance of differentiating CHO intake based on the training zone. From a quantitative point of view, a human cannot resynthesize glycogen from lactate (Cori cycle) during anaerobic exercise.[19–21] Instead, the resynthesis must occur from glucose that is derived from dietary CHO. Therefore, the CHO need for ZIII or ZIV training is significantly larger than for ZI and ZII training. This larger need should be considered in nutrition recommendations. In addition, we found large differences in CHO demand among the EDR. As noted, a TI runner, who has strength for high speeds and short distances, has a much larger demand for CHO than does a TIII runner, who performs well at long distances. The TIII runner usually meets energy needs during ZI and ZII training with fat. Therefore, his or her CHO expenditure is much lower than those of the TI runner. Because we considered all of these factors in our recommendations for an adequate nutrition intake for EDR, our concept is more precise than earlier recommendations.

Recommendations Regarding Carbohydrate Intake in Terms of Percentage of Energy Versus Grams per Kilogram of Body Mass

The dietary guidelines for athletes are not uniform in their recommendations for CHO intake in terms of percentage of energy or CHO intake in grams per kilogram of body mass per day. General dietary guidelines provide traditional energy-ratio terminology to recommend the CHO intake of athletes. Considering their strict training schedules, EDR may need to use the recommendations for CHO intake in grams in relation to individual body mass, because this guideline provides more flexibility for their individual nutrient needs. Burke et al[8] described the recommendation in terms of percentage contributions to total dietary energy intake as neither user-friendly nor strongly related to the absolute needs for fuel. Our calculations showed that the expression of CHO intake in terms of percentage of dietary energy or in grams per kilogram of body mass did not make a difference. Because energy expenditure, CHO exhaustion, and body mass are interconnected, the differences between these 2 kinds of recommendations are rather small. Thus, if EDR consume their recommended energy intake, both recommendations would apply, and a discussion is dispensable. During nutrition training, EDR should receive individual advice, and both recommendations should be taken into consideration. The athletes then could choose the recommendation that gives them the biggest advantage when applied to their daily activities and training schedules.

Recommendations for Carbohydrate Intake in Type I Runners

The TI runners exhausted 722 g CHO · d^{-1}, or 77.0% of total energy expenditure. The CHO demand of the runners can be more than 80% of total energy expenditure in MIII and MIV, which are present on days with ZIII, ZIV, or both training sessions. However, a corresponding CHO intake of about 80% is not achievable, because high food volume and lack of time make such large CHO diets impractical to consume. Furthermore, a CHO intake of more than 70% of total energy is not recommended because, after deducting 11% of energy from protein, the intake of fat would be less than 19% of energy. With such a low fat intake, the demand for essential fatty acids would not be fulfilled. Another concern is the intake of vitamins; fat-soluble vitamins can be ingested only if the meal includes enough fat. Therefore, only CHO intakes of 65% to 70% of total energy are realizable for these athletes. In practical terms, these CHO intakes can be achieved by consuming a mixed Western diet; consuming large amounts of food with a high glycemic index, such as simple sugars and other compact forms of CHO[45,52]; increasing the frequency of meals and snacks[3]; consuming from 1 to 1.5 g CHO · kg body $mass^{-1}$ from 1 to 2 hours before and after the training[53,54]; avoiding food with a high dietary-fiber content[53,54]; and choosing liquid CHO meals.[55,56] The TI runners should pay attention to this high CHO consumption in MI through MIV in each training period. However, in MIII through MIV, they can benefit even more from the described recommendations. Because TI runners cannot meet their CHO needs of more than 70% of total energy, their bodies can adapt to the lower muscle glycogen stores resulting from moderate CHO intakes.[57] Researchers[58,59] have shown that moderate CHO intakes do not impair the training outcomes. In addition, investigators[8] have shown that long-term intake of low-CHO diets causes metabolic adaptations that substantially enhance the fat oxidation during exercise and compensate for the reduced CHO availability. These adaptations may be advantageous for TI runners, because they could improve their fat oxidation rates and consequently decrease their RQ. Because muscle fibers could be created by metabolic processes, the alteration of the RQ possibly has a lasting effect.[2]

Recommendations for Carbohydrate Intake in Type II Runners

The TII runners exhaust an average of 58.0% of energy in the form of CHO in MIII and 67.8% of energy in this form in MIV. In MI and MII, the CHO demand is usually less than 60% of total energy expenditure. In those training phases, TII runners easily can meet their CHO needs by following common dietary guidelines.[25,26] However, in MIII and MIV, the CHO supply can be critical. Due to the large number of anaerobic training units in these mesocycles, TII runners can need more than 70% of total energy from CHO on some days to achieve an ideal CHO maintenance. To realize CHO intakes of 65% to 70%, TII runners should consider consuming large amounts of CHO immediately before or after the training on those training days. To increase CHO availability, TII runners should eat from 1 to 1.5 g CHO · kg body mass^{-1} 1 to 2 hours before anaerobic training sessions. In addition, they should eat from 1 to 1.5 g CHO · kg body mass^{-1} every 2 hours after these training sessions until they achieve at least 7 g CHO · kg body mass^{-1} to quickly recover muscle glycogen.[44,45]

Recommendations for Carbohydrate Intake in Type III Runners

Because TIII runners exhaust 36.6% of total energy in the form of CHO, they usually do not need large CHO intakes. We recommend an average CHO intake of 50% of energy, which is easily achievable with a normal Western diet. A larger CHO intake is only necessary during periods with ZIII and ZIV training sessions. During those training periods, the recommendations for TII runners also apply to TIII runners; they need a large CHO intake before and after anaerobic training units.

Recommended Nutrition Training: From Theory to Practice

Due to their large CHO requirements, EDR need nutrition experience to apply the calculated nutrition recommendations. They must have nutrition training to fine-tune their eating habits to their training schedules. Because EDR need much time for training and recovery during most training mesocycles, they should take part in selective nutrition training during the out-of-season mesocycle (that is, M0). The purpose of the nutrition training should be the application of our nutrition recommendations for EDR into their daily physical training schedules. The EDR can learn to calculate and acknowledge their individual nutrient requirements and to fine-tune their eating habits to meet their nutrient intake targets. Contents of the nutrition training are the basis of healthy sport nutrition, the specific knowledge of food composition, the preparation of meals, and the design of a meal plan that follows the recommendations. Furthermore, EDR learn how to complement nutrition with appropriate instant meals (when time to eat is limited) and still follow the nutrition recommendations. The nutrition training is of the highest importance for TI runners, because those athletes have the greatest risk of developing CHO deficiencies. Due to their extremely large CHO demand, they need to carefully plan their diets throughout the entire training year. These runners should give first priority to the planning of adequate CHO supplies, especially before a competition. In addition, the nutrition training should emphasize the planning of nutrition during critical training phases. Thus, all EDR need to learn how to meet their large CHO demands during periods with many ZIII and ZIV training sessions.

Application of the Concept

The Figure provides a generalized overview of our nutrition concept for EDR. For M0 through MV, the number of training sessions (ZI–ZIV and strength or alternative workouts) per week and appropriate recommendations regarding CHO and protein are represented. Based on Tables 2 and 3, our concept provides the opportunity to create individual training schedules and to calculate personal fuel expenditures. The Appendices exemplify a typical training schedule. In the beginning of the macrocycle (in M0), EDR and their trainers, physiologists, and nutrition experts plan the training schedules and the nutrition for the following training year. Most important is the design of the appropriate training schedules. According to the training schedules, the required values (kilograms, $\dot{V}O_{2max}$, RQ) for the calculation of the nutrient oxidation are determined by general performance diagnostics. If possible, a field test should be conducted with each EDR. After the designation of all values, the individual energy, CHO, and protein needs can be calculated. Critical mesocycles, training days, and training sessions subsequently can be assigned. Training days requiring that EDR give special attention to energy and CHO intakes should be noted in a training book. The recommendations must be transferred to food choices that are consistent with preferences and training schedules of the EDR. After the training schedules have been designed, EDR should receive nutrition training so that they can put these theoretical recommendations into practice.

Our concept also can be used for club athletes who run 80 km or more per week as well as for athletes in other endurance disciplines. However, because club athletes rarely reach the point where they could develop a nutrient deficiency, the general guidelines for athletes are sufficient for them. A balanced supply of energy, CHO, nitrogen, and other nutrients is achieved easily by adapting the common dietary guidelines, such as the reference values for nutrient intake and the 10 dietary guidelines of the German Nutrition Society,[25] the United States' Recommended Daily Allowances,[26] and the public food-guide pyramids. These guidelines recommend consuming 55% to 60% of total energy in the form of CHO, 30% of energy in the form of fat, and 10% to 15% of energy in form of protein.

CONCLUSIONS

In M0, all types of EDR can meet their CHO needs with an intake of 50% of total energy from CHO. In MI through

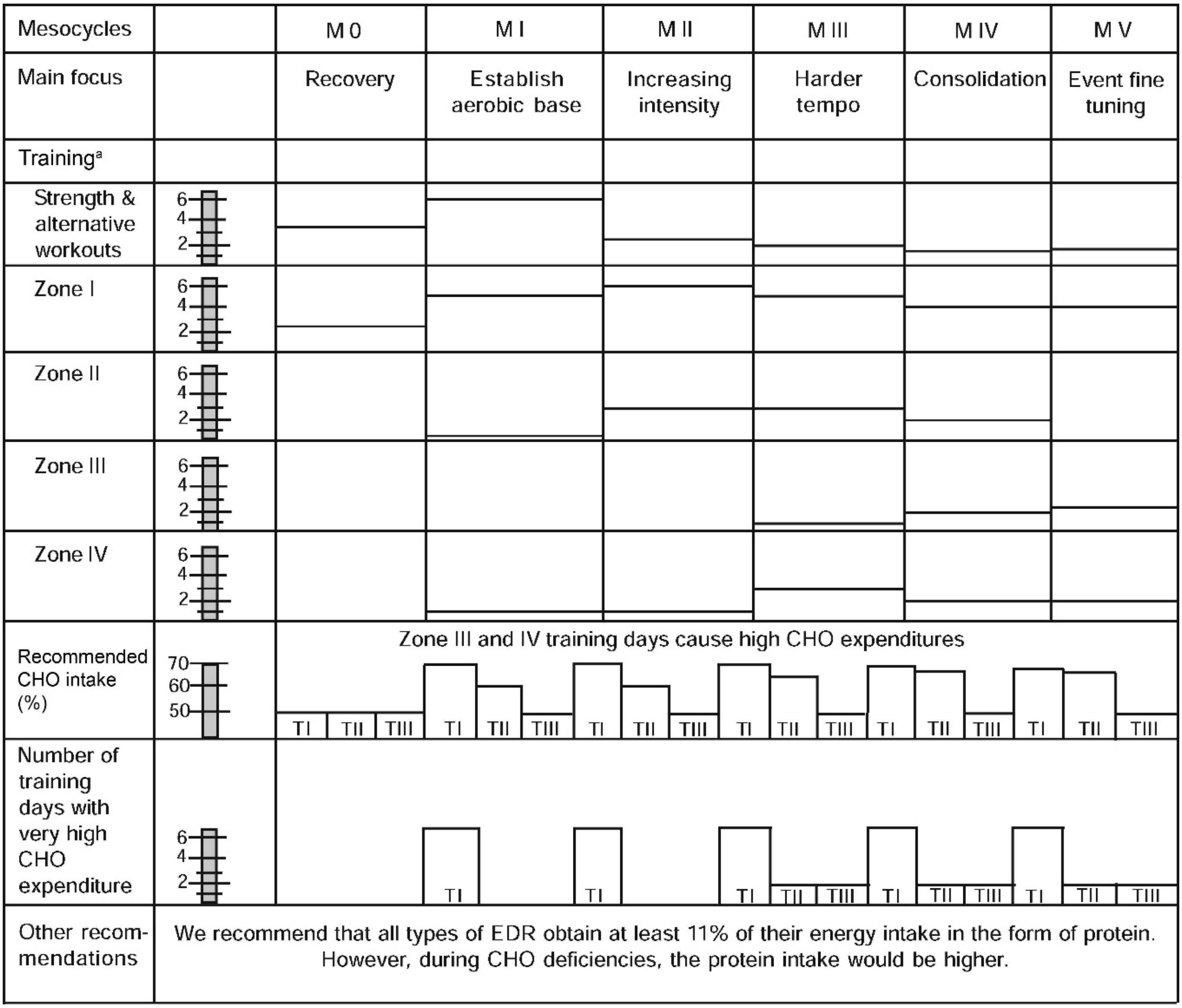

Figure. Overview of the methodical succession of the training zones for a macrocycle. [a] Indicates number of training sessions per week. EDR indicates elite distance runners; CHO, carbohydrate.

MV, CHO intakes of at least 70% of total energy for TI runners, 60% to 65% of total energy for TII runners, and 50% of total energy for TIII runners are recommended. The TI runners have very large CHO expenditures at all times and consequently are at high risk of not consuming enough CHO. The TII and TIII runners on average have 2 critical training days per week in MIII through MV, during which they have larger CHO needs. Critical training days generally are training days with 1 or 2 ZIII and/or ZIV training sessions. For all types of EDR, we recommend a protein intake of 11% of total energy, with the exception of those with too low energy and/or CHO intakes.

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Appendix 1. Typical Annual Training Schedule of Elite Distance Runners With Indication of the Calculated Macronutrient Oxidation as a Function of Training Zone and Type of Elite Distance Runner Within Mesocycle I

	Monday			Tuesday			Wednesday			Thursday			Friday			Saturday			Sunday			Week
Mesocycle I	AM	PM	Total	AM	PM	Total	AM	PM	Total	AM	PM	Total	AM	PM	Total	AM	PM	Total	AM	PM	Total	Total
Zone	I	I[a]	I	I[a]	I[a]	I	I	I[a]	I	I[a]	I[a]	I	I	I[a]	I	I[a]	I[a]	I	I	Rest	I	I
km	15.00	16.36	31.36	8.18	24.55	32.73	15.00	16.36	31.36	16.36	6.14	22.50	15.00	16.36	31.36	8.18	16.36	24.54	20.00	0.00	20.00	193.85
min	55.0	60.0	115.0	30.0	90.0	120.0	55.0	60.0	115.0	60.0	22.5	82.5	55.0	60.0	115.0	30.0	60.0	90.0	73.3	0.0	73.3	710.8
Type I runner																						
CHO (g)	266	290	556	145	300[b]	445	266	290	556	290	109	399	266	290	556	145	290	435	300[b]	0	300	3247
Fat (g)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Protein (g)	14	15	29	8	23	31	14	15	29	15	6	21	14	15	29	8	15	23	18	0	18	180
Energy (kcal)	1119	1221	2340	610	1831	2441	1119	1221	2340	1221	458	1679	1119	1221	2340	610	1221	1831	1491	0	1491	14 462
CHO[c] (energy %)			78.5			67.0			78.5			75.7			78.5			76.4			68.6	74.9
Type II runner																						
CHO (g)	204	223	427	111	300[b]	411	204	223	427	223	83	306	204	223	427	111	223	334	272	0	272	2604
Fat (g)	17	19	36	9	28	37	17	19	36	19	7	26	17	19	36	9	19	28	23	0	23	222
Protein (g)	13	14	27	7	21	28	13	14	27	14	5	19	13	14	27	7	14	21	17	0	17	166
Energy (kcal)	1019	1112	2131	556	1668	2224	1019	1112	2131	1112	417	1529	1019	1112	2131	556	1112	1668	1358	0	1358	13 172
CHO[c] (energy %)			60.7			57.8			60.7			57.3			60.7			58.2			56.2	58.9
Type III runner																						
CHO (g)	107	116	223	58	175	233	107	116	223	116	44	160	107	116	223	58	116	174	142	0	142	1378
Fat (g)	47	52	99	26	77	103	47	52	99	52	19	71	47	52	99	26	52	78	63	0	63	612
Protein (g)	11	12	23	6	18	24	11	12	23	12	5	17	11	12	23	6	12	18	15	0	15	143
Energy (kcal)	898	980	1878	490	1470	1960	898	980	1878	980	367	1347	898	980	1878	490	980	1470	1197	0	1197	11 608
CHO[c] (energy %)			31.5			31.9			31.5			28.8			31.5			29.4			27.8	30.5

Abbreviation: CHO, carbohydrate.

[a] Alternative workout (eg, cycling, circuit training, or aquajogging).

[b] This value assumes a maximal carbohydrate expenditure of 300 g per training session.

[c] Including basal metabolic rate.

Appendix 2. Typical Annual Training Schedule of Elite Distance Runners With Indication of the Calculated Macronutrient Oxidation as a Function of Training Zone and Type of Elite Distance Runner Within Mesocycle II

	Monday			Tuesday			Wednesday			Thursday			Friday			Saturday			Sunday			Week
Mesocycle II	AM	PM	Total	AM	PM	Total	AM	PM	Total	AM	PM	Total	AM	PM	Total	AM	PM	Total	AM	PM	Total	Total
Zone	I	II	I + II	I	I[a]	I	I	II	I + II	I	Rest	I	I	II	I + II	II	II[b]	II	I	Rest	I	I + II
km	15.00	6.00	21.00	15.00	8.18	23.18	12.00	12.00	24.00	15.00	0.00	15.00	15.00	13.50	19.50	12.00	10.00	22.00	20.00	0.00	20.00	144.68
min	55.0	18.0	73.0	55.0	30.0	85.0	44.0	36.0	80.0	55.0	0.0	55.0	55.0	4.5	68.5	36.0	30.0	66.0	73.3	0.0	73.3	500.8
Type I runner																						
CHO (g)	266	102	368	266	145	411	213	205	418	266	0	266	266	77	343	205	171	376	300[c]	0	300	2482
Fat (g)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Protein (g)	14	9	23	14	8	22	11	18	29	14	0	14	14	7	21	18	15	33	18	0	18	160
Energy (kcal)	1119	445	1564	1119	610	1729	895	891	1786	1119	0	1119	1119	334	1453	891	742	1633	1491	0	1491	10 775
CHO[d] (energy %)			74.7			75.9			75.5			72.3			74.2			74.1			68.6	73.7
Type II runner																						
CHO (g)	204	95	299	204	111	315	163	191	354	204	0	204	204	72	276	191	159	350	272	0	272	2070
Fat (g)	17	0	17	17	9	26	14	0	14	17	0	17	17	0	17	0	0	0	23	0	23	114
Protein (g)	13	8	21	13	7	20	10	17	27	13	0	13	13	6	19	17	14	31	17	0	17	148
Energy (kcal)	1019	415	1434	1019	556	1575	815	829	1644	1019	0	1019	1019	311	1330	829	691	1520	1358	0	1358	9880
CHO[d] (energy %)			58.1			57.6			60.8			53.4			57.1			62.5			56.2	58.1
Type III runner																						
CHO (g)	107	70	177	107	58	165	85	140	225	107	0	107	107	52	159	140	116	256	142	0	142	1231
Fat (g)	47	6	53	47	26	73	38	12	50	47	0	47	47	5	52	12	10	22	63	0	63	360
Protein (g)	11	7	18	11	6	17	9	14	23	11	0	11	11	5	16	14	12	26	15	0	15	126
Energy (kcal)	898	363	1261	898	490	1388	719	726	1445	898	0	898	898	272	1170	726	605	1331	1197	0	1197	8690
CHO[d] (energy %)			31.8			29.0			36.0			25.6			30.4			41.4			27.8	31.9

Abbreviation: CHO, carbohydrate.
[a] Alternative workout (eg, cycling, circuit, or aquajogging).
[b] Running coordination.
[c] Assuming a maximal carbohydrate expenditure of 300 g per training session.
[d] Including basal metabolic rate.

Appendix 3. Typical Annual Training Schedule of Elite Distance Runners With Indication of the Calculated Macronutrient Oxidation as a Function of Training Zone and Type of Elite Distance Runner Within Mesocycle III

	Monday			Tuesday			Wednesday			Thursday			Friday			Saturday			Sunday			Week
Mesocycle III	AM	PM	Total	AM	PM	Total	AM	PM	Total	AM	PM	Total	AM	PM	Total	AM	PM	Total	AM	PM	Total	Total
Zone	IV, I[a]	II	I, II + IV	I	II[b]	I + II	I	II	I + II	I	I[c]	I	IV, I[a]	II	I, II + IV	I	Rest	I	I	Rest	I	I, II + IV
km	2.00, 6.00	8.00	16.00	15.00	10.00	25.00	12.00	12.00	24.00	15.00	8.18	23.18	1.60, 6.00	6.00	13.16	15.00	0.00	15.00	20.00	0.00	20.00	136.78
min	4.27, 22.00	24.00	50.27	55.00	30.00	85.00	44.00	36.00	80.00	55.00	30.00	85.00	3.41, 22.00	18.00	43.41	55.00	0.00	55.00	73.30	0.00	73.30	471.98
Type I runner																						
CHO (g)	300[d]	137	437	266	171	437	213	205	418	266	145	411	300[d]	102	402	266	0	266	300[d]	0	300	2671
Fat (g)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Protein (g)	6	12	18	14	15	29	11	18	29	14	8	22	6	9	15	14	0	14	18	0	18	145
Energy (kcal)	599	594	1193	1119	747	1861	895	891	1786	1119	610	1729	568	445	1013	1119	0	1119	1491	0	1491	10 192
CHO[e] (energy %)			91.5			76.0			75.5			75.9			92.2			72.3			68.6	78.4
Type II runner																						
CHO (g)	300[d]	127	427	204	159	363	163	191	354	204	111	315	300[d]	95	395	204	0	204	272	0	272	2330
Fat (g)	7	0	7	17	0	17	14	0	14	17	9	26	7	0	7	17	0	17	23	0	23	111
Protein (g)	5	11	16	13	14	27	10	17	27	13	7	20	5	8	13	13	0	13	17	0	17	133
Energy (kcal)	548	553	1101	1019	691	1710	815	829	1644	1019	556	1575	520	415	935	1019	0	1019	1358	0	1358	9342
CHO[e] (energy %)			81.1			60.7			60.8			57.6			81.4			53.4			56.2	64.0
Type III runner																						
CHO (g)	300[d]	93	393	107	116	223	85	140	225	107	58	165	277	70	347	107	0	107	142	0	142	1602
Fat (g)	19	8	27	47	10	57	38	12	50	47	26	73	19	6	25	47	0	47	63	0	63	342
Protein (g)	4	10	14	11	12	23	9	14	23	11	6	17	4	7	11	11	0	11	15	0	15	114
Energy (kcal)	485	484	969	898	605	1503	719	726	1445	898	490	1388	459	363	822	898	0	898	1197	0	1197	8222
CHO[e] (energy %)			67.0			35.1			36.0			29.0			63.6			25.6			27.8	39.8

Abbreviation: CHO, carbohydrate.
[a] Warm-up and cool-down.
[b] Running coordination.
[c] Alternative workout (eg, cycling, circuit, or aquajogging).
[d] Assuming a maximal carbohydrate expenditure of 300 g per training session.
[e] Including basal metabolic rate.

Appendix 4. Typical Annual Training Schedule of Elite Distance Runners With Indication of the Calculated Macronutrient Oxidation as a Function of Training Zone and Type of Elite Distance Runner Within Mesocycle IV

	Monday			Tuesday			Wednesday			Thursday			Friday			Saturday			Sunday			Week
Mesocycle IV	AM	PM	Total	AM	PM	Total	AM	PM	Total	AM	PM	Total	AM	PM	Total	AM	PM	Total	AM	PM	Total	AM
Zone	I	I	I	IV, I[a]	III, I[a]	I, III, IV	I	Rest	I	I, II[b]	I	I, II	IV, I[a]	III, I[a]	I, III, IV	I	Rest	I	I	Rest	I	I–IV
km	12.0	10.0	22.0	2.0, 6.0	6.0, 6.0	20.0	15.0	0.0	15.0	12.0, 6.6	12.0	30.6	1.6, 6.0	6.0, 6.0	19.6	15.0	0.0	15.0	20.0	0.0	20.0	142.2
min	44.00	36.60	80.6	4.27, 22.00	15.30, 22.00	63.57	55.00	0.00	55.00	44.00, 20.00	44.00	108.00	3.41, 22.00	15.30, 22.00	62.71	55.00	0.00	55.00	73.30	0.00	73.30	498.18
Type I runner																						
CHO (g)	213	177	390	300[c]	300[c]	600	266	0	266	300[c]	213	513	300[c]	300[c]	600	266	0	266	300[c]	0	300	2935
Fat (g)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Protein (g)	11	9	20	6	6	12	14	0	14	21	11	32	6	6	12	14	0	14	18	0	18	122
Energy (kcal)	895	745	1640	599	893	1492	1119	0	1119	1390	895	2285	568	893	1461	1119	0	1119	1491	0	1491	10 607
CHO[d] (energy %)			75.5			102.0			72.3			75.6			102.8			72.3			68.6	81.3
Type II runner																						
CHO (g)	163	136	299	300[c]	300[c]	600	204	0	204	269	163	432	300[c]	300[c]	600	204	0	204	272	0	272	2611
Fat (g)	14	11	25	7	7	14	17	0	17	14	14	28	7	7	14	17	0	17	23	0	23	138
Protein (g)	10	8	18	5	5	10	13	0	13	19	10	29	5	5	10	13	0	13	17	0	17	110
Energy (kcal)	815	678	1493	548	822	1370	1019	0	1019	1276	815	2091	520	822	1342	1019	0	1019	1358	0	1358	9692
CHO[d] (energy %)			57.1			95.4			53.4			61.8			96.2			53.4			56.2	67.8
Type III runner																						
CHO (g)	85	71	156	300[c]	300[c]	600	107	0	107	163	85	248	277	300[c]	577	107	0	107	142	0	142	1937
Fat (g)	38	32	70	19	19	38	47	0	47	45	38	83	19	19	38	47	0	47	63	0	63	386
Protein (g)	9	7	16	4	4	8	11	0	11	17	9	26	4	4	8	11	0	11	15	0	15	95
Energy (kcal)	719	598	1317	485	730	1215	898	0	898	1122	719	1841	459	730	1189	898	0	898	1197	0	1197	8555
CHO[d] (energy %)			28.5			89.3			25.6			34.6			86.9			25.6			27.8	45.6

Abbreviation: CHO, carbohydrate
[a] Warm-up and cool-down.
[b] Running coordination.
[c] Assuming a maximal carbohydrate expenditure of 300 g per training session.
[d] Including basal metabolic rate.