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Guidelines for Daily Carbohydrate Intake

Do Athletes Achieve Them?

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Abstract

Official dietary guidelines for athletes are unanimous in their recommendation of high carbohydrate (CHO) intakes in routine or training diets. These guidelines have been criticised on the basis of a lack of scientific support for superior training adaptations and performance, and the apparent failure of successful athletes to achieve such dietary practices. Part of the problem rests with the expression of CHO intake guidelines in terms of percentage of dietary energy. It is preferable to provide recommendations for routine CHO intake in grams (relative to the body mass of the athlete) and allow flexibility for the athlete to meet these targets within the context of their energy needs and other dietary goals. CHO intake ranges of 5 to 7 g/kg/day for general training needs and 7 to 10 g/kg/day for the increased needs of endurance athletes are suggested. The limitations of dietary survey techniques should be recognised when assessing the adequacy of the dietary practices of athletes. In particular, the errors caused by under-reporting or undereating during the period of the dietary survey must be taken into account.

A review of the current dietary survey literature of athletes shows that a typical male athlete achieves CHO intake within the recommended range (on a g/kg basis). Individual athletes may need nutritional education or dietary counselling to fine-tune their eating habits to meet specific CHO intake targets. Female athletes, particularly endurance athletes, are less likely to achieve these CHO intake guidelines. This is due to chronic or periodic restriction of total energy intake in order to achieve or maintain low levels of body fat. With professional counselling, female athletes may be helped to find a balance between bodyweight control issues and fuel intake goals.

Although we look to the top athletes as role models, it is understandable that many do not achieve optimal nutrition practices. The real or apparent failure of these athletes to achieve the daily CHO intakes recommended by sports nutritionists does not necessarily invalidate the benefits of meeting such guidelines. Further longitudinal studies of training adaptation and performance are needed to determine differences in the outcomes of high versus moderate CHO intakes. In the meantime, the recommendations of sports nutritionists are based on plentiful evidence that increased CHO availability enhances endurance and performance during single exercise sessions.

Official dietary guidelines for athletes all recommend high carbohydrate (CHO) intakes in routine or training diets.[1-4] Periodically, however, these guidelines are questioned. For example, in the Wolffe Memorial Lecture presented to the American College of Sports Medicine in 1996 by Professor Timothy Noakes,[5] CHO intake guidelines were identified as being one of five key paradigms in sports science that need to be revisited. He argued that the position that all endurance athletes should ingest diets rich in CHO could be refuted by at least 2 observations.[5] First, the present literature fails to support the benefits of long term high CHO intakes on the training adaptations and performance of athletes undertaking intensive daily workouts. Second, it was asserted by Prof Noakes that 'despite the recent intrusion of sports nutritionists dedicated to the promotion of high CHO diets', athletes do not eat such CHO-rich diets in training and have not increased their CHO intake over the past 50 years. Presumably, if it were advantageous to athletic performance, we might expect athletes to follow a high CHO diet. The argument concluded that the absolute conflict between sports nutrition guidelines and the reported dietary intakes of athletes makes it important for scientists to reconsider whether their advice is correct.

Whilst CHO intake guidelines may be used to benchmark the dietary patterns of groups, they also provide specific dietary advice and can help to assess the nutritional status of individual athletes in a clinical situation. The aims of this review are: to clarify guidelines for routine CHO intake of athletes undertaking heavy training loads; to examine the actual CHO intakes of athletes; and, to consider if this information is sufficient to confirm that such guidelines are unnecessary or incorrect. Particular emphasis will be directed towards the methodologies used to collect and interpret dietary survey data on the CHO intakes of athletes, since these are often badly understood by those not trained in nutrition.

1. Guidelines for Carbohydrate (CHO) Intakes By Athletes

The availability of CHO as a substrate for muscle and the central nervous system is a critical factor in the performance of prolonged sessions (>90 minutes) of submaximal or intermittent, high-intensity exercise, and it plays a permissive role in the performance of brief high-intensity work (for reviews, see Hawley & Hopkins[6] and Hargreaves[7]). Total body CHO stores are limited, and they are often substantially lower than the fuel requirements of the daily exercise programmes of many athletes. CHO intake before and during exercise, and in the recovery periods between prolonged exercise bouts, provides a variety of options for increasing body CHO availability in the short term. CHO intake strategies that maintain or enhance CHO status have been shown to reduce or delay the onset of fatigue, and enhance performance during a single session of prolonged exercise.[7]

There is abundant literature describing beneficial effects of CHO feeding strategies, singly or in combination, on the performance of a single exercise session.[8-19] These results have been summarised into specific guidelines (table I). Since a primary goal is to provide fuel for the working muscle, it makes sense to describe CHO needs relative to the body mass of the athlete. While this does not entirely account for differences in the amount of muscle actively involved in an exercise task, it at least recognises that athletes vary considerably in body size. Thus, single guidelines can be written to include the 45kg marathon runner as well as the 100kg football player.

The extrapolation of these CHO intake guidelines into recommendations for the routine diet of the athlete has been problematic. This is partly due to misunderstandings arising from the terminology used to describe CHO intake. Since the 1960s, general population dietary guidelines have included recommendations for the intake of macronutrients in terms of the proportion of total dietary energy they should typically contribute. CHO has been considered an 'energy filler'; the energy component (usually expressed as a ratio) that is left after protein requirements have been met and health benefits of moderating fat intake to a lower, 'healthier' level have been taken into account. Population guidelines in developed countries typically recommend an increased CHO intake, particularly from nutritious CHO-rich foods, to provide at least 50 to 55% of total dietary energy.[20,21] These generic guidelines promote the health benefits of a relative decrease in fat intake and an increase in CHO intake across a population, but they may be unable to address the specific needs of certain subgroups. Athletes who have specific CHO needs to fuel their daily training programmes and a wider range of energy requirements than found in the general population are one such subgroup.

Within the dietary guidelines specially prepared for athletes, information on ideal CHO intakes has generally followed the tradition of describing CHO as an energy ratio. For example, in official position statements prepared by sports nutrition expert groups, athletes are advised to consume diets pro-

Table I. Guidelines for CHO intake by athletes

Situation	Recommended CHO intake[a]
Short term/single event	
Optimal daily muscle glycogen storage (e.g. for post-exercise recovery, or to fuel up or CHO load prior to an event)	7-10 g/kg BM/day[8,9]
Rapid post-exercise recovery of muscle glycogen, where recovery between session is <8h	1 g/kg BM immediately after exercise, repeated after 2h[10,11]
Pre-event meal to increase CHO availability prior to prolonged exercise session	1-4 g/kg BM eaten 1-4h pre-exercise[12-14]
CHO intake during moderate-intensity or intermittent exercise of >1h	0.5-1.0 g/kg/h (30-60 g/h)[15-17]
Long term or routine situation	
Daily recovery/fuel needs for athlete with moderate exercise programme (i.e. <1h, or exercise of low intensity)	5-7 g/kg/day
Daily recovery/fuel needs for endurance athlete (i.e. 1-3h of moderate to high intensity exercise)	7-10g/kg BM/day[8,9]
Daily recovery/fuel needs for athlete undertaking extreme exercise programme (i.e. >4-5h of moderate to high intensity exercise such as Tour de France)	10-12+ g/kg BM/day[18,19]

a Key references have been provided in the form of original studies, except in the case of CHO intake during exercise where reviews or consensus papers summarising data from numerous studies are available.

BM = body mass; **CHO** = carbohydrate.

viding at least 55% of energy from CHO,[3] or 60 to 65% of energy from CHO.[1] In the case of 'endurance' or 'endurance training' athletes, who undertake prolonged daily exercise session with increased fuel requirements, CHO intake recommendations have been set variously at >60% of energy[2] or 65 to 70% of dietary energy.[1] It should be noted that dietary guidelines or position statements have a different focus than individual studies in which CHO intake is manipulated to achieve a short term effect such as glycogen supercompensation.[22,23] In such studies, where extreme or atypical diets are often used to ensure that the desired effect is produced, participants may be fed CHO intakes of >70% of total energy consumption. However, in setting guidelines for long term intakes of CHO, nutrition experts must take into account the practicality of planning meals and long term nutritional issues such as requirements for energy, other macronutrients and micronutrients. Thus, the CHO intake goal is moderated (to <70% of energy) to ensure that other nutritional goals can be met simultaneously.

Unfortunately, the rigid interpretation of guidelines based on energy ratios can prove unnecessary and unfeasible for some athletes. Athletes who consume very high energy diets (e.g. >4000 to 5000 kcal/day or 16 to 20 MJ/day) will achieve absolute CHO intakes of over 650 to 900 g/day with a dietary prescription of 65 to 70% of total energy. This may exceed their combined requirement for daily glycogen storage and training fuel and, furthermore, it may be bulky and impractical to consume. Athletes with such large energy intakes may be able to meet their daily needs for glycogen recovery with a CHO intake providing 45 to 60% of total energy. On the other hand, other athletes report eating lower energy intakes than might be expected. These athletes may need to devote a greater proportion of their dietary intake (e.g. up to 65 to 70% of total energy) to CHO intake, and even then may fail to meet the absolute CHO intakes suggested for optimal daily glycogen recovery. This is particularly true of female athletes (for review, see Burke[24]).

In practice, the CHO and energy needs of athletes are not always well synchronised. Therefore, we believe it is preferable to provide recommendations for routine CHO intake in grams (relative to the body mass of the athlete) and allow flexibility for the athlete to meet these intakes within the context of their energy needs and other dietary goals. We have suggested some guidelines, interpolated from studies of short term fuel needs for training, in table I. We propose that such guidelines are not only more specific to the fuel needs of muscle, but are more 'user friendly'. For example, the athlete can be provided with a range of daily CHO intakes that might be considered suitable, and can use food composition information or a ready reckoners of the CHO content of food to plan or assess their food intake. The ranges are quite generous to allow for the variation in fuel needs among individuals and the opportunity to achieve these. With the specialised and individualised advice of a sports nutrition expert, an athlete should be able to fine-tune their daily CHO intake goals.

Although this gram per kilogram terminology is a familiar concept to most exercise scientists, and is the means by which most reviewers have described CHO intake in the exercise literature, it has not been incorporated into the official sports nutrition guidelines promoted by sporting bodies or sports nutrition groups. Indeed, we only could only find 1 recent position paper on nutrition for athletes and physically active people that used this preferred terminology, in which the daily CHO intake requirements were set at 6 to 10 g/kg body mass.[4] Therefore, a secondary goal of this review is to provide evidence that percentage energy and gram per kilogram nomenclature for CHO intake are not interchangeable, and that the use of percentage energy guidelines to set or assess CHO intakes for athletes can lead to misinterpretations.

In presenting guidelines for CHO intakes in the routine or long term diets of athletes, we must acknowledge that the direct application of recommendations from short term CHO feeding studies, while logical, has not been demonstrated to have unequivocal benefits for training adaptations and performance.[25-29] One possible conclusion from the available studies of long term dietary patterns and exercise performance is that athletes can adapt to the lower muscle glycogen stores resulting from lower CHO intakes, such that it does not impair training or competition outcomes.[30] However, there are other interpretations of this literature, and it should be pointed out that no study shows that moderate CHO intakes promote superior training adaptations and performance compared with higher CHO diets. Several methodological issues are important, including the overlap between what is considered a ‘moderate’ and a ‘high’ CHO diet in various studies. Other important issues include whether sufficient time was allowed for differences in the training responses of athletes to lead to significant differences in the study performance outcome, and whether the protocol used to measure performance was sufficiently reliable to detect small but real improvements that would be of significance to a competitive athlete.[31]

Clearly, further research needs to be undertaken, using specialised and rigorous protocols, to better examine the issue of long term CHO intake in heavily training athletes. Since such studies require painstaking control over a long duration, it is not surprising that there are few such reports. In the meantime, although the lack of clear support in the literature is curious, the evidence from studies of short term CHO intake and exercise performance remains our best guess to the long term CHO needs of athletes. It is of interest to see how well athletes appear to have responded to these short term guidelines.

2. Dietary Survey Methodology

Assessing the dietary intake of individuals or groups is complex and challenging. Details of approaches to these assessments are provided in the numerous reviews on dietary survey methodology.[32-36] Since the 1940s, nutrition experts have developed and validated a number of dietary survey techniques, the features of which are summarised in table II.

In populations of athletes, the written food diary (both weighed and household measures) has been the popular choice of dietary survey instrument. Once dietary intake data are collected, they are analysed using computer programs based on food composition databases. Section 2.1 focuses on the main limitations and sources of error in dietary intake data collected by food diaries. Errors involved in the analysis of food records, which must be taken into account when interpreting nutrient intake data, are briefly discussed in section 2.2.

2.1 Recording Errors

All dietary survey techniques are challenged by errors of validity (how accurately the data measure actual food intake) and reliability (how well the data reflect typical intake). Food diaries propose to monitor intake over a specific period of observation, which is representative of a generalised period of interest. The period of interest may vary from a specific dietary/exercise activity (e.g. CHO loading, racing in a tour) to the athlete’s ‘overall’ or ‘typical’ diet. Unfortunately, there is considerable evidence that inaccurate reporting of intake is a universal problem of self-reported dietary assessments.[48-57] Inaccurate reporting can occur in a number of separate ways.

- The athlete may alter their dietary intake during the period of recording, and therefore it does not reflect their usual intake.
- The athlete records their dietary intake inaccurately to improve the perception of what they are eating (i.e. they omit or underestimate the intake of foods or meals considered undesirable, or they falsely report the intake of foods considered desirable).
- The athlete makes errors in quantification or description while recording their food intake.

Fortunately, energy requirements and energy balance can be assessed independently by observing changes in body composition while participants are fed in metabolic wards, by calorimetric methods or, more recently, via tracer technology using the double-labelled water technique.[58] These methods have allowed nutritionists to validate the accuracy of self-reported dietary intake. Extensive study of the accuracy of food diaries has found that the bias of reporting errors is towards under-reporting

Table II. Commonly used methods for collecting dietary intake data[a]

Method	Description	Period of food intake	Advantages	Disadvantages
Retrospective				
24h recall	Subjects describe foods consumed over the last 24h or on a 'typical day'	24h	Speedy	Relies on subject's honesty, memory, and food knowledge
	Widely used in epidemiological research		Low subject burden	Requires trained interviewer
			Interview can be structured around daily activities	Day chosen may be 'atypical'
			Doesn't alter usual intake	Suitable for group analysis but not representative of individual's normal intake
			Food models assist estimation of food serves[37]	
Food frequency questionnaires	Subjects asked how often they eat foods from a number of groups on a standardised list	From 24h period to open-ended (eg. *How often do you eat a certain food?*)	Self administered	Relies on responder's honesty, memory, literacy and food knowledge
			Can be used to cross-check data obtained from other methods	Validity dependent on the food list and the quantification method
			Validated for ranking individual intake[38]	
			Validated against 7 day weighed record[39]	
			Can be modified to target certain nutrients or populations	
Diet history	Open-ended interview concerning food use, food preparation, portion sizes, food like/dislikes and a food checklist Originally also incorporated 24h recall & food frequency techniques	Open-ended or over a specified period	Accounts for daily variation in food intake by investigating a 'typical' day	Relies on responder's honesty, memory, food knowledge
			Can target contrasts between seasons, training status etc	Labour intensive & time consuming
			Food models assist estimation of food serves[37]	Requires trained interviewer
Prospective				
Written dietary record	Weighed/semi weighed (household measures) Considered the gold standard for dietary assessment	*One Day*: Not suitable for individual assessment due to large daily variability in food intake. Used for large population studies - maximising subject numbers rather than number of recorded days is best way to minimise variability when looking for usual intake[40]	More accurate quantification of foods	Relies on responder's honesty, memory, food knowledge
		Three Day: Widely used. Originally promoted as minimum requirement to indicate intake of individuals. Should include weekday and weekend days to reduce bias	Use of PETRA (Portable electronic tape recorded automatic scales) decreases subject workload[41]	Time consuming for subjects
		Seven Day: Increased record length reduces compliance, especially in less motivated or educated groups.[42] However, it increases reliability of data, especially when looking at intakes of individuals	Improved compliance with subjects compared with weighed record	Subjects often alter their diet to improve their intake or to reduce the workload of recording

table II continued

usual dietary intake, and the extent of this under-reporting is widespread and significant.[48-57]

2.1.1 Extent of Under-Reporting

Studies using different methodologies have reported consistent results on the extent of under-reporting in dietary surveys across mixed populations. Mertz et al.[51] examined the accuracy of 14 years of dietary records kept by 266 individuals (general population) participating in various intervention studies in their research centre. In all of the protocols, each participant was trained by a dietitian on how to complete a record of their habitual diet prior to their participation, and they were subsequently fed a diet that was adjusted to maintain their bodyweight. A comparison of the energy intakes reported in the records and the amounts required for bodyweight maintenance yielded a mean under-reporting error of 18%.

Another study comparing the self-reported intakes of individuals randomly sampled from a national dietary survey with measurements of their energy expenditure determined by the double-labelled water method calculated that the dietary surveys under-reported energy intake by an average of 20%.[53] These 2 studies were also consistent in finding that about 80% of the participants were significant under-reporters.[51,53]

It is tempting to infer from these studies that a simple correctional factor could be applied to the data collected in dietary surveys. However, it should be noted that reporting errors are not consistent, in terms of extent or direction, within a group. For example, in the study by Mertz et al.,[51] 81% of participants were noted to be under-reporters, 11% of the participants reported intakes within their approximate energy requirements and 8% significantly over-reported their intake. Other studies have identified the types of people who are most likely to under-report, noting that mean under-reporting errors can exceed 30%.[48,52-54,57,59] Thus, while a correctional factor of 20% might be cautiously applied to group data, especially when they are derived from large and varied populations, it is not appropriate for correcting data reported by individuals or by

		For adults: 7 days is minimum record length required to rank subjects according to intakes of energy, protein, fat, carbohydrate[43]	Less alteration of normal eating pattern compared to weighed or semi-weighed records	See weighed record comments
				Requires checking by trained person
				Needs standardised set of household measures
				Relies on subject assessment of portion sizes[44]
Duplicate portion	Subject places exact duplicates of consumed food items into a container. The foods are then homogenised and analysed for nutrients. Subjects may also have to keep food records as back up	24h – open-ended	Analysis is independent of food databases	Relies on subject's honesty and memory
				Large compliance burden for subject
				Food analysis expensive
				Causes alteration to usual food intake[45]
Photographic dietary record	Subjects are issued with a camera and a food record book. Photographs are taken of all foods consumed and details including meal preparation method and ingredients for each meal are recorded	24h - open-ended	Standardised photographic lengths (i.e. distance between the camera and the meal) are useful to validate portion sizes	Relies on subject's honesty, memory and food knowledge
			Cost effective compared with weighed food records[46]	Requires subject education on photographic technique
			Can be used when dining out	Requires completion of food record to detail cooking methods, ingredient list etc.
			Useful in population with lower literacy skills	

a **Other methods for making dietary assessments:** Interactive touch screen computer techniques;[47] video record for collecting a 24h recall, or taking a food record; tape recorders utilising computer chips.

groups with unusual characteristics related to their nutrition.

2.1.2 Characteristics of People Likely to Under-Report

Several studies have identified special populations who are more likely to under-report, or who under-report to a greater extent. Those who are obese or are dissatisfied with their body mass and body image are commonly identified in these categories.[48,52-54,57,59] Scientists who have attempted to explain why people under-report their food intake speculate that at least some of the error occurs because participants tend to report intakes that are similar to the expectations of the general population. For example, obese individuals report intakes similar to those of nonobese people, and athletes may report intakes similar to their less active counterparts.[46] In one study[56] participants continued to under-report, despite being told that the researchers could verify their intake. It was concluded that some under-reporting may be an intentional attempt to present a better image to a society that is increasingly critical of overweight people and overeating.

Other factors explaining under-reporting include omitting items such as second helpings or snacks because of the inconvenience of recording, or failing to report items considered 'unhealthy'.[49,51] Individuals may either fail to record their actual intake of these foods (maintaining but under-reporting their usual intake) or omit these troublesome items from their diet for the period of recording (failing to record usual dietary habits). These factors might be expected to operate in populations of people with busy lifestyles and/or a sense of obligation about what they *should* be eating. These characteristics remain true for many groups of athletes.

Although under-reporting errors can be subdivided into undereating (reducing food intake during the period of recording) and under-recording (failing to record all food consumed during the observation period), few studies have tried to measure the relative contribution of each aspect to the total error. Theoretically, an estimation could be made if independent measures of the energy expenditure of the participants during the period of recording were available, as well as measures of changes in body composition to estimate energy surplus or deficit[60] and, ideally, a marker of the accuracy of recording. Such a dietary study was conducted on female dietitians, who were characterised as lean individuals with a high degree of motivation and knowledge about food.[61] Using double-labelled water to measure water loss, a high correlation between recorded and predicted water intake was observed, suggesting a high precision in dietary recording. However, bodyweight loss measured during the recording period indicated that the dietitians under-reported their habitual energy intake by a mean of 16%, with this discrepancy being almost entirely explained by undereating.[61]

Several sophisticated energy balance studies have also been carried out on athletes and most,[61-65] but not all,[65,66] have found discrepancies between reported energy intakes and energy requirements. Double-labelled water estimations of energy expenditure by cyclists competing in the Tour de France produced values that were 13 to 35% greater than the reported energy intakes, despite the maintenance of body composition throughout the study periods.[61] Edwards et al.[64] found that the mean reported energy intake of a group of female distance runners was 32% below the double-labelled water estimates of energy expenditure over the same period of energy balance monitoring. Interestingly, the energy discrepancies in individual runners ranged from 4 to 58% and were the greatest in the heavier runners who also displayed a greater dissatisfaction with their body image.[64] Similar outcomes were reported in another study where indirect calorimetry was used to estimate energy expenditure.[65] Whereas no difference was found between mean reported energy intake and energy expenditure required for energy balance in a group of elite female soccer players, a group of female athletes in 'aesthetic' sports (figure skaters and gymnasts) reported intakes that were only 45% of estimated energy expenditure.[65]

Finally, some energy balance studies have been able to show that athletes reduce their food intake while recording dietary surveys. Schulz et al.[62]

studied female distance runners who during a 6-day period of observation, reported energy intakes that were only 78% of the energy expenditure estimated by the double-labelled water technique. Although eating during this period was supposed to reflect usual intake, participants lost bodyweight during the study. When, this loss of body stores was taken into account, the reported energy intake was within 10% of the estimated actual intake.

In summary, it seems reasonable to expect that most athletes will under-report or underconsume their usual intakes when filling dietary records, and that groups or individuals who are bodyweight/physique conscious or are dissatisfied with their body image are at the highest risk for significant underestimation. The best accuracy with self-reported dietary assessment tools might be expected from athletes who are confident of their eating habits and body image, and who are highly motivated to receive valuable feedback. Training of such individuals is likely to enhance their record-keeping skills.

2.1.3 Other Quantification Errors

The quantification of food portions is a problem in dietary surveys if food diaries that are not weight-based are used, or if dietary recalls and dietary histories are used. Food models, food images, household measures and training have each been proposed to assist in the estimation of food quantities; however, studies generally report that people find it difficult to estimate portion sizes accurately.[67,68] Significant under- and overestimation of food quantities are both common.[68]

Selective bias arising from the characteristics of the individual, such as age, gender and body size, is possible, as is bias due to characteristics of the food. Of most interest to athletes is a US study conducted on state-level rowers who were asked to estimate the quantities of a range of liquid foods, set-shape foods (e.g. meat) and amorphous foods (e.g. cereals, pasta) [M.K. Martin, unpublished observations]. The mean value for estimations across all foods was within 5% of the actual portion size. However, there was a large variation in precision between foods (mean estimations ranging from –30% for one food to +27% for another), and between individuals (with individual estimates ranging from 19 to 400% of the true portion size). Further study is required to ascertain if biases exist among groups of athletes or foods commonly eaten by athletes.

2.1.4 Effect of Quantification Errors on Estimations of Macronutrient Intake

Under-reporting or quantification errors may not affect estimated intakes of various nutrients equally. It is possible that intakes of certain types of meals or foods are selectively misreported because of the embarrassment of admitting the intake of ‘undesirable’ foods, the desire to be seen to be consuming ‘good’ foods, or the difficulty and inconvenience of recording ‘hard to report’ foods. For example, some researchers have found that identified under-reporters record a lower intake of snacks and lower intakes of high-fat and/or high-sugar foods and alcoholic beverages than the rest of their survey sample.[52,55]

Similar studies of populations of athletes are required to determine whether there is a systematic bias to under- or over-report certain foods. At present, no such data are available. For the purposes of this review, it would be useful to focus interest on dietary CHO sources such as CHO-rich snacks eaten between meals, food/fluid supplies consumed during exercise and special sports foods. It is possible that bodyweight-conscious athletes might deem snacks as undesirable, or that foods/fluid consumed in relation to exercise sessions might be inconvenient to record or not regarded as part of the ‘routine diet’. Alternatively, the focus on the importance of CHO intake to athletic performance may lead some athletes to increase their reported intake of these foods during a period of dietary recording. If so, these biases would have a greater impact on the estimated CHO intakes of athletes in dietary surveys than the apparent energy intake discrepancies.

2.1.5 Reliability: How Many Days Need to Be Recorded?

The goal of many dietary surveys is to comment on the long term or usual intake of their participants. However, because we eat differently from day to day, there is considerable variability in our daily intake of energy and nutrients. This affects the statistical precision of estimated intakes of such nutrients. Several studies have investigated the number of days of recording that are necessary to estimate the intakes of individuals or groups with a reasonable degree of precision.[46,69,70] For most populations, energy and CHO intakes are found to be among the most stable. For individuals, accepting that an estimate would be within 10% of the true intake value for 95% of the time, 31 days of recording are needed to predict the usual intake of energy or CHO.[70] In the case of group data, precision can be improved by increasing the number of participants or the number of recording days. Where sample sizes are typically 10 to 20 people, it has been estimated that approximately 3 days, and 4 to 5 days are needed to estimate average group data for energy and CHO intake, respectively.[70] A longer recording period is needed, however, if individuals are to be ranked within the group according to their intake.[46]

2.2 Errors in Data Analysis

The processing of the information provided by a food record involves its interpretation by the investigator so that coding decisions may be made. This is followed by data entry into a computerised dietary analysis program. Such programs access a food composition database. The various databases can differ in terms of the source of the food composition data, the number of foods that are included, the range of nutrients for which data are available and the method of analysis used in obtaining these nutrient data. Although computer dietary analysis programs are now widely available, and are apparently easy to use, it is recommended that data entry and the interpretation of dietary survey information remain the role of appropriately trained investigators. This may help to eliminate errors and reduce the variability in decisions such as quantifying the portions of foods described by participants, and matching food descriptions to foods contained in the database.

However, even when differences in decisions regarding data entry are eliminated, there are still considerable differences in nutritional analysis results produced by various computerised food composition databases.[71,72] This suggests that some caution must be applied when comparing dietary surveys of different groups, and that if longitudinal studies are undertaken over a period of years, data analysis should be performed using the same dietary program. Inaccuracies or variability may be a particular problem for surveys where participants consume a large proportion of their intake from unusual foods for which nutrient analysis is not readily available in the food composition database. Foods that are often under-represented on such databases include ethnic and commercially prepared foods, home recipes and formula products such as sports foods.

3. Dietary Surveys of Athletes

This section reviews the literature on self-reported CHO intakes of high-grade athletes. We collected this literature by undertaking searches using the Medline and Sport Discus databases and by cross-referencing the articles located from these sources. Abstracts were not included. We focused our review on dietary intake data representing the long term or routine eating patterns of subelite and elite athletes. We also included competition dietary intake data from stage races involving participation of more than 5 days, since this also represented a type of longer term eating practice. An objective description of the calibre of the athletes surveyed is presented where it was available in the literature. We discarded studies involving groups of athletes described as ‘recreational’. We also discarded surveys of undifferentiated entrants in sporting events (e.g. registrants of a city marathon) and groups of athletes with a training history that failed to meet our expectations (e.g. distance runners with a mean training distance of <70km per week). Surveys involving groups with a mean age of less 15 years were not included unless they concerned sports where it is typical for young athletes to be undertaking a full training load (e.g. swimmers, gym-

Table III. Dietary data from athletes published ≤1970

Population	n	Method	Age (y)	BM (kg)	Energy		CHO			Reference
					MJ	KJ/kg	g	g/kg	%E	
International athletes at 1948 London Olympic Games		4d duplicate meal collection, chemical assay	17-41							73
Endurance athletes (distance runners, cyclists, swimmer)	8M			64	14.01	219	375	5.9	45	
Non-endurance athletes (track and field athletes, gymnasts, wrestler, basketball)	20			69	14.03	203	412	6.0	49	
US collegiate non-endurance (track, football, basketball)	60M	4-5d food diary kept by observer	20	85						74
preseason training					18.26	215	487	5.7	45	
season					19.14	225	438	5.2	38	
International athletes at 1952 Helsinki Olympic Games					18.8		450		40	75
Phillipino national team athletes (track & field, swimmers, cyclists, weightlifters, team athletes)	17M	3d weighed food diary kept by observer	24	64	10.45	163	388	6.1	63	76
	8F		21	56	9.05	163	321	5.7	61	
Australian Olympic athletes		7d food diary (household measures)	14-40							77
females	14							4.8	40	
heavy training males	27							5.9	44	
medium training males	20							4.7	41	
light training males	16							4.6	40	

BM = body mass; **CHO** = carbohydrates; **F** = females; **M** = males; **n** = number of athletes; **%E** = CHO : total energy ratio.

nasts). We divided the athletic groups into classifications of endurance and nonendurance events, based on the characteristics of their training programmes as well as competitive event.

We summarised the data from these dietary surveys into 3 separate time periods. The few dietary surveys of athletes published in or before 1970 were included simply for their historical value. Table III presents all of the data from this era, including surveys undertaken during Olympic Games (reporting competition intake rather than routine intake). These surveys are particularly interesting since they predate most of the important scientific studies of sports nutrition as well as the advent of computerised dietary analysis programs. It is impressive that the data from the 1948 London Olympic Games were generated by collecting duplicate samples of the meals eaten by the athletes included in the survey, and conducting chemical analyses of homogenates of this food.

Dietary surveys from the last 30 years were separated into 2 time periods: (i) 1971 to 1989 (tables IV to VII); and (ii) the 1990s (tables VIII to XI). The results of dietary surveys made during prolonged competitive events are provided in table XII, while surveys that could not be classified within our system are presented in table XIII.

3.1 How Well Do Athletes Appear to Be Meeting CHO Intake Guidelines?

Before examining the data presented in tables IV to XII, we must reflect on the limitations of the methods used to collect them. Our review shows that most surveys used a 3- to 4-day food diary with the quantification of intake described by household measures. Small participant numbers (10 or less)

Table IV. Dietary data from female endurance athletes published 1971-1989

Population	n	Method	Age (y)	BM (kg)	Energy		CHO			Reference
					MJ	KJ/kg	g	g/kg	%E	
US collegiate swimmers	9	4 × 4d food record (household measures)	19	64	10.31 ± 2.23	161	315	4.9	49 ± 8	78
US collegiate swimmers	20	3d food diary (household measures)			12.98		333		42	79
US national level swimmers	14	3d food diary (household measures)	17	62	9.61 ± 3.5	155	318	5.1	53 ± 6	80
Canadian national level swimmers	10	3d food diary (household measures)	16	62	8.64 ± 2	140	284 ± 85	4.6	54 ± 7	81
US collegiate swimmers	19	2 × 3d food diary (household measures)	19	63	10.42 ± 2.3	163	337 ± 84	5.3	54	82
Canadian collegiate swimmers	6	2 × 3d food diary (household measures)	22	62.5	10.33	165	334	5.4	52	83
Chinese elite swimmers	3	3-5d weighed food diary	20	65	19.21 ± 0.72	297 ± 12	405 ± 58	6.2 ± 0.9	35 ± 5	84
Club level marathon runners	19	4d food diary (household measures)	29	53	9.59	182	248	4.7	44	85
Canadian collegiate distance runners	17	7d weighed food diary	22		8.47 ± 2.2		252 ± 56		48	86
US national level marathon runners	51	3d food diary (household measures)	29	52	10.02 ± 3.1	193	323 ± 109	6.2	55	87
Dutch international level distance runners	18	2 × 4-7d food diary (household measures)	31	52	8.75	168	301	5.8	50	88
US collegiate distance runners	11	3d food diary (household measures)	21	53	7.62 ± 2.8	144	268	5.0	56 ± 10	89
Dutch international level cyclists	21	3 × 4-7d food diary (household measures)	23	66	10.82	164	352	5.3	52	88
US national level & collegiate cyclists	12	3d food diary (household measures)			12.66 + 3.16		386		51 ± 7	90
International group of triathletes	10	3d food diary (household measures)	39	57	10.34 ± 4.19	181	351 ± 180	6.2	54	91
US national team speed skaters	7	3d food diary (household measures)	21		9.32 ± 1.75		349 ± 84		63	92
US collegiate rowers	24	3d food diary (household measures)		68	9.78	144	272	4	46	93
Dutch international level rowers	8	2 × 4-7d food diary (household measures)	23	70	12.98	186	374	5.4	46	88
US national team x skiers	14	4 × 3d food diary (household measures)	20	57	13.08	230	349	6.1	43	93
Weighted mean	**293**				**10.37**	**174**	**316**	**5.38**	**50**	

BM = body mass; **CHO** = carbohydrates; **n** = number of athletes; **%E** = CHO : total energy ratio.

Table V. Dietary data from female non-endurance athletes published 1971-1989

Population	n	Method	Age (y)	BM (kg)	Energy		CHO			Reference
					MJ	kJ/kg	g	g/kg	%E	
US collegiate sprinters	12	3d food diary (household measures)	20	55	8.43 ± 3.16	153	237	4.3	45 ± 12	89
Dutch international level hockey players	9	4-7d food diary (household measures)	24	62	9.0	145	264	4.3	4.7	88
US collegiate hockey players	8	2 × 3d food diaries (household measures)	19	60	8.18 ± 1.57	136	228 ± 44	3.8	47	82
US collegiate basketball players	19	1-3d food diary (household measures)		71	12.20	172	348	4.9	46	79
US collegiate basketball players	10	3d food diary (household measures)	19	72	7.23 ± 2.4	100	229 ± 95	3.2	51	94
US collegiate lacrosse players	7	3d food diary (household measures)			9.28		257		50	79
US collegiate volleyball players	31	1-3d food diary (household measures)			8.89		271		49	79
Dutch international level volleyball players	9	4-7d food diary (household measures)	23	66	9.24	140	263	4.0	46	88
Dutch international level handball players	8	4-7d food diary (household measures)	22	63	8.97	142	251	4.0	45	88
US high school gymnasts	13	2 × 3d food diary (household measures)	15	50	8.04 ± 2.82	159	222 ± 77	4.4	46 ± 4	95
US special school gymnasts	97	3d food diary (household measures)	13	43	7.68	178	220	5.1	49	96
US junior elite gymnasts	22	2d food diary (household measures)	11-14	31	7.13 ± 1.76	230	227 ± 64	7.3	53 ± 6	97
US national level & collegiate gymnasts	10	3d food diary (household measures)			8.09 ± 1.66		237		49 ± 5	90
US artistic gymnasts	26	6d food diary (household measures)	12	38	6.49 ± 2.13	171	194	5.1	48 ± 7	98
Chinese elite gymnasts	5	3-5d weighed food diary	18	45	9.61 ± 1.4	213 ± 29	242 ± 49	5.4 + 1.1	42 ± 9	84
Dutch international level gymnasts	11	4-7d food diary (household measures)	15	47	7.41	158	246	5.2	53	88
US collegiate gymnasts + 1 body builder	10	5d food diary (household measures)	19	54	7.28	134	197	3.6	43	99
Dutch international level body builders	4	4-7d food diary (household measures)	25	56	6.16	110	196	3.5	51	88
US competitive body builders	12	3d food diaries (household measures)	29	58	6.81 ± 2.3	120	208 ± 60	3.6	53 ± 11	100
US competitive body builders	6	4 × 3d food record (household measures)	18-30	57	5.91	104	234	4.1	63	101
Chinese elite throwers	6	3-5d weighed food diary	21	84	18.58 ± 3.1	222 ± 38	386 ± 57	4.6 ± 0.7	35 ± 5	88
US collegiate synchronised swimmers	15	4 × 4d food diary (household measures)	19-20	66	9.54 ± 3.2	144	292	4.2	49	78
US national level and collegiate figure skaters	29	3d food diary (household measures)			7.56 ± 2.04		235		52 ± 7	90
Italian Olympic level mixed skill sports	22	Dietary history	19	53	11.59 ± 2.2	217	306 ± 87	5.7	42	102
Weighted mean	401				8.42	169	244	4.87	49	

BM = body mass; **CHO** = carbohydrates; **n** = number of athletes; **%E** = CHO : total energy ratio.

Table VI. Dietary data from male endurance athletes published 1971-1989

Population	n	Method	Age (y)	BM (kg)	Energy		CHO			Reference
					MJ	kJ/kg	g	g/kg	%E	
US national level speed skaters	10	3d food diary (household measures)	22		16.49 ± 3.67		553 ± 177		56	92
Dutch international level marathon skaters	5	4-7d food diary (household measures)	33	72	16.05	222	554	7.7	55	88
Scandinavian swimmers					15.71		478		51	103
US national level swimmers	13	3d food diary (household measures)	22	80	18.14 ± 4.18	227	555	6.9	49 ± 10	80
Canadian national level swimmers	10	3d food diary (household measures)	16	72	14.79 ± 3.2	209 ± 46	456 ± 126	6.3	51 ± 5	81
Dutch international swimmers	20	4-7d food diary (household measures)	18	73	16.11	221	486	6.7	48	88
Chinese elite swimmers	3	3-5d weighed food diary	22	74	24.82 ± 3.3	334 ± 46	484 ± 228	6.5 ± 3.1	33 ± 7	88
US national level & collegiate swimmers	15	3d food diary (household measures)			16.80 ± 2.62		513			90
French national & regional level cyclists	32	7d food diary (household measures)	23	68	14.48 ± 2.58	214 ± 38	366	5.1	40	104
Irish Olympic team cyclists	6	3d weighed food diary	21	71	16.25 ± 2.2	228	525	7.4	52	105
Dutch international level cyclists	14	3 × 4-7d food diary (household measures)	20	72	18.29	253	663	9.2	58	88
US national level & collegiate cyclists	18	3d food diary (household measures)			17.32 ± 3.67		476		46 ± 5	90
German national team cyclists	9	3d semi-weighed food diary	19-26	73	26.5	363	795	10.9	48	106
International group of distance triathletes	19	3d food diary (household measures)	44	75	15.14 ± 5.82	202	506 ± 222	6.8	54	91
Australian national level triathletes	20	7d food diary (household measures)	27	69	17.2 ± 3.4	250 ± 50	627 ± 152	9.1	60 ± 8	107
Dutch international level triathletes	33	4-7d food diary (household measures)	26	70	19.09	272	612	8.7	51	88
Dutch Olympic team rowers	8	7d food diary (household measures)		87	17.31 ± 2.11	199	467	5.4	43	108
US collegiate rowers	27	1-3d food diary (household measures)		85	16.91	199	456	5.4	44	79
Dutch international level rowers	18	2 × 4-7d food diary (household measures)	22	77	14.59	189	472	6.1	52	88
German national team rowers	3	3d semi-weighed food diary	18-23	88	25	284	812	9.2	52	106
US collegiate mountain climbers	12	2d food diary (household measures)			16		411		43	79
Scandinavian X-runners					14.87		408		46	103

table VI continued

were often encountered, and many surveys failed to describe any techniques aimed to minimise or standardise the errors in their methodological design. It also appears that some studies were undertaken without the involvement of trained nutritionists in the collection, entry or interpretation of their data.

Although the pooling of studies to describe overall trends adds strength in the form of increased participant numbers, it cannot overcome the problems of flawed study design. Furthermore, the differences in survey collection methods and in the databases used to estimate nutrient intakes mean that caution is needed when trying to compare or collate data from separate surveys. It is probable that under-reporting or atypical eating occurred across all studies, so that the reported intakes do not accurately represent the true habitual intakes of some of the athletes surveyed. However, it is difficult to determine the likely extent of these errors, other than to focus suspicion on dietary intakes that appear unrealistically low, or to come from groups that are documented to be conscious of bodyweight control and body image. Unfortunately, many of the studies included in this review did not question or explore their data in light of the limitations of their dietary survey technique.

We noted that studies published in the last decade tended to be more informative with regard to survey methodology and the discussion of data. This may reflect a better understanding of the issues of dietary surveys in recent times, as well as the publication interests and standards of the new journal *International Journal of Sport Nutrition and Exercise Metabolism*, in which a substantial number of the recent data appear. It is interesting that several recent articles have specifically discussed the benefits of using gram per kilogram nomenclature when setting or assessing CHO intake guidelines.[132,158]

Taken together, the dietary surveys reviewed here suggest that male athletes appear to be more successful than female athletes in achieving the CHO intake goals suggested in table I. The mean value for the self-reported CHO intakes across all surveys of male endurance athletes is ≈7.5 g/kg/day,

Canadian collegiate distance runners	35	7d food diary (household measures)	22		12.62 ± 2.84		374 ± 86		47	86
US runners	8	3d food diary (household measures)	29	68	13.02 ± 3.56	200 ± 57	424	6.3	52 ± 10	109
US national level & collegiate distance runners	10	3d food diary (household measures)			12.68 ± 2.4		372		49 ± 9	90
Dutch international level runners	56	2 × 4-7d food diary (household measures)	30	69	13.28	193	417	6.1	50	88
German national team distance runners	10	3d semi-weighed food diary	19-25	61	22.14	326	733	12	53	106
US national team X skiers	13	4 × 3d food diary (household measures)	22	73	18.70	256	498	6.8	43	93
Canadian elite distance runners and X-skiers	6	7d food diary (household measures?)	22	73	18.97 ± 0.2	259	708	9.7 ± 0.4	62	110
German national team biathletes	12	3d semi-weighed food diary	15-17	65	21.2	326	636	9.8	48	106
Italian Olympic level endurance athletes (incl. cycling, X-skiing)	58	Dietary history	25	70	18.13 ± 4.79	259	558 ± 122	7.9	49	102
Weighted mean	503				16.56	236	506	7.29	49	

BM = body mass; **CHO** = carbohydrates; **n** = number of athletes; **%E** = CHO : total energy ratio.

Table VII. Dietary intake from male non-endurance athletes published from 1971-1989

Population	n	Method	Age (y)	BM (kg)	Energy		CHO			Reference
					MJ	KJ/kg	g	g/kg	%E	
US collegiate American football players	56	3d food diary (household measures)		95	20.23	213	541	5.7	44	79
US collegiate American football players	11	3d semi-weighed food diary (recorded by observer)	20	108	15.02 ± 3	139	329 ± 86	3	39	111
US senior high school American football players	88	24h dietary recall	15-18	76	14.06 ± 6.65	200 ± 87	366 ± 170	4.8	42	112
US national level & collegiate American football players	55	3d food diary (household measures)			16.25 ± 2.8		428		46	90
US collegiate American football players	35	3d food diary (household measures)	20	99	15.87 ± 3.75	160	443	4.5	45	113
Professional Australian Football layers	54	7d food diary (household measures)	24	82	14.2 ± 3	170 ± 40	373 ± 94	4.5	44 ± 5	114
Swedish professional soccer players	15	7d food diary (household measures)	24	74	20.7 ± 4.71	282	596 ± 127	8.1	47 ± 3	115
US collegiate soccer players	8	3d food diary (household measures)			12.39		320		43	79
US collegiate soccer players		3d food diary (household measures)	20	72						116
conditioning on campus	17				18.7	260	596	8.3	52	
season on campus	8				15.92 ± 2.69	221	487 ± 107	6.8	52 ± 11	
season off campus	9				12.79 ± 4.89	178	306 + 118	4.2	42 ± 15	
Dutch international level soccer players	20	4-7d food diary (household measures)	20	74	14.3	192	420	5.6	47	88
Dutch international level hockey players	8	4-7d food diary (household measures)	27	75	13.58	181	365	4.9	43	88
US collegiate basketball players	38	1-3d food diary (household measures)			20.44		528		42	79
US collegiate basketball players	16	3d food diary (household measures)	19	83	14.87 ± 4.51	179	437 ± 158	5.3	47	94
US national level & collegiate basketball players	11	3d food diary (household measures)			17.04 ± 3.2		448		44 ± 7	90
US collegiate lacrosse players	20	3d food diary (household measures)			16.41		470		45	79
Dutch international level water polo players	30	4-7d food diary (household measures)	24	86	16.59	194	467	5.5	45	88
US national level & collegiate baseball players	11	3d food diary (household measures)			19.45 ± 3.74		523		45 ± 11	90
Scandinavian shotput throwers					18		452		42	103
US national level discus throwers	16	24h dietary recall	26	111	19.5 ± 5	176	446 ± 153	4	37	117
Chinese elite throwers	6	3-5d weighed food diary	25	109	22.38 ± 2.9	205 ± 25	450 ± 52	4.1 ± 0.5	34 ± 1	84
Swedish shot put throwers					18		452		42	103

US collegiate track and field athletes	7	3d food diary (household measures)			14.75		489		55	79
US collegiate track athletes	19	1-3d food diary (household measures)			16.98		484		46	79
US collegiate gymnasts	10	3d food diary (household measures)			8.69		231		44	79
Chinese elite gymnasts	4	3-5d weighed food diary	21	59	13.84 ± 0.23	234 ± 38	357 ± 77	6.1 ± 1.3	43 ± 9	84
Chinese elite weight lifters	10	3-5d weighed food diary	21	80	19.21 ± 2.52	238 ± 25	431 ± 96	5.4 ± 1.2	38 ± 8	84
Dutch international level weight lifters	7	4-7d food diary (household measures)	27	76	12.76	167	320	4.2	40	88
US national level & collegiate weight lifters	28	3d food diary (household measures)			15.2 ± 3.9		392		43 ± 8	90
German national team weight lifters	15	3d semi-weighed food diary	15-19	95	31.35	330	764	8	39	106
US collegiate body builders	6	3d food diary (household measures)			16.56		350		36	79
South African competitive body builders	76	7d food diary (household measures)	27	82	15.01 ± 4.22	183	320 ± 132	3.9	34	118
Canadian elite body builders	6	7d food diary (household measures)	24	80	20.07 ± 0.2	251	592	7.4 ± 0.3	49	110
Dutch international level body builders	8	4-7d food diary (household measures)	30	87	13.71	157	424	4.9	50	88
US competitive body builders	35	2 × 3d food diary (household measures)	28	88	23.98 ± 10.45	270	637 ± 259	7.2	44	119
US competitive bodybuilders	7	3d food diary (household measures)	28	91	15.04 ± 4.86	165	457 ± 148	5	52± 11	100
Dutch international level judo participants	28	4-7d food diary (household measures)	18	69	12.16	177	376	5.5	50	88
US national level & collegiate judo participants	13	3d food diary (household measures)			14.0 ± 3.2		386		46 ± 5	90
US collegiate wrestlers	40	1-3d food diary (household measures)			12.17		340		48	79
US national level & collegiate wrestlers	10	3d food diary (household measures)			9.0 ± 3.0		291		54 ± 6	90
German national team wrestlers	20	3d semi-weighed food diary	19-22	85	18.78	221	516	6.1	44	106
Japanese Sumo wrestlers	60				23.1		780		54	120
US national level & collegiate figure skaters	15	3d food diary (household measures)			11.11 ± 3.53		312		47 ± 9	88
Italian Olympic level team and combative sport players	100	Dietary history	23	75	15.68 ± 3.06	209	444 ± 119	6	45	102
Italian Olympic level sprint events (incl. Canoeing)	71	Dietary history	23	80	17.49 ± 3.83	222	498 ± 154	6.2	46	103
Italian Olympic level sprinters, throwers and jumpers	14	Dietary history	24	80	17.35 ± 3.42	217	496 ± 98	6.2	46	102
Italian Olympic level mixed group of skill based athletes (incl. bob sledding)	126	Dietary history	25	73	14.3	199	397	5.5	44	102
Weighted mean	1267				16.45	213	450	5.71	44	

BM = body mass; **CHO** = carbohydrates; **n** = number of athletes; **%E** = CHO : total energy ratio.

Table VIII. Dietary data from female endurance athletes published from 1990

Population	n	Method	Age (y)	BM (kg)	Energy		CHO			Reference
					MJ	kJ/kg	g	g/kg	E%	
Swiss age group swimmers	18	9d food diary (household measures)	13	48	7.91 ± 1.86	165 ± 44	253	5	51 ± 7	121
US collegiate swimmers	10	3 × 24h recall	18	65	7.93 ± 2.65	122	258 ± 83	4	52	122
US collegiate swimmers	14	3d food diary (household measures)	20	63	9.59 ± 1.95	152	324 ± 66	5.1	56	123
US national level swimmers	21	5d food diary (household measures)	15	58	14.93 ± 2.8	256	428 ± 110	7.4	48	124
US collegiate swimmers	9	7d food diary (household measures)	20	64	7.6 ± 1.7	119	293 ± 67	4.6	61	125
British regional swimmers	15	3d weighed food diary	12		9.66		313		52	126
NZ age group swimmers	11	4d weighed food diary	13	56	8.9 ± 0.6	158 ± 67	292 ± 87	5.5 ± 2.5	56 ± 6	127
US collegiate X-country runners	6	7d food diary (household measures)	19	53	6.96 ± 2.4	135 ± 49	247	4.8	57 ± 8	128
Australian well-trained distance runners	11	7d weighed food diary	33	51	8.85 ± 2.1	174	299 ± 58	5.9	57	129
US highly trained distance runners	9	6d food diary (household measures)	26	52	9.17	176	333	6.4	59	62
US trained distance runners	10	3d weighed (?) food diary	22	54	8.16 ± 1.6	152 ± 37	296 ± 68	5.5	60 ± 8	130
US High school runners	7	2 × 7d food diary (household measure)	16	51	7.99 ± 1.88	157	238 ± 48	4.7	48	131
US collegiate X-runners	10	4d food diary (household measures)	20	55	8.31 ± 1.84	152 ± 33	331 ± 70	6.1 ± 1.3	67 ± 2	132
US state-level high school distance runners	22	3d food diary (household measures) longitudinal	17	50	8.99	175	283	5.5	53	133
			20	53	6.88	130	253	4.7	60	
Japanese national team distance runners	7	3d food diary (household measures)	24	47	11.37 ± 1.48	244 ± 37	337 ± 59	7.2 ± 1.4	51 ± 5	134
Finnish international level X-skiers	7	4 × 7d food diary (household measures)	25	58	11.79	204	427	7.4	58	135
Swedish national X-skiers	4	5d weighed food diary	25	54	18.2 ± 1.9	337 ± 35	666 ± 69	12.2 ± 3	58	66
Weighted mean	213				9.42	172	313	5.73	55	

BM = body mass; **CHO** = carbohydrates; **n** = number of athletes; **%E** = CHO : total energy ratio.

Table IX. Dietary data from female non-endurance athletes published from 1990

Population	n	Method	Age (y)	BM (kg)	Energy		CHO			Reference
					MJ	KJ/kg	g	g/kg	%E	
Swiss national gymnasts	12	7d food diary (household measures)	12	35	6.45 ± 1.66	165 ± 56	205	5.9	53 ± 6	121
US collegiate gymnasts	26	Food frequency questionnaire	20	54	5.77 ± 2.3	107	180 ± 60	3.3	50	136
US national artistic gymnasts	29	3d food diary (household measures)	15	49	7.01 ± 2.27	143	283 ± 96	5.8	66	137
South African national throwers	10	7d food diary (household measures)	22	88	9.28 ± 2.0	112 ± 28	257	3	46 ± 8	138
Japanese national team throwers	8	3d food diary (household measures)	25	67	10.94 ± 2.36	167 ± 39	336 ± 58	5.1 ± 1.1	54 ± 3	134
Australian internationally ranked surfers	10	5d food diary (household measures)	23	58	8.40 ± 1.83	141	276 ± 72	4.8 ± 1.5	53 ± 5	139
US collegiate volleyball players	12	3 × 24h dietary recall	20	66	6.73 ± 2.4	102	216 ± 69	3.3	51	122
US collegiate basketball players	9	3 × 24h dietary recall	20	70	7.52 ± 3.64	109	227 ± 104	3.3	48	122
Turkish handball players	10	3d food diary (household measures)	22	62	7.3	118	229	3.7	53	140
US collegiate hockey players	9	7d food diary (household measures)	19	64	6.32 ± 1.7	100 ± 26	213	3.4	54 ± 8	128
US collegiate tennis players	4	7d food diary (household measures)	19	53	6.96 ± 2.2	130 ± 31	213	4	49 ± 3	128
US collegiate golf players	5	7d food diary (household measures)	20	61	8.45 ± 1.5	147 ± 29	253	4.2	48 ± 7	128
Japanese national team middle distance runners	4	3d food diary (household measures)	18	47	11.54 ± 2.29	245 ± 50	335 ± 42	7.1 ± 0.9	50 ± 5	134
Japanese national team sprinters	11	3d food diary (household measures)	20	52	10 ± 2.2	192 ± 46	305 ± 79	5.8 ± 1.6	53 ± 5	134
Japanese national team jumpers	4	3d food diary (household measures)	21	54	8.28 ± 2.21	152 ± 37	244 ± 60	4.5 ± 1	51 ± 3	134
Weighted mean	163				7.56	125	237	4.46	54	

BM = body mass; **CHO** = carbohydrates; **n** = number of athletes; **%E** = CHO : total energy ratio.

Table X. Dietary data from male endurance athletes published from 1990

Population	n	Method	Age (y)	BM (kg)	Energy		CHO			Reference
					MJ	KJ/kg	g	g/kg	%E	
US international triathlete	1	7d food diary (household measures)	24	74	28.8	389	1014	13.7	59	141
US highly trained runners, triathletes, biathletes		7d weighed food diary								142
adequate eaters	4		27	68.5	18.91 ± 4.52	280	659 ± 233	9.8 ± 3.8	54 ±7	
small eaters	6		26	67.2	11.86 ± 3.22	180	468 ± 149	7 ± 2.4	62 ± 7	
French national and international level middle distance runners	6	2 × 7d weighed food diary	22	64	11.9	190	352	5.5	47	143
US elite distance runners	17	3 × 3d food diary (household measures)	26	66	13.11 ± 4	201	401 ± 140	6.1	48	144
Australian national level marathon runners	19	7d food diary (household measures)	30	64	14.9 ± 2.8	230 ± 40	487 ± 111	7.6	52 ± 5	145
Australian well-trained distance runners	12	7d weighed food diary	38	69	14.58 ± 2.65	211	482 ± 131	7	54	129
Scots well-trained distance runners	6	7d weighed food diary	32	58	13.8	238	449	7.7	52	146
South African distance runners		Food frequency questionnaire								147
elite black	11			56	13 ± 5.49	260 ± 63	432	7.8	56	
elite white	9			70	14.34 ± 4.75	207 ± 75	437	6.2	51	
US collegiate X-runners	14	4d food diary (household measures)	19	64	15.17 ± 3.45	238 ± 55	504 ± 136	7.9 ± 2.2	55 ± 6	132
Italian national level runners	35	7d food diary (household measures)	27	62.7	14.03 ± 0.94	230	502 ± 36	8	60	148
US collegiate X-runners	12	2 × 4d food diary (household measures)	20	66	13.58 ± 2.46	206	497 ± 134	7.5	61	149
Japanese national team distance runners	8	3d food diary (household measures)	25	60	14.32 ± 2.11	229 ± 18	382 ± 19	7.1 ± 0.8	52 ± 5	134
Finnish international level X-skiers	5	4 × 7d food diary (household measures)	27	73	15.88	217	576	7.9	58	135
Italian national level X-skiers	73	7d food diary (household measures)	27	67.5	14.45 ± 1.89	210	499 ± 38	7.4	58	148
Swedish national team X-skiers	4	4d weighed food diary	26	75	30.2 ± 4.6	402	1095	14.6	58	66
US collegiate lightweight rowers	13	24h dietary recall	19	71	11.58 ± 5.97	163	492	6.9	71 ± 10	150

table X continued

which falls into the lower end of the daily CHO intakes recommended for the typical training programmes of these athletes. Similarly, male nonendurance athletes reported a mean CHO intake across all studies of 5.5 g/kg/day, which is at the lower end of their recommended intake range. From the dietary survey literature, it would be reasonable to expect that these values underestimate the actual CHO intakes of these athletes by 10 to 20%. Therefore, it is likely that the true CHO intakes of male endurance athletes were 8.0 to 8.7 g/kg/day (1971 to 1989) and 8.4 to 9.1 g/kg/day (1990 to 1999). Similarly, the true intakes of nonendurance athletes were likely to be 5.9 to 6.4 g/kg/day and 6.3 to 6.8 g/kg/day, respectively, for the 2 periods. Thus, the typical male athlete appears to be within reach of their recommended CHO intakes, even in the case of endurance athletes who have higher CHO intake targets.

Of course, across the range of surveys of male endurance athletes, there are groups who report higher intakes of CHO and others whose apparent CHO intakes fall below the recommended intake range for their likely needs. This is also true of male nonendurance athletes. Given the large standard deviations of the absolute CHO intake values, it is likely that even within a group of athletes who appear to meet their general CHO intake targets, there are individuals who consume less CHO than these guidelines.

It should also be noted that the CHO intake guidelines are sufficiently flexible to cover a range of fuel requirements, and the suitability of the intake of individuals or groups cannot be measured precisely against these goals. As in all areas of nutrition, judgements of inadequacy or deficiency cannot be made from a single piece of evidence, particularly when it is provided by a food record or other dietary survey tool. Rather, such a decision can only be made for individual athletes, by assessing their total nutritional goals and dietary practices from various sources of information. Assessment of the training load, training performances and ability to recover between sessions over a pe-

US collegiate cyclists	14	5d weighed food diary	23	69	17.40 ± 2.9	251	609 ± 114	8.8	58 ± 8	151
Italian national level cyclists	18	7d food diary (household measures)	30	68.6	16.26 ± 1.89	240	562 ± 48	8.2	59	148
US national level swimmers	22	5d food diary (household measures)	16	77	21.83 ± 2.97	282	600 ± 99	7.7	46	124
New Zealand age group swimmers	9	4d weighed food diaries	13	56	12.9 ± 3	230 ± 58	404 ± 88	7.3 ± 1.7	55 ± 7	127
British regional swimmers	15	3d weighed food diary	12		10.7		337		50	126
US collegiate swimmers		2d food diary (household measures)	19							152
pre-study	24			75	15.3 ± 3.9	204	501 ± 141	6.7	55	
↑ training load	11			72	17.7 + 3	246	600 + 126	8.3	57	
Canadian international level swimmers	9	5 × 2d food diary (household measures)	23	76	19.16	252	718	9.6	60	153
Weighted mean	377				15.13	227	508	7.62	56	

BM = body mass; **CHO** = carbohydrates; **n** = number of athletes; **%E** = CHO : total energy ratio.

Table XI. Dietary data from male non-endurance athletes published from 1990

Population	n	Method	Age (y)	BM (kg)	Energy		CHO			Reference
					MJ	MJ/kg	g	g/kg	%E	
Italian national level roller skiers	33	7d food diary (household measures)	26	70	13.92 ± 1.23	200	488 ± 51	7	58	148
Italian national level ice hockey players	20	7d food diary (household measures)	24	73	14.25 ± 1.12	190	456 ± 38	6.5	53	148
Italian professional soccer players	33	7d dietary recall (household measures)	26	76	12.81 ± 2.37	169	449	5.9	56	154
Danish professional soccer players	7	10d food diary (household measures)	23	77	15.7	204	426	5.5	46	155
Italian national level soccer players	16	7d food diary (household measures)	25	74	13.44 ± 1.48	180	454 ± 32	6.1	57	148
Italian professional soccer players	25	4d food diary (household measures)	25	71	15.26 ± 1.81	213	532	7.4	56	156
Puerto Rico Olympic team soccer players	8	12d food diary (household measures)	17	63	16.52 ± 4.48	260 ± 50	526 ± 62	8.3	53 ± 6	157
Professional Australian football players	40	4d food diary (household measures)	23	86	13.2 ± 2.5	154 ± 28	415 ± 110	4.8 ± 1.3	52 ± 9	158
Italian national level alpine skiers	7	7d food diary (household measures)	23	75	14.77 ± 1.48	200	475 ± 31	6.3	54	148
South African national level throwers	20	7d food diary (household measures)	22	99	14.61 ± 3.27	152 ± 36	358	3.6	41 ± 7	138
Japanese national team throwers	2	3d food diary (household measures)	31	104	15.01 ± 2.79	144 ± 20	429 ± 81	4.1 ± 0.6	55 ± 7	134
Italian body builders – steroid users	14	4d food diary (household measures)	27	82	11.27 ± 11.58	137	331	4	47 ± 52	159
Italian body builders – non-users	17	4d food diary (household measures)	25	78	13.69 ± 13.77	176	436	5.6	51 ± 23	159
US state and regional bodybuilders	14	3d food diary (household measures)	26	93	18.68 ± 5.88	201	544 ± 193	5.8	49	160
Italian well-trained body builders	20	4d food diary (household measures)	25	77	15.4 ± 4.34	200	531	6.9	55	156
Australian national level weightlifters	19	7d food diary (household measures)	22	84	15.2 ± 5	190 ± 60	373 ± 94	4.8	42 ± 5	145
Japanese national team middle distance runners	4	3d food diary (household measures)	24	63	14.32 ± 2.11	229 ± 18	383 ± 19	6.2 ± 0.7	49 ± 7	134
Japanese national team sprinters	10	3d food diary (household measures)	22	67	11.09 ± 1.52	167 ± 33	340 ± 57	5.1 ± 1	54 ± 4	134
Japanese national team jumpers	4	3d food diary (household measures)	26	69	11.97 ± 1.16	174 ± 25	359 ± 51	5.2 ± 1	54 ± 5	134
Weighted mean	313				14.13	183	446	5.81	52	

BM = body mass; **CHO** = carbohydrates; **n** = number of athletes; **%E** = CHO : total energy ratio.

Insert table XII here

riod of time can help to identify whether fuel needs are being met.

Female athletes report lower CHO intakes than male athletes, principally as a result of lower total energy intakes. At mean values of 5.5 g/kg/day for endurance athletes and 4.7 g/kg/day for non-endurance athletes, the apparent CHO intakes of these women fall below their respective CHO intake guidelines. Mean values for energy intake per kg body mass of both endurance and nonendurance female athletes were considerably lower than that of their male counterparts. For example, the mean reported energy intake for female athletes was 170 kJ/kg compared with 230 kJ/kg for male endurance athletes. These values remain lower even when allowances are made for differences in lean body mass between genders, and are apparent in the surveys from the 1990s as well as from the earlier periods. These discrepancies are puzzling if we assume that female endurance athletes share similar training loads to their male competitors (at least over the last decade) and that the energy expenditure of these training programmes is considerable.

There are a number of scenarios to explain the apparent energy discrepancies of female endurance athletes, which have been the topic of various studies[62-65,130] or reviews.[172] The first possibility is that these athletes actually consume less energy over prolonged periods because they are, or have become, metabolically efficient and have reduced their true energy needs. Although this hypothesis has been raised because of the strikingly consistent reports of low energy intake in female endurance athletes, studies have failed to find evidence that significant metabolic adaptations occur.[62-65,130] Nevertheless, many female endurance athletes appear to undertake repeated periods of energy restriction and negative energy balance in the desire to achieve or maintain the low body fat levels believed to be necessary for optimal performance. It is likely that these athletes become conscious of their dietary patterns or body composition goals when taking part in dietary surveys, and consequently they undereat or under-report their intake during these observation periods. Energy balance studies of female athletes, par-

Table XII. Dietary data from competition stage events >5d

Population	n	Method	Age (y)	BM (kg)	Energy		CHO			Reference
					MJ	kJ/kg	g	g/kg	%E	
Long distance solitary sailors: 4 stages @ 2-5d	11M	Weighed food inventory for each stage (total = 13d) kept by observer	29-42	74	18.53 ± 2.3	259 ± 36	551	7.3 ± 1.2	51 ± 4	161
Professional cyclists Tour de l'Avenir stage race	4M	4-7d food diary (household measures)	24	74	23.29	316	873	11.8	60	88
Professional cyclists in Tour de France stage race: 22d, 4000km	5M	22d food diary (household measures)		69	24.2 ± 5.3	352	849	12.3	61	18
Elite professional cyclists in Tour of Spain, 3600km, 21d	10M	3d weighed food diary kept by observer	28	71	23.5	352	841	12.6	60	162
US cyclists in 11d, 500km stage race	3F	11d food diary (household measures) partially kept by observer	26	60	10.99	188	343	5.8	52	163
US ultradistance runners in 20d, 500km stage race (1982 Hawaiian Foot race)	15M	8d food diary (household measures)	36	69	18.43	267	564	8.2	49	164
Greek ultradistance runner in 960km, 5d non-stop race	1M	Food diary (weighed? kept by observer?) throughout race (5d)	28	64	49.8	778	2640	41	95	165
Australian ultradistance runner in 1005km, 9d non-stop race	1M	9d food diary (household measures) kept by observer	38	55	24.96	454	947	16.8	64	166
Weighted mean	50				20.74	305	706	10.26	55	

BM = body mass; **CHO** = carbohydrates; **F** = female; **M** = male; **n** = number of athletes; **%E** = CHO : total energy ratio.

Insert table XIII here

ticularly endurance athletes and those in 'aesthetic sports', where lean body physique is important, have found evidence of one or both of these behaviours.[62-65,130]

If under-reporting is the major contributor to energy discrepancies, the true CHO intakes of female athletes will be higher than estimated from the present overview of surveys. However, it is also likely that moderate energy restriction occurs either periodically or over the long term, which limits total CHO intake. This pattern will vary between female athletes or over time in the same athletes. Therefore, while we may feel less confident of the reported CHO intake values of female athletes in the present literature, it is reasonable to conclude that female athletes have greater difficulty meeting CHO intake guidelines, particularly the higher intakes recommended for endurance athletes.

There are few data concerning the reported dietary intakes of athletes who undertake competition events lasting 5 days or more. However, the available studies tend to show higher CHO intakes than achieved in the routine training diet, and it is noted that male athletes undertaking extreme exercise loads associated with cycling or running stage races generally achieve the CHO guidelines suggested in table I. This appears to occur as a result of higher energy intakes as well as a modest increase in the percentage of energy contributed by CHO in the diet.

If the traditional CHO intake guidelines, based on CHO : total energy ratios, are used to judge the adequacy of the self-reported intakes of athletes, a different pattern emerges. Overall, males and female athletes appear to choose diets providing 50 to 55% of total energy from CHO, with the trend towards a greater CHO ratio in endurance athletes compared with nonendurance athletes, and greater energy intake over the past decade. Therefore, the typical modern endurance athlete appears to choose dietary patterns that are more closely aligned to healthy eating guidelines than their sedentary counterparts, according to recent population surveys in Western countries that report mean values for

Table XIII. Dietary data from miscellaneous surveys

Population	n	Method	Age (y)	BM (kg)	Energy		CHO			Reference
					MJ	kJ/kg	g	g/kg	%E	
Internationally competitive triathletes	4M, 2F	2 × 7d food diaries (household measures)	31	69						167
precounselling					9.69 ± 0.63	138	344 ± 156	4.9 ± 2	59 ± 5	
postcounselling					16.69 ± 1.78	238	650 ± 118	9.3 ± 2	65 ± 4	
Austrian top athletes (mixed endurance and nonendurance athletes)	27M, 10F	7d food diary (household measures?)	23	71	14.55	205	394	5.6	46	168
US collegiate athletes (mixed endurance & nonendurance sports)		24h recall								169
untreated	29		20	62	7.47 ± 2.7	120	233	3.8	0 ± 10	
treated group pre-education	10			59	7.2 ± 4.4	122	216	3.7	48 ± 8	
treated group posteducation	10				7.4 ± 3.6	121	273	4.5	59 ± 11	
US distance: international and recreational distance runners	11M, 11F	Food diary		66	12.59	191	300	4.5	40	170
French collegiate mixed athletes (wrestling, handball and cross country)	55	7d weighed food diary	20	71	12.6 ± 0.6	178	356 ± 22	5	47 ± 2	171
Italian Olympic level female endurance and nonendurance sports athletes	15F	Dietary history	21	56	13.42 ± 2.9	238	374 ± 146	6.7	45	102
Weighted mean					11.74	175	337	5.03	48	

BM = body mass; **CHO** = carbohydrates; **F** = females; **M** = males; **n** = number of athletes; **%E** = CHO : total energy ratio.

CHO : total energy ratios of young and middle-aged adults of about 46 to 47%.[173-175]

These mean values, however, fall short of the CHO : total energy ratios that are outlined in the traditional sports nutrition guidelines reviewed in section 1. Judged on this basis alone, the dietary patterns of many groups of male endurance athletes (or individual athletes) would be considered inadequate. However, we have shown that many of these athletes are likely to be achieving their muscle fuel requirements when judged on the basis of grams CHO per kilogram body mass. Conversely, some female endurance athletes appear to be achieving adequate intakes of dietary CHO based on the energy contribution, but fall well below targets based on gram per kilogram guidelines.

This conflict is shown more clearly by examining the relationship between intake of CHO (g/kg) and the proportion of dietary energy contributed by CHO from the dietary surveys. Figure 1 plots this correlation using mean values from all of the dietary surveys of male and female endurance athletes reviewed here. The limitations of these self-reported data are again acknowledged, as well as our failure to weight each study according to the number of participants and the spread of data around the mean values. However, the striking feature that emerges is an apparent gender difference in the relationship between absolute intakes of CHO and the total energy contribution from dietary CHO intake. In male endurance athletes there is a strong positive correlation; that is, athletes who change their dietary mix to increase the contribution from CHO-rich foods are likely to increase their success in meeting CHO intake guidelines (g/kg). By contrast, there is no relationship between the CHO : total energy ratio in the diets reported by female endurance athletes and their total CHO intake (g/kg body mass). A high CHO : total energy ratio does not necessarily ensure that the typical female athlete will increase her total CHO intake or meet the CHO guidelines based on grams per kilogram body mass. Total energy intake presents the confounding variable in this relationship. It is possible for the diet of a female athlete to have a high CHO : total energy ratio through the athlete's restricted fat intake and reduced total energy intake. In this scenario, CHO intake based on grams per kilogram body mass may still be well below the daily CHO guidelines for athletes. It appears that female athletes require more complex and individualised nutrition education messages to improve their CHO intakes. Such messages may include encouragement to soften the restrictions on total energy intake to allow for increased amounts of CHO-rich foods and drinks.

3.2 Have CHO Intakes Increased Over Time?

To examine whether CHO intakes have increased over time we plotted CHO intake as a percentage of total energy intake (fig. 2), and as intake per

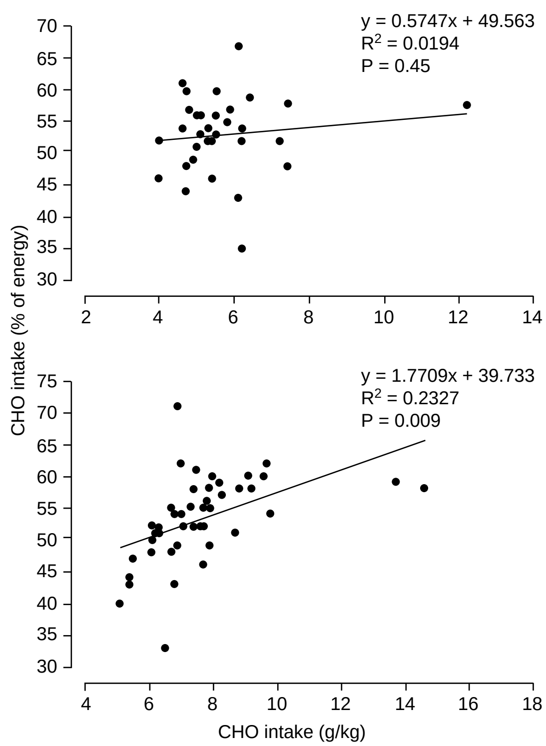

Fig. 1. Mean values from dietary surveys of female (**top**) and male (**bottom**) endurance athletes plotted against time: reported carbohydrate (CHO) intake versus percentage of **total** energy.

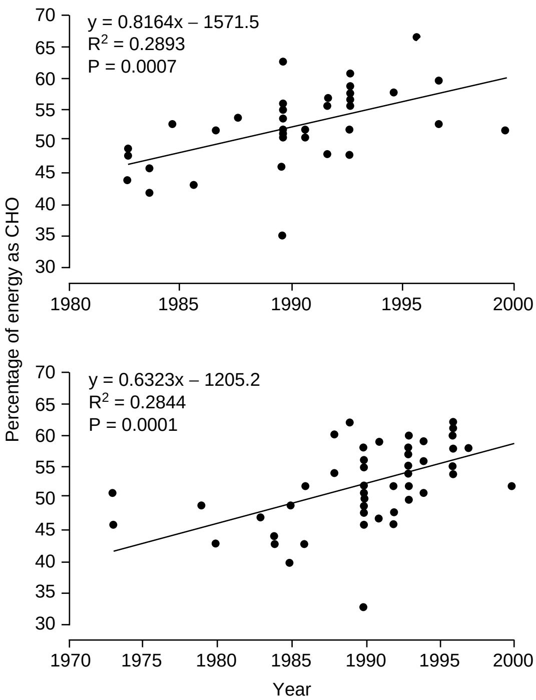

Fig. 2. Mean values from dietary surveys of female (**top**) and male (**bottom**) endurance athletes plotted against time: reported carbohydrate (CHO) intake (percentage of energy).

kilogram of the athlete's body mass (fig. 3), against the year of publication of surveys from male and female endurance athletes. We recognise that the groups of athletes who have been surveyed have not been randomly selected. Therefore, it is possible that there is a bias over time towards particular groups of athletes who may be more or less successful in their nutritional practices. Nevertheless, figure 2 shows that athletes appear to have increased the proportion of CHO in their diets over the past decades during which dietary survey literature is available. This increase occurs both for male and female endurance athletes and is similar in the direction but slightly ahead of the change in intake reported in general population studies.[173-175] Figure 3 shows that this dietary change has caused a trend towards higher intakes of CHO per kilogram body mass for both male and female endurance athletes; however, the increase over time is not statistically significant.

4. Do Athletes' Eating Practices Demonstrate Optimal Intake?

The opening arguments in the present article proposed that competitive athletes would self-select, or have access to information promoting, the diet that would best enhance their performance. However, there are several arguments against accepting the principle that top athletes eat an optimal diet, as well as the specific idea that the reported CHO intakes summarised in this review are ideal.

First, in real life, we observe that athletes utilise a mixture of science, superstition, circumstance and popular belief in all aspects of their preparation. Trial and error is a slow and inexact teacher, and it may not lead the athlete to optimal practice in all areas.[176] Since nutrition plays an important but facilitatory role in sports performance, it is likely that some athletes are successful in spite of, as well as because of, their dietary practices. Second, although the dietary surveys reviewed here included some top competitors within their samples, the dietary intakes of most of the world's best athletes remain unknown. For example, little is known of the nutritional practices of the Kenyan runners who dominate middle and distance running, although there are anecdotal reports that the native diet is heavily focused on CHO-rich grains.[177] Finally, dietary surveys do not have the power to test the effect of dietary intake on performance. Although descriptive studies may, within limits, identify varying CHO intakes within and across groups, they are not able to test how much this contributes to the performance of individuals or groups.

4.1 Factors Causing Suboptimal CHO Intake

Admittedly, with the majority of sports nutrition education promoting high CHO diets, it is curious that a modern athlete would fail to meet the CHO intake goals outlined in table I. However, there are a number of factors that can interfere with the achievement of such targets, particularly with the

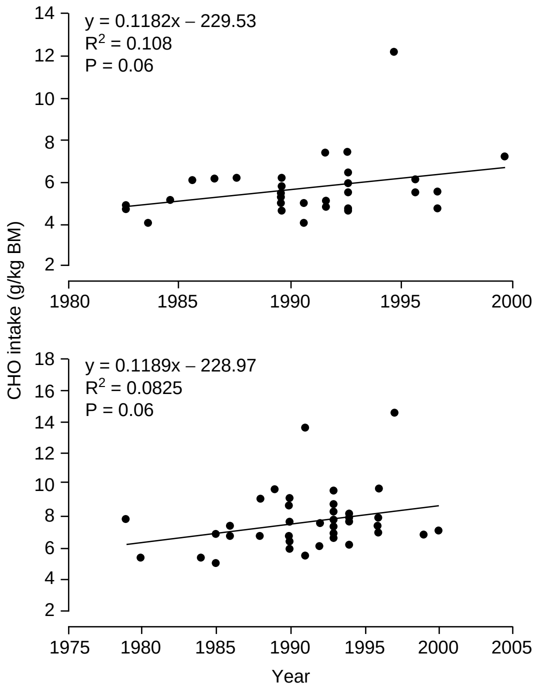

Fig. 3. Mean values from dietary surveys of female (**top**) and male (**bottom**) endurance athletes plotted against time: reported carbohydrate (CHO) intake [grams per kilogram body mass (BM)].

higher intakes recommended for endurance athletes, and these include:

- restricted energy intake
- inadequate practical nutrition skills or food composition knowledge
- background dietary practices and food culture of the country are inadequate in terms of CHO intake
- poor availability of CHO-rich foods in the immediate eating environment
- gastrointestinal limits to bulky, high fibre food intake
- fad diets promoting lower CHO intakes (e.g. the Zone diet)
- chaotic lifestyle and constant travel commitments.

The presence of several of these factors are evident from the dietary survey literature. Total energy intake represents the most important individual factor in determining CHO intake. Athletes who consume high energy intakes increase their opportunity to meet their CHO intake requirements, especially when these are above 7 g/kg/day. These absolute requirements can be met by a diet providing 50 to 70% of energy from CHO as long as the total energy intake is sufficiently high. Endurance athletes with low to moderate energy intakes may be unable to achieve CHO intakes within the recommended range even when the CHO : total energy ratio of their diets is around 70 to 75% of energy intake. Yet, it is difficult to further increase the CHO : total energy ratio for prolonged periods without compromising other nutrient intake goals.

Several individual studies have showed the importance of total energy intake in the achievement of CHO intake goals. Wiita and Stombaugh[133] undertook a longitudinal study of female distance runners over a 3-year period. Although the runners showed an increased awareness of CHO-rich foods, and self-reported food diaries suggested an increased ratio of CHO energy over the 3-year period (60% *vs* 54%), the actual quantity of CHO consumed decreased because of a large drop in reported energy intake. Thompson et al.[142] studied 2 groups of male endurance athletes who described themselves as ‘adequate eaters’ and ‘small eaters’. Dietary records revealed that the former group reported a mean CHO intake of 9.8 g/kg/day from a diet providing 54% of energy from CHO. On the other hand, small eaters reported a mean contribution of 62% of energy from CHO yet achieved a lower apparent CHO intake of 7.0 g/kg/day.

Dietary surveys and nutritional practice reveal that, for many athletes, the desire to restrict energy intake to achieve or maintain the low body fat levels that are deemed necessary for optimal performance is a primary concern. We have seen that this is especially true for female athletes and athletes competing in weight division sports, and it may occur despite the high energy expenditure of the training programmes of those involved in endurance events. The extent to which energy intakes are restricted is skewed by the under-reporting errors seen in dietary surveys. However, it is likely that many female endurance athletes, who strive to achieve or maintain low body fat levels, will fail to consume sufficient energy to allow CHO intakes greater than 7 to 8 g/kg/day in routine eating. Instead, they may need to focus on bodyweight control priorities for most of the season, and increase dietary CHO intake for particular periods such as precompetition preparation and during multiday competitive events. However, other athletes, including females in nonendurance sports, should be able to meet their CHO requirements by increasing the percentage of CHO consumed within their usual energy intakes.

Whether athletes have sufficient knowledge of food selection and preparation to construct suitable CHO-rich diets is another important issue. It is not unexpected that the food choices and dietary patterns of a group of people will tend to mirror the eating practices of the larger population in which they live. After all, cultural patterns of eating and food availability within a country will set the baseline from which individual food habits are drawn. Some studies have noted that, although their athletic groups consume different amounts of energy than the general population from which they are drawn, they appear to share similar food choices, as demonstrated by a similar CHO : total energy ratio. If the typical dietary habits of the background population are not focused on CHO-rich foods, this might present as a barrier preventing the athletic subpopulation from meeting higher CHO intake guidelines. For example, Grandjean[90] noted that the reported food intake of a pooled group of US athletes did not differ greatly in CHO : total energy ratio to the dietary intake data collected in a 1985 general population survey in the US. By contrast, the authors of a dietary survey of Italian national athletes[148] found that the apparent contributions of CHO and fat in their diets was different to the intakes reported in other dietary surveys of athletes from other countries. They suggested that the high proportion of CHO energy was due to the 'mediterranean' dietary practices. Clearly, it is difficult for athletes to achieve significant dietary changes that conflict with the eating practices of the general community.

On a more direct level, the dietary practices of some athletes may be influenced by the food available in their immediate environment. When athletes live in communal facilities such as a college, sports institute or training camp, they may be reliant on catering facilities to supply most of their food intake over long periods. Several studies have noted that residential dining facilities influence the dietary intake of groups of athletes, both to enhance[111] and decrease[93] CHO intake compared with their usual home practices. This highlights the responsibility of such catering services to organise suitable CHO-rich menu plans and optimise food availability.

Finally, general sports nutrition knowledge and a commitment to sports nutrition goals must be matched by specific knowledge of food composition and practical food preparation skills before suitable dietary intake practices can be guaranteed. We have previously reported, in regard to the CHO loading practices of athletes,[178] that even a sophisticated knowledge of the physiology of endurance performance and the principles of increased CHO intake does not guarantee that goals will be achieved. We observed that such athletes avoided sugar-containing foods and chose bulky, fibre-rich foods during a period in which they claimed to be maximising CHO intake.[178] Other studies have reported that simple but specific education to increase the intake of compact CHO foods and liquid forms of CHO can enhance the total CHO intakes of endurance athletes.[92]

5. Conclusion

The traditional CHO intake guidelines for athletes, expressed in the form of dietary energy ratios, have confused both the guidance and assessment of sports nutrition practices. This is particularly important for endurance athletes who have increased CHO needs to meet the fuel requirements of prolonged training or competition programmes. Setting guidelines in grams of CHO relative to the athlete's body mass and training load provides a more straightforward approach.

The limitations of dietary survey techniques should also be recognised when assessing the adequacy of the dietary practices of athletes. In particular, the errors caused by under-reporting or undereating during the period of dietary survey must be taken into account. In this light, dietary surveys of athletes have shown that the typical male athlete achieves a CHO intake within the recommended range; namely, a daily CHO intake of 5 to 7 g/kg for general training needs, and an intake of 7 to 10 g/kg for periods of increased training or competition. However, individual athletes may need nutrition education or dietary counselling to fine-tune their eating habits to meet specific CHO intake targets. Female athletes, particularly endurance athletes, are less likely to achieve these CHO intake guidelines. This is due to the long term or periodic restriction of total energy intake in order to achieve or maintain low levels of body fat. With professional counselling, females may be helped to find a balance between bodyweight control issues and fuel intake goals.

Although we look to top athletes as role models, it is understandable that many do not achieve optimal nutrition practices. The real or apparent failure of these athletes to achieve the daily CHO intakes recommended by sports nutritionists does not necessarily invalidate the benefits of meeting such guidelines. These recommendations are based on plentiful evidence that strategies that enhance CHO availability also enhance exercise capacity and performance during a single exercise session. Although the present literature fails to provide clear support that long term high CHO intakes enhance the training adaptations and performances of endurance athletes, there is the challenge for sports scientists to undertake well-controlled studies that will better test this hypothesis.

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