International Journal of Sport Nutrition and Exercise Metabolism, 2010, 20, 87-103

Methods to Standardize Dietary Intake Before Performance Testing

Nikki A. Jeacocke and Louise M. Burke

When testing is undertaken to monitor an athlete's progress toward competition goals or the effect of an intervention on athletic outcomes, sport scientists should aim to minimize extraneous variables that influence the reliability, sensitivity, or validity of performance measurement. Dietary preparation is known to influence metabolism and exercise performance. Few studies, however, systematically investigate the outcomes of protocols that acutely control or standardize dietary intake in the hours and days before a performance trial. This review discusses the nutrients and dietary components that should be standardized before performance testing and reviews current approaches to achieving this. The replication of habitual diet or dietary practices, using tools such as food diaries or dietary recalls to aid compliance and monitoring, is a common strategy, and the use of education aids to help athletes achieve dietary targets offers a similarly low burden on the researcher. However, examination of dietary intake from real-life examples of these protocols reveals large variability between and within participants. Providing participants with prepackaged diets reduces this variability but can increase the burden on participants, as well as the researcher. Until studies can better quantify the effect of different protocols of dietary standardization on performance testing, sport scientists can only use a crude cost–benefit analysis to choose the protocols they implement. At the least, study reports should provide a more comprehensive description of the dietary-standardization protocols used in the research and the effect of these on the dietary intake of participants during the period of interest.

Keywords*:* research methodology, dietary control, habitual dietary practices

Many of the studies published in this journal involve an intervention in a trained population to examine its effects on the performance of exercise or sport. In a review of the design and analysis of such research, Hopkins, Hawley, and Burke (1999) noted the importance of controlling behaviors and conditions that could influence performance between participants and trials. Currell and Jeukendrup (2008) also identified the importance of maximizing the validity, reliability, and sensitivity of measures of sporting performance. Given that pretrial diet is an extraneous variable that can profoundly influence metabolism and exercise performance, not to mention the effect of the intervention itself, many authors have proposed that consideration be given to standardizing food intake in the hours or days before a performance trial (Braun & Brooks 2008; Burke et al., 2010; Hopkins et al., 1999)

The aim of the current article is to discuss common approaches to standardizing diet before performance monitoring, whether it be to measure the effect of an intervention on performance or to measure the reliability of the performance protocol per se. We will assume that the research design involves free-living participants undertaking laboratory or field-testing, because these are the normal conditions under which most intervention studies of exercise or athletic performance are conducted. We will identify the characteristics of several common protocols for dietary standardization, discuss the advantages and disadvantages of each approach, and provide guidelines for how they should be described in the Methods and Results sections of study reports.

Unfortunately, there are no studies that systematically quantify the effect of standardizing various components of the preexercise diet on the reliability of performance. Therefore, our review will focus on within- and between- subjects variability in dietary intake when different protocols of dietary standardization have been undertaken and speculate on the likely effects on metabolism and performance based on the general literature. A secondary outcome of this review will be the identification of a future line of investigation that can better quantify the effect of dietary standardization on performance testing. In the meantime, we will make recommendations about approaches to dietary standardization that balance the resources involved to achieve them with the likely benefits to the scientific process. Our aim is to enhance the reliability and validity of performance testing, as well as improve the quality of scientific reports.

The authors are with Sports Nutrition, Australian Institute of Sport, Canberra, ACT, Australia.

Dietary Factors Affecting Outcomes of Performance Testing in Sport-Science Research

The goal of dietary standardization in sport-science research is to minimize the difference in nutritional status between and within subjects that might otherwise influence a study's findings. Study outcomes may be affected if dietary issues interact with the intervention (changes to a signal) or change the reliability of the performance that is being monitored (changes to the noise that may alter our ability to detect the signal). Therefore, the starting point in undertaking dietary standardization is to identify the nutrients or dietary components that could affect either the outcome of an intervention or the performance of an exercise or sport protocol. Some nutrients or issues of nutritional status may be important for all studies, and others become important according to the nature of the intervention. We will use the term *dietary standardization* to describe all methods of minimizing preexisting differences in the dietary intake or nutritional status of participants. This will include issues of "controlling" intakes of nutrients (eliminating or limiting intakes of components that have an unwanted impact on the study), as well as "standardizing" intakes (achieving a target intake of important nutrients or ensuring that the same intake was achieved before each trial).

In some cases, particularly those involving chronic interventions that rely on the synthesis of new tissues or other adaptations to a training stimulus, there may be longer term issues of nutritional status or intake of nutrients and supplements that need to be controlled or standardized. For example, the response to a chronic period of altitude training may rely on iron status, and preexisting antioxidant status may be important in protocols in which an antioxidant intervention or oxidative stress is being studied. The contribution of supplement use to nutritional status or physiological adaptations (e.g., the effect of creatine supplementation on muscle creatine stores) is also important. Although these factors need to be considered in the selection of participants in a study or standardization of nutritional intake in some intervention studies, this review will focus largely on the brief periods of hours and days immediately before an exercise trial.

Nutrients and dietary components that commonly need to be standardized or controlled, particularly in the 24–72 hr before testing, are summarized in Table 1. This table describes the ways in which these nutritional components may influence the outcome of an intervention or performance variability and summarizes the common goals or approaches to dietary standardization.

Approaches to Dietary Standardization in Research Design

The current sport science literature includes a number of different approaches to standardizing diet before a performance study or test. These methods have evolved on an ad hoc basis, possibly as outcomes of the increased involvement of nutrition experts in sport science research, the peer-review process, or imitation of methodologies used in other studies. We have identified some common themes in both the implementation and the reporting of dietary standardization in the current sport science literature that we will discuss. To provide a framework for this discussion, we examined all the studies published in *IJSNEM* over the previous 6 years (2004–2009) that investigated the effect of an acute intervention on sport or exercise performance. We identified the methods that were employed to standardize dietary intake in the days before a trial and how the outcomes of these protocols were reported in the article. Table 2 summarizes the findings of this exercise.

Our investigation found that that nearly one in six studies apparently failed to implement any dietary standardization in the hours or days before a performance trial or limited their concerns to the avoidance of alcohol or caffeine during the pretrial period. This is a potentially inadequate approach to study preparation, given the number of ways in which variability in pretrial dietary intake can influence the outcomes of a performance study (see Table 1). We have no way of knowing whether the authors of these studies failed to recognize the potential variability introduced by the lack of pretrial dietary control, failed to report dietary-control techniques that were included in their study methodology, or made a calculated decision that pretrial diet would not substantially influence the outcomes of their particular study. Given that many of these same studies detailed careful techniques such as standardization of laboratory temperatures or familiarization with testing protocols, it is unfortunate that the role of nutritional preparation was not identified in the study methodology.

The most common approach to dietary standardization in the studies we reviewed was to ask participants to follow their usual dietary intake before undertaking a trial. This approach was identified in ~60% of all the studies and nearly three quarters of all studies that reported implementing pretrial dietary control. An account of the pretrial diet was usually collected by having participants keep a food diary or, less frequently, by undertaking a dietary recall on the morning of a trial. However, one fifth of the studies that identified replication of usual diet as a dietary-standardization method did not appear to use any tool to support or evaluate compliance with the protocol.

An additional approach used for dietary standardization was to set targets for the intake or absence of key nutrients or food components in the dietary-control period and provide participants with education tools to help them choose meals and snacks to achieve these goals. Such a technique was used by 10% of studies and was often used in conjunction with food diaries to aid compliance with the protocol. Finally, just over 10% of studies used a complete dietary-standardization protocol by supplying participants with prepackaged foods for all their meals and snacks during the pretrial period.

Table 1 Nutrients and Dietary Components Requiring Standardization or Control

Nutrient	Background	Common approaches to dietary standardization or control

Energy	• In most studies, it is desirable or assumed that participants are in a state of
	  • Reasonable energy balance (energy intake roughly equals total energy expenditure) and/or
	  • Adequate energy availability (where energy availability is defined as the energy available for body functions once the energy cost of daily exercise is subtracted from total energy intake; Hilton & Loucks 2000)
	• Acute or chronic periods of energy deficit (intake below expenditure) or low energy availability (<30 kcal · kg fat-free mass–1 · day–1) alter metabolic rate, nitrogen balance, glycogen storage, and hormonal responses (Butterfield, 1987; Hilton & Loucks, 2000; Tarnopolsky et al., 2001). Such alterations could be expected to alter metabolism and exercise performance.
		• Several strategies can be used to promote reasonable energy balance in the days leading into a study:
		  • Impose a standard energy intake for the group or individual participants. Energy requirements can be set from predictions of resting metabolic rate and the energy cost of daily activity (Manore & Thompson 2010) or from a standard energy availability of 45 kcal/kg fat-free mass (Hilton & Loucks 2000). A disadvantage is that the true energy requirements of individuals may be different than these predicted values, and energy balance may not actually be achieved.
		  • Ask participants who are weight stable to follow their usual diet during the pretrial control period.
		  • Ask participants to keep records of their usual diet for a period before the study to provide an estimate of their usual energy intake. This may be used to set targets for self-chosen dietary-control methods or for preparation of prepackaged standard diets. Note, however, that self-reported energy intakes of free-living participants generally underestimate true intake on the order of ~20% (Black et al., 1993; Mertz et al., 1991). Underreporting of other nutrients will also occur, but there has not been systematic study of the degree to which this occurs.
		• If an energy surplus or deficit is part of the study intervention or background, the two approaches above can be used to manipulate energy balance toward the desired state.

CHO	• A known or given level of CHO availability and CHO utilization may be desired or assumed for the performance of an exercise task.
	• Researchers may want to investigate performance with a standardized or specific muscle glycogen content (e.g., normalized, supercompensated, depleted) that can be achieved via attention to training and CHO intake during the 24–48 hr pretrial (for reviews see Burke, Kiens, & Ivy 2004; Hargreaves, Hawley, & Jeukendrup, 2004).
	• Consuming CHO in the hours before a performance trial restores liver glycogen after an overnight fast and tops up suboptimal muscle glycogen stores, but it also changes substrate use (reduced fatty-acid oxidation, increased CHO use) during subsequent exercise at submaximal intensities (Coyle, Coggan, Hemmert, Lowe, & Walters, 1985). The net effect on CHO availability during exercise depends on the amount of CHO consumed preexercise vs. the increase in CHO utilization.
	• In some participants, intake of small amounts of CHO in the hour before exercise is associated with hypoglycemia and reduced endurance (Kuipers, Fransen, & Keizer, 1999).
	• There is an interaction between intake of CHO before and during prolonged exercise in terms of the effect of muscle CHO availability on performance (Wright, Sherman, & Dernbach, 1991). However, the consumption of CHO before exercise may also alter the response of the central nervous system to the ingestion or mouth sensation of CHO intake during nonendurance protocols (Beelen et al., 2009).
		• As in the case of energy, researchers may choose to provide a standardized approach to CHO intake before and during a performance trial for all participants or allow athletes to follow their usual dietary practices. The advantages and disadvantages identified above also apply to CHO intake.
		• When a standardized or desired level of muscle glycogen is required, researchers may provide or withhold CHO (and manipulate training) during the 24–72 hr before a trial. Daily CHO intake may be set according to the expert guidelines for normalizing or supercompensating glycogen stores, with these guidelines outlined in terms of g/kg of participants' body mass (Burke et al., 2004).
		• The general guideline for CHO in the 1–4 hr before exercise is 1–4 g/kg (Hargreaves et al., 2004).
		• A range of approaches can be found for CHO intake during exercise tasks
		  • To provide a muscle fuel substrate: 30–60 g/hr (Coyle, 2004),
		  • To maximize utilization of consumed CHO during very prolonged events: ~1–1.5 g/min (Kimber, Ross, Mason, & Speedy, 2002), and
		  • To provide a favorable effect on the central nervous system when muscle needs are not limiting: minimal amounts, including a mouthwash (Carter, Jeukendrup, & Jones 2004).

(continued)

Table 1 *(continued)*

Nutrient	Background	Common approaches to dietary standardization or control
Protein	• Habitual protein intake will affect protein metabolism and requirements (Millward, 2003), and a pretrial standardization period is needed for certain interventions such as measurements of nitrogen balance or whole-body protein utilization. • Although intake of protein before or during a trial, particularly in comparison with habitual intake, may alter metabolism or protein kinetics, it is unlikely that these issues will directly affect performance of a single exercise bout.	• Researchers can choose between setting a standardized protein intake and allowing participants to follow habitual intakes (see comments for energy). • Protein intakes are often standardized in the 24-hr pretrial diet to provide a certain protein amount (g/kg body mass) or a certain percentage of total energy intake. This may be more for convention than real standardization to protein per se, because habituation to different levels of protein intake is usually carried out over longer periods (e.g., 5–7 days).
Fluid	• Dehydration is likely to impair performance of prolonged or strenuous exercise undertaken in a hot environment (Cheuvront, Carter, & Sawka 2003; Judelson et al., 2008), especially when additional fluid loss incurred during a performance trial is added to a preexisting fluid deficit. • In most situations, researchers will desire or assume that participants begin a performance trial in a euhydrated state. • In some studies, hypo- or hyperhydration may be involved in the research intervention.	• To ensure euhydration, dietary standardization protocols may require participants to consume a certain volume of fluid on the evening before or hours before a performance trial, leaving sufficient time for excess fluid to be excreted as urine. • Hyper- or hypohydration may also be achieved by prescribing fluid intake and, in the case of fluid deficits, implementing sweat-inducing activities. In other studies, participants may be required to follow their usual hydration practices. • Urine characteristics such as specific gravity or osmolality may be measured before a trial to monitor pretrial hydration status (Maughan & Shirreffs, 2008).
Caffeine	• Caffeine has various profound effects on metabolism (Graham, 2001) and can enhance the performance of a range of exercise protocols (Burke, 2008). • Caffeine is consumed as part of the background diets of most adults, as well as for its specific ergogenic effects on sports performance. • Some tissues become tolerant to repeated caffeine use whereas others do not. However, the importance of various tissues and the mechanisms underpinning the performance effects of caffeine are not fully known. • Traditional research design has encouraged intervention studies to be undertaken without the influence of the acute effects of caffeine, unless an interaction with caffeine intake is being investigated. • It has also been traditional in studies of caffeine supplementation to withdraw participants from caffeine use (i.e., remove their habituation to repeated use) before the study. However, there do not seem to be differences in the performance effects of caffeine between regular users and nonusers of caffeine or as a result of withdrawal from regular caffeine use (for review, see Graham, 2001). • Withdrawal from habitual caffeine use can cause side effects such as lethargy and headaches. It can also increase the risk, with subsequent caffeine intake, of the negative effects often seen with large caffeine doses (irritability, tremor, heart-rate increases; for review, see Graham, 2001).	• It is common practice to require participants to avoid the acute effects of caffeine by abstaining from caffeine-containing products in the pretrial period of up to 24 hr. • In the case of caffeine-supplementation studies, it is also common practice to withdraw participants from all caffeine intake for longer periods (48–72 hr) to restore caffeine "naiveté." • Avoidance of caffeine intake requires participants to abstain from caffeine-containing drinks, foods, and specialized "energy" or sports products; this is often achieved by providing them with a region-specific list of caffeine-containing products that they should avoid. • Despite these traditions, there are several disadvantages to avoiding or withdrawing caffeine from the pretrial diet. There are no apparent changes in the performance effects of caffeine (Van Soeren & Graham, 1998). In addition, caffeine withdrawal can be associated with unnecessary side effects and discomfort for participants. It has also been suggested that the benefits of caffeine seen in controlled studies may be overstated and actually be explainable as the reversal of adverse withdrawal symptoms rather than an ergogenic effect of caffeine per se (James & Rogers, 2005). • An alternative approach is to allow participants to follow and document habitual caffeine practices. • Compliance with pretrial caffeine protocols can be monitored by measuring plasma or urinary caffeine concentrations at the commencement of a trial.
Alcohol	• Alcohol intake, particularly in excess, affects CHO metabolism, protein synthesis, and hydration status (for review, see Burke & Maughan, 2000). It can also distract participants from following their usual dietary practices or complying with instructions. These effects can directly or indirectly impair a participant's ability to achieve a standardized nutritional status before a performance test. • Acute intake of alcohol and an alcohol "hangover" (period of up to 24 hr after excessive alcohol intake) can impair performance of various exercise protocols (for reviews, see ACSM, 1982; Burke & Maughan, 2000).	• It is common practice to require participants to completely avoid intake of alcohol for 24 hr before a performance test. • In some situations, researchers may not require strict avoidance of alcohol but limit intake to small amounts (<20 g/day) in line with population guidelines for healthy use of alcohol.

(continued)

Table 1 *(continued)*

Nutrient	Background	Common approaches to dietary standardization or control
Vitamins and minerals	• Vitamin and mineral status is achieved as a result of chronic periods of dietary intake (weeks to months) and utilization. • Performance and recovery from strenuous exercise may be impaired by a deficiency or suboptimal status of various vitamins and minerals (see Fogelholm, 2010), particularly iron (see Deakin, 2010). • The effect of acute or chronic supplementation with vitamins and minerals on performance may be altered in participants who have a preexisting vitamin deficiency. • See also comments on antioxidants.	• Typically, most researchers do not worry about measuring or standardizing vitamin and mineral status or intake of participants before acute intervention studies. • If participants are at risk for suboptimal or deficient vitamin or mineral states that have bearing on the results of their performance test or intervention, researchers may measure their prestudy status. Participants with identified problems may be excluded from participation in a study or treated with a period of supplementation.
Antioxidants and other food chemicals	• Exercise may be a cause of both positive and negative oxidative changes, and antioxidant status is generally enhanced as an adaptation to chronic exercise. • Antioxidant status is a highly complex system, and there are a large number of compounds found in foods and special supplements that have antioxidant activity. • The effect of acute or chronic supplementation with antioxidants on performance, exercise-induced damage, and recovery may vary in participants who have altered antioxidant status. • Periods of supplementation with high doses of single antioxidant compounds may interfere with positive oxidative reactions induced by exercise and may impair training adaptations (Gomez-Cabrera et al., 2008).	• Typically, most researchers do not worry about measuring or standardizing participants' antioxidant status or intake before acute intervention studies. New research on the acute effects of antioxidant intake may show that we need to revise this practice. • There is a need for guidelines to standardize antioxidant status or intake during the pretrial period in studies of acute or chronic supplementation with an antioxidant compound.

Supplements	• Some of the compounds provided in supplements, such as creatine and buffering agents, can enhance exercise performance when used according to evidence-based protocols (for review, see Burke et al., 2010). These may interact with other interventions or supplements.
	• The effect or activity of a supplement may vary from hours (e.g., bicarbonate) to months (creatine or beta-alanine; for review, see Burke et al., 2010); this may affect the period of standardization or withdrawal from the supplement.
		• Typically, most researchers do not worry about reporting or altering background supplement use by participants in performance testing or intervention studies, unless the product is the focus of the study.
		• When supplement use is known to affect performance or interact with other supplements, researchers should review participants' background supplement use. Options include
		  • Requiring participants to withdraw from supplement use for an appropriate period
		  • Standardizing use
		  • Allowing participants to continue with habitual use but documenting such practices

Miscellaneous: volume and fiber content	• Factors such as the volume and fiber content of food and fluid affect gastrointestinal factors such as hunger and comfort. These factors can be independent of the energy or nutrient content of a diet and differ between individual participants. This can be important over the day, or in the period just before exercise.	• When standardized pretrial diets are provided to participants it is important to be able to manipulate volume and fiber content of meals and snacks to achieve an appropriate level of comfort for each individual.
Miscellaneous: 13C background	• Stable isotopes such as 13C are often used to monitor substrate utilization during exercise, including the oxidation of CHO consumed during a bout (Péronnet, Massicotte, Brisson, & Hillaire-Marcel, 1990). The background diet contains varying amounts of naturally occurring 13C in CHO-rich foods (Wagenmakers, Rehrer, Brouns, Saris, & Halliday, 1993) that become bound into endogenous substrates.	• If 13C tracers are being employed in a study to monitor exogenous fuel use, participants may be required to undertake depleting exercise and alter the type of CHO-rich foods in their diets for 2–5 days before a trial or throughout the experimental period to standardize the background 13C contribution from endogenous substrates (Jeukendrup et al., 2006).

Note. CHO = carbohydrate.

Table 2 Dietary Standardization Protocols Used in *IJSNEM* Publications (2004–2009) Involving Acute Interventions With a Performance Outcome

		Nil or Minimal Approach to Dietary Standardization (*n*)		Recognized Approaches to Dietary Standardization (*n*)					Reporting of Outcomes of Recognized Dietary Standardization A pproaches (*n*), Pretrial Diet Reported		
				Replication of Usual Diet Noting Compliance Tool							
Year	Acute intervention studies (*n*)	No protocol reported	Avoidance of caffeine, alcohol	Nil	Recall	Food diary	Education tools for specific dietary targets	Provision of standard diet packages	Nil	Qualitative	Quantitative
2009	15	1	0	4	2	6	0	2	6	2	6
2008	12	0	3	1	2	3	2	1	3	1	5
2007	9	1	2	2	0	2	0	1	4	0	1
2006	5	0	0	0	0	5	0	0	2	1	2
2005	15	1	1	1	0	9	3	1	9	0	5
2004	6	1	0	0	0	1	1	3	3	1	1
Total	**62**	**4**	**6**	**8**	**4**	**26**	**6**	**8**	**27**	**5**	**20**

In addition to examining the dietary-standardization methods reported by researchers, we also summarized the level to which the articles detailed the outcomes of these protocols—that is, compliance with protocol instructions or the variability in dietary intake between and within subjects during the period of dietary control. We found that more than half the studies that reported undertaking some measure of dietary standardization provided no information on what participants consumed before their trials or how well they complied with any protocols. A small number of studies provided a qualitative assessment that their participants "followed instructions" or "consumed their usual diets" but provided no information on when and how this assessment was made. Just over a third of the studies provided quantitative information on pretrial dietary intake of their participants. This was usually in the form of values for the mean and standard deviation of self-reported intakes of energy and macronutrients and a statement that there were no significant differences between trials based on probability statistics. In many cases, however, only a single estimation of intakes across all trials was presented, rather than the results for each of the trials. Therefore, it was often not possible to gauge the actual variability between and within trials.

In the following section we will examine the different approaches to dietary standardization we have identified. We will discuss in detail the different characteristics of the protocols, potential advantages and disadvantages, and potential implications for the study outcome. We will present data from the dietary-standardization component of past studies from our own group to provide real-life examples of the varying degrees of control in the pretrial diet that are possible using the different approaches.

Approaches to Dietary Standardization

Replicating Usual Diet

This protocol requires participants to follow their habitual or self-chosen eating and drinking patterns over a defined period before the performance trial. Furthermore, when several trials are undertaken by the participants (such as in a crossover intervention or a study on the reliability of an exercise protocol), they are asked to repeat the same menus as closely as possible. In many cases, participants are also asked to avoid consuming particular food components such as alcohol or caffeine.

Reporting tools are important to promote participant adherence and to provide researchers with a measure of compliance or quantification of dietary intake during the control period. Both retrospective (recall) and prospective (food diary) measures can be used to record food and fluid intake, and in a crossover trial, the researcher commonly provides a copy of the diary from the first trial to use as a template for menu planning for subsequent trials.

The advantages and disadvantages of using a technique that relies on the participants to replicate their usual dietary practices before a trial are summarized in Table 3. The clearest advantage is the low level of burden for both the researcher and the participant, which explains why it has become the default protocol for implementing dietary control. It is an appealing choice for studies that have limited resources in terms of manpower, funding, and sport nutrition expertise. In other cases, it is useful for researchers who have limited access to their participant pool before the day of the trial or need to minimize the demands on participants. Major disadvantages of this approach are the inability to control participants' nutrient intake and the "leap of faith" that normal intake will be appropriate and similar between subjects, as well as between repeated-measures trials.

Examples from two of our previous studies that used replication of usual diet supported by diet recall (Burke, unpublished data) or food diaries (Burke et al., 2003) illustrate the pros and cons of these methods of standardizing diets. We chose these methods because of their practicality (low participant burden and low resource allocation) and suitability for the research design. In one case, when we needed to maximize the reliability of a 100-m swim race, we decided to focus our resources on standardizing training in the day leading up to the event, having swimmers undertake their usual race warm-up and wear their racing swimsuit, and replicating the conditions of a race meet with a race timetable, electronic timing, and prize money. We felt that these factors would be more important to swimming performance than having swimmers replicate identical energy and carbohydrate intakes over the 24 hr before the race. In the second study (Burke et al., 2003), the dietary preparation preceded a cycling protocol aimed at depleting muscle glycogen stores before refueling interventions. The aim was to avoid extreme differences in muscle glycogen before the depletion ride rather than require identical starting points.

In both studies, our goal was that participants would avoid caffeine and alcohol intake and achieve reasonable similarity in energy and carbohydrate intake between subjects and between trials. To achieve this we instructed participants individually about the dietary-standardization protocol and provided them with copies of their self-reported food and fluid intake from the first trial to guide their intake before the subsequent trials. On the morning of each trial, participants were interviewed by the same dietitian, who either observed their food diary or collected a food recall from the control period and decided whether to permit or bar the participant from undertaking the trial. The criteria used to make this judgment included adherence to the ban on intake of caffeine or alcohol and a qualitative judgment that energy and macronutrient intakes were similar. A post hoc analysis of self-reported intake during these control periods, however, demonstrates the true variability of intake using this method of dietary standardization. Tables 4 and 5 summarize the mean and standard deviation of intakes of energy, carbohydrate, and protein reported by participants during a 24-hr period (diet recall) and 48-hr period (food diary) of standardization. The between-subjects values (intersubject differences within each trial) and the within-subject differences (intrasubject repeatability from Trial 1 to Trial 2) are reported.

Table 3 Summary of the Different Approaches to Dietary Standardization

Approach	Pros and cons of method	Characteristics of situations when approach may be considered	Examples of appropriate information to include in study report

Replicating usual training diet (food diary as compliance and monitoring tool)	**Advantages**
	• Minimal cost (time, money, convenience, or resources) for both the researcher and the participant.
	• Participants can consume foods they like and usually eat.
	• Minimal requirement of participants on the day of the study.
	• No pretrial requirements of participants apart from keeping food diary.
	Disadvantages
	• Usual or self-chosen diet may not be suitable preparation for the specific study.
	• Requirement for appropriately trained researcher to "check off" compliance to study requirements from food diary on entry to trial. This step is poorly appreciated.
	• Also has larger requirement for post hoc analysis of diets for study report.
	• Variability of intake between and within subjects during standardization period; this may be masked if mean values for self-reported intakes are considered.
	• Accuracy of food diary:
	  • Participant may not record their intake in sufficient detail for an accurate analysis of energy and nutrient intake. Assumptions may have to be made, which introduces error into the analysis.
	  • Food diaries typically underestimate habitual energy intake (Black et al., 1993; Mertz et al., 1991).
	• Interference with habitual dietary practices.
	• Participants may change their normal food choices as a result of recording activities; intake may not be a true reflection of habitual practices if this is the intended dietary preparation.
	• Inadvertent intake of controlled nutrients or dietary components when left to participant choice or food knowledge.
	• Repeated-measures design: Repetition of the exact food and drink intake before each trial may be difficult in some situations and, in the case of multiple trials, may become boring for participants.
		• Dietary intake during trial preparation has low level of influence on trial intervention or performance.
		• Anticipation of a large effect of the intervention (signal) that can be easily detected within the "noise" of the performance.
		• Low level of resources (time, funding, and appropriate personnel) available for the study.
		• Experimental question targets the effect of an intervention on performance when athletes follow their usual dietary practices (i.e., mimicking real-life conditions and expected outcomes).
		• Logistics prevent participants from eating a prepackaged diet (e.g., absence of food storage and preparation facilities).
			Protocol (Methods)
			"Participants were instructed to follow their normal training diet and fluid intake for *x* hr before each trial. They were also asked to refrain from all caffeine and alcohol during this period. Instructions on how to keep a food diary were provided. On arrival at the lab on a trial day, a participant's diary was qualitatively assessed by a dietitian for compliance with these dietary instructions before the participant was cleared to start. (In the case of a repeated-measures design: A copy of the food diary kept before the first trial was provided to participants with the instructions to replicate this eating pattern as closely as possible before subsequent trials.) Dietary analysis of the self-reported intake of each participant was undertaken on completion of the study/ trial using *x* software package [name and details]."
			Results
			Report should note
			• Compliance of participants to avoidance of specified dietary components
			• Estimated intake of controlled or important nutrients
			• Some comment on the variability of intake of controlled or important nutrients between participants and trials and the clinical significance this contributes to study results

(continued)

Table 3 *(continued)*

Approach	Pros and cons of method	Characteristics of situations when approach may be considered	Examples of appropriate information to include in study report

Replicating usual training diet (24-hr recall as monitoring or compliance tool)	**Advantages**
	• Minimal cost (as above).
	• Participants can consume foods they like and usually eat.
	• No pretrial requirements of participants.
	Disadvantages
	• Suitability of usual diet (as above).
	• Variability of intake (as above).
	• Requirement of appropriately trained researcher to take and interpret 24-hr recall is greater than food diary (see above).
	• Accuracy of 24-hr recall:
	  • Reliant on participant memory and food knowledge.
	  • Underestimates intakes of energy (Briefel, Sempos, McDowell, Chien, & Alaimo, 1997) and presumably other nutrients.
	• Inadvertent intake of controlled nutrients or dietary components (as above).
	• Difficulty in repeating exact food and drink before each trial in repeated-measures design (as above).
		Same as above, plus
		• Restricted access to participants during pretrial period or requirement to minimize the inconvenience to them.
		Note that participants must be capable of recalling and describing food intake.
			Protocol (Methods)
			"Participants were instructed to follow their normal training diet and fluid intake for *x* hr before each trial. They were also asked to abstain from all caffeine and alcohol during this period. On arrival at the lab on a trial day, a dietitian collected a recall of food and fluid intake over this period from the participants and qualitatively assessed their compliance with these dietary instructions before they were cleared to start. (In the case of a repeated-measures design, a copy of the food recall from the first trial was provided to participants with the instructions to replicate this eating pattern as closely as possible before subsequent trials.) Dietary analysis of the self-reported intakes was undertaken on completion of the study/ trial using *x* software package [name and details]."
			Results
			As above.

Dietary prescription aided by education tools	**Advantages** • Potential for better control of selected nutrients than "usual diet" methods. • Participants can consume foods they like and usually eat. • Allows participants to change menu items (flexible eating) while still achieving a target amount of key nutrients. • Requires greater resources and planning by researchers (preparation of education tools) but is less "expensive" than providing standardized diets. **Disadvantages** • Reliant on education tools (trade-off between simplicity and detail). Researcher needs appropriate expertise and time to compile study-specific tools. • Reliant on participant nutrition knowledge and ability to use education tools to pace intake over the day to meet targets. • Variability of intake between and within participants during standardization period still potentially high; this may be masked if mean values for self-reported intake are considered. • Requirement for appropriately trained researcher to "check off" compliance with study requirements from food diary on entry to trial. This step is poorly appreciated. • Has larger requirement for post hoc analysis of diets for study report. • Errors in accuracy of food diary (see above). • May expose some participants to a diet that is markedly different than habitual practices, causing shifts in metabolism and nutritional status. • Additional "cost" to study and to participants.	• Dietary intake during trial preparation has greater level of influence on trial intervention or performance. Researchers can quantify nutritional goals for pretrial period. • Anticipation of a large effect of the intervention (signal) that can be easily detected within the "noise" of the performance. • Participants are motivated and nutritionally aware. • Researcher has nutrition expertise and knowledge of likely food environment to construct appropriate education tools. • Logistics prevent participants from eating a prepackaged diet (e.g., absence of food storage and preparation facilities).	**Protocol (Methods)** "We instructed participants to follow a diet providing *a* grams of Nutrient 1 and *b* g of Nutrient 2 over the *x* hr before each trial. Participants were provided with a checklist of the Nutrients 1 and 2 content of common foods to allow them to achieve these targets. Participants were also instructed to avoid caffeine and alcohol during this period, and a checklist of caffeine-containing foods and drinks was provided. Food diaries were kept to check compliance, and we checked these records on the morning of each trial. Dietary analysis of the self-reported intake of each participant was undertaken on completion of the study/ trial using *x* software package [name and details]." **Results** As above.

Table 3 *(continued)*

Approach	Pros and cons of method	Characteristics of situations when approach may be considered	Examples of appropriate information to include in study report
Standardized diets	**Advantages** • Best guarantee of compliance to pretrial nutrition targets in a free-living situation. • Can eliminate variability in nutrient intake between and within trials. • Food packages can be manipulated to suit individual dietary preferences and tolerances. • Minimal effort and nutrition knowledge required by participants. • Cost and availability of food in study conditions may attract participants. • Compliance check on day of trial is simple (crosscheck of food checklist) and does not require expertise. • Quick posttrial analysis of diets for study report. **Disadvantages** • Major resource allocation to the study (expense, time, and expertise required to plan, purchase, weigh, and package all the food—see Table 8) • Researchers may have limited flexibility for individual diet prescription (it may be necessary to eliminate participants with specific food requirements, intolerance, or preferences). • Participants may experience practical problems with eating prepackaged food (e.g., coping with travel, busy schedule, or social events). • May expose some participants to a diet that is markedly different than habitual practices, causing shifts in metabolism and nutritional status. • Reliant on participant compliance to eat only packaged diet: burden and boredom increase with multiple trials in repeated-measures study. • Difficulty in achieving nutrient standardization targets with an appropriate food volume (balancing hunger vs. gastric comfort). When nutritional targets are provided per kg body mass, discrepancies in food volumes occur at extremes of body size. • Large time commitment with individual participants to assess personal food needs and educate on compliance with food plan.	• Dietary intake during trial preparation has important level of influence on trial intervention or performance. Researchers can quantify nutritional goals for pretrial period. • Recognition that desired study outcomes will only be possible if enhanced reliability of performance (reduced noise) increases the ability to detect small effect from intervention (signal) with clear confidence limits. • Adequate expertise, time, logistics, and funding are available.	**Protocol (Methods)** "Participants were fed a standard diet providing *x* kJ/kg, *y* g/kg Nutrient 1, and *z* g/kg Nutrient 2. A 24-hr menu was constructed using *x* software package [name and details] and adapted to the individual characteristics of each participant (body mass, food preferences, etc.). Participants received all food and drinks intended for the control period in prepackaged and weighed form, with instructions for preparation and time of eating. They were given a checklist to tick off the items as eaten and to record any deviations from the menu. When participants reported to the lab for a trial, this checklist was assessed for compliance with study requirements before they were cleared to start. An analysis of the actual diet was undertaken on completion of the study using the same software." **Results** As above.

Table 4 Self-Reported Intakes of Selected Nutrients Over 24 hr Before a Performance Trial by Elite Swimmers (*N* = 15)

	Energy (kJ · kg BM^{-1} · day^{-1})	Carbohydrate (g · kg BM^{-1} · day^{-1})	Protein (g · kg BM^{-1} · day^{-1})
Trial 1, *M* ± *SD*	143 ± 30	4.9 ± 1.4	1.6 ± 0.4*
Trial 2, *M* ± *SD*	133 ± 32	5.0 ± 1.7	1.3 ± 0.3*
Between-subject values (intersubject differences) within each trial	Trial 1: 99–213	Trial 1: 2.7–8.1	Trial 1: 1.0–2.3
	Trial 2: 80–198	Trial 2: 1.9–8.1	Trial 2: 1.0–2.0
Within-subject differences (intrasubject repeatability) from Trial 1 to Trial 2	1–45	0.1–3.3	0–0.7

Note. BM = body mass. Dietary-standardization method = replication of usual training diet with dietary recall support (data taken from Burke et al., unpublished observations).

*Mean differences between Trials 1 and 2 are significant (p = .01).

Table 5 Self-Reported Intakes of Selected Nutrients Over 48 hr Before a Carbohydrate-Depletion and -Restoration Study by Well-Trained Cyclists (*N* = 6)

	Energy (kJ · kg BM^{-1} · 48 hr^{-1})	Carbohydrate (g · kg BM^{-1} · 48 hr^{-1})	Protein (g · kg BM^{-1} · 48 hr^{-1})
Trial 1, *M* ± *SD*	284 ± 65	8.5 ± 2.3	3.3 ± 0.9
Trial 2, *M* ± *SD*	267 ± 57	8.5 ± 1.9	2.6 ± 0.9
Between-subject values (intersubject differences) within each trial	Trial 1: 186–365	Trial 1: 5–11.2	Trial 1: 1.9–4.5
	Trial 2: 194–358	Trial 2: 5.8–11.1	Trial 2: 1.8–4.4
Within-subject differences (intrasubject repeatability) from Trial 1 to Trial 2	7–55	0.1–1.6	0–2.1

Note. BM = body mass. All differences between Trials 1 and 2 were nonsignificant. Dietary-standardization method = replication of usual training diet with dietary records (data taken from Burke et al., 2003).

A statistical analysis of the self-reported carbohydrate intakes failed to detect significant differences between trials at an alpha level of .05.

Further analysis of these data shows that simple calculations of mean intake can hide a large amount of variability both between participants and between trials. For example, in our study in which diet recall was used as a compliance and reporting tool (Table 4), self-reported 24-hr carbohydrate intake within a single trial varied 3-fold from 2.7 g/kg body mass in one participant to 8.1g/kg in another. Similarly, although several participants were consistent with their carbohydrate intake between trials (a difference of 0.1g/kg body mass), the meals reportedly eaten by one participant differed in carbohydrate content by 3.3g/kg between trials. The practical outcome of such findings is that participants who differ significantly in their preparation for the two trials could experience "noise" in their performances, preventing the true effect of an intervention from being detected in the study. In addition, some participants might be considered to have undertaken a totally different study than their colleagues because of their different fuel status, and in situations when dietary preparation is a covariate in the effectiveness of an intervention, the true outcomes could also be masked. Although in our case variability in carbohydrate availability has little influence on performance of a single 100-m swim race, in many other situations or protocols the difference in fuel status between subjects or treatments might be important. Analysis of self-reported intakes from the study in which a food diary was used as the compliance and reporting aid (Table 5) shows similar results of variability within and between subjects that might be of importance in some protocols.

In summary, this approach to dietary standardization has a low burden for both researcher and participant but provides a low level of dietary control that often goes unrecognized. Even when an analysis of dietary-intake data fails to find differences in the intake of key nutrients across a trial, it is likely that there are large differences in the nutritional preparation of participants within the group or across trials. As well as adding to the potential "noise" of the performance protocol, this variability of nutritional preparation may make it difficult to detect the dietary characteristics that interact with an intervention.

Dietary Prescription Aided by Education Tools

Dietary prescription aided by education tools is the method of dietary standardization often used in research protocols in which a targeted intake of one or more specific nutrients is desired. In such studies, researchers will

have determined that ad hoc or variable intakes of these nutrients might affect the study outcome or that there is an "ideal" or recommended intake that should be achieved. Typically, the implementation of this method involves educating participants on target intakes of key nutrients and providing tools to help them meet these targets in a freely chosen food environment. Education tools might include "ready reckoners" or food checklists (tables showing portion sizes of foods that provide a "unit" of a nutrient—e.g., 10 g protein or 25 g carbohydrate) or tables of nutrient composition (tables of usual portion sizes of foods that provide information on energy or nutrient composition). As with the "usual intake" method of dietary standardization, participants usually also use a compliance and recording tool such as a food diary to demonstrate their achievement of dietary-intake targets.

The benefits of this dietary-standardization protocol are summarized in Table 3 and include providing participants with some freedom of choice with their food and fluid intake during the dietary-standardization periods while potentially reducing the variability of energy and nutrient intake. This method also provides a relatively low burden on researchers, especially when preexisting education tools can be used. However, the disadvantages include an increased responsibility for participants to plan their food intake appropriately. Such a commitment must be underpinned by a greater degree of knowledge and commitment to the project.

Another study from our group (Ebert et al., unpublished data) demonstrates the pros and cons of the aided dietary-prescription method for standardizing diets. We chose this method because of the specific conditions under which subjects participated in the study; a cohort of junior elite cyclists was recruited to undertake a research project embedded into an intensive training camp, based on residential living with a buffet-style food service. We determined that muscle glycogen stores, determined primarily by diet and training during the 24 hr preceding each trial and the prerace meal, would be an important factor in the performance of the study cycling protocol (2.5 hr of cycling). Given the duration of the training camp and study, we decided that it was important to allow participants some flexibility with menu choices; however, we wanted to direct their selections to meet targets for energy and carbohydrate intake. We felt that our ability to access and influence the dining-hall menu would provide some control over the cyclists' intake without enforcing a complete dietary standardization. A group education session was set up with the cyclists to explain the rationale for setting dietary targets and to teach them how to use a ready reckoner of carbohydrate units from foods available in the dining hall or provided in the study to meet their targets (8 ± 1 g/kg for 24 hr and 2 ± 0.5 g/kg for the preevent meal eaten 2 hr before the commencement of the cycling protocol). Customized food-diary sheets were used to record total food intake for the period, highlighting the calculations made by the athletes for carbohydrate intakes, and to provide a template for each cyclist's subsequent trials.

Table 6 summarizes the results of self-reported intakes of energy, carbohydrate, and protein for the 24 hr and pretrial breakfast period of standardization. Means and standard deviations, the range between subject values in each trial, and the within-subject differences from Trial 1 to Trial 2 are reported. As in our previous examples, a traditional statistical analysis of the data found that the difference in mean intake of all variables between trials was not significant at the .05 alpha level. However, again we observed a range in carbohydrate intakes between subjects (4.9–11.9 g/kg) and in the degree to which they were able to match carbohydrate intakes across trials (from a trivial difference of 0.1 g/kg in one participant to 3.6 g/kg in another). Although this variation was greater than our target and similar to the levels seen using a "replication of usual intake" protocol, we thought that our participants consumed intakes (i.e., carbohydrate) that were more suited to ideal preparation for the protocol than might have been habitually consumed.

Table 6 Self-Reported Intakes of Selected Nutrients Over Day Before and Prerace Meal Before a Performance Trial by Well-Trained Cyclists (*N* = 7)

		Carbohydrate (g/kg BM)		
	Actual energy (kJ/kg BM)	Actual	Aim	Actual protein (g/kg BM)
Trial 1, *M* ± *SD*	192 ± 40	7.9 ± 2	8	1.8 ± 0.4
Trial 1 breakfast, *M* ± *SD*	66 ± 14	2.8 ± 0.5	2	0.6 ± 0.1
Trial 2, *M* ± *SD*	212 ± 43	8.5 ± 1.7	8	1.9 ± 0.5
Trial 2 breakfast, *M* ± *SD*	64 ± 15	2.7 ± 0.6	2	0.5 ± 0.1
Between-subject values (intersubject differences) within each trial	Trial 1: 139–259	Trial 1: 4.9–11.2	8	Trial 1: 1.2–2.3
	Trial 2: 159–284	Trial 2: 6.1–10.9		Trial 2: 1.3–2.5
Within-subject differences (intrasubject repeatability) from Trial 1 to Trial 2	1–64	0.3–3.6	0	0.1–0.9

Note. BM = body mass. All differences between Trials 1 and 2 were nonsignificant. Dietary-standardization method = dietary prescription aided by education tools (data taken from Ebert et al., unpublished observations).

Standardized Diets

This method of dietary standardization shares similarities with the previous approach in that the researcher has determined that variability or the presence of certain nutritional components in the pretrial diet will affect the study outcome or that a specific target for certain nutrients is desirable. However, factors such as the impact of nutritional preparation on performance outcomes, the ability of participants to achieve a desired nutritional preparation, the resources available for the study, and the location or logistics of the study may warrant or allow greater investment in the preparation of participants before a trial (see Table 3). In our experience, providing a prepared and prepacked diet to participants offers the greatest opportunity to standardize and control their intake of various nutritional components in the pretrial period.

The steps taken to implement such dietary standardization commence with the construction of a generic plan of food and fluid intake that achieves the desired nutritional characteristics of the pretrial period, either in absolute amounts or amounts scaled to factors such as body mass or exercise load. This menu plan must also take into consideration the logistics under which participants will store, prepare, and eat their food during the dietary-control period. Once individual participants are recruited, this menu will be further tailored to their specific characteristics such as body mass, food preferences and intolerances, comfortable food volume, and other special needs. Food and drink items will then be purchased in bulk or prepackaged units or prepared from standard recipes so that they can be supplied to participants in a convenient form. On some occasions, participants may be required to consume some of these meals under supervision, but in other cases, they will consume the diet in their own environment. Aids to encourage full compliance to the menu (i.e., consumption of all foods and drinks and the exclusion of extraneous items) can include a daily menu guide with a checklist of items.

The advantages and disadvantages of using this technique to standardize nutrient intake before a trial are summarized in Table 3. The clearest advantage is the increased ability to control the intake of specific nutrients within and between subjects. For example, Table 7 summarizes data from a recent study (Burke et al., unpublished data) in which participants were provided with individualized prepackaged diets for consumption in the 24 hr before a trial. We found that participants were compliant in consuming their pretrial dietary provisions, leading to almost universal achievement of the chosen dietary targets and small variability in the intake of key nutrients between and within trials.

This approach, however, requires more time and resources by the researcher to plan and implement diets for each participant; Table 8 provides a summary of the main steps in the process. There is both an increase and a decrease in participant burden. Although many participants enjoy the provision of preprepared and free food, there are also some restrictions on free choice during dietary-control periods, which may become cumbersome when there are repeated trials or a prolonged period of dietary control. It takes time and expertise to design standardized diets that meet nutrient intake goals while meeting a range of practical challenges such as individual food preferences and gastric comfort and opportunities for storage and preparation of meals. Some potential participants may need to be excluded from a study because of their inability or unwillingness to undertake the dietary-control protocol.

Finally, imposing a dietary prescription on participants may also contribute some problems or a level of artificiality to the study. The usual protocol for the provision of standardized diets involves the development of a single dietary profile, albeit scaled to body size or characteristics, which is provided to all participants. As shown in the previous example, this is likely to be the actual diet consumed by participants in each trial in a study. However, it may not be representative of their habitual diet or their usual dietary practices before a performance trial or competition.

Table 7 Self-Reported Intakes (via Checklist) of Selected Nutrients Over Day Before a Performance Trial by Well-Trained Strength Athletes (*N* = 10)

	Energy, kJ/kg BM		Carbohydrate, g/kg BM		Protein, g/kg BM	
	Actual	Aim	Actual	Aim	Actual	Aim
Trial 1, *M* ± *SD*	157 ± 5	158	4.0 ± 0.1	4	2.0 ± 0.0	2
Trial 2, *M* ± *SD*	157 ± 5	158	4.0 ± 0.2	4	2.0 ± 0.1	2
Between-subject values (intersubject differences) within each trial	Trial 1: 147–166 Trial 2: 147–166	158	Trial 1: 3.7–4.2 Trial 2: 3.6–4.2	4	Trial 1: 1.9–2.1 Trial 2: 1.9–2.1	2
Within-subject differences (intrasubject repeatability) from Trial 1 to Trial 2	0–13	0	0–0.5	0	0–0.2	0

Note. BM = body mass. All differences between Trials 1 and 2 were nonsignificant. Dietary standardization method = dietary prescription aided by full diet provision (data are from Burke et al., unpublished data).

Table 8 Cost of Standardizing Diets per 24-hr Pretrial Period as the Approach of Dietary Standardization (Based on Study of 10 Participants)

Activity	Average time (hr/participant)	Average cost ($AUS, per participant trial[a])
Developing generic diet to meet nutrient targets over a range of body masses using dietary-analysis program (trained individual: 2.5 hr for familiar dietary goals and athletic population to 10 hr for novel diet or population)	0.25–1.00	
Adjusting diet to individual participants' body weight and food preferences (trained individual)	0.5	
Grocery shopping[b] (2.5 hr if undertaken by trained individual; longer if food-composition information or further dietary modifications needed)	0.25	15–20
Collating food for each individual participant's food packages (untrained individual can be used)	0.5	
Participant pick-up and explanation of diet (trained individual)	0.25	
Trouble shooting/answering participants' questions during dietary control period (trained individual)	0.25	
Assessment of diet checklist before commencement of a trial (untrained individual can be used)	0.25	
Analysis of actual intake using dietary-analysis program (trained individual)	0.25	
Total	**2.50–3.25**	**15–20**

[a]Does not cover labor, cost of software package, etc.

[b]Based on use of convenience or standard/packaged foods; additional time for cooking special dishes may be needed in some studies.

If there are large differences between usual intake and the pretrial diet this can lead to alterations in metabolism that could also interfere with performance or the detection of the effects of the study intervention and dietary covariates.

Another possible research design might involve investigating a participant's habitual dietary intake or usual practices, which are then incorporated into the standardized diet provided to that participant. Although this protocol might result in different diets being provided to each participant, it would allow close matching of diets between repeated trials undertaken by a participant and a precise knowledge of the actual diets consumed by participants in preparation for a trial or exercise test. Such a protocol would be appropriate for investigations focusing on the effect of certain real-life dietary practices on performance or their interaction with another intervention. However, such investigations are rare. The downside of allowing participants to follow different dietary preparation for a study is that, as we have discussed in this article, they may respond differently to an intervention. Unless such a study is sufficiently powered, it may be impossible to identify different dietary preparation as a covariate.

Future Work on Dietary Standardization

We have determined that various factors in dietary preparation or nutritional status may influence exercise or sports performance (Table 1) and stated that these should be controlled or standardized in any experimental design aimed at clearly detecting the effect of an intervention on exercise outcomes. Of course, this represents an ideal world in research methodology, and the true effects of dietary influences on performance, or the enhancements in reliability associated with controlling these factors, are not known. The failure of researchers to undertake such investigations is surprising and unfortunate, because there is a sizeable literature on the reliability of performance testing (see review by Currell & Jeukendrup, 2008); this includes individual investigations that have identified and quantified the effect of extraneous variables such as familiarization with a performance protocol (Laursen, Shing, & Jenkins, 2003), verbal encouragement of participants (Andreacci et al., 2002), listening to music during a performance trial (Atkinson, Wilson, & Eubank, 2004), and receiving feedback about performance (Nikolopoulos, Arkinstall, & Hawley, 2001). The collection of physiological measurements during a trial has also been identified as a potentially confounding factor (Currell & Jeukendrup, 2008), although its impact has not been investigated.

Accordingly, we encourage future research on the effect of various nutritional factors in preexercise preparation on performance and promote the benefits of standardizing these factors in improving the reliability and validity of performance tests. Clearly, there is a range of different types of performance protocols of interest to researchers and practitioners in sport, and each will have specific physiological limiting factors that interact

with pretrial diet or nutritional status. It is beyond the scope of this review to identify all the possible research questions that could be posed. In addition, we recognize the large number of protocols of exercise performance or endurance to which these questions could be applied and the issue of whether dietary components should be absolute intakes or scaled to a factor such as body mass. However, we propose that the most interesting areas to investigate include but are not limited to

- Variability of muscle glycogen concentrations with different dietary-standardization techniques (e.g., self-chosen habitual intake, fixed diets based on reported habitual intakes, fixed diets based on targeted carbohydrate intakes) and the effect on reliability of performance protocols
- Variability of hydration status with different dietary-standardization techniques (e.g., self-chosen drinking patterns, fixed volume of fluid intake, small fluid overload with sufficient time to excrete excess fluid) and the effect on reliability of performance protocols
- Effect of overnight fast versus range of preevent meals (self-chosen habitual intakes, fixed meals based on reported habitual intakes, fixed diets based on targeted nutrient intakes) on reliability of performance
- Effect of standardization of energy intake, energy availability, and macronutrient contribution in pretrial diet on substrate storage, substrate utilization during exercise, and reliability of performance protocols and the effect of different techniques of standardization of these factors (e.g., self-chosen habitual intake, fixed diets based on reported habitual intakes, fixed diets based on targeted intakes)
- Variability of protein intake in pretrial diet and effect of protein/amino acid intake during exercise on reliability on performance
- Effect of withdrawal or standardization of caffeine intake in pretrial period on reliability of performance testing and of response to caffeine exposure during exercise
- Effect of withdrawal or exposure to alcohol intake in pretrial period on reliability of performance testing
- Effect of withdrawal or standardization of use of various sports supplements in pretrial diet on reliability of performance testing, including identification of adequate withdrawal periods

Until such studies are done, researchers are encouraged to undertake a cost–benefit analysis of the various protocols of dietary standardization according to the characteristics of their study. In addition, they should provide a comprehensive description of the protocols used in their projects and the effect of these on the dietary intake of participants during the period of interest. Guidelines for such reporting are summarized in Table 3.

Conclusion

There are various levels of control or standardization of diet and nutritional preparation before a study or performance test. The unique characteristics of the individual study or test will determine the best approach to standardizing participants' diet in the days before a performance trial. Researchers need to consider the advantages and disadvantages of each approach and match the level of dietary control required to maximize the findings with the logistics and resources of the study. However, given the potential impact that poor dietary control can have on the outcome of a study, more attention should be given to dietary standardization while planning and implementing the project. In addition, more details should be provided in research publications to describe how dietary standardization was undertaken and how well participants complied with protocols. Finally, measurement of the effect of dietary-standardization protocols on the reliability of metabolism and performance of various exercise protocols is an area of research that offers a wide range of possibilities with the potential for valuable insights. The outcomes could help us better understand the effects of nutrition on performance, as well as sharpen our ability to detect small but worthwhile differences in performance from a variety of other interventions.

References

American College of Sports Medicine. (1982). Position statement on the use of alcohol in sports. *Medicine and Science in Sports and Exercise, 14,* ix–x.

Andreacci, J.L., LeMura, L.M., Cohen, S.L., Urbansky, E.A., Chelland, S.A., & Von Duvillard, S.P. (2002). The effects of frequency of encouragement on performance during maximal exercise testing. *Journal of Sports Sciences, 20,* 345–352.

Atkinson, G., Wilson, D., & Eubank, M. (2004). Effects of music on work-rate distribution during a cycling time trial. *International Journal of Sports Medicine, 25,* 611–615.

Beelen, M., Berghuis, J., Bonaparte, B., Ballak, S.B., Jeukendrup, A.E., & van Loon, L.J. (2009). Carbohydrate mouth rinsing in the fed state: Lack of enhancement of time-trial performance. *International Journal of Sport Nutrition and Exercise Metabolism, 19*(4), 400–409.

Black, A.E., Prentice, A.M., Goldberg, G.R., Jebb, S.A., Bingham, S.A., Livingstone, M.B.E., et al. (1993). Measurements of total energy expenditure provide insights into the validity of dietary measurements of energy intake. *Journal of the American Dietetic Association, 93*(5), 572–579.

Braun, B., & Brooks, G.A. (2008). Critical importance of controlling energy status to understand the effects of "exercise" on metabolism. *Exercise and Sport Sciences Reviews, 36*(1), 2–4.

Briefel, R.R., Sempos, C.T., McDowell, M.A., Chien, S., & Alaimo, K. (1997). Dietary methods research in the third National Health and Nutrition Examination Survey:

Underreporting of energy intake. *The American Journal of Clinical Nutrition, 65*(4, Suppl.) 1203S–1209S.

Burke, L., Broad, E., Cox, G., Desbrow, B., Dziedzic, C., Gurr, S., . . . Slater, G. (2010). Supplements and sports foods. In L. Burke & V. Deakin (Eds.), *Clinical sports nutrition* (4th ed., pp. 419–500). Sydney, Australia: McGraw-Hill.

Burke, L.M. (2008). Caffeine and sports performance. *Applied Physiology, Nutrition, and Metabolism, 33*(6), 1319–1334.

Burke, L.M., Collier, G.R., Broad, E.M., Davis, P.G., Martin, D.T., Sanigorski, A.J., & Hargreaves, M. (2003). Effect of alcohol intake on muscle glycogen storage after prolonged exercise. *Journal of Applied Physiology, 95,* 983–990.

Burke, L.M., Kiens, B., & Ivy, J.L. (2004). Carbohydrates and fat for training and recovery. *Journal of Sports Sciences, 22,* 15–30.

Burke, L.M., & Maughan, R.J. (2000). Alcohol in sport. In R.J. Maughan (Ed.), *Nutrition in sport* (pp. 405–414). Oxford, UK: Blackwell Science.

Butterfield, G.E. (1987). Whole-body protein utilization in humans. *Medicine and Science in Sports and Exercise, 19*(5 Suppl.), S157–S165.

Carter, J.M., Jeukendrup, A.E., & Jones, D.A. (2004). The effect of carbohydrate mouth rinse on 1-h cycle time trial performance. *Medicine and Science in Sports and Exercise, 36*(12), 2107–2111.

Cheuvront, S.N., Carter, R., III, & Sawka, M.N. (2003). Fluid balance and endurance exercise performance. *Current Sports Medicine Reports, 2*(4), 202–208.

Coyle, E.F. (2004). Fluid and fuel intake during exercise. *Journal of Sports Sciences, 22,* 39–55.

Coyle, E.F., Coggan, A.R., Hemmert, M.K., Lowe, R.C., & Walters, T.J. (1985). Substrate usage during prolonged exercise following a preexercise meal. *Journal of Applied Physiology, 59,* 429–433.

Currell, K., & Jeukendrup, A.E. (2008). Validity, reliability and sensitivity of measures of sporting performance. *Sports Medicine (Auckland, N.Z.), 38*(4), 297–316.

Deakin, V. (2010). Iron depletion in athletes. In L. Burke & V. Deakin (Eds.), *Clinical sports nutrition* (4th ed., pp. 222–267). Sydney, Australia: McGraw-Hill.

Fogelholm, M. (2010). Vitamin, mineral and anti-oxidant needs of athletes. In L. Burke & V. Deakin (Eds.), *Clinical sports nutrition* (4th ed., pp. 268–294). Sydney, Australia: McGraw-Hill.

Gomez-Cabrera, M.C., Domenech, E., Romagnoli, M., Arduini, A., Borras, C., Pallardo, F.V., . . . Viña, J. (2008). Oral administration of vitamin C decreases muscle mitochondrial biogenesis and hampers training-induced adaptations in endurance performance. *The American Journal of Clinical Nutrition, 87*(1), 142–149.

Graham, T.E. (2001). Caffeine and exercise: Metabolism, endurance and performance. *Sports Medicine (Auckland, N.Z.), 31*(11), 785–807.

Hargreaves, M., Hawley, J.A., & Jeukendrup A.E. (2004). Pre-exercise carbohydrate and fat ingestion: Effects on metabolism and performance. *Journal of Sports Sciences, 22,* 31–38.

Hilton, L.K., & Loucks, A.B. (2000). Low energy availability, not exercise stress, suppresses the diurnal rhythm of leptin in healthy young women. *The American Journal of Physiology, 278,* E42–E49.

Hopkins, W.G., Hawley, J.A., & Burke, L.M. (1999). Design and analysis of research on sport performance enhancement. *Medicine and Science in Sports and Exercise, 31*(3), 472–485.

James, J.E., & Rogers, P.J. (2005). Effects of caffeine on performance and mood: Withdrawal reversal is the most plausible explanation. *Psychopharmacology, 182*(1), 1–8.

Jeukendrup, A.E., Moseley, L., Mainwaring, G.I., Samuels, S., Perry, S., & Mann, C.H. (2006). Exogenous carbohydrate oxidation during ultraendurance exercise. *Journal of Applied Physiology, 100*(4), 1134–1141.

Judelson, D.A., Maresh, C.M., Yamamoto, L.M., Farrell, M.J., Armstrong, L.E., Kraemer, W.J., . . . Anderson, J.M. (2008). Effect of hydration state on resistance exercise-induced endocrine markers of anabolism, catabolism, and metabolism. *Journal of Applied Physiology, 105*(3), 816–824.

Kimber, N.E., Ross, J.J., Mason, S.L., & Speedy, D.B. (2002). Energy balance during an Ironman triathlon in male and female triathletes. *International Journal of Sport Nutrition and Exercise Metabolism, 12*(1), 47–62.

Kuipers, H., Fransen, E.J., & Keizer, H.A. (1999). Pre-exercise ingestion of carbohydrate and transient hypoglycemia during exercise. *International Journal of Sports Medicine, 20,* 227–231.

Laursen, P.B., Shing, C.M., & Jenkins, D.G. (2003). Reproducibility of a laboratory-based 40-km cycle time-trial on a stationary wind-trainer in highly trained cyclists. *International Journal of Sports Medicine, 24,* 481–485.

Manore, M., & Thompson, J. (2010). Energy requirements of the athlete: Assessment and evidence of energy efficiency. In L. Burke & V. Deakin (Eds.), *Clinical sports nutrition* (4th ed., pp. 96–115). Sydney, Australia: McGraw-Hill.

Maughan, R.J., & Shirreffs, S.M. (2008). Development of individual hydration strategies for athletes. *International Journal of Sport Nutrition and Exercise Metabolism, 18*(5), 457–472.

Mertz, W., Tsui, J.C., Judd, J.T., Reiser, S., Hallfrisch, J., Morris, E.R., . . . Lashley, E. (1991). What are people really eating? The relation between energy intake derived from estimated diet records and intake determined to maintain body weight. *The American Journal of Clinical Nutrition, 54,* 291–295.

Millward, D.J. (2003). An adaptive metabolic demand model for protein and amino acid requirements. *The British Journal of Nutrition, 90*(2), 249–260.

Nikolopoulos, V., Arkinstall, M.J., & Hawley, J.A. (2001). Pacing strategy in simulated cycle time-trials is based on perceived rather than actual distance. *Journal of Science and Medicine in Sport, 4*(2), 212–219.

Péronnet, F., Massicotte, D., Brisson, G., & Hillaire-Marcel, C. (1990). Use of 13C substrates for metabolic studies in exercise: Methodological considerations. *Journal of Applied Physiology., 69*(3), 1047–1052.

Tarnopolsky, M.A., Zawada, C., Richmond, L.B., Carter, S., Shearer, J., Graham, T., & Phillips, S.M. (2001). Gender differences in carbohydrate loading are related to energy intake. *Journal of Applied Physiology, 91,* 225–230.

Van Soeren, M.H., & Graham, T.E. (1998). Effect of caffeine on metabolism, exercise endurance, and catecholamine responses after withdrawal. *Journal of Applied Physiology, 85,* 1493–1501.

Wagenmakers, A.J., Rehrer, N.J., Brouns, F., Saris, W.H., & Halliday, D. (1993). Breath $13CO_2$ background enrichment during exercise: Diet-related differences between Europe and America. *Journal of Applied Physiology, 74,* 2353–2357.

Wright, D.A., Sherman, W.M., & Dernbach, A.R. (1991). Carbohydrate feedings before, during, or in combination improve cycling endurance performance. *Journal of Applied Physiology, 71,* 1082–1088.