Development and Validation of a Food-Frequency Questionnaire to Assess Short-Term Antioxidant Intake in Athletes

Andrea J. Braakhuis, Will G. Hopkins, Timothy E. Lowe, and Elaine C. Rush

A quantitative food-frequency questionnaire (FFQ) was developed to determine antioxidant intake in athletes. The questionnaire will be valuable for researchers wishing to standardize antioxidant intake or simply document habitual intake during an intervention trial. One hundred thirteen athletes participated in the validity study, of whom 96 completed the questionnaire and blood test, 81 completed the 7-d food diary and questionnaire, and 63 completed the 7-d food diary and blood test. Validity was investigated by comparing total and food-group antioxidant intakes from the questionnaire with those from a subsequent 7-d food diary. Measures of construct validity were determined by comparing a biomarker of antioxidant capacity (ferric-reducing ability of plasma) in a blood sample with antioxidant intakes from the questionnaire and diary. The correlation between the diary and questionnaire energy-adjusted estimates of total antioxidant intake was modest (.38; 90% confidence limits, ± .14); the correlation was highest for antioxidants from cereals (.55; ± .11), which contributed the greatest proportion (31%) of the total antioxidant intake. Correlations were also high for coffee and tea (.51; ± .15) and moderate for vegetables (.34; ± .16) and fruit (.31; ± .16). The correlation of the plasma biomarker with the questionnaire estimate was small (.28; ± .15), but the correlation with the diary estimate was inconsequential (~.03; ± .15). One-week test–retest reliability of the questionnaire’s estimates of antioxidant intake in 20 participants was high (.83; ± .16). In conclusion, the FFQ is less labor intensive for participants and researchers than a 7-d diary and appears to be at least as trustworthy for estimating antioxidant intake.

Keywords: biomarker, diary, diet, reliability

Common questions directed to dietitians, physiologists, and coaches focus on whether high-antioxidant diets are beneficial and if supplementation should be incorporated into athletes’ nutritional plans. To determine this, a questionnaire that characterizes an athlete’s antioxidant intake is important to develop. This questionnaire will be useful for researchers investigating the impact of dietary supplementation over an intervention and placebo period or for sport dietitians wishing to investigate the total antioxidant intake in athletes.

Many antioxidant-supplementation studies are completed with little regard for dietary control of habitual antioxidant intake, other than to instruct subjects to continue with usual dietary intake or avoid micronutrient antioxidant supplements (Lafay et al., 2009; Larcombe et al., 2008; Nieman et al., 2004; Senturk et al., 2005; Teixeira, Valente, Casal, Marques, & Moreira, 2009). The likely reason for this omission is that food-dairy completion and analysis are time consuming. It is estimated that food diaries take a minimum of 30 min for the subject to complete and a further 45 min/day for researchers to analyze. Even the simple task of analyzing dietary intake for antioxidant consumption is difficult, with current protocols reporting single antioxidant micronutrient intake rather than attempting to characterize total antioxidant consumption. The complexities of antioxidant absorption, digestion, and metabolism add further complication to the seemingly simple task of characterizing an athlete’s antioxidant intake. One method that may minimize the complexity of assessing antioxidant intake is to incorporate the calculation of total antioxidant capacity (TAC) into food-dairy and questionnaire estimates.

TAC is a measure of how well a food product or biological sample can reduce an oxidant and thus takes into account the synergies between antioxidants found in a single sample. The TAC measurement is defined as the moles (or millimoles) of radicals neutralized per gram of tested sample and therefore provides a measure of total antioxidant activity within the sample (Dragland, Senoo, Wake, Holte, & Blomhoff, 2003; Halvorsen et al., 2006). Figures for foods assessed for TAC can then be added up over a day or week to provide a total antioxidant intake over a period of time. At this stage, making recommendations to athletes regarding ideal total antioxidant intake is difficult, because no studies to date have used TAC to characterize the antioxidant intake of athletes; however, with this antioxidant questionnaire, researchers and dietitians will better able to obtain this information.
Assessing the dietary intake of only the antioxidant vitamins could result in misguided conclusions about the effects that dietary antioxidant intake has on physiology, health, and athletic performance. An example is blueberries, which contain vitamin C but also less recognized antioxidant nutrients, for example, phenolic compounds such as anthocyanins and flavonols (Mason, Sun, Wang, Hider, & Bekhit, 2006). Therefore, an assessment of vitamin C in blueberries will only estimate a portion of their true antioxidant capacity.

The individual antioxidant nutrients that are commonly analyzed to characterize dietary antioxidant intake include vitamin C, vitamin E, vitamin A, selenium, fructose, phytochemicals, and β-carotene. However, an alternative strategy is to analyze the TAC of the foods consumed by using existing antioxidant databases (Prior et al., 2003), thus allowing assessment of the antioxidant capacity from the entire diet. The antioxidant capacities reported in the published database are based on various assays including FRAP (ferric-reducing ability of plasma; Halvorsen et al., 2006), total radical trapping antioxidant parameter (Pellegrini et al., 2006), Trolox-equivalent antioxidant capacity, and oxygen radical absorbance capacity (Prior et al., 2003). These same assays have been modified to assess TAC of plasma.

To date, a small number of questionnaires have been developed to assess antioxidant intake. Pellegrini et al. (2007) developed a short questionnaire to assess total antioxidant intake validated with a group of 285 older individuals. The questionnaire assessment correlated moderately (Spearman: \(r = .52\)) with that of the 3-day food diary, but there was only a weak correlation between the plasma biomarkers (Trolox-equivalent antioxidant capacity and FRAP) and the questionnaire (\(r = .13\)). The authors concluded that the blood (specifically plasma) biomarker was a poor reflection of dietary intake. Another antioxidant questionnaire-validation study on 108 older women estimated that antioxidant intake correlated moderately with oxygen radical absorbance capacity and total radical trapping antioxidant parameter (Pearson’s \(r = .24\) and \(.23\)) but not FRAP (\(r = .07\)) in plasma samples (Rautiainen, Serafini, Morgenstern, Prior, & Wolk, 2008).

Both the studies mentioned correlated dietary antioxidant intake and plasma biomarkers focused on older, less active individuals and did not fully adjust for energy intake. Therefore, a questionnaire to assess antioxidant intake, validated on an active population, is necessary.

Dietary assessment to investigate the effect of antioxidant supplements or related dietary interventions requires accurate reports and control of all foods consumed that contain antioxidants. A likely reason for failure of such assessment is poor compliance with food diaries, which are time-consuming for participants to complete and researchers to analyze (Bingham et al., 1994). Food-frequency questionnaires could be more successful in this respect, because they require little effort to complete and are inexpensive to process. The objective of this study was therefore to develop a food-frequency questionnaire for assessing total dietary antioxidant intake in athletes and to investigate its validity by comparing it with a 7-day food diary. The questionnaire was also assessed for its ability to accurately determine the relative contribution of different antioxidant foods to the total antioxidant intake. The construct validity of the questionnaire was determined by comparing with the FRAP in blood samples.

Methods

Study Design

A total of 113 athletes (56 males, 57 females; age 17–36 years) from Rowing New Zealand and local rowing clubs volunteered to participate. There are approximately 200 rowers in the national or regional performance squads; we recruited over half those available. An estimated 30 athletes declined the invitation to participate. Those who did complete the questionnaire, provided a blood sample for analysis of plasma FRAP (the biomarker for antioxidant capacity), and received oral and written instructions regarding accurate completion of the 7-day food diary. Athletes were instructed to weigh their food and were provided with food scales accurate to 2 g (Salter digital food scales, model 1004SSDR, HoMedics Group Ltd., UK). When athletes ate meals away from home they provided estimates of intake based on household measures, as instructed. They were asked to follow their usual eating pattern. On Day 8, food diaries were reviewed for completion, and athletes were asked by the dietitian to clarify any omissions and ambiguity. Questionnaires with more than three questions missing were excluded from the study, and those with one to three missing questions were assigned a value of zero for those questions. According to Cade, Thompson, Burley, and Warm (2002), correct validation of a dietary questionnaire must occur by having subjects complete the questionnaire at a time different than when they complete the food diary. The purpose of this time separation is to minimize subject memory of what was recorded on each method, so the questionnaire was completed first, followed by the food diary. We recognize this as a potential source of error in the validation against the blood biomarker (taken at the time of the questionnaire; Cade et al., 2002). Of the 113 athletes in this validity study, 96 completed the questionnaire and blood test, 81 completed the 7-day food diary and questionnaire, and 63 completed the 7-day food diary and blood test. Exclusion criteria included smoking and reporting energy intake lower than the minimal calculated requirement according to the Goldberg equation (Goldberg et al., 1991). Only two athletes were excluded, both because of inadequate energy intake.

A further 20 athletes of age similar to those completing the validation study volunteered for the reliability study by completing the antioxidant questionnaire on two occasions, 1 week apart.

Exercise performance data were obtained using a 30-min rowing-ergometer effort on a wind-resistance braked rowing ergometer (Concept IIc, Nottingham,
questions in the food-frequency questionnaire: per serving and those that were commonly consumed were included. All antioxidant food values from the antioxidant database were reported as absolute values in mmol of electrons/hydrogen atoms donated in the redox reaction for each food (Halvorsen et al., 2006). Antioxidant content of foods tested by Lister, Wilson, Sutton, and Morrison (2002) and Wu et al. (2004) but not Halvorsen et al. was also included.

Commonly consumed foods of the subject group were identified by a registered dietitian familiar with the participants. Foods included on the questionnaire were those that, although relatively low in antioxidant content, may be eaten frequently and in a quantity that would contribute an important proportion of the total antioxidant intake. Identified foods were then grouped by food group and antioxidant content into individual questions. For example, one question asked, “How often in the last month did you consume plums and/or pineapple?” because plums and pineapple are a similar food type and have a similar antioxidant content (Halvorsen et al., 2006). The antioxidant content of vegetables was as raw, unless the vegetable is generally eaten in cooked form only, for example, potatoes.

The following 70 food items were covered by 45 questions in the food-frequency questionnaire:

- Cereals: bran flakes, whole-grain breakfast cereal (Weet-bix, VitaBrits), All-Bran, Sultana-Bran, Cocoa crisp breakfast cereals, Corn flakes, Rice Krispies, Grinners
- Fruit and berries: blackberries, black currants, dried fruit, strawberries, blueberries, boysenberries, raspberries, cranberries, cherries, plums, pineapple, pears, oranges, kiwi fruit
- Fruit juice and fruit drinks: blueberry drink, black currant drink, orange juice, apple juice, pineapple juice, grape juice, blackberry drink, strawberry drink, cranberry drink, raspberry drink
- Vegetables: artichokes, artichoke hearts, cabbage, potatoes, spinach, capsicum, broccoli, tomato juice, vegetable juice
- Coffee and tea: coffee, black tea, green tea, oolong tea, iced tea
- Wine and beer: red wine, beer
- Chocolate: unsweetened cooking chocolate, sugar-free dark chocolate, milk chocolate, dark chocolate, chocolate cake, chocolate-chip cookies, chocolate ice cream
- Other: pecans, walnuts, canned spaghetti, meat lasagna, canned tomato soup, milk, flavored milk, yogurt, cinnamon, cloves, oregano, ginger, mustard seeds, turmeric, canned baked beans, canned kidney beans

Questions relating to antioxidant supplementation were also included in the questionnaire. The intake of multivitamin and mineral supplements was questioned in four categories, as suggested by Park, Murphy, Wilkens, Yamamoto, and Kolonel (2006).

Separate questions relating to supplement intake, meal pattern, and portion size were included. The questionnaire invited respondents to report their intake over the previous month. The frequency section of each question consisted of nine categories: never, once a month, two or three times per month, one or two times per week, three or four times per week, five or six times per week, once a day, two or three times per day, four or five times per day, or six or more times per day. Portion sizes included various descriptions based on the food item, for example, less than 1 cup, 1–2 cups, 3–4 cups, or more than 4 cups. The antioxidant content of each food was then multiplied by the weighted frequency and volume of consumption to calculate antioxidant intake.

The questionnaire requested additional information related to physical activity and sport competition. The physical activity questions asked for the average number of hours spent per week doing on-water resistance and additional aerobic training. The competition questions asked the number of years the athlete had been competing. The answers were given as a frequency checkbox. The questionnaire was trialed on a group of 10 participants with age, activity, and eating habits similar to those of the main study group. Techniques of cognitive testing and in particular retrospective probing were applied (Willis, 1994). Questions that lacked clarity were reworded before the start of the study.

Food Diaries

Nutrient intake from the food diaries was determined by a registered dietitian using the New Zealand Food Database on Foodworks nutritional software (Version 5, Xyris Software, Brisbane, Australia). For antioxidant intake, each food item in the New Zealand Food Composition tables was assigned an antioxidant value based on the same databases (Bingham et al., 1994; Lister et al., 2002; Park et al., 2006) used to develop the questionnaire. The final antioxidant database generated from the Foodworks program was checked by an independent registered nutritionist to ensure that certain assumptions were acceptable. Data for each participant were imported into Microsoft Excel from Foodworks and used to calculate the consumption of antioxidants from all foods and by category: cereals, fruits and berries, fruit juice and drinks, vegetables, coffee and tea, wine and beer, chocolate items, other, and vitamin C supplements.
Antioxidant Biomarker

Blood was collected from the antecubital vein into EDTA-containing evacuated tubes by a registered nurse or phlebotomist. Collected blood was centrifuged at 2,700 g at room temperature for 2 min, the plasma separated and stored at –80 °C until analysis. The plasma TAC was analyzed with the FRAP assay as described by Benzie and Strain (1999). The FRAP method was used by Halvorsen et al. (2006) to determine the TAC of the foods in a large antioxidant database that was used as the basis of this questionnaire. The coefficient of variation between runs was 4.5%, which compares well with other studies that have measured FRAP in human plasma (CV range 1–5%; Cao & Prior, 1998; Fernandez-Pachon, Villano, Troncoso, & Garcia-Parrilla, 2005).

Statistical Analysis

General characteristics of the analysis are presented as $M \pm SD$. To evaluate validity and reliability between the diary and questionnaire, we calculated Pearson’s correlation coefficients and 90% confidence limits using a published spreadsheet (Hopkins, 2000). All data were log-transformed before analysis to improve uniformity. The correlations were adjusted for energy intake using the residual methods as described by Willet and Stampfer (Willet, 1998). Correlation coefficients are described by the following descriptors: .0–.1, insubstantial; .1–.3, low; .3–.5, moderate, .5–.7, high; .7–.9, very high; and .9–1, nearly perfect (Cohen, 1988; Hopkins, Marshall, Batterham, & Hanin, 2009). Bias in the questionnaire relative to the diary was analyzed by linear regression (Hopkins, 2000). Intraclass correlation and 90% confidence limits were calculated to assess the reliability of the questionnaire retest.

Results

The food diary and questionnaire were completed by 113 athletes (age 22 ± 3 years, body mass 78 ± 11 kg, and training period 4.5 ± 2.2 years). Reported weekly durations of training were on-water, 9.6 ± 2.7 hr; resistance or weights, 3.5 ± 1.7 hr; and biking, running, or other aerobic training, 4.5 ± 5.3 hr. In a 30-min maximal ergometer time trial, the females covered a distance of 7,300 ± 260 m, and the males, 8,080 ± 320 m. This compares with the current world record of 8,275 m for women (USA, 2004) and 9,063 m for men (Great Britain, 2009; Concept2, 2010). Immediate follow-up with participants who failed to complete the questionnaire adequately resulted in no complete exclusions for missing data, but nine questionnaires still had one to three missing responses for frequency of intake of antioxidant food items; these missing values were set to zero.

The daily total energy intake of the group reflected by food diaries was 14.5 ± 5.8 MJ (range 7.5–25.9 MJ), and the average percentages of energy from carbohydrate, protein, and fat intake were 53.5% ± 6.8%, 17.9% ± 5.8%, and 28.0% ± 6.2%, respectively. The average number of fruit servings consumed per day was 2.5 ± 1.3. Twenty-eight percent of participants reported consuming antioxidant supplements (vitamin C, E, or A or selenium) more than once weekly. Dietary intakes of the macronutrients and antioxidant micronutrients are presented in Table 1.

The total antioxidant intakes from the various food groups reported from the diary and questionnaire are presented in Table 2. Cereal, fruit and berries, and vegetables contributed 31%, 9.8%, and 9.6% of the total antioxidant intake of the food diary and 19%, 21%, and 21% of the questionnaire, respectively. The remaining food groups showed only small percentage differences between the food-diary and questionnaire antioxidant intakes.

Using linear-regression modeling, the mean bias in the questionnaire compared with the criterion measure of food diaries was 4.8%, a trivial difference. However, for participants with low antioxidant intakes (20 mmol/day) the questionnaire overestimated by 42%, and at high intakes (120 mmol/day) it underestimated by 73%, both moderate to large differences. With the exception of beer and wine, the antioxidant food groups displayed a

<table>
<thead>
<tr>
<th>Intake, mmol/week ($M \pm SD$)</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Food diary</td>
</tr>
<tr>
<td>Total intake</td>
<td>57 ± 30</td>
</tr>
<tr>
<td>Cereals</td>
<td>18 ± 16</td>
</tr>
<tr>
<td>Fruit and berries</td>
<td>5.6 ± 5.0</td>
</tr>
<tr>
<td>Fruit juice and drinks</td>
<td>7 ± 2</td>
</tr>
<tr>
<td>Vegetables</td>
<td>5.5 ± 3.4</td>
</tr>
<tr>
<td>Coffee and tea</td>
<td>2 ± 5</td>
</tr>
<tr>
<td>Beer and wine</td>
<td>1.2 ± 3.5</td>
</tr>
<tr>
<td>Chocolate items</td>
<td>2.0 ± 2.2</td>
</tr>
<tr>
<td>Vitamin C supplements</td>
<td>0.7 ± 1.1</td>
</tr>
<tr>
<td>Other</td>
<td>15 ± 10</td>
</tr>
</tbody>
</table>

Note. FRAP = ferric-reducing ability of plasma. 90% confidence limits are approximately ±.11 for the highest correlation through ±.18 for the lowest. Adjusted for energy.
greater mean bias, vegetables being the highest at 140%, a moderate difference.

The food groups with a high correlation between diary and questionnaire included cereals, alcoholic drinks (beer and wine), and vitamin C supplements; coffee and tea consumption had moderate correlations. Food groups with a low correlation were chocolate items and fruit juice and fruit drinks. The overall correlation between questionnaire and diary for antioxidant intake was moderate.

The correlations between FRAP in the plasma sample and the questionnaire estimate of antioxidant intake were small but clear \( (r = .25; \text{energy-adjusted } r = .28, 90\% \text{ confidence limits } \pm .20) \). Correlations between the food diary and the biomarker were insubstantial \( (r = .15, \text{energy-adjusted } r = -.03, \pm .15) \).

The retest correlations for total antioxidant, cereal, and vitamin C supplement intake from the questionnaire and diary were very high. Retest correlations for fruit and berry intake were small but clear \( (r = .25; \text{energy-adjusted } r = .28, 90\% \text{ confidence limits } \pm .20) \). Correlations between the food diary and the biomarker were insubstantial \( (r = .15, \text{energy-adjusted } r = -.03, \pm .15) \).

The retest correlations for total antioxidant, cereal, and vitamin C supplement intake from the questionnaire were very high. Retest correlations for fruit and berries were high. Retest correlations for the antioxidant intakes of the other food groups were moderate—fruit drinks, vegetables, coffee and tea, and wine and beer—

and insubstantial for chocolate. The retest correlations between questionnaires are presented in Table 3.

### Table 2 Daily Intake \( (M \pm SD) \) of Antioxidant Micronutrients for 81 Subjects Who Completed the 7-Day Food Diary

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Intake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (MJ)</td>
<td>14.5 ± 5.7</td>
</tr>
<tr>
<td>Protein (g)</td>
<td>150 ± 80</td>
</tr>
<tr>
<td>Carbohydrate (g)</td>
<td>470 ± 190</td>
</tr>
<tr>
<td>Fat (g)</td>
<td>114 ± 54</td>
</tr>
<tr>
<td>β-carotene (μg)</td>
<td>5,300 ± 2,900</td>
</tr>
<tr>
<td>Retinol (μg)</td>
<td>540 ± 430</td>
</tr>
<tr>
<td>Selenium (μg)</td>
<td>75 ± 41</td>
</tr>
<tr>
<td>Vitamin A (mg)</td>
<td>1,400 ± 790</td>
</tr>
<tr>
<td>Vitamin C as supplements (mg)</td>
<td>92 ± 250</td>
</tr>
<tr>
<td>Vitamin C total (mg)</td>
<td>340 ± 360</td>
</tr>
<tr>
<td>Vitamin D (mg)</td>
<td>4.1 ± 4.9</td>
</tr>
<tr>
<td>Vitamin E (mg)</td>
<td>26 ± 56</td>
</tr>
</tbody>
</table>

### Table 3 Intraclass Correlation Coefficients (ICCs) Between Log-Transformed Values for 20 Athletes Who Completed the Questionnaire Twice 1 Week Apart

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>ICC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total antioxidant intake</td>
<td>.83</td>
</tr>
<tr>
<td>Cereals</td>
<td>.76</td>
</tr>
<tr>
<td>Fruit and berries</td>
<td>.81</td>
</tr>
<tr>
<td>Fruit juice and drinks</td>
<td>.56</td>
</tr>
<tr>
<td>Vegetables</td>
<td>.34</td>
</tr>
<tr>
<td>Coffee and tea</td>
<td>.46</td>
</tr>
<tr>
<td>Beer and wine</td>
<td>.62</td>
</tr>
<tr>
<td>Chocolate items</td>
<td>.08</td>
</tr>
<tr>
<td>Vitamin C supplements</td>
<td>.81</td>
</tr>
</tbody>
</table>

Note. 90% confidence limits are approximately ±.14 for the highest correlation through ±.30 for the lowest.

### Discussion

A new questionnaire designed to assess total dietary antioxidant intake in athletes has been validated. This targeted questionnaire offers a user-friendly, convenient, and quick method to obtain limited dietary antioxidant intake, which will prove useful for researchers wishing to characterize the antioxidant intake of athletes. Examples of when researchers may wish to use this questionnaire include acute or chronic nutrition intervention studies in which results may be influenced by habitual antioxidant intake and when funds preclude full dietary control. The use of the questionnaire will provide information on differences in antioxidant intake between two groups or if a subject has altered antioxidant intake between trials or during a washout period. This questionnaire is at least as reliable as a 7-day food diary.

Previous studies using a questionnaire to determine total antioxidant intake (Andersen, Bere, Kolbjørnsen, & Klepp, 2004; Kristjansdottir, Andersen, Haraldsdottir, de Almeida, & Thorsdottir, 2006; Pellegrini et al., 2007; Rautiainen et al., 2008) were validated on older, less active subjects. The correlations were not corrected for energy intake in any of those studies, so previous associations may be erroneously high. The current study used an extensive database of antioxidant-containing foods and validated the questionnaire with an athletic group. In addition to the development and validation of the questionnaire, this study provides valuable insight into the antioxidant intakes of this population. According to Svilaas et al. (1994), a group of sedentary participants had a total antioxidant intake of 17.3 ± 9.43 mmol/day, cereal 0.8 ± 0.3 mmol/day, fruit and berries 1.8 ± 1.2 mmol/day, and coffee and tea 13 ± 11 mmol/day. The antioxidant intake was higher in the sedentary group than the athletes tested in the current study, but this can be explained by the higher tea and coffee intake alone. It is interesting to note that the antioxidant intake came from greater amounts of cereal and vegetables (Svilaas et al., 2004).

Fruit and vegetables are high in antioxidants (Cao, Booth, Sadowski, & Prior, 1998), but other food items with low antioxidant activity, such as cereals, might be consumed in sufficient quantity to contribute a large proportion of dietary antioxidant. Grains and cereal products are known to contain antioxidants, but their potential contribution to health through the diet has essentially been ignored (Miller, Rigelhof, Marquart, Prakash, & Kanter, 2000). We found grains and cereals to be a major contributor to the total antioxidant intake in both the food diary and the questionnaire (19–31%), higher than what is consumed by a sedentary population (Svilaas et al., 2004). Examples of the types of foods included in the cereal group were bagels, dry biscuits, bread crumbs, tortillas, bread rolls, egg noodles, English muffins, oatmeal, French bread, wheat bread, rice, and pasta. The quantities of cereals commonly consumed suggest that this food group makes an important contribution.
to antioxidant consumption. Grain products contain many kinds of antioxidant not found in fruits and berries, including avenanthramides and avenalumic acid (Miller et al., 2000). Fat-soluble monoesters of caffeic and ferulic acids are also commonly found in grain products and are equal to vitamin E in antioxidant activity (Miller et al., 2000). Cereals also had the highest correlation between antioxidant values calculated from the questionnaire and food diary. It is possible that including an antioxidant questionnaire in future dietary research will demonstrate that cereals are an important contributor to total antioxidant intake in other populations.

The use of a blood biomarker has been suggested as a good method to validate dietary questionnaires because of problems with self-reports of dietary intake, bioavailability, variation in the antioxidant content of foods, and analytical errors (Svilas et al., 2004). According to a review on validating questionnaires, only 19% of studies used a biomarker (Cade et al., 2002). Relying on blood biomarkers to validate nutritional questionnaire data is problematic, and finding an adequate marker of dietary antioxidant intake is no exception. Although there are biological markers for energy, nitrogen, and sodium (Cade et al., 2002) intake, there is no single criterion marker for antioxidant intake. According to Chow and Chang (2007), the use of a questionnaire and biomarker as a validation tool for antioxidant intake is fraught with problems arising from the way antioxidants in food are digested and absorbed. Those authors suggest that antioxidants are complex nutrients that may be altered in the gastrointestinal tract before absorption or excreted altogether. Despite the concerns with using a blood biomarker to validate antioxidant intake, it is still considered the gold standard and therefore important to include (Cade et al., 2002). Questions do remain as to whether a biomarker is appropriate when assessing antioxidant intake. We found agreement between the food-frequency questionnaire and blood-biomarker antioxidant estimates not seen in previous studies using the same blood tests (Andersen et al., 2004; Kristjandsdottir et al., 2006; Pellegrini et al., 2007; Rautiainen et al., 2008). However, we did not find substantial agreement between the blood biomarker and the food-diary antioxidant estimate, once it was adjusted for energy intake. The lack of correlation between the food diary and the blood test is likely at least in part a result of the mismatch between the time the blood was taken and the food diary completed, whereas the questionnaire was completed at the same time as the blood test. The blood biomarker may represent an adequate tool for validation of antioxidant intake, if used concurrently. The activity of an antioxidant in food and plasma depends on a multitude of factors, including the reactive species present, the localization of antioxidants, and absorption of intact antioxidant function. Most antioxidant measures of blood are one-dimensional and thus useful for food but less reliable on plasma or other biological samples (Frankel & Meyer, 2000). So the antioxidant food database used in this study is probably a true reflection of the antioxidant content in vitro; the issue is whether the antioxidant content in the food reaches the bloodstream and is thus available for an in vivo blood test.

The greatest food-group discrepancy between the diary and questionnaire was for fruit and berries, chocolate items, and vegetables, suggesting that there are different patterns of under- or overreporting for certain food groups. It is possible that because these food groups are considered either healthy or unhealthy, athletes may misreport their true consumption on the questionnaire. In a study that demonstrated participants’ opinion about healthy foods, 80% of respondents agreed that both fruit and vegetables are an important component of a healthy diet (Margetts, Martinez, Saba, Holm, & Kearney, 1997). In the current study, participants indicated that they consumed fruit and berries and vegetables in greater amounts on the questionnaire than the food diary. If we infer that fruit and berries and vegetables are considered “more healthy,” participants may overestimate their consumption of them. The higher fruit and vegetable intake in the questionnaire compared with the food diary suggests an overestimation of intake for food items or supplements perceived to be beneficial. Although it is possible to overstate the consumption of “healthy” food in a food diary, it is probably easier to exaggerate in a checkbox questionnaire. Therefore, using a questionnaire for information on the antioxidant dietary intake of isolated food groups, in particular, fruit, vegetables, and chocolate, should be avoided until the questionnaire can be developed further.

A common question plaguing human dietary research is the concern regarding the appropriate length of time that a subject should complete a food diary to provide meaningful data. At present, it is unclear how many days subjects would be required to complete a food diary to determine antioxidant intake with adequate precision. For most macronutrients a period of 3–4 days may be an adequate time frame, because the variability from day to day is well regulated by appetite. However, for some micronutrients found in a small range of food items in large quantities, the variability from day to day can be large (Braakhuis, Meredith, Cox, Hopkins, & Burke, 2003). To minimize the variability of nutrient intake by participants, or the variability in coding food diaries, a 7-day food diary is 2–3 times less variable than a 1-day food record (Braakhuis et al., 2003). In addition, nutrients such as vitamin C, vitamin A, and cholesterol require a longer sampling period than energy or carbohydrate because their intake is around three times as variable (Braakhuis et al., 2003). Previous studies have relied on a shorter time frame (anywhere from 1 to 3 days) to determine antioxidant intake from food diaries, in comparison with the 7-day food diary used in this study.

In conclusion, we have developed a food-frequency questionnaire to determine total antioxidant intake. The questionnaire also estimates the contribution of various food groups to total antioxidant intake. It provides a useful estimate of total antioxidant intake that can be used by researchers to assess antioxidant intake from foods,
without the time-consuming completion and analysis of food diaries.

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