The Healthy Eating Index-2010 Is a Valid and Reliable Measure of Diet Quality According to the 2010 Dietary Guidelines for Americans[1–3]

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Abstract

The Healthy Eating Index (HEI), a measure of diet quality, was updated to reflect the 2010 Dietary Guidelines for Americans and the accompanying USDA Food Patterns. To assess the validity and reliability of the HEI-2010, exemplary menus were scored and 2 24-h dietary recalls from individuals aged ≥2 y from the 2003–2004 NHANES were used to estimate multivariate usual intake distributions and assess whether the HEI-2010 *1*) has a distribution wide enough to detect meaningful differences in diet quality among individuals, *2*) distinguishes between groups with known differences in diet quality by using *t* tests, *3*) measures diet quality independently of energy intake by using Pearson correlation coefficients, *4*) has >1 underlying dimension by using principal components analysis (PCA), and *5*) is internally consistent by calculating Cronbach's coefficient α. HEI-2010 scores were at or near the maximum levels for the exemplary menus. The distribution of scores among the population was wide (5th percentile = 31.7; 95th percentile = 70.4). As predicted, men's diet quality (mean HEI-2010 total score = 49.8) was poorer than women's (52.7), younger adults' diet quality (45.4) was poorer than older adults' (56.1), and smokers' diet quality (45.7) was poorer than nonsmokers' (53.3) ($P < 0.01$). Low correlations with energy were observed for HEI-2010 total and component scores ($|r| \leq 0.21$). Cronbach's coefficient α was 0.68, supporting the reliability of the HEI-2010 total score as an indicator of overall diet quality. Nonetheless, PCA indicated multiple underlying dimensions, highlighting the fact that the component scores are equally as important as the total. A comparable reevaluation of the HEI-2005 yielded similar results. This study supports the validity and the reliability of both versions of the HEI. J. Nutr. 144: 399–407, 2014.

Introduction

The Healthy Eating Index (HEI) is a diet quality index that measures conformance with federal dietary guidance (1–3). The HEI can be used for a variety of applications, including population monitoring (4,5); epidemiologic research (6,7); and evaluations of the food environment (8,9), food assistance packages, nutrition interventions (10), and the relation between diet cost and diet quality (11,12). The HEI-2010 is an updated version of the index that reflects the 2010 Dietary Guidelines (13). The HEI-2010 includes 12 components, 9 of which assess adequacy of the diet, including *1*) total fruit; *2*) whole fruit; *3*) total vegetables; *4*) greens and beans; *5*) whole grains; *6*) dairy; *7*) total protein foods; *8*) seafood and plant proteins; and *9*) FAs. The remaining 3, refined grains, sodium, and empty calories (i.e., energy from solid fats, alcohol, and added sugars), assess dietary components that should be consumed in moderation. For all components, higher scores reflect better diet quality because the moderation components are scored such that lower intakes receive higher scores. The scores of the 12 components are summed to yield a total score, which has a maximum value of 100. The components of the HEI-2010 and their respective standards are listed in **Supplemental Table 1** and have been described in additional detail previously (14).

A previous analysis confirmed the content validity of the HEI-2010, that is, the extent to which the index qualitatively represents the variety of attributes that make up the intended domain: diet quality as specified by the 2010 Dietary Guidelines for Americans. For that study, we checked the set of components

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against the key recommendations of the Dietary Guidelines for Americans and confirmed that they were represented in the HEI-2010 (14). The primary purpose of the current study was to evaluate the construct validity and reliability of the HEI-2010. A secondary purpose was to reevaluate the validity and reliability of the HEI-2005 by using the same methods used for the HEI-2010 evaluation so that the results of the 2 evaluations could be compared. Most researchers will be more interested in the 2010 version because it reflects the more recent science; however, in some studies, such as interventions, it may be more appropriate to use the HEI-2005 if it better reflects the dietary recommendations that were given to participants in a particular study.

Methods

The HEI-2010 was evaluated and the HEI-2005 reevaluated by assessing validity and reliability, as summarized in **Table 1**. Several types of construct validity were evaluated by using exemplary menus and estimated multivariate distributions of usual dietary intakes (i.e., long-run average daily intakes) by the U.S. population. One type of reliability, internal consistency, was also assessed. These analyses are described below.

HEI-2010 scores of exemplary menus. We examined 4 sets of menus developed by other nutrition experts to represent very high-quality diets and scored them using the HEI-2010 as an initial check of the construct validity of the index (how well the index measures what it is supposed to measure). The results were compared with a comparable analysis using the HEI-2005 scores (3). The menus included the following: *1*) the sample 7-d 2000 kcal menu for the USDA Food Patterns (15); *2*) the sample 7-d menu for the Dietary Approaches to Stop Hypertension (DASH) Eating Plan, developed by the National Heart, Lung, and Blood Institute (16); *3*) the 2 1-wk sample menus for Harvard Medical School's Healthy Eating Pyramid (17); and *4*) the 2 1-d sample menus from the 2005 version of the AHA No-Fad Diet (18). Each menu item was coded by a registered dietitian using the Food Intake Analysis System, version 3.99 (1998, University of Texas–Houston School of Public Health). This system uses the USDA food coding system and, therefore, enables the linking of the menu items to the MyPyramid Equivalents Database (19). This database makes it possible to quantify the total intake of guidance-based food groups and estimate HEI component scores. The dietitian created recipes and modification codes as needed. The HEI-2010 scores for the menus were calculated by using the ratio of means method because the Dietary Guidelines are intended to be met over time and not necessarily every day. In the case of most components, this is calculated by summing the appropriate dietary constituent (food group or nutrient) over all the intake days, summing the energy over all the days, dividing the total amount of the dietary constituent by the total energy, and comparing this ratio with the appropriate scoring standard. For FAs, the only component that is not expressed relative to energy, PUFA and MUFA are summed over all days and divided by the total SFA from all days before comparing with the standard.

The 2005 AHA menus did not achieve perfect scores for 2 of the new components of the HEI-2010: *1*) greens and beans, and *2*) seafood and plant proteins; therefore, we looked to the more recent 2011 edition of the AHA No-Fad Diet book, which includes 3 sets of 2-wk menus with 1200, 1600, and 2000 kcal/d (18). A registered dietitian coded those menu items that counted toward greens and beans and seafood and plant proteins, the 2 components that had less than perfect scores for the 2 older 1-d menus, as well as total protein foods and total vegetables, because the scoring of these 4 components is interrelated (14). Because of more recent emphasis in the literature on plant proteins and fish, it was anticipated that the updated version of the menus might address the shortfalls in these components observed in the earlier menus.

Usual HEI-2010 scores for the U.S. population. The remaining strategies for evaluating the HEI-2010 are similar to those that were used previously for the HEI-2005 with 1 major exception (3). Recent advances in statistical methods now enable the estimation of the distribution of usual HEI scores, calculated from multivariate distributions of usual intakes (i.e., long-run daily average intakes) rather than the estimation of distributions of scores on a single day. These advances are important for 2 reasons: *1*) dietary recommendations are intended to be met over time rather than on each and every day; and *2*) the HEI was designed to reflect the multidimensional nature of diet quality.

Data. This set of analyses was performed using data from 8262 respondents from the dietary component of the NHANES 2003–2004 conducted by the CDC National Center for Health Statistics (20). The survey was approved by the Research Ethics Review Board of the

TABLE 1 Strategies used to evaluate the HEI-2010 and to re-evaluate the HEI-2005[1]

Question	Strategy
Construct validity[2]	
Does the index give maximum scores to menus developed by nutrition experts to illustrate high diet quality?	Computed scores for sample menus for USDA Food Patterns, DASH Eating Plan, Harvard Medical School Guide to Healthy Eating, and AHA No-Fad Diet (Table 2)
Does the index allow for sufficient variation in scores among individuals?	Estimated percentiles of component and total scores (Table 3)
Does the index distinguish between groups with known differences in diet quality; that is, does it have concurrent criterion validity?	Compared scores of men and women, younger and older adults, and smokers and nonsmokers (Table 4)
Does the index measure diet quality independent of diet quantity?	Estimated Pearson correlations between component scores and energy intake (Table 5 and Supplemental Table 2)
What is the underlying structure of the index; that is, does it have >1 dimension?	Estimated structure by using a principle components analysis (Fig. 1)
Reliability	
How internally consistent is the total score?	Determined Cronbach's coefficient α
What are the relations among the index components?	Estimated Pearson correlations between component scores (Table 5 and Supplemental Table 2)
Which components have the most influence on the total score?	Estimated correlations between each component and the sum of all others (Table 5 and Supplemental Table 2)

[1] DASH, Dietary Approaches to Stop Hypertension; HEI, Health Eating Index.
[2] Content validity was established previously (14).

National Center for Health Statistics. These data were the most recent for which the USDA MyPyramid Equivalents Database was available at the time of the analysis. Only dietary recalls that were judged to be complete and reliable were included (21). Children aged <2 y (n = 574) were excluded because the Dietary Guidelines for Americans apply only to those aged ≥2 y. Ten additional children were excluded because their intake included "infant formula," which is not assigned a food group in the MyPyramid Equivalents Database (19); therefore, complete food-group intake could not be assessed for these children. Data for 2 interviewer-administered 24-h dietary recalls were available for 7638 respondents, and data for 1 recall were available for 624. Sodium intake data in NHANES 2003–2004 did not include salt added at the table but were adjusted for salt used in cooking.

Statistical analyses. Analyses were conducted using SAS (version 9.2; SAS Institute). The analytic technique used to estimate the multivariate distributions of usual intake is an extension of the National Cancer Institute method and uses a multipart, nonlinear mixed model with correlated random effects to produce distributions of usual intake, accounting for covariates (e.g., age and sex), nuisance effects (e.g., weekend/weekday, interview sequence), and skewness (22). All random effects used to produce distributions of usual intake were allowed to be correlated. Details about the covariates and stratification used in all analyses are given in the supplemental material. Estimating distributions of usual HEI scores is complex because the HEI contains multiple foods and nutrients, including those that are consumed nearly every day by nearly everyone and those that are consumed episodically by most persons. Early implementations of the National Cancer Institute method enabled estimation of distributions of usual intake of both non-episodically and episodically consumed dietary components but were limited to the analysis of only 1 or 2 dietary components at a time (23–28). To address this limitation, Zhang et al. (22) developed an approach that uses Markov Chain Monte Carlo computational methods to model, simultaneously, the multiple food groups and nutrients included in the HEI; we used that approach in this analysis.

As noted above, the HEI-2010 includes both components that are consumed nearly every day by nearly everyone and those that are episodically consumed by nearly everyone. The model addresses the challenge of episodically consumed dietary components by modeling both the probability of consumption and the consumption-day amount for such components, while only modeling the amount for non-episodically consumed dietary components. Non-episodically consumed components were defined as those for which <10% of recalls had 0 intakes. The HEI-2010 model includes 5 episodically consumed components (total fruit, whole fruit, greens and beans, whole grains, and seafood and plant proteins) and 7 non-episodically consumed components (total vegetables, dairy, total protein foods, FAs, refined grains, sodium, and empty calories), and the HEI-2005 model includes 4 episodic (total fruit, whole fruit, dark green and orange vegetables and legumes, and whole grains) and 8 non-episodically consumed components (total vegetables, total grains, dairy, meat and beans, oils, SFAs, sodium, and calories from solid fats, alcohol, and added sugars) (Supplemental Table 1). For both the HEI-2010 and HEI-2005, beans and peas (legumes) are modeled separately and then allocated to either the protein or vegetable components, as specified by the USDA Food Patterns (14,29). Because the HEI evaluates diets on a per kilocalorie basis, energy intake, which is always non-episodic, is also considered in the model.

Stable estimation of the usual intake distributions requires that a substantial number of individuals consume each component of interest on multiple days to separate within-person from between-person variance. Because the variance components may vary by age and sex, the sample was stratified into 3 large groups (children aged 2–8 y, males aged ≥9 y, and females aged ≥9 y). Categorical covariates for sex (necessary for the children aged 2–8 y stratum only), age group, and race/ethnicity were included because these characteristics are considered in the construction of the sample weighting factors. Variables to indicate whether the dietary recall was conducted for a weekend day or weekday and whether it was the first or second recall were also included to account for these nuisance effects (30,31). Consistent with the previous evaluation of the HEI-2005, a P value of 0.01 was used to determine statistically significant differences (3).

We conducted 4 analyses to assess construct validity (Table 1). First, we examined the estimated population distributions of the total and component scores of the HEI-2010 and HEI-2005 to assess whether the distribution was wide enough to detect meaningful differences.

Second, we examined concurrent-criterion validity, a type of construct validity, by evaluating whether the HEI could distinguish between groups with known differences in the quality of their diets. Because previous studies have shown that men have poorer-quality diets than women, young adults have poorer-quality diets than older adults, and current smokers have poorer-quality diets than nonsmokers, we assessed the ability of the HEI to distinguish differences in diet quality by comparing the mean of the usual HEI scores between these groups by using t tests (32). This analysis was limited to adults aged ≥20 y because the smoking questions asked of younger people were different. It was conducted for both the HEI-2010 and HEI-2005 so that the relative ability of the 2 versions of the index to differentiate diet quality could be determined.

Third, we determined whether the HEI-2010 could assess diet quality independent of diet quantity as measured by the energy value of the diet. Because nutrient intake is positively correlated with energy intake, a diet quality index could overrate high-calorie diets if it was not somehow uncoupled from energy intake. To evaluate this independence, the weighted Pearson correlations of the HEI-2010 and HEI-2005 total and component scores with energy intake were calculated using the multivariate distribution of usual intake (22). Low correlations between energy and the scores are consistent with independence.

Fourth, we examined the underlying structure of the HEI-2010 and HEI-2005 through principal components analysis (PCA) for the purpose of determining whether 1 or >1 dimension accounted for the systematic variation observed in the data (33). Based on the correlations among the 12 HEI components, PCA determined the number of principal components or independent dimensions that composed the index.

We also assessed internal consistency, a form of reliability, for both the HEI-2010 and HEI-2005 using Cronbach's coefficient α. This statistic examines the degree of association among the components within an index and is mathematically equivalent to the mean of the correlations among all possible split-half combinations of the 12 components. It thereby captures any systematic variation underlying the dietary components that are measured and included in the HEI. Measures with reliability estimates >0.70 are considered reliable for making group-level comparisons on diet quality.

Finally, to provide additional insights into the relations among components, the intercomponent correlations were examined. To determine which components have the most influence on the total score, we examined the correlations of each of the components with the total score (minus that component score) for both the HEI-2010 and HEI-2005.

Results

Validity. The HEI-2010 total scores for the 4 exemplary sets of menus ranged from 87.8 to 100.0 (**Table 2**). Component scores were at the maximum level with the following exceptions. The Harvard and AHA menus did not receive full points for dairy (0.9 and 8.7, respectively) or sodium (6.9 and 8.3, respectively). In addition, the 2005 edition of the AHA menus did not receive full points for greens and beans (1.8) or seafood and plant proteins (4.8); however, the more recent edition of the AHA menus earned perfect scores (5.0) for greens and beans and for seafood and plant proteins. HEI-2005 total scores for the menus ranged from 86.4 to 98.1.

According to the NHANES analysis, the range of total and component scores was wide enough to allow meaningful differences to be detected for both the HEI-2010 and HEI-2005 (**Table 3**). Total scores ranged from 26.2 at the 1st percentile to 78.5 at the 99th (of 100). This indicates that, if diet

TABLE 2 HEI-2010 and HEI-2005 component and total scores for menus exemplifying the 2010 USDA Food Patterns (15), the DASH Eating Plan (16), Harvard's Healthy Eating Pyramid (17), and the AHA No-Fad Diet (18)[1]

	Food Guide			
Component (maximum score)	USDA[2]	DASH[2]	Harvard[3]	AHA[4]
HEI-2010				
Total fruit (5)	5.0	5.0	5.0	5.0
Whole fruit (5)	5.0	5.0	5.0	5.0
Total vegetables (5)	5.0	5.0	5.0	5.0
Greens and beans (5)	5.0	5.0	5.0	1.8[5]
Whole grains[6] (10)	10.0	10.0	10.0	10.0
Dairy (10)	10.0	10.0	0.9	8.7
Total protein foods (5)	5.0	5.0	5.0	5.0
Seafood and plant proteins (5)	5.0	5.0	5.0	4.8[5]
FAs (10)	10.0	10.0	10.0	10.0
Refined grains (10)	10.0	10.0	10.0	10.0
Sodium (10)	10.0	10.0	6.9	8.3
Empty calories (20)	20.0	20.0	20.0	20.0
Total score (100)	100.0	100.0	87.8	93.6
HEI-2005				
Total fruit (5)	5.0	5.0	5.0	5.0
Whole fruit (5)	5.0	5.0	5.0	5.0
Total vegetables (5)	5.0	5.0	5.0	5.0
Dark green and orange vegetables and legumes (5)	5.0	5.0	5.0	5.0
Total grains (5)	5.0	4.8	5.0	5.0
Whole grains[6] (5)	5.0	5.0	5.0	5.0
Milk (10)	10.0	10.0	0.9	8.7
Meat and beans (10)	10.0	10.0	10.0	10.0
Oils (10)	10.0	10.0	10.0	10.0
Saturated fat (10)	10.0	10.0	10.0	10.0
Sodium[7] (10)	8.1	8.3	5.5	6.7
Calories from SoFAAS (20)	20.0	20.0	20.0	20.0
Total score[7] (100)	98.1	98.1	86.4	92.9

[1] DASH, Dietary Approaches to Stop Hypertension; HEI, Healthy Eating Index; SoFAAS, solid fats, alcoholic beverages, and added sugars.
[2] Based on 1 1-wk sample menu with 2000 kcal/d.
[3] Based on 2 2-wk sample menus, 1 with 1600 kcal/d and 1 with 2000 kcal/d.
[4] Based on 2 1-d sample menus, 1 with 1200 kcal and 1 with 2000 kcal.
[5] Three sets of 3-wk sample menus in a later edition earned a score of 5.0 (18).
[6] All grain products described as ''whole'' were assumed to be 100% whole grain.
[7] These scores supersede previously published scores, which were affected by a programming error (3).

quality were to change such that overall scores shifted up to 20 points in either direction, the change could be detected. For nearly all components, scores at the 1st percentile were near 0, and at the 99th percentile, at their optimum value. The whole grains component was the only one for which not even 1% of the population reached the optimum score; at the 99th percentile, the score was 7.8 of 10. At the 5th percentile, scores were near 0 for most components, except those representing total vegetables, total dairy, and total protein foods. At the 95th percentile, scores were at or near the maximum score for most components, except those representing whole grains, sodium, FAs, and empty calories.

The tests of concurrent criterion validity conducted using the diets of adults aged ≥20 y revealed that the men's mean HEI-2010 total score (49.8) was significantly lower than the women's (52.7), and 5 of the 12 HEI-2010 component scores were significantly lower ($P < 0.01$) for men compared with women (**Table 4**). Similarly, with the HEI-2005, 6 of the 12 individual component scores were significantly lower for men compared with women. Most of the component scores increased with age. For the HEI-2010, the oldest age group (≥51 y) had a significantly higher total score (56.1) and higher scores for 8 of the 12 components compared with the youngest group of adults (20–30 y), and the pattern for the HEI-2005 was similar. Nonsmokers' and smokers' scores also differed for both the HEI-2010 and HEI-2005. Smokers' mean HEI-2010 total score (45.7) was significantly lower than nonsmokers' (53.3). Furthermore, 7 of the 12 HEI-2010 component scores were significantly lower for smokers compared with nonsmokers. For the HEI-2005, the pattern was similar.

The correlations between each of the HEI component scores and energy intake are found in **Table 5** and **Supplemental Table 2** for the HEI-2010 and HEI-2005, respectively. Among the HEI-2010 components, the scores for empty calories and total fruit had the strongest correlation with energy, but they were low (−0.21), suggesting that each of the component scores is independent of energy intake. Of the 7 components that were significantly correlated with energy, all were negatively correlated except refined grains. The total score also had a low negative correlation with energy intake (−0.15). The correlations of the component scores for the HEI-2005 with energy were similar to those of the HEI-2010. The correlation between the HEI-2005 total score and energy was slightly stronger

TABLE 3 Estimated mean and percentiles of HEI-2010 and HEI-2005 total and component scores, aged ≥2 y, United States, 2003–2004[1]

Component	Mean ± SE	Percentile								
		1st	5th	10th	25th	50th	75th	90th	95th	99th
HEI-2010										
Total fruit[2]	2.7 ± 0.1	0.1 ± 0.0	0.3 ± 0.1	0.5 ± 0.1	1.2 ± 0.1	2.4 ± 0.2	4.4 ± 0.2	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0
Whole fruit[3]	2.6 ± 0.1	0.0 ± 0.0	0.1 ± 0.0	0.3 ± 0.1	0.9 ± 0.1	2.4 ± 0.2	4.8 ± 0.2	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0
Total vegetables[4]	3.2 ± 0.0	1.1 ± 0.1	1.5 ± 0.1	1.8 ± 0.1	2.3 ± 0.0	3.1 ± 0.0	4.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0
Greens and beans[4]	1.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.4 ± 0.0	1.1 ± 0.1	2.4 ± 0.1	4.2 ± 0.2	5.0 ± 0.0	5.0 ± 0.0
Whole grains	1.9 ± 0.1	0.0 ± 0.0	0.1 ± 0.0	0.3 ± 0.1	0.7 ± 0.1	1.4 ± 0.1	2.6 ± 0.1	4.1 ± 0.2	5.2 ± 0.2	7.8 ± 0.4
Dairy[5]	6.1 ± 0.1	1.3 ± 0.1	2.1 ± 0.1	2.7 ± 0.1	4.0 ± 0.1	5.9 ± 0.1	8.3 ± 0.2	10.0 ± 0.0	10.0 ± 0.0	10.0 ± 0.0
Total protein foods[6]	4.5 ± 0.0	2.3 ± 0.1	3.0 ± 0.1	3.4 ± 0.1	4.2 ± 0.1	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0
Seafood and plant proteins[6,7]	3.1 ± 0.1	0.3 ± 0.1	0.7 ± 0.1	1.0 ± 0.1	1.7 ± 0.1	3.1 ± 0.2	5.0 ± 0.1	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0
FAs[8]	4.3 ± 0.1	0.0 ± 0.1	1.0 ± 0.1	1.6 ± 0.1	2.7 ± 0.1	4.1 ± 0.1	5.6 ± 0.1	7.2 ± 0.1	8.4 ± 0.2	10.0 ± 0.0
Refined grains	5.6 ± 0.2	0.0 ± 0.0	0.8 ± 0.3	2.1 ± 0.3	3.9 ± 0.2	5.8 ± 0.2	7.4 ± 0.2	8.8 ± 0.2	9.6 ± 0.2	10.0 ± 0.0
Sodium	4.9 ± 0.1	0.0 ± 0.0	0.3 ± 0.2	1.5 ± 0.2	3.3 ± 0.1	5.0 ± 0.1	6.6 ± 0.1	8.0 ± 0.1	8.8 ± 0.1	10.0 ± 0.0
Empty calories[9]	9.4 ± 0.2	0.0 ± 0.0	1.5 ± 0.2	3.2 ± 0.2	6.2 ± 0.2	9.4 ± 0.2	12.6 ± 0.3	15.5 ± 0.3	17.2 ± 0.3	20.0 ± 0.0
Total score	49.9 ± 0.5	26.2 ± 0.7	31.7 ± 0.6	35.0 ± 0.6	41.3 ± 0.5	49.3 ± 0.5	57.8 ± 0.7	65.7 ± 0.9	70.4 ± 0.9	78.5 ± 1.1
HEI-2005										
Total fruit[2]	2.7 ± 0.1	0.1 ± 0.0	0.3 ± 0.1	0.5 ± 0.1	1.2 ± 0.1	2.4 ± 0.2	4.3 ± 0.2	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0
Whole fruit[3]	2.6 ± 0.1	0.0 ± 0.0	0.1 ± 0.0	0.3 ± 0.1	0.9 ± 0.1	2.4 ± 0.2	4.8 ± 0.2	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0
Total vegetables[4]	3.2 ± 0.0	1.0 ± 0.1	1.4 ± 0.1	1.7 ± 0.1	2.3 ± 0.0	3.1 ± 0.0	4.2 ± 0.1	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0
Dark green and orange vegetables and legumes	1.2 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.4 ± 0.0	0.8 ± 0.0	1.7 ± 0.1	2.7 ± 0.1	3.5 ± 0.2	5.0 ± 0.0
Total grains	4.7 ± 0.0	2.9 ± 0.1	3.6 ± 0.1	3.9 ± 0.1	4.5 ± 0.1	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0	5.0 ± 0.0
Whole grains	0.9 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.3 ± 0.0	0.7 ± 0.0	1.3 ± 0.1	2.1 ± 0.1	2.6 ± 0.1	4.0 ± 0.2
Milk[5]	6.1 ± 0.1	1.2 ± 0.1	2.1 ± 0.1	2.7 ± 0.1	4.0 ± 0.1	5.9 ± 0.1	8.3 ± 0.2	10.0 ± 0.0	10.0 ± 0.0	10.0 ± 0.0
Meat and beans[6]	9.0 ± 0.1	4.5 ± 0.3	5.8 ± 0.2	6.6 ± 0.2	8.3 ± 0.2	10.0 ± 0.0	10.0 ± 0.0	10.0 ± 0.0	10.0 ± 0.0	10.0 ± 0.0
Oils[10]	7.1 ± 0.1	2.9 ± 0.2	3.8 ± 0.1	4.4 ± 0.1	5.5 ± 0.1	7.0 ± 0.2	8.8 ± 0.2	10.0 ± 0.0	10.0 ± 0.0	10.0 ± 0.0
Saturated fat	5.6 ± 0.1	0.0 ± 0.0	0.3 ± 0.3	1.7 ± 0.2	3.8 ± 0.2	6.0 ± 0.1	8.0 ± 0.1	8.8 ± 0.1	9.2 ± 0.1	10.0 ± 0.1
Sodium	3.9 ± 0.1	0.0 ± 0.0	0.2 ± 0.2	1.2 ± 0.2	2.6 ± 0.1	4.0 ± 0.1	5.3 ± 0.1	6.4 ± 0.1	7.1 ± 0.1	8.1 ± 0.1
Calories from SoFAAS	8.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.1	1.7 ± 0.3	4.9 ± 0.3	8.4 ± 0.3	11.9 ± 0.3	15.1 ± 0.3	17.0 ± 0.3	20.0 ± 0.0
Total score	55.6 ± 0.6	33.4 ± 0.5	38.1 ± 0.5	41.1 ± 0.6	47.2 ± 0.6	55.1 ± 0.7	63.4 ± 0.7	70.7 ± 0.7	74.8 ± 0.8	81.9 ± 0.8

[1] Values are means ± SEs, n = 8262. HEI, Healthy Eating Index; SoFAAS, Solid fats, alcoholic beverages, and added sugars.
[2] Includes fruit juice.
[3] Includes all forms except juice.
[4] Includes any beans and peas (called legumes in HEI-2005) not counted as total protein foods (called meat and beans in HEI-2005).
[5] Includes all milk products, such as fluid milk, yogurt, and cheese, and fortified soy beverages.
[6] Beans and peas are included here (and not with vegetables) when the total protein foods (called meat and beans in HEI-2005) standard is otherwise not met.
[7] Includes seafood, nuts, seeds, and soy products (other than beverages), as well as beans and peas counted as total protein foods.
[8] Ratio of PUFA and MUFA to SFA.
[9] Calories from solid fats, alcohol, and added sugars; threshold for counting alcohol is >28 g/d.
[10] Includes nonhydrogenated vegetable oils and oils in fish, nuts, and seeds.

(−0.24) than that for the HEI-2010 total but still relatively low. This suggests that the HEI-2005 total score is also independent of energy intake.

The HEI-2010 scree plot from the PCA showed that the curve connecting the dots appeared to level off at ~5 dimensions (**Fig. 1**). These results indicate that multiple dimensions underlie the HEI-2010 and that no single linear combination of the components of the HEI-2010 accounts for a significant proportion of the covariation in the key food groups and nutrients that make up a total diet, as estimated from the NHANES data. The scree plot for the HEI-2005 was very similar (data not shown).

Reliability. For the HEI-2010, the standardized Cronbach's coefficient α was 0.68 (unstandardized, 0.61). For the HEI-2005, it was nearly the same (0.65 standardized and 0.59 unstandardized).

Correlations among the various component scores varied widely (Table 5 and Supplemental Table 2). Correlations between standardized component scores and the total score (minus each component score) for the HEI-2010 ranged from −0.22 for sodium to 0.67 for empty calories. Seven of the components had moderate correlations (r = 0.45–0.67) with the HEI total score. Similar associations were observed for the HEI-2005.

Discussion

The HEI-2010 evaluation results provide evidence that it is a valid and reliable tool for assessing diet quality. The results for the reevaluation of the HEI-2005 were similar.

Construct validity of the HEI was supported by the analyses of exemplary menus, which demonstrated the ability of the index to capture the theoretical construct of a high-quality diet. The menus received perfect scores on nearly all components for

TABLE 4 Estimated mean HEI-2010 and HEI-2005 component and total scores, adults aged ≥20 y, by sex, age group, and smoking status, United States, 2003–2004[1]

Component	Men	Women	Aged 20–30 y	Aged 31–50 y	Aged ≥51 y	Smokers	Nonsmokers
HEI-2010							
Total fruit[2]	2.2 ± 0.1	2.8 ± 0.1*	1.9 ± 0.2	2.3 ± 0.2	3.1 ± 0.1**	1.7 ± 0.2	2.8 ± 0.1***
Whole fruit[3]	2.3 ± 0.1	2.9 ± 0.1*	1.7 ± 0.1	2.4 ± 0.2	3.4 ± 0.1**	1.6 ± 0.2	3.0 ± 0.1***
Total vegetables[4]	3.3 ± 0.1	3.7 ± 0.1*	3.1 ± 0.1	3.4 ± 0.0	3.9 ± 0.1**	3.2 ± 0.1	3.7 ± 0.1***
Greens and beans[4]	1.8 ± 0.1	2.2 ± 0.1*	1.5 ± 0.1	2.0 ± 0.1	2.3 ± 0.1**	1.6 ± 0.2	2.1 ± 0.1***
Whole grains	1.9 ± 0.1	2.1 ± 0.1	1.3 ± 0.1	1.7 ± 0.1	2.8 ± 0.1**	1.4 ± 0.1	2.3 ± 0.1***
Dairy[5]	5.2 ± 0.1	5.6 ± 0.1*	5.6 ± 0.2	5.2 ± 0.2	5.4 ± 0.1	5.5 ± 0.2	5.4 ± 0.1
Total protein foods[6]	4.8 ± 0.0	4.7 ± 0.0	4.7 ± 0.1	4.7 ± 0.0	4.8 ± 0.0	4.8 ± 0.0	4.7 ± 0.0
Seafood and plant proteins[6,7]	3.4 ± 0.2	3.3 ± 0.1	2.9 ± 0.2	3.4 ± 0.1	3.6 ± 0.1**	3.0 ± 0.3	3.6 ± 0.1
FAs[8]	4.5 ± 0.1	4.9 ± 0.1	4.4 ± 0.2	4.6 ± 0.2	5.1 ± 0.2	3.9 ± 0.2	5.0 ± 0.1***
Refined grains	5.9 ± 0.2	5.8 ± 0.2	5.4 ± 0.2	5.9 ± 0.3	6.0 ± 0.2**	6.3 ± 0.3	5.7 ± 0.2
Sodium	4.7 ± 0.1	4.6 ± 0.2	4.9 ± 0.2	4.8 ± 0.2	4.3 ± 0.1	5.0 ± 0.2	4.5 ± 0.1
Empty calories[9]	9.7 ± 0.2	10.1 ± 0.4	8.2 ± 0.5	9.3 ± 0.3	11.4 ± 0.2**	7.7 ± 0.4	10.7 ± 0.3***
Total score	49.8 ± 0.6	52.7 ± 0.9*	45.4 ± 1.1	49.6 ± 0.8	56.1 ± 0.6**	45.7 ± 0.8	53.3 ± 0.7***
HEI-2005							
Total fruit[2]	2.2 ± 0.1	2.8 ± 0.1*	1.9 ± 0.1	2.3 ± 0.2	3.1 ± 0.1**	1.7 ± 0.2	2.8 ± 0.2***
Whole fruit[3]	2.3 ± 0.1	2.9 ± 0.1*	1.7 ± 0.1	2.4 ± 0.2	3.4 ± 0.1**	1.6 ± 0.1	3.0 ± 0.2***
Total vegetables[4]	3.4 ± 0.1	3.7 ± 0.1*	3.1 ± 0.1	3.5 ± 0.0	3.9 ± 0.1**	3.1 ± 0.1	3.7 ± 0.1***
Dark green and orange vegetables and legumes[4]	1.3 ± 0.1	1.6 ± 0.1	1.0 ± 0.1	1.4 ± 0.1	1.7 ± 0.1**	1.0 ± 0.1	1.6 ± 0.1***
Total grains	4.7 ± 0.0	4.6 ± 0.1	4.7 ± 0.0	4.6 ± 0.1	4.7 ± 0.0	4.5 ± 0.1	4.7 ± 0.0
Whole grains	1.0 ± 0.0	1.1 ± 0.0	0.7 ± 0.1	0.8 ± 0.1	1.4 ± 0.0**	0.7 ± 0.1	1.1 ± 0.0***
Milk[5]	5.2 ± 0.1	5.6 ± 0.1*	5.6 ± 0.2	5.2 ± 0.1	5.4 ± 0.1	5.5 ± 0.2	5.4 ± 0.1
Meat and beans[6]	9.6 ± 0.1	9.4 ± 0.1	9.3 ± 0.1	9.5 ± 0.1	9.6 ± 0.1	9.6 ± 0.1	9.4 ± 0.1
Oils[10]	7.0 ± 0.2	7.7 ± 0.2*	6.7 ± 0.1	7.3 ± 0.2	7.7 ± 0.2**	7.0 ± 0.3	7.4 ± 0.1
Saturated fat	5.9 ± 0.1	5.7 ± 0.2	6.1 ± 0.3	5.8 ± 0.3	5.7 ± 0.2	5.4 ± 0.2	5.9 ± 0.2
Sodium	3.7 ± 0.1	3.7 ± 0.1	3.9 ± 0.2	3.8 ± 0.1	3.4 ± 0.1	4.0 ± 0.2	3.6 ± 0.1
Calories from SoFAAS	7.7 ± 0.2	9.4 ± 0.3*	6.9 ± 0.4	7.7 ± 0.3	10.4 ± 0.2**	5.5 ± 0.3	9.6 ± 0.3***
Total score	54.0 ± 0.5	58.1 ± 0.9*	51.6 ± 1.0	54.2 ± 0.8	60.5 ± 0.6**	49.6 ± 0.6	58.3 ± 0.7***

[1] Values are means ± SEs, n = 2135 men, 2313 women; 885 aged 20–30, 1426 aged 31–50, 2137 aged ≥51; 1005 smokers and 3438 nonsmokers. *$P < 0.01$, different from men; **$P < 0.01$, different from aged 20–30 y; ***$P < 0.01$, different from smokers. HEI, Healthy Eating Index; SoFAAS, Solid fats, alcoholic beverages, and added sugars.
[2] Includes fruit juice.
[3] Includes all forms except juice.
[4] Includes any beans and peas (called legumes in HEI-2005) not counted as Total Protein Foods (called Meat and Beans in HEI-2005).
[5] Includes all milk products, such as fluid milk, yogurt, and cheese, and fortified soy beverages.
[6] Beans and peas are included here (and not with vegetables) when the Total Protein Foods standard is otherwise not met.
[7] Includes seafood, nuts, seeds, and soy products (other than beverages), as well as beans and peas counted as total protein foods.
[8] Ratio of PUFA and MUFA to SFA.
[9] Calories from solid fats, alcohol, and added sugars; threshold for counting alcohol is >28 g/d.
[10] Includes nonhydrogenated vegetable oils and oils in fish, nuts, and seeds.

the HEI-2010; scores were just slightly lower for the HEI-2005. The finding that some components did not receive full points was anticipated based on the philosophy underlying a particular menu (dairy) or how the recommendations are operationalized in the scoring system (sodium). For dairy, the Harvard menus did not receive optimal points because dairy products were intentionally limited (17). All 4 sets of menus had <2300 mg as the target sodium level, including the AHA menus, although the AHA recommends <1500 mg/d sodium (34,35). However, only those menus with 2000 kcal consistently met the energy-adjusted sodium standard because the lower-calorie versions made the energy-adjusted sodium standard of the HEI more difficult to meet.

The construct validity of the HEI-2010 and HEI-2005 is also supported by the findings of the NHANES analyses. The distributions of usual HEI scores suggest that the HEI is sensitive enough to detect meaningful differences in diet quality among individuals in the population as well as changes over time. Although the maximum score is met at the 50th percentile for total protein foods, this ceiling is not a limitation. It would be inappropriate to give higher scores to diets that exceed the standard because consuming more than the recommended amounts of protein foods confers no advantage.

The HEI-2010 and HEI-2005 demonstrated concurrent criterion-related validity by detecting differences in the expected direction among groups known to differ in the quality of their diets.

Like the HEI-2005, the HEI-2010 uncouples diet quality and diet quantity, as demonstrated by the relatively low correlations between each of the component and total scores and energy intake. Although it may seem desirable to include an assessment of the appropriateness of energy intake level in a diet quality measure, such an evaluation would require determining usual energy intakes and requirements to a level of precision (e.g., within 100 kcal) that is not currently possible among free-living individuals. To address energy balance considerations, researchers are encouraged to use an anthropometric measure, such as waist circumference or BMI, as a complement to the HEI-2010, which focuses on the appropriate mix of foods in the diet.

The PCA found no evidence for a single, systematic underlying relation among all the components of the HEI-2010; that

TABLE 5 Estimated correlations of HEI-2010 component and total scores and energy intake, aged ≥2 y, United States, 2003–2004[1]

Component	Total Fruit[2]	Whole Fruit[3]	Total Vegetables[4]	Greens and Beans[4]	Whole Grains	Dairy[5]	Total Protein Foods[6]	Seafood and Plant Proteins[6,7]	FA[8]	Refined Grains	Sodium	Empty Calories[9]	Total Score
Whole fruit[3]	0.79*												
Total vegetables[4]	0.14	0.32*											
Greens and beans[4]	0.16*	0.29*	0.63*										
Whole grains	0.34*	0.42*	0.29*	0.32*									
Dairy[5]	0.19*	0.18*	−0.15*	−0.19*	0.13								
Total protein foods[6]	−0.10	−0.02	0.39*	0.44*	0.05	−0.32*							
Seafood and plant proteins[6,7]	0.19*	0.33*	0.25*	0.35*	0.28*	−0.04	0.21*						
FAs[8]	0.11	0.18*	0.33*	0.41*	0.18*	−0.43*	0.27*	0.40*					
Refined grains	−0.04	−0.02	0.06	0.10	0.11	0.12	0.12*	0.10	−0.11				
Sodium	0.11*	−0.01	−0.46*	−0.30*	−0.10	0.09	−0.30*	−0.03	−0.14	0.15			
Empty calories[9]	0.52*	0.56*	0.50*	0.51*	0.50*	0.06	0.23*	0.41*	0.39*	−0.09	−0.29*		
Total score[10]	0.47*	0.60*	0.45*	0.54*	0.49*	−0.07	0.18*	0.48*	0.30*	0.09	−0.22*	0.67*	
Energy	−0.21*	−0.20*	−0.19*	−0.18*	−0.16*	−0.01	0.02	0.04	−0.02	0.13*	0.14	−0.21*	−0.15*

[1] $n = 8262$. $*P < 0.01$. HEI, Healthy Eating Index.
[2] Includes fruit juice.
[3] Includes all forms except juice.
[4] Includes any beans and peas (called legumes in HEI-2005) not counted as total protein foods (called meat and beans in HEI-2005).
[5] Includes all milk products, such as fluid milk, yogurt, and cheese, and fortified soy beverages.
[6] Beans and peas are included here (and not with vegetables) when the total protein foods (called meat and beans in HEI-2005) standard is otherwise not met.
[7] Includes seafood, nuts, seeds, and soy products (other than beverages), as well as beans and peas counted as total protein foods.
[8] Ratio of PUFA and MUFA to SFA.
[9] Calories from solid fats, alcohol, and added sugars; threshold for counting alcohol is >28 g/d.
[10] HEI-2010 total score minus specified component.

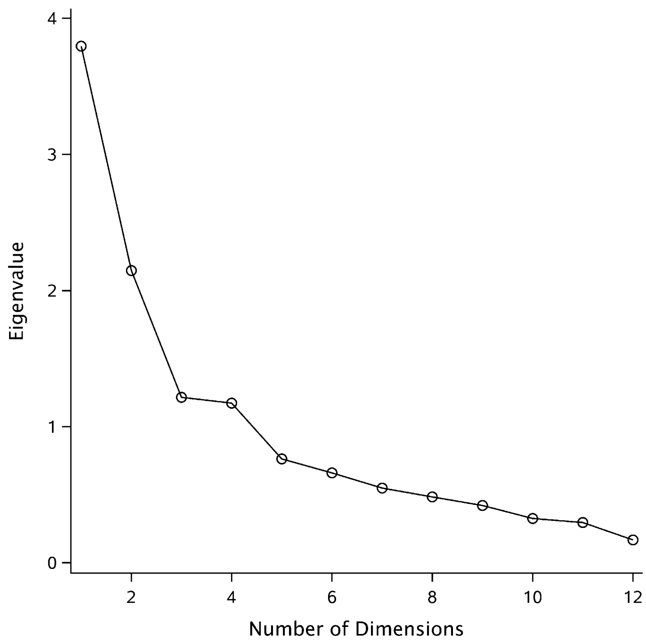

FIGURE 1 Scree plot from principal component analysis of the Healthy Eating Index-2010 showing the amount of variance accounted for by each of the principal components or dimensions. Source of intake data was NHANES 2003–2004.

is, no single linear combination of the 12 components explained a significant amount of the variation in the data. This finding was expected because diet quality comprises a broad array of differing and, to some extent, independent aspects.

The predictive criterion validity of the HEI-2010 has not yet been evaluated. However, the predictive validity of the HEI-2005 was demonstrated for 1 type of cancer in a prospective cohort study of nearly 500,000 Americans. This study compared how the HEI-2005, the Alternate Healthy Eating Index, the Mediterranean Diet Score, and the Recommended Food Score are associated with colorectal cancer (6). Scores for all indexes predicted a similar risk among men, whereas only HEI-2005 scores were positively associated with decreased risk among women. The predictive validity of the HEI-2005 was also demonstrated for several chronic diseases in another prospective cohort study of >130,000 physicians and nurses in the United States (7). That study compared how the HEI-2005 and the Alternate Healthy Eating Index-2010 are associated with total cardiovascular disease, coronary heart disease, stroke, diabetes, and total cancer. Both indexes predicted a reduced risk of these chronic diseases among both men and women.

The most widely recognized form of reliability is test–retest reliability, which determines whether an index can be expected to yield the same score, time after time, in identical situations. We did not evaluate this type of reliability because the HEI, by definition, is identical for identical diets that are recalled, recorded, and coded the same way. That is, all sources of test–retest measurement error can be attributed to respondent recall or data collection and processing. Inter-rater reliability is not an issue with the HEI because no judgment is required for scoring once food intakes are recorded and coded.

Both the HEI-2010 and HEI-2005 total scores nearly reached the commonly accepted standard of 0.70 for reliability of an index in terms of internal consistency as measured by Cronbach's coefficient α, suggesting that the HEI captures an underlying construct of overall diet quality. The coefficient α had been expected to be rather low because diet quality is known to be a complex and multidimensional construct and because individuals do not consistently meet, or fail to meet, all the dietary standards used to assess diet quality. Although internal consistency is not a necessary characteristic of the HEI, it has implications for how much confidence can be placed in the total score.

Variation in the total score is reflective of the variation in the components that have higher correlations with the total score. The correlations of each of the component scores with the total score varied in strength for both the HEI-2010 and HEI-2005. In both cases, among all the components, the one representing empty calories had the most influence on the total score, followed by whole fruit. The components having the lowest correlations with the total score may not be adding much information about the variation in the total score, but rather they provide important independent information.

A previous analysis confirmed the content validity of the HEI-2010 (14). This study provided evidence of its construct validity and reliability, demonstrated by the high scores achieved by menus of acknowledged high nutritional quality, the wide distribution of scores observed for usual dietary intakes among the U.S. population, its ability to distinguish between groups with known differences in diet quality, the independence of diet quality and diet quantity as measured by correlations between usual HEI scores and usual energy intake, and its internal consistency. The PCA confirmed the multidimensional nature of diet quality and demonstrated that the individual components of the HEI-2010 provide equally valuable and important information regarding diet quality in addition to that provided by the total score. Therefore, both the HEI-2010 and HEI-2005 can be considered valid and reliable indexes of diet quality.

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