Comparing the Predictive Accuracy of Health Risk Appraisal: The Centers for Disease Control Versus Carter Center Program

ABSTRACT

Background. From 1986 to 1987 the Carter Center of Emory University joined with the Centers for Disease Control (CDC) to develop a new, probability-based, adult health risk appraisal (HRA) instrument for the public domain. This new instrument is compared with the CDC HRA version to determine which is a more accurate predictor of mortality.

Methods. We compared predicted mortality risks from the CDC HRA and the Carter Center HRA with the observed mortality among 3135 smokers and never-smoking persons, aged 25 to 60, followed from 1959 to 1979 as part of the Tecumseh Community Health Study.

Results. When individuals were classified according to the difference between their actual age and risk age, for the CDC HRA, there was a progressively increasing risk of 10-year mortality as the difference increased. The Carter Center HRA did not show this trend. An analysis using relative operating characteristic curves showed that the mortality risk predictions for both programs were very similar for men and women. However, differences between actual age and risk age for the two programs were not similar for men or women, particularly older men. Therefore, actual age minus risk age for the CDC program was a more accurate predictor of 10-year mortality than was this difference for the Carter Center program.

Conclusions. The results from both types of analyses suggest that the validity of risk ages obtained from the Carter Center version may not be sufficient to justify updating programs for those currently using the CDC instrument. (*Am J Public Health.* 1991;81:1296–1301)

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Introduction

The health risk appraisal (HRA) has become a popular approach to help people identify the risks associated with personal characteristics (biological, life-style, family history).[1] Risk factors identified from various epidemiologic studies are combined with mortality statistics in order to assess an individual's risk of mortality within the next 10 years. An individual's risk is usually expressed as risk age (or appraised age), which enables one to compare one's own modifiable risk with that of a cohort. Thus the HRA could be a reasonably efficient method for transmitting this mortality risk information to individuals and stimulating them to change in terms of attitudes, beliefs, and life-styles, if so indicated.[2,3]

Although there are numerous variations of the HRA instrument, the majority are adapted from techniques developed by Robbins and Hall.[4] The accuracy of the mortality predictions from this methodology has been questioned repeatedly.[1–3,5–9] For example, Smith et al.[10] report that this method systematically overestimates the probability of mortality from coronary heart disease when the predictions are correlated with those from the Framingham Heart Study and the Risk Factor Update Project. Foxman and Edington assessed the accuracy of the Centers for Disease Control (CDC) HRA by comparing HRA-predicted risks of mortality with deaths that actually occurred among 3135 persons followed from 1959 to 1979 as part of the Tecumseh Community Health Study.[7] They found that the differences between actual age and CDC HRA risk age correctly classified individuals into high- and low-risk groups.

In an effort to update the scientific base of the HRA instrument, the Carter Center of Emory University joined with the CDC from 1986 to 1987 to develop a new, probability-based, adult health risk appraisal instrument for the public domain. The result of this project is "Healthier People," the Carter Center of Emory University Health Risk Appraisal Program.[11] The Carter Center HRA incorporates mortality tables from 1980 to 1982; integrates recommendations from the Breslow Risk Factor Update Project; uses regression equations from heart attack and stroke estimates developed by the Framingham Study; employs new models for cancer estimates developed from National Cancer Institute data; corrects height-weight recommendations; includes high-density lipoprotein as a risk factor; eliminates race as a predictor variable, so that mortality estimates are based only on age and sex; replaces the credit-debit method with multivariate statistical techniques; adjusts reference mortality projections for causes of death where risks are quantified by nonmodifiable precursors, so that individuals are not penalized if they have high levels of fixed risk, e.g., family history of breast cancer, diabetes, etc.; and calculates an individual's risk from 19, rather than 11, quantifiable causes of

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death. The Carter Center promises continuous updating of software as new scientific findings are determined and evaluated and technical enhancements developed.[11,12]

We have compared this new HRA instrument (version 3.1, released in late 1988) with the CDC HRA version that was used in our previous study[7] to see if this new version more accurately predicts mortality. This comparison has important implications for those using the HRA instrument for scientific and research purposes as well as for those using it for health education or intervention.

Methods

As in our previous study,[7] data available from the Tecumseh Community Health Study were used as input to the HRA programs. In order to compare the two instruments, we calculated the average HRA-predicted 10-year mortality risk (predicted risks) and risk age for both programs.

Risk age is defined for a given individual as the expected age of someone in the reference population of the same age, sex, and other fixed characteristics for whom the average 10-year mortality risk is the same as the HRA-predicted 10-year mortality risk. Thus, for the CDC HRA method a risk age of 50 for a 40-year-old White male means that the 10-year mortality risk predicted for that person is equal to the life-table estimate of the 10-year mortality risk for a 50-year-old White male in the 1975 to 1977 US population (the reference population for the CDC HRA). Hence this 40-year-old person is in poorer health than someone of the same age, sex, and race in the reference population.

The Carter Center HRA compares the predicted risk to the cohort average risk mortality, i.e., the population average risk for a person of the same age and sex adjusted for the presence of nonmodifiable risk factors.[11] Thus an individual with a family history of breast cancer would be compared with a reference population different from that of an individual without a family history of breast cancer. This reference mortality adjustment is made only for causes of death where risks are quantified by nonmodifiable precursors (US population projections are used as the reference mortality for all other causes of death).[12] A detailed comparison between the CDC HRA and the Carter Center HRA calculation of an individual's predicted risk of mortality and risk age is outlined in Appendix A.

Data Instruments

The Carter Center HRA (version 3.1) computes health risks based on a 45-item questionnaire[11]; the CDC HRA uses a 37-item questionnaire.[13] Twenty-nine of the 45 questions for the Carter Center HRA and 31 of the 37 questions for the CDC HRA are used directly for computation of risk (predicted risks and risk age, Appendix B). These questions were selected by the program's developers for their presumed causal relationship rather than mere statistical association. When items are not answered, both programs assign population norms.

Study Population

The Tecumseh Community Health Study began in 1959 as a comprehensive prospective investigation of health and disease in a community.[14] The principal aim was to identify causes and precursors of coronary heart disease, hypertension, chronic respiratory disease, diabetes mellitus, and other chronic diseases. Mortality ascertainments were completed successfully on more than 99% of previously examined subjects on three occasions, the most recent being 1978 to 1979.

In the 20-year period following the first cycle of examinations, 1059 (12.3%) of the 8641 participants died. Since the HRA is considered most accurate in the 25- to 60-year age range, we limited our analyses to the 3762 persons aged 25 to 60 in 1959 to 1960. Time since stopped smoking was not available for the 564 former smokers but is required by the CDC HRA; excluding former smokers from the current study restricted our sample to 3198; vital status after 10 years was available for 3166, and 3135 had sufficient information to calculate HRA. Thus a total of 3135 never-smoking or currently smoking individuals aged 25 to 60 in 1959 were included in this analysis.

Of the 29 variables used by the Carter Center HRA in predicting risk age, 13 were collected during the 1959 to 1960 Tecumseh survey, and 14 of the 31 variables used by the CDC HRA were available (Appendix B). Some recoding of the Tecumseh survey responses (mainly collapsing of categories to correspond to the precoded responses of both HRAs) was necessary for six of the variables. Although the wording was somewhat different in the two HRA instruments, the meanings were judged to be the same.

Data Analysis

Using both programs for each individual from data gathered during the 1959 to 1960 Tecumseh Community Survey, we compared the predictions of the CDC HRA with the Carter Center HRA, calculating the average HRA-predicted 10-year mortality risk from all causes (predicted risks) and risk age. The difference between each individual's age at the baseline survey and risk age (age difference) was compared by gender and age groups. To determine if risk age was a good predictor of observed mortality, we examined the proportion dying at 10 years for both men and women by the difference between actual age and risk age. The average HRA-predicted mortality risk, observed mortality, and age-adjusted mortality risk were calculated for each category of this difference between actual age and risk age. Since variations in age, sex, and race explain much of the variability in death rates, examining the gender, age, and race-specific differences between actual age and risk age represents the contribution of nondemographic inputs to the HRA.[15]

In order to assess which instrument more accurately predicted mortality, we performed relative operating characteristic (ROC) curve analysis[16] to compare both the predicted risks and the difference between actual age and risk age for each prediction method. ROC curve analysis plots the proportion of individuals correctly classified among those who died (true-positives/deaths = sensitivity) versus the proportion of individuals incorrectly classified among those living (false-positives/survivors = 1 − specificity) for various cut points of the predictor score, i.e., predicted mortality risk or age difference. A center line is called the "chance line" because, for every point, the probability of a true-positive response equals the probability of a false-positive response, i.e., does not predict any better than chance. The greater the area of the curve above this chance line, the greater the predictive accuracy of the instrument (HRA program). Points below the diagonal reflect values of false-positive greater than those of true-positive, i.e, worse results than would be expected by chance alone. Statistical tests were conducted using the Corroc2 program[17] in order to compare the ROC curves of the CDC and Carter Center HRA programs.

TABLE 1—Number (n) of Subjects, Predicted Risk (HRA)[a], Observed 10-Year Mortality Risk (R), and Age-Adjusted 10-Year Mortality Risk (aR)[b] by HRA Method and Difference between Actual Age and Risk Age for Men

Actual Age Minus Risk Age	CDC HRA				Carter Center HRA			
	n	HRA, %	R, %	aR, %	n	HRA, %	R, %	aR, %
>+1[c]	37	1.40	0.0	0.0	464	6.62	8.8	8.0
−1 to +1	212	2.46	0.5	0.5	597	4.20	4.2	3.7
−5 to −1	512	6.00	2.5	2.4	363	6.75	9.6	9.0
−10 to −5	489	16.10	12.3	11.6	62	12.30	21.0	20.3
<−10	257	29.37	17.1	16.4	21	13.32	19.0	17.9
Overall	1507	12.65	7.8	7.4	1507	6.02	7.8	7.2

[a]Average HRA-predicted 10-year mortality risk.
[b]Age-adjusted risks for each sex and HRA method are predicted from the results of four logistic regression models, where each category of risk is transformed into dummy variables and the average risk (−1 to +1) category is left out of the model; age is set equal to 39.6 years (the total sample mean).
[c]Expected to be lowest risk category.

TABLE 2—Number (N) of Subjects, Predicted Risk (HRA)[a], Observed 10-Year Mortality Risk (R), and Age-Adjusted 10-Year Mortality Risk (aR)[b] by HRA Method and Difference between Actual Age and Risk Age for Women

Actual Age Minus Risk Age	CDC HRA				Carter Center HRA			
	n	HRA, %	R, %	aR, %	n	HRA, %	R, %	aR, %
>+1[c]	33	.64	0.0	0.0	84	4.05	1.2	5.0
−1 to +1	576	1.52	0.9	0.9	672	1.98	1.6	2.4
−5 to −1	673	4.45	3.0	2.9	695	4.75	3.0	3.6
−10 to −5	251	10.60	5.2	5.1	126	10.60	8.7	8.4
<−10	95	22.71	10.5	10.4	51	19.84	7.8	7.2
Overall	1628	5.35	2.9	2.9	1628	4.45	2.9	3.6

[a]Average HRA-predicted 10-year mortality risk.
[b]Age-adjusted risks for each sex and HRA method are predicted from the results of four logistic regression models, where each category of risk is transformed into dummy variables and the average risk (−1 to +1) category is left out of the model; age is set equal to 39.6 years (the total sample mean).
[c]Expected to be lowest risk category.

Results

All 3135 never- or current-smoking, 25 to 60 year olds in the 1959 to 1960 Tecumseh Community Health Survey included in this study were White, and 48% were male. Observed mortality risk was 5.3% after 10 years and 13.9% after 20 years.

Correlation of HRA Predictions and Comparison of Difference between Actual Age and Risk Age

Predicted risks of mortality from the two programs were highly correlated (Pearson's r = .81; 95% confidence interval (CI) = 0.78, 0.84), as were the risk ages (Pearson's r = .92; 95% CI = 0.88, 0.95). These correlations remained high when examined by age group and sex. However, the difference between risk age and actual age (age difference) for the two methods was not correlated (Pearson's r = .18; 95% CI = 0.14, 0.21). The average age differences were −0.8 years for the Carter Center HRA and −4.2 years for the CDC HRA. The average age differences between the two programs were 3.4 years (95% CI = 3.2, 3.6) overall, 5.9 years (95% CI = 5.6, 6.2) for men, and 1.1 years (95% CI = 0.79, 1.4) for women. This difference increased when stratified by actual age.

Comparison of 10-Year Mortality Risks by Difference between Actual Age and Risk Age

A risk age that is the same (−1 to +1 category) as actual age signifies that the individual is at an average risk level for his/her age, race, and sex for the CDC HRA (and for Carter Center HRA presence of nonmodifiable risk factors). Thus, we would expect to see an increase in observed mortality risk as the difference between actual age and risk age increases (from > +1 category to < −10 category). The predicted, observed, and age-adjusted mortality risks by age difference are shown in Tables 1 and 2. Overall, the CDC HRA program classifies more people in the higher risk categories than the Carter Center HRA, and thus the predicted mortality risks are almost double those observed among men (12.65% predicted vs 7.8% observed) and among women (5.35% predicted vs 2.9% observed). In contrast, the Carter Center slightly underestimates these risks among men (6.02% predicted vs 7.8% observed) but overestimates risks among women (4.45% predicted vs 2.9% observed).

With the CDC HRA program, as the difference between actual age and CDC HRA risk age increases for both men and women, so do the predicted risks and the total observed and age-adjusted 10-year mortality risks. Using the Carter Center HRA, the lowest age difference (> +1 category) had a higher predicted and observed mortality risk than the next highest category (−1 to +1), after which risks rise steadily for both men and women (Tables 1 and 2).

Relative Operating Characteristic Curve Analysis

We examined ROC curves for both the CDC and Carter Center HRA-predicted risks by 10-year mortality rates, since HRA predictions are based on the

10-year appraised chance of dying. The ROC curves for both programs were quite similar and were not significantly different from each other for men (P = .925) or women (P = .9775). The HRA predictions by age group for each sex were also examined and showed similar results; predictions were best for those under age 45.

The difference between actual age and risk age examined by ROC curves showed that for both men and women (Figures 1 and 2) and within each age group (not shown), actual age minus risk age is a better predictor of mortality with the CDC HRA than the Carter Center HRA. In fact, the ROC curve for the Carter Center HRA was below the chance line for men (Figure 1) but not for women (Figure 2). Thus, for men the Carter Center age difference, on average, predicted 10-year mortality no better than chance alone. As depicted in Figures 1 and 2, these ROC curves were different between the two programs for men (P = .0083) and for women (P = .0257). Further examination of the data in Figure 1 showed that at the point where the Carter Center HRA crosses the chance line (approximately 60%), the difference between actual age and risk age is −3.6 years, whereas for the CDC HRA it is 1.4 years. Moreover, the mean age for those individuals below the chance line (Carter Center) is 43.3 years, and for the same area of the CDC calculations it is 32.7 years. Those individuals below the chance line for the Carter Center HRA were also more likely to be smokers (99.4%) compared with those before the curve crosses the chance line (79.7%).

We also examined this difference by age groups for the two programs. The results were similar for all ages except for those ages 45 to 60, for whom the Carter Center HRA age difference was consistently below the chance line, indicating that it predicted worse than chance alone for this age group (P = .0005).

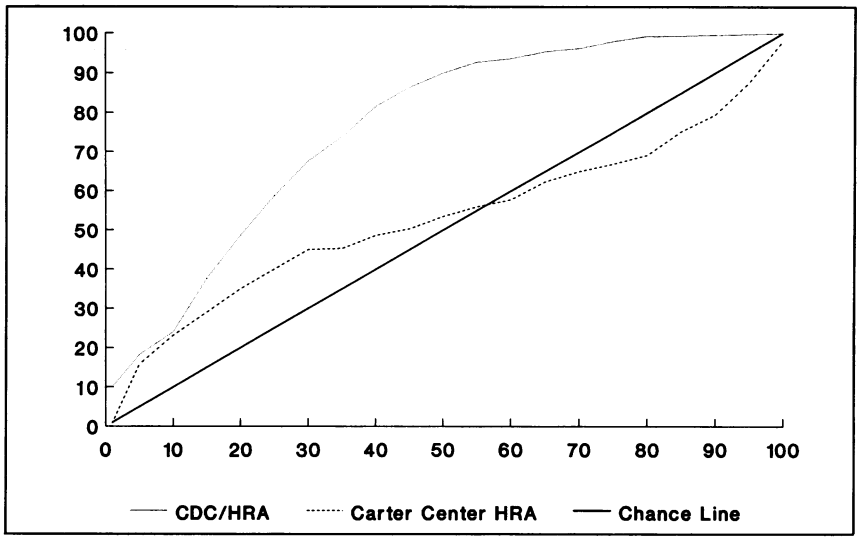

FIGURE 1—ROC Curve Analysis of the Difference between Actual Age and HRA-Predicted Risk Age: Comparison of CDC and Carter Center Methods for *Men*, Using Observed 10-Year Mortality as the Outcome Variable, Tecumseh Community Health Study (n = 1507). Risks were ordered from high to low: CDC difference ranged from −21.5 to 3.7. Carter difference ranged from −16.3 to 7.

Discussion

Although mortality risk predictions from the two HRA programs were highly correlated, the calculated risk ages were quite different. It seems unlikely that this result is due to the different reference populations used (the Carter Center program used 1980 to 1982 vital statistics as the reference population and the CDC HRA used 1975 to 1977 vital statistics), because mortality rates have changed little during that time period. More likely, there are differences in how risk age is determined, e.g., mortality risks predicted by the Carter Center more closely approximated those observed than the CDC HRA mortality risks. Further analysis of the specific calculations of risk age is recommended, particularly the implications of using population risk (CDC HRA) versus "adjusted" population risk (Carter Center HRA).

On average, the Carter Center HRA age difference was less than that of the CDC HRA age difference. However, when the age differences for the two programs were compared with the observed 10-year mortality using ROC curve analysis, the CDC HRA age difference was consistently a more accurate (i.e., more sensitive and specific) predictor of individual mortality than was the Carter Center HRA age difference, especially in older men. In addition to performing poorly with the calculation of risk age for older

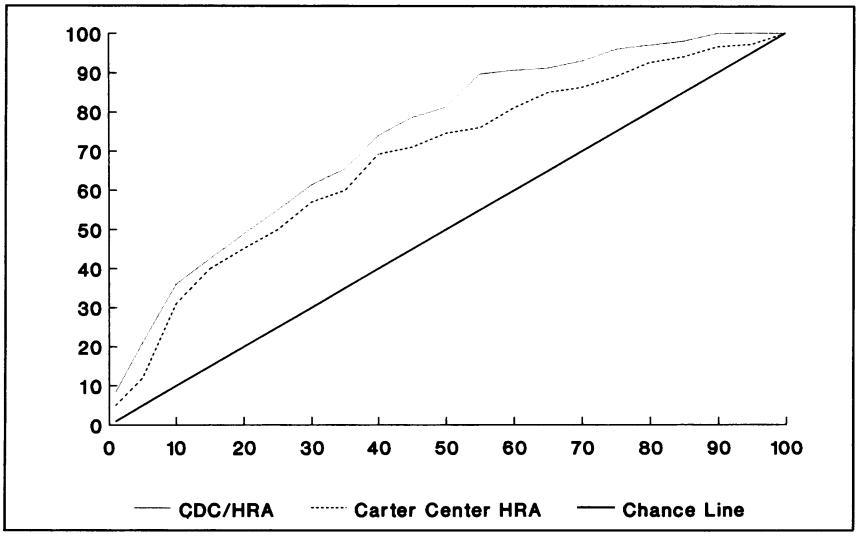

FIGURE 2—ROC Curve Analysis of the Difference between Actual Age and HRA-Predicted Risk Age: Comparison of CDC and Carter Center Methods for *Women*, Using Observed 10-Year Mortality as the Outcome Variable, Tecumseh Community Health Study (n = 1628). Risks were ranked from high to low: CDC difference ranged from −21 to 2.8. Carter difference ranged from −33 to 4.2.

men, the Carter Center HRA may have erred in the weight used for the smoking risk factor.

One of the criticisms of HRA concerns the reliability of self-reported clinical information.[9,10] Reliability was not a problem for blood pressure, weight, and cholesterol in this study, because we used the results of clinical examinations. Although we had data for only approximately 45% of the items used to calculate the predictions (14 of 31 items for CDC/HRA and 13 of 29 items for Carter Center HRA), we did have information on the major risk factors for the common causes of death (e.g., stroke [7.5%], heart disease [39.4%], and lung cancer [5.8%], which accounted for 52.7% of the Tecumseh deaths). Since cardiovascular disease (CVD) is the leading cause of death[18], we also performed ROC curve analysis on the difference between actual CVD risk and predicted CVD risk for each program. The ROC curves for this analysis were virtually identical to those for total mortality; thus the CDC HRA was also a better predictor of CVD mortality.

The variables that we did not have available (e.g., miles traveled per year, social ties) are used as risk factors for less common causes of death, such as motor vehicle accidents and suicide.[8,15] Moreover, we restricted our sample to those individuals older than 25 years of age, and these less common causes of death occur more frequently among younger age groups.[18] Both programs defaulted to population norms for missing values; thus, we would expect the missing items to be extreme to make large changes in the resulting predictions.

Intrinsic errors of the HRA instrument, such as the scientific uncertainty of some risk factors or errors inherent in statistical calculations, will introduce possible problems of accuracy.[15] Our comparison may have been biased toward one program or another because of inherent characteristics of the data used. We attempted to make the comparison as fair as possible by using the same set of variables, calculating ROC curves for 10-year mortality, and using default missing values for each program. Given the constraints of the current software programs and the limitations of the Tecumseh Community Health Study, the CDC HRA appears to be a superior predictor of mortality in the population.

HRA has also been criticized because its effectiveness as a health education/promotion tool has not been demonstrated.[3,8] The revised Carter Center HRA program was primarily developed to update the scientific base of the HRA instrument in order to improve the accuracy of the mortality predictions.[11] If the predictions are improved with this revision, it would seem that this instrument would also be a better health education tool, at least providing more accurate information to the participant. It appears that the revisions did not necessarily improve the mortality predictions (as they were very similar to the CDC HRA mortality predictions) and may have erred on the risk-age calculations for men. If the risk-age calculations are incorrect for a particular program, the effectiveness of that HRA as a health education tool should be questioned. Current HRA users may want to continue using their existing program until the potential problems with the Carter Center Healthier People HRA program are examined further and the effectiveness of the two HRAs in altering behavior has been compared. Those considering the use of the HRA must judge which program better suits the needs of their health education programs. □

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APPENDIX A—CDC vs Carter Center Health Risk Appraisal Program Calculation of an Individual's Overall Predicted Risk of Mortality and Risk Age

CDC HRA	Carter Center HRA
Uses age-sex-race-specific mortality rates for 52 causes of death and "all other" causes	Uses age-sex-specific mortality rates for 41 causes of death and "other causes"
The 10-year expected risk of mortality for each leading cause of death is then "adjusted" by the measured risk factors using the credit-debit method	The individual's current cause-specific mortality risk is estimated using multivariate statistical techniques or population average risk
The cause-specific risks of mortality are summed to determine an overall 10-year expected risk of mortality (predicted risk)	The appraised risks for each cause are summed to get the participant's total appraised risk (predicted risk)
This overall total is compared with age-sex-race-specific risks for the general population to determine "risk age," the age for the given sex-race category with the same overall mortality risk as that predicted from the risk factors	The total appraised risk is compared with either the US population projections for causes of death with modifiable risk factors or an adjusted US population projection for causes of death quantified by nonmodifiable risk factors. This comparison determines the individual's risk age

APPENDIX B—Variables Classified as Precursors and Used Directly by the Carter Center HRA and CDC HRA for Computation of Risk and Those Available from 1959 Tecumseh Community Health Study

Variables Not Available from Tecumseh Study	Variables Available from Tecumseh Study that Required Some Recoding	Variables Available from Tecumseh Study Requiring No Recoding
Smokeless tobacco use[a]	Drinks per week	Age
Miles traveled per year	Hysterectomy	Relative weight
Car size[a]	Diabetes	Blood pressure
Speeding[a]	Cigarettes	Serum cholesterol
Safety belt use	Cigars	Race/origin[b]
Drive after drinking[a]	Pipes	Marital status[b]
Mammogram[a]	Family history of heart disease and diabetes[b]	Sex
HDL cholesterol[a]	Rectal problems[b]	
Pap smear	Lung disease[b]	
Family history of breast cancer		
Menarche[a]		
Age at birth of first child		
Drugs/medication use[b]		
Physical activity level[b]		
Overall health[b]		
Satisfaction with life[b]		
Social ties[b]		
Sleep habits[b]		
Loss/misfortune[b]		
Witness/involved in violent argument[b]		
Risky behaviors[b]		
Breast self-examination[b]		

[a]New variables used by the Carter Center HRA program that were not included in the CDC HRA program calculations.
[b]Variables used by the CDC HRA program that were not included in the Carter Center HRA program calculations.