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Cardiovascular Health through Young Adulthood and Cognitive Functioning in Midlife

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Abstract

Objective—To examine the association between overall cardiovascular health as recently defined by the American Heart Association in young adulthood to middle-age and cognitive function in midlife. Overall ideal cardiovascular health incorporates 7 metrics, including the avoidance of overweight or obesity, a healthful diet, nonsmoking, and physical activity, total cholesterol, blood pressure, and fasting glucose at goal levels.

Methods—This analysis of the Coronary Artery Risk Development in Young Adults (CARDIA) Study, a multicenter community-based study with 25 years of follow-up, included 2,932 participants aged 18 to 30 years at baseline (Year 0) who attended follow-up exams at Years 7 and 25. Cardiovascular health metrics were measured at each examination. The Digit Symbol Substitution Test (DSST), modified Stroop Test, and Rey Auditory Verbal Learning Test (RAVLT) were completed at Year 25.

Results—A greater number of ideal cardiovascular metrics in young adulthood and middle-age was independently associated with better cognitive function in midlife (p-trend<0.01, for all). Specifically, each additional ideal metric was associated with 1.32 more symbols on the DSST (95% CI: 0.93 to 1.71), a 0.77-point lower interference score on the Stroop Test (−1.03 to −0.45), and 0.12 more words on the RAVLT (0.04 to 0.20). Participants who had ≥5 ideal metrics at a greater number of the 3 examinations over the 25-year period exhibited better performance on each cognitive test in middle-age (p-trend<0.01, for all).

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Interpretation—Ideal cardiovascular health in young adulthood and its maintenance to middle-age is associated with better psychomotor speed, executive function, and verbal memory in midlife.

Currently, modifiable lifestyle behaviors and the control or avoidance of cardiovascular disease risk factors represent some of the most promising strategies for the prevention of dementia. Obesity, poor diet, smoking, lack of physical activity, and elevated levels of total cholesterol, blood pressure, and fasting glucose in middle-age have each been found to be associated with cognitive decline and dementia in later adulthood.[1–6] In their recently released Strategic Impact Goals for 2020, the American Heart Association (AHA) detailed ideal levels for all 7 of these modifiable health behaviors and factors in order to define a new concept termed "cardiovascular health," which has subsequently been shown to be strongly associated with a lower incidence of cardiovascular disease and related mortality.[7, 8] Since many of these behaviors and factors often coexist and participate in mutual causal pathways, an overall ideal cardiovascular health profile may also be more effective in reducing the risk of cognitive dysfunction with aging than any single factor; however, little is known about the collective association between these 7 cardiovascular health components and cognition.

Cardiovascular risk factors measured during middle-age are associated with later adulthood cognitive dysfunction and decline.[9–11] However, few, if any, studies have determined whether health factor levels in young adulthood may be associated with cognitive function in middle-age. If early adult cardiovascular health is associated with cognitive function in middle-age, increased efforts to encourage young adults to achieve and maintain these levels might lead to more adults reaching midlife at low risk for cognitive impairment and dementia in later life. The present study was conducted to investigate the simultaneous association between the 7 AHA ideal cardiovascular health components in young adulthood to middle-age and cognitive function in midlife.

The Coronary Artery Risk Development in Young Adults (CARDIA) Study provided an ideal setting in which to address this question because the community-based sample of participants were prospectively followed for 25 years with repeat detailed assessments of all 7 AHA cardiovascular health components beginning early in adulthood. The hypothesis was that a greater number of ideal components present during young adulthood to middle-age would be associated with better cognitive health in midlife.

Subjects and Methods

Study population

The CARDIA Study is a multicenter longitudinal study of the development and determinants of cardiovascular disease over time in 5,115 young adults initially aged 18–30 years in 1985–1986. Black and white adults were recruited from 4 US cities (Birmingham, Alabama; Chicago, Illinois; Minneapolis, Minnesota; and Oakland, California) with population-based samples approximately balanced within center by sex, age (18–24 years and 25–30 years), race (white, black), and education (≤high school, >high school). To date, participants have been re-examined 2, 5, 7, 10, 15, 20, and 25 years after baseline and retention rates across examinations were 91%, 86%, 81%, 79%, 74%, 72%, and 72%, respectively. Further details of study recruitment and design are available.[12] All participants provided written informed consent at each examination, and institutional review boards from each field center and the coordinating center approved the study annually.

Participants for the current study included 2,932 adults who attended the Year 0 (baseline), 7, and 25 examinations and completed cognitive testing at Year 25. The choice of these 3 examinations was based on the assessment of dietary intake (Years 0, 7, and 20) and

cognitive function (Year 25) in CARDIA. Dietary intake collected at Year 20 was used to approximate diet at Year 25. Women who were pregnant at the time of the Year 0, 7, 20, or 25 examinations were excluded.

Ascertainment of health behaviors and factors

Standardized protocols for data collection and quality control were used across study centers and examinations. Participants were asked to fast for at least 12 h before each examination and to avoid smoking or engaging in heavy physical activity for at least 2 h. Weight and height were measured at each examination with participants wearing light examination clothes and no shoes. Body weight was measured to the nearest 0.2 kg with a calibrated balance-beam scale. Height was measured with a vertical ruler to the nearest 0.5 cm. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared. Dietary intake for the past 28 days was collected through an interviewer-administered diet history questionnaire specifically developed for the CARDIA study at Year 0, 7, and 20.[13] The validity and reliability of this diet history questionnaire was evaluated and was described in detail.[14] Diet data for participants with extreme energy intake (<800 or >8,000 kcal/d for men and <600 or > 6,000 kcal/d for women) were set to missing. Cigarette smoking status was based on self-report. Physical activity was measured with the CARDIA Physical Activity History questionnaire which queries the amount of time per week spent in 13 categories of leisure, occupational, and household physical activities over the past 12 mo.[15] Physical activity level was summarized as units of total activity incorporating moderate and high intensity activities.

Blood pressure was measured on the right arm with a Hawksley random zero sphygmomanometer (WA Baum Company, Copaigue, NY) by trained and certified technicians using standardized methods after the participant had rested for 5 minutes at Year 0 and 7. At Year 25, a digital blood pressure monitor was used (Omron HEM-907XL; Online Fitness, Santa Monica, CA). Three measurements were obtained at 1-min intervals. The average of the second and third measurements was used in analyses.

Blood was drawn by venipuncture according to a standard protocol.[16] Total cholesterol was measured enzymatically as previously described.[17] Glucose was measured at Year 0 using the hexokinase ultraviolet method by American Bio-Science Laboratories (Van Nuys, CA), and at Year 7 and 25 using hexokinase coupled to glucose-6-phosphate dehydrogenase by Linco Research (St. Louis, MO).

Definition of cardiovascular health metrics

We classified each health behavior and factor using the AHA definition of ideal, intermediate, and poor health with slight modifications made only for diet and physical activity (Supplemental Table 1).[18]

Cognitive function assessment

A battery of standardized tests to measure cognitive function was included at the Year 25 examination. Cognitive training and certification of CARDIA technicians was performed centrally by CARDIA investigators and coordinating center data quality assurance staff. The Digit Symbol Substitution Test (DSST), a subtest of the Wechsler Adult Intelligence Scale (3rd edition), assesses an array of cognitive domains, most prominently visual motor speed, sustained attention, and working memory. The range of scores is 0 to 133, with increasing scores indicating better performance. The Stroop Test evaluates the ability to view complex visual stimuli and to respond to one stimulus dimension while suppressing the response to another dimension, an “executive” skill largely attributed to frontal lobe function.[19] The interference score provides a measure of how much additional executive processing is

needed to respond to an incongruent trial; thus, a higher interference score indicates worse performance on the task. The Rey Auditory Verbal Learning Test (RAVLT) assesses the ability to memorize and to retrieve words (verbal memory). Results from the long delay (10 min) free recall were used in analyses. The range of scores is 0 to 15, with increasing scores indicating better performance.

Statistical analysis

Multiple imputation was used to impute missing values using the sequential regression imputation approach that is implemented in the software package IV Eware.[20] Five datasets were generated using data from all 8 examinations resulting in complete Year 0, 7, and 25 data for the sample of 2,932 participants. Each complete data set was analyzed separately and results from the 5 analyses were combined using Rubin's rules.[21] We also performed a sensitivity analysis on 1,753 participants who had complete information on all health behaviors and factors across all 3 exams and covariates.

The total number of cardiovascular health components at ideal levels was calculated based upon the average level of each factor across the Year 0, 7, and 25 exams as well as the number present at Year 0 and 25, separately. The score ranged from 0 (no health behaviors or factors at ideal levels) to 7 (all health behaviors and factors at ideal levels). We also examined mean cognitive function scores according to the presence of 5 or more ideal health metrics at none, 1, 2, or all 3 of the Year 0, 7, and 25 examinations. A threshold of 5 or more ideal metrics was used to provide more statistically stable estimates since too few participants had 6 or 7 ideal metrics.

Multivariable linear regression was used to estimate the association between the cardiovascular health components, the number of exams with 5 or more at ideal levels, and each cognitive function score after adjusting for age (years), sex, race (black, white), educational attainment (years), alcohol use (ml/day, average, Year 0, or Year 25), and study center (Birmingham, Chicago, Minneapolis, Oakland). Tests for a linear trend were determined by entering each individual health component, the total number of ideal components, or the number of examinations with 5 or more at ideal levels into the model as an ordinal term. Tests of statistical significance were 2-tailed, with an alpha level of 0.05. SAS version 9.1 (Cary, NC) was used to perform all analyses.

Results

Of the 2,932 participants who attended the Year 0, 7, and 25 examinations and completed cognitive testing at Year 25, 44.8% were black and 55.4% were women. Supplemental Table 2 compares the baseline characteristics of those included in the analysis to those who were not included. A similar proportion of women and nondrinkers were included in the analysis as compared to those who were not included. The prevalence of ideal health for BMI, physical activity, total cholesterol, blood pressure, and glucose at baseline were also similar. However, included participants were somewhat more likely to be younger, white, have a higher education, and have an ideal diet score and smoking status.

Prevalence of ideal health for the individual and total number of components at baseline and Year 25 are displayed in Figures 1 and 2. After 25 years, the prevalence of meeting each ideal metric decreased for all behaviors and factors except nonsmoking, which increased during this period (Figure 1). At baseline, few participants met only 0, 1, or 2 ideal metrics; most met 4 or 5, while 17.5% and 1.5% met 6 or 7, respectively (Figure 2). At Year 25, fewer participants met 4 or more metrics; participants most commonly had 3. Those who met a greater number throughout young adulthood were younger at baseline, more likely to be white, and attain a college education (Table 1). Mean levels of the individual behaviors

and factors at baseline were associated with the total number of ideal health components, except for sodium intake.

Mean scores at Year 25 on the DSST, Stroop Test, and RAVLT were 70.1±16.2 symbols (range: 8 to 125), 22.7±11.1 points (range: −24 to 127), and 8.4±3.3 words (range: 0 to 15), respectively. A greater number of ideal cardiovascular health components present at Year 0, Year 25, and based on the average of Year 0, 7, and 25 levels was strongly associated with better performance on all 3 cognitive tests (Table 2). Specifically, each additional ideal component (based on average levels) was associated with 1.32 more symbols on the DSST (95% CI: 0.93 to 1.71), a 0.77-point lower interference score on the Stroop Test (95% CI: −1.03 to −0.45), and 0.12 more words recalled on the RAVLT (95% CI: 0.04 to 0.20). These associations did not vary significantly by race (p-interaction >0.2, for all).

Table 3 shows the multivariable-adjusted mean scores for the DSST, Stroop Test, and RAVLT for participants who had 5 or more ideal health components at none, 1, 2, or all 3 of the Year 0, 7, and 25 examinations. Mean scores were higher for the DSST and RAVLT, and lower for the Stroop Test among participants who had 5 or more ideal components at a greater number of exams (p-trend<0.01, for all).

We also examined the association between each of the 7 individual health behaviors and factors and cognitive function (Table 4). Smoking status and blood pressure displayed significant graded associations with all 3 tests of cognition (p-trend<0.01, for all). BMI, diet, physical activity, and glucose were each associated with performance on the DSST (p-trend<0.01, for all). BMI, physical activity, and glucose were also associated with scores on the Stroop Test (p-trend<0.05, for all). Total cholesterol was associated with results on the RAVLT only (p-trend<0.001).

We also created a score out of the 7 health behaviors and factors ranging from 0 to 14 by assigning a value of 0 for poor health, 1 for intermediate health, and 2 for ideal health based upon average levels for each component. Each unit increase in the score was associated with 1.08 more symbols on the DSST (95% CI: 0.81, 1.35), a 0.65-point lower interference score on the Stroop Test (95% CI: −0.86, −0.45), and 0.11 more words recalled on the RAVLT (95% CI: 0.06, 0.17).

A sensitivity analysis on the 1,753 participants with complete information on all health behaviors and factors and covariates revealed similar results. Specifically, each additional component in the ideal range (based upon average levels of the components) was associated with 1.39 more symbols on the DSST (95% CI: 0.91, 1.89), a 0.78-point lower interference score on the Stroop Test (95% CI: −1.13, −0.43), and 0.11 more words recalled on the RAVLT (95% CI: 0.01, 0.22).

Discussion

In this longitudinal community-based study of adults, we found a strong graded association between a greater number of ideal cardiovascular health components from young adulthood to middle-age and better visual motor speed, executive function, and verbal memory in middle-age. This association was independent of a number of potential confounding factors including educational attainment and alcohol consumption. In addition, participants who achieved and maintained a greater number of ideal components throughout young adulthood exhibited better performance on each test of cognition during middle-age.

It is becoming increasingly clear that dementia has a long preclinical period. This observation has led to calls for the study of risk factors and cognitive outcomes many years prior to the clinical diagnosis of disease.[22, 23] Several longitudinal studies have shown that

midlife risk factor levels, including blood pressure, cholesterol, glucose, and lifestyle behaviors are associated with cognitive function and impairment in later adulthood.[24, 25] In addition, early pathologic evidence of Alzheimer's disease and white matter hyperintensities on magnetic resonance images has been observed in middle-aged adults.[26, 27] Our results add to the previous evidence by showing that cardiovascular behaviors and factors beginning at a younger age in the adult lifecourse may influence cognitive function at older ages. Future studies are needed to determine whether ideal cardiovascular health in young adulthood contributes to delays in aging related cognitive decline and a lower risk of dementia through older adulthood.

Previous studies have investigated the individual components or groups of components of the ideal cardiovascular health score included in the current study. Mid- or late-life hypertension, dyslipidemia, diabetes, obesity, smoking, physical inactivity, and poor diet have each been shown to be independently associated with a greater risk of developing cognitive impairment or dementia due to vascular disease or Alzheimer's disease.[1, 2, 4–6, 11, 28] The metabolic syndrome, a cluster of metabolic risk factors, including abdominal obesity, hypertension, dyslipidemia, and hyperglycemia has been shown to contribute to cognitive decline and impairment.[29, 30] In addition, a greater number of behaviors, including smoking, alcohol abstinence, low physical activity, and low fruit and vegetable intake has been reported to be associated with poor executive function and memory in late middle-age.[25] However, to the best of our knowledge, no available study has investigated the combined association between both cardiovascular health behaviors and metabolic factors and cognitive function. Accumulating evidence suggests ideal cardiovascular health defined using various definitions including the AHA 2020 goals is strongly associated with a lower risk of cardiovascular events and related mortality, a greater quality of life, and lower Medicare expenditures in later life.[7, 31–34] The results of the present study further suggest that ideal cardiovascular health consistent with AHA 2020 goals from young adulthood to middle-age is also strongly associated with better performance on tests designed to assess a wide variety of cognitive domains in mid-life.

The mean differences we observed in cognitive test scores with each additional ideal health component was clearly modest; nevertheless, effect sizes of that magnitude may have clinical relevance. For example, in our study population every 1-year increase in age was associated with 0.56 less symbols substituted correctly on the DSST, a 0.28 higher interference score on the Stroop Test, and 0.03 less words recalled correctly on the RAVLT (data not shown). Therefore, the effect sizes we observed with each additional ideal health component correspond to an age difference of 2–4 years. In addition, in a 3-year follow-up study of individuals with minimal cognitive impairment, a 1-point difference in baseline DSST score was significantly associated with a higher risk of Alzheimer's disease.[35] In another study of community dwelling adults aged >70 years, a 1-point difference in baseline DSST score was associated with a 3% higher risk of dementia.[36]

Results of the current study are also consistent with a number of recent reports suggesting that few US adults meet the AHA 2020 ideal goals for all 7 ideal health components.[7, 8, 31, 37] Only 1.5% and 0.4% of participants met all 7 ideal metrics in young adulthood and middle-age, respectively. In an analysis of data from the National Health and Nutrition Examination Survey, Yang et al.[8] estimated that only about 1.2% to 2.0% of the US adult population aged ≥20 years met all 7 ideal goals between 1988–1994 and 2005–2010. Despite these low prevalence estimates, the majority of participants in the current study (51.9%) achieved at least 5 ideal metrics in young adulthood (i.e., baseline; Figure 2), however, only 12.1% of participants maintained this number through early adulthood to middle-age (Table 3). It is clear that reaching the AHA 2020 ideal goals poses a significant challenge for clinical and public health professionals. Our data suggest that coordinated

efforts should begin earlier in adulthood in order to stem the adoption of adverse health behaviors that become more frequent in middle-age.

Of the 7 behaviors and factors investigated in the current study, 6 showed significant graded associations with visual motor speed, 5 with executive function, and 3 with memory. These results suggest that delays in aging related declines in these cognitive domains may be feasible when individuals move from poor to intermediate health and intermediate to ideal health. The reasons for the differences in the associations between the specific health behaviors and factors and the cognitive domains are not clear, but may be due at least in part to the fact that memory is likely to be less influenced by vascular risk factors, findings that have been observed by a number of studies.[10, 25, 30]

Blood pressure and smoking during young adulthood to middle-age displayed strong, graded associations with each cognitive domain in midlife. Midlife blood pressure ranks as an important modifiable risk factor for late-life cognitive decline,[10] mild cognitive impairment,[9] and vascular dementia.[38] Several prospective studies also show an increased risk for cognitive decline in smokers compared to nonsmokers.[1] As mentioned earlier, our findings provide further evidence that the levels of these behaviors and factors as well as others during early adulthood to middle-age may also be important determinants of cognitive outcomes in later life.

Important strengths of our study include a population-based sampling method; a biracial cohort; extensive data on potential confounders; a large sample size well balanced with respect to age, sex, race, and education that increased precision and permitted simultaneous adjustment for multiple variables; repeat detailed assessments of cardiovascular health behaviors and factors across a 25-year period beginning in early adulthood; and the standardized data collection protocols and rigorous quality control of the CARDIA study.

Nevertheless, several limitations deserve mention. First, we assessed cognitive function at only a single time in midlife and therefore we were unable to determine whether ideal cardiovascular health in young adulthood is associated with delays in aging related cognitive decline. It may be possible that greater cognitive ability led to a lifestyle of healthier behaviors in young adulthood to middle-age.[39] Second, participants included in the analysis were somewhat more likely at baseline to have a healthier diet and an ideal smoking status than those not included. This may have led to an underestimation of the association between ideal cardiovascular health and cognitive function. Third, since our analysis included several health behaviors and factors measured across 3 examinations, many participants were missing at least 1 measurement. However, we noted similar results using our multiple imputed datasets and another dataset including participants with complete information on all study variables. Fourth, this is an observational analysis, and residual confounding, particularly by socioeconomic status, may be present. Conversely, our results were robust to adjustment for midlife educational attainment, making it improbable that the observed associations are owing completely to residual confounding.

In summary, the present long-term community-based study showed that few adults in young adulthood or middle-age met all 7 AHA 2020 goals for ideal cardiovascular health. Nevertheless, there was a strong graded association between the presence of a greater number of ideal cardiovascular health components in young adulthood to middle-age and better cognitive health in midlife. In addition, participants who achieved and maintained a greater number of ideal components throughout young adulthood exhibited better performance on each test of cognition in middle-age. These results suggest that attainment of the AHA 2020 goals for ideal cardiovascular health in young adulthood and maintenance to middle-age could have important implications for cognitive outcomes in later life.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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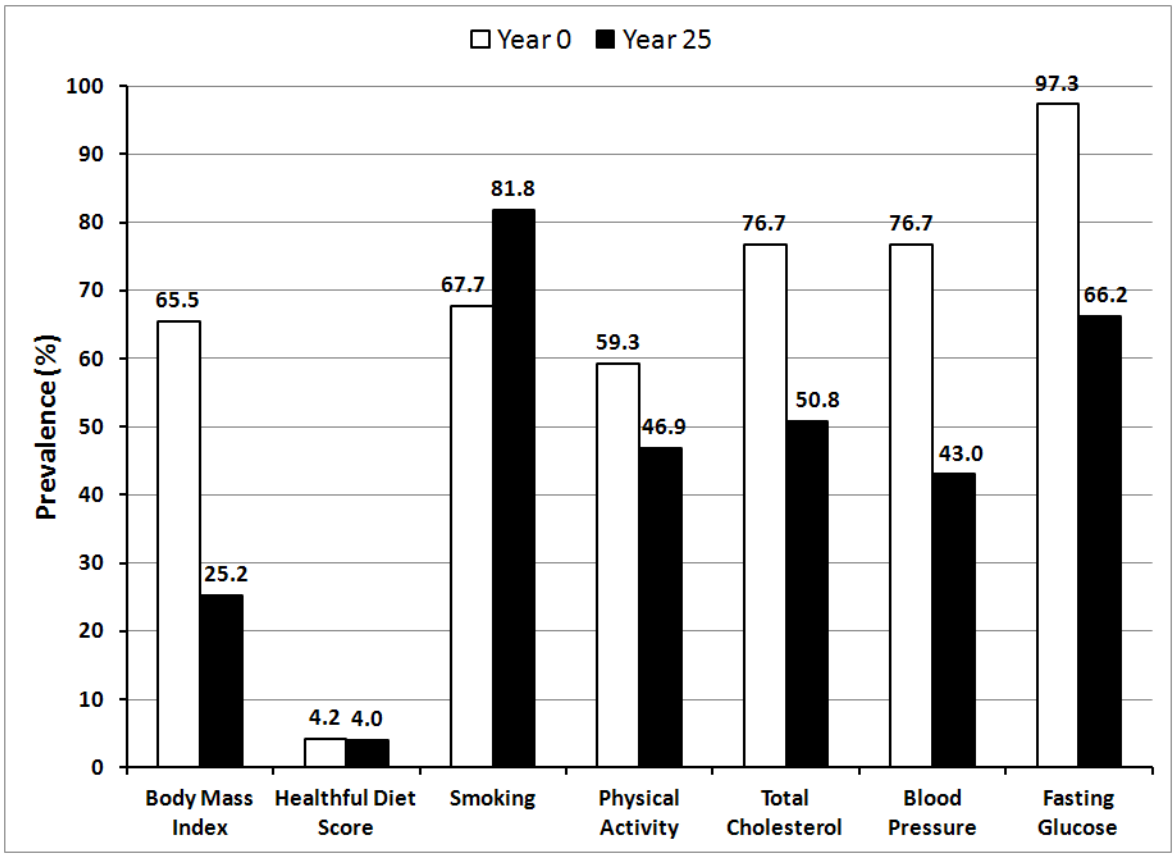

Figure 1.
Prevalence of individual ideal cardiovascular health components at baseline and Year 25, CARDIA (n = 2,932). Healthful diet score is based on diet measured at baseline and Year 20.

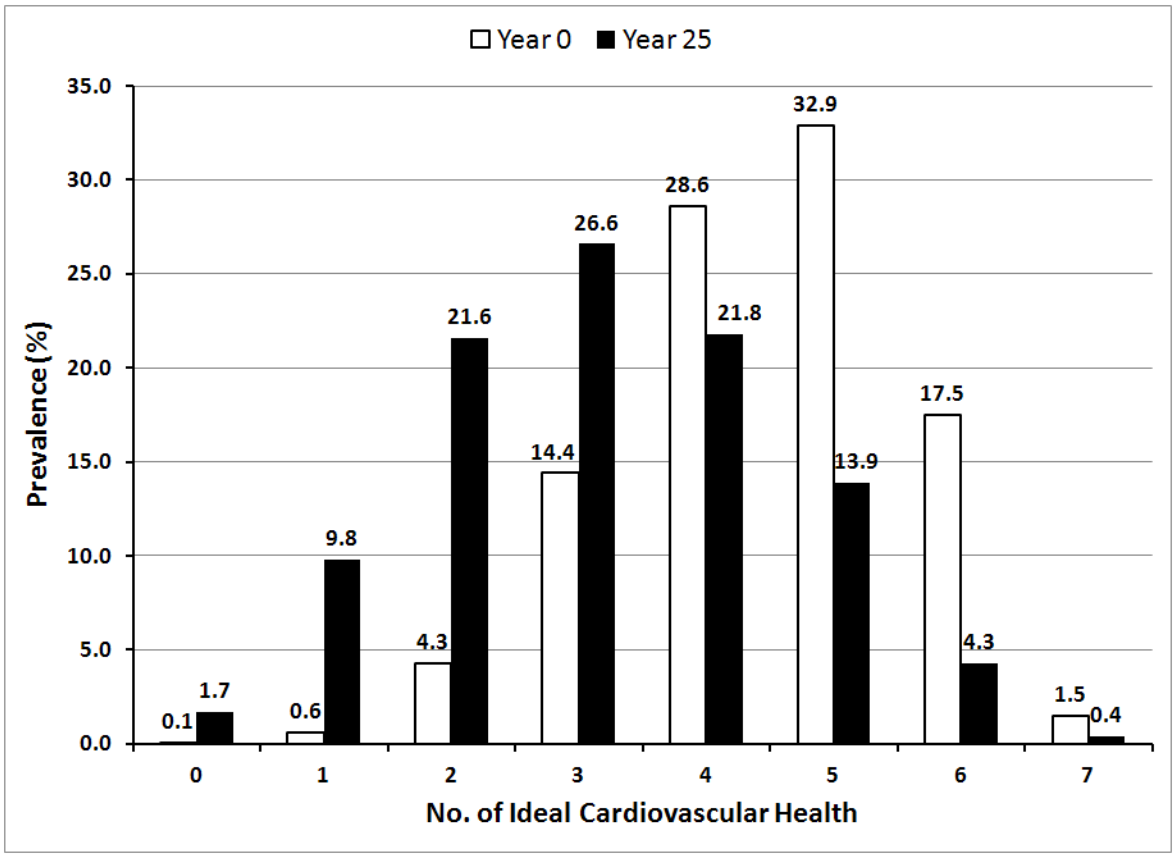

Figure 2.
Prevalence of ideal cardiovascular health components at baseline and Year 25, CARDIA (n = 2,932).

Table 1

Baseline characteristics according to the number of ideal cardiovascular health components based upon the average of baseline, Year 7, and Year 25 values, CARDIA (n = 2,932).

	No. of ideal cardiovascular health components							
	0–1 (n = 149)	**2 (n = 347)**	**3 (n = 547)**	**4 (n = 807)**	**5 (n = 707)**	**6 (n = 361)**	**7 (n = 14)**	**p-trend**
Age, years	26.0	26.1	25.1	25.0	25.0	24.8	26.3	< 0.001
Men, %	41.6	45.0	44.4	46.2	45.3	41.0	40.0	> 0.2
Black, %	69.1	61.1	57.0	48.6	31.8	18.8	7.1	< 0.001
Education (college), Year 25, %	26.2	35.2	41.7	48.0	60.7	76.2	78.6	< 0.001
Nondrinker, %	41.6	39.2	37.8	40.2	36.5	33.5	35.7	0.08
Health behaviors and factors								
Body mass index, kg/m^2	29.1	27.9	26.0	24.4	22.5	21.3	21.6	< 0.001
Never smoker or quit > 12 mo, %	46.3	56.5	62.5	68.8	73.9	79.8	92.9	< 0.001
Physical activity, exercise units	250.6	345.6	357.0	419.9	464.5	590.4	611.4	< 0.001
Total cholesterol, mg/dL	199.5	192.9	182.6	175.2	171.0	163.2	165.8	< 0.001
Systolic blood pressure, mmHg	115.6	115.1	111.4	110.3	107.7	105.6	103.4	< 0.001
Diastolic blood pressure, mmHg	73.1	70.9	69.1	68.5	67.1	66.4	64.4	< 0.001
Fasting glucose, mg/dL	89.2	85.7	82.1	81.1	80.6	80.7	81.9	< 0.001
Dietary intake								
Total energy, kcal/d	2,831.7	2,844.8	2,917.5	2,861.8	2,777.6	2,729.0	2,208.4	0.09
Total fruits/vegetables, servings/d	4.3	4.5	4.6	4.9	5.4	6.2	8.2	< 0.001
Sodium, mg/d	4,079.5	4,190.6	4,324.5	4,284.5	4,142.3	4,076.0	3,198.4	> 0.2
Fish, oz/wk	4.3	4.6	4.7	5.3	5.4	6.0	13.9	< 0.001
Whole grains, servings/d	0.9	1.0	1.1	1.2	1.5	1.9	3.7	< 0.001
Sugar-sweetened beverages, oz/wk	97.8	84.0	88.1	76.4	60.3	44.5	4.3	< 0.001

Values are mean or percent as appropriate.

Table 2

Multivariable-adjusted[1] mean (95% CI) Digit Symbol Substitution Test (DSST), Stroop Test, and Rey Auditory Verbal Learning Test (RAVLT) scores at Year 25 according to number of ideal cardiovascular health components at baseline (Year 0), Year 25, and average of Year 0, 7, and 25 values, CARDIA (n = 2,932).

	Year 0	Year 25	Average
DSST (symbols)			
No. of ideal health components			
0–1	62.9 (56.6, 69.2)	66.7 (65.2, 68.2)	66.8 (64.6, 69.1)
2	67.3 (64.9, 69.8)	68.1 (67.0, 69.1)	65.8 (64.4, 67.3)
3	68.0 (66.7, 69.4)	68.8 (67.8, 69.8)	66.8 (65.6, 67.9)
4	68.5 (67.6, 69.4)	70.5 (69.4, 71.6)	70.4 (69.5, 71.4)
5	69.8 (68.9, 70.6)	69.9 (68.5, 71.3)	70.3 (69.3, 71.3)
6	70.2 (69.0, 71.5)	72.5 (70.0, 75.0)	71.4 (70.0, 72.9)
7	69.7 (65.5, 73.8)	71.7 (64.2, 79.2)	72.9 (65.8, 80.0)
p-trend	< 0.001	< 0.001	< 0.001
Per each additional ideal component	0.84 (0.37, 1.30)	0.94 (0.55, 1.34)	1.32 (0.93, 1.71)
Stroop Test (points)			
No. of ideal health components			
0–1	30.7 (26.0, 35.4)	24.2 (23.1, 25.4)	25.7 (24.0, 27.3)
2	25.1 (23.3, 27.0)	23.4 (22.6, 24.2)	25.0 (23.9, 26.1)
3	23.8 (22.8, 24.8)	22.9 (22.2, 23.7)	23.4 (22.5, 24.2)
4	23.2 (22.5, 23.9)	23.0 (22.1, 23.8)	22.7 (22.0, 23.4)
5	22.6 (22.0, 23.3)	22.4 (21.4, 23.5)	22.3 (21.5, 23.1)
6	22.2 (21.3, 23.1)	21.5 (19.6, 23.3)	22.0 (20.9, 23.1)
7	24.0 (20.9, 27.1)	21.8 (16.2, 27.4)	21.4 (16.1, 26.6)
p-trend	< 0.001	0.004	< 0.001
Per each additional ideal component	−0.65 (−0.99, −0.31)	−0.40 (−0.69, −0.11)	−0.77 (−1.03, −0.45)
RAVLT (words)			
No. of ideal health components			
0–1	6.7 (5.4, 8.0)	7.8 (7.5, 8.2)	7.5 (7.1, 8.0)
2	8.0 (7.4, 8.5)	8.0 (7.7, 8.2)	7.8 (7.5, 8.1)
3	8.0 (7.7, 8.3)	8.3 (8.1, 8.5)	8.2 (7.9, 8.4)
4	8.2 (8.0, 8.4)	8.2 (8.0, 8.4)	8.4 (8.2, 8.6)
5	8.2 (8.0, 8.3)	8.4 (8.1, 8.7)	8.2 (8.0, 8.4)
6	8.5 (8.3, 8.8)	8.6 (8.1, 9.1)	8.3 (8.0, 8.6)
7	7.5 (6.6, 8.3)	8.6 (7.1, 10.2)	7.5 (6.0, 9.0)
p-trend	0.003	0.003	0.005
Per each additional ideal component	0.12 (0.02, 0.22)	0.12 (0.04, 0.20)	0.12 (0.04, 0.20)

[1] Adjusted for age (years), sex, race (black, white), educational attainment (years), alcohol use (ml/d at baseline, Year 25, or average), and study center (Birmingham, Chicago, Minneapolis, Oakland).

Table 3

Multivariable-adjusted[1] mean (95% CI) Digit Symbol Substitution Test (DSST), Stroop Test, and Rey Auditory Verbal Learning Test (RAVLT) scores at Year 25 by presence of ≥5 ideal cardiovascular health components at none, 1, 2, or all 3 of the baseline (Year 0), Year 7, and Year 25 examinations, CARDIA (n = 2,932).

≥5 ideal cardiovascular health components present at:	n (%)	DSST (symbols)	Stroop Test (points)	RAVLT (words)
No exams	1091 (37.2)	67.8 (67.0, 68.7)	23.8 (23.2, 24.4)	8.0 (7.8, 8.1)
1 exam	806 (27.5)	69.0 (68.0, 69.9)	23.0 (22.3, 23.7)	8.3 (8.1, 8.5)
2 exams	679 (23.2)	70.1 (69.0, 71.3)	22.5 (21.7, 23.3)	8.2 (8.0, 8.5)
All 3 exams	356 (12.1)	71.4 (69.8, 73.1)	21.8 (20.7, 23.0)	8.5 (8.2, 8.8)
p-trend		< 0.001	0.001	0.006

[1] Adjusted for age (years), sex, race (black, white), educational attainment (years), alcohol use (average ml/d), and study center (Birmingham, Chicago, Minneapolis, Oakland).

Table 4

Multivariable-adjusted[1] mean (95% CI) Digit Symbol Substitution Test (DSST), Stroop Test, and Rey Auditory Verbal Learning Test (RAVLT) scores at Year 25 by individual cardiovascular health components based upon the average of baseline, Year 7, and Year 25 levels, CARDIA (n = 2,932).

	DSST (symbols)	Stroop Test (points)	RAVLT (words)
Body mass index			
Ideal health	69.7 (68.9, 70.5)	22.7 (22.0, 23.2)	8.1 (8.0, 8.3)
Intermediate health	68.9 (68.0, 69.7)	22.7 (22.1, 23.3)	8.2 (8.0, 8.4)
Poor hevalth	68.3 (67.3, 69.4)	24.3 (23.6, 25.1)	8.2 (7.9, 8.4)
p-trend	0.04	0.002	>0.2
Diet score			
Ideal health	70.0 (66.1, 74.7)	23.1 (19.9, 26.3)	7.8 (6.9, 8.7)
Intermediate health	69.9 (69.0, 70.8)	22.6 (21.9, 23.3)	8.3 (8.1, 8.5)
Poor health	68.6 (67.9, 69.3)	23.3 (22.8, 23.8)	8.1 (8.0, 8.2)
p-trend	0.03	0.1	>0.2
Smoking			
Ideal health	70.1 (69.5, 70.6)	22.6 (22.2, 23.1)	8.3 (8.2, 8.4)
Intermediate health	67.3 (64.1, 70.4)	22.8 (20.4, 25.1)	7.9 (7.3, 8.6)
Poor health	64.3 (62.9, 65.6)	25.3 (24.3, 26.3)	7.6 (7.3, 7.9)
p-trend	<0.001	<0.001	<0.001
Physical activity			
Ideal health	70.1 (69.4, 70.8)	22.6 (22.1, 23.1)	8.1 (8.0, 8.3)
Intermediate health	68.2 (67.3, 69.0)	23.5 (22.9, 24.1)	8.4 (8.2, 8.5)
Poor health	66.0 (64.1, 67.8)	24.3 (23.0, 25.8)	7.7 (7.3, 8.1)
p-trend	<0.001	0.006	>0.2
Total cholesterol			
Ideal health	69.2 (68.6, 69.8)	22.9 (22.4, 23.3)	8.3 (8.2, 8.4)
Intermediate health	68.6 (67.8, 69.5)	23.5 (22.9, 24.2)	8.0 (7.8, 8.2)
Poor health	70.5 (67.4, 73.6)	23.1 (20.8, 25.4)	7.5 (6.8, 8.1)
p-trend	>0.2	0.2	<0.001
Blood pressure			
Ideal health	69.9 (69.3, 70.6)	22.6 (22.1, 23.1)	8.3 (8.2, 8.4)
Intermediate health	68.1 (67.3, 68.9)	23.5 (22.9, 24.1)	8.0 (7.8, 8.2)
Poor health	63.4 (59.8, 67.1)	29.0 (26.3, 31.6)	8.0 (7.3, 8.7)
p-trend	<0.001	<0.001	0.008
Glucose			
Ideal health	69.3 (68.8, 69.9)	22.9 (22.4, 23.3)	8.2 (8.1, 8.3)
Intermediate health	68.8 (67.4, 70.3)	23.9 (22.8, 25.0)	8.1 (7.8, 8.4)
Poor health	62.2 (59.1, 65.4)	25.6 (23.3, 28.0)	7.5 (6.8, 8.1)
p-trend	0.001	0.006	0.1

[1]Adjusted for age (years), sex, race (black, white), educational attainment (years), alcohol use (average ml/d), and study center (Birmingham, Chicago, Minneapolis, Oakland).