Heart Rate Recovery After Cognitive Challenge Is Preserved With Age

Olga V. Shcheslavskaya, PhD, Matthew M. Burg, PhD, Paula S. McKinley, PhD, Joseph E. Schwartz, PhD, William Gerin, PhD, Carol D. Ryff, PhD, Maxine Weinstein, PhD, Teresa E. Seeman, PhD, and Richard P. Sloan, PhD

Objective: To investigate the effect of age on heart rate recovery (HRR) from cognitive challenge. **Background:** Aging is an independent risk factor for the development of cardiovascular disease. HRR from exercise is an established predictor of cardiac morbidity and mortality, and evidence suggests that HRR from cognitive challenge is predictive of cardiac morbidity as well. Aging is associated with delayed HRR from exercise stress, but little is known about the effect of aging on HRR from psychological stress. We tested the hypothesis that age would be related to delayed HRR from psychological stress. **Methods:** HRR post exposure to cognitive challenge (mental arithmetic and Stroop) was investigated in a sample of 436 participants aged 35 to 84 years in MIDUS II, a national study of health and well-being. HRR was measured as 1) the amount of change from the stress level; 2) time to recover; and 3) the area under the curve. The analyses were controlled for medical comorbidities and medications that influence HR, such as body mass index, smoking, sex, menopausal status, and amount of physical activity/exercise. **Results:** There was no effect for age on HRR as evaluated by all three recovery assessment methods. **Conclusions:** Contrary to expectation and in contrast to findings concerning HRR from exercise, HRR from cognitive challenge was preserved with age. These findings require further inquiry into differential mechanism(s) underlying HRR from psychological versus exercise stress, including any role for improved emotion regulation with greater age. **Key words:** heart rate recovery, aging, autonomic nervous system, area under the curve, rumination.

HR = heart rate; **HRR** = heart rate recovery; **AUC** = area under the curve; **ECG** = electrocardiogram.

INTRODUCTION

Aging is strongly associated with elevated risk for cardiovascular morbidity and mortality. For example, the prevalence of coronary artery disease and hypertension increases significantly with age, whereas >80% of cardiovascular deaths occur in people aged ≥65 years (1). To understand these findings, the Baltimore Longitudinal Study on Aging reported age-related changes to cardiovascular structure and function that per se represent a risk for the development of cardiovascular disease, even in otherwise healthy individuals (2). Aging is associated with changes in cardiac autonomic control including chronically elevated sympathetic activation (3,4), which is also seen in essential hypertension (5). This chronic elevation in sympathetic activity may be one factor that contributes to arterial stiffening and the associated increase in the vascular afterload on the heart seen as age increases (2,5). At rest, age-related vascular changes are compensated for by alterations in the structure of the heart and its contractile properties (2). These effects, however, become striking during exposure to physical challenge. For example, during exercise, older individuals demonstrate an attenuated heart rate (HR) response, which is indicative of decreased sensitivity to β-adrenergic stimulation (2,5). Moreover, the effects of age persist during the postexercise recovery period, as older individuals recover considerably more slowly compared with their younger counterparts (6–9).

In both cross-sectional (10) and longitudinal (11,12) studies, heart rate recovery (HRR) from physical exercise is an important predictor of cardiovascular health. Delayed HRR after exercise is associated with carotid atherosclerosis (10) and acute cardiac events (11,12). The recovery literature provides compelling evidence demonstrating the prognostic value of HRR from exercise for both cardiovascular and all-cause mortality in patients (6,13) and initially healthy cohorts (14–16). Like recovery from exercise, faster recovery after cognitive challenge is also associated with better cardiovascular outcomes in healthy cohorts (17–19). For example, Heponiemi et al. (17) found that faster HRR after the mental arithmetic task was associated with lower prevalence of atherosclerosis at the 2-year follow-up assessment. As delayed HRR from both exercise and cognitive challenge increases the risk for cardiovascular morbidity, the effect of age on this parameter may be important for understanding more completely the relationship of age to disease.

Existing research reveals that age is associated with poor HRR from physical exercise (6–9). Only one study, however, has addressed the influence of age on HRR from cognitive challenge. Steptoe et al. (20) investigated HRR after three 5-minute cognitive tasks derived from the Wechsler Adult Intelligence Scale and Wechsler Memory Scale in a sample of 152 healthy men and women aged 27 years to 80 years. The averaged data from the three tasks and corresponding recovery periods were aggregated, and a repeated-measures approach was used to analyze the effects of age, education, and gender on HRR. The results showed that, irrespective of gender, older

From the Division of Behavioral Medicine (O.V.S., R.P.S., P.S.M.), Department of Psychiatry, Columbia University Medical Center, New York, New York; Division of General Medicine (J.E.S., M.M.B.), Columbia University School of Medicine, New York, New York; Department of Internal Medicine (M.M.B.), Yale University School of Medicine, New Haven, Connecticut; Department of Biobehavioral Health (W.G.), College of Health and Human Development, Pennsylvania State University, University Park, Pennsylvania; Department of Psychology (C.D.R.), and Institute on Aging and Adult Life, University of Wisconsin-Madison, Madison, Wisconsin; Center for Population and Health (M.W.), Georgetown University, Washington, DC; and the Division of Geriatrics (T.E.S.), University of California, Los Angeles David Geffen School of Medicine, Los Angeles, California.

This study was supported, in part, by Grant P01-AG020166 from the National Institute on Aging to conduct a longitudinal follow-up of the MIDUS (Midlife in the U.S.) investigation (Dr. Ryff). The original study was supported by a grant from the John D. and Catherine T. MacArthur Foundation Research Network on Successful Midlife Development (Dr. Ryff). The study also received support from Grant M01-RR023942 (Georgetown), Grant M01-RR00865 (UCLA) from the General Clinical Research Centers Program, and Grant 1UL1RR025011 (UW) from the Clinical and Translational Science Award (CTSA) program of the National Center for Research Resources, National Institutes of Health, and the Nathaniel Wharton Fund.

Address correspondence and reprint requests to Olga V. Shcheslavskaya, Division of Behavioral Medicine, Department of Psychiatry, Columbia University Medical Center, New York, NY 10032. E-mail: os2184@columbia.edu

DOI: 10.1097/PSY.0b013e3181c94ca0

0033-3174/10/7202-0128

participants had slower HRR compared with younger participants. In addition, those older participants who had lower education recovered more slowly compared with those older participants who had higher education. Although suggestive, the reliance of these analyses on averaged scores, rather than on a more complete poststress trajectory of HRR, limits the interpretation of these findings.

In summary, previous studies have established the contribution of age to incident cardiovascular events and revealed that age-related changes in cardiovascular autonomic control, structure, and function represent independent risk factors for the development of cardiovascular disease (2,5). HRR from both exercise and cognitive challenge have been found to predict cardiovascular morbidity (10–12,17), but only one study has investigated the association of age to HRR from cognitive challenge (20), and this study has important limitations. The purpose of the present study was to test the hypothesis that greater age would be associated with slower HRR from cognitive challenge.

METHODS

Participants

The data for the current study are from the MIDUS II, a 9-year follow-up of the MIDUS I cohort. MIDUS is a national study of midlife development in the United States. MIDUS II included four new studies, one of which, the Biomarker Study conducted from July 2004 to June 2006, included a laboratory-based psychophysiology protocol from which the current data were drawn. Among 507 participants in this project, laboratory HR data were available for 436 participants. The age of these 207 male and 229 female participants ranged from 35 to 84 years (mean = 58.26 ± 11.46 years). Table 1 provides detailed information concerning demographics, body mass index, level of physical exercise, smoking status, menopausal status, medical comorbidities, and medications that can influence cardiac autonomic control. Thirty-seven participants (8.5% of the sample) did not show an HR increase in response to the cognitive challenges, and therefore had no HR recovery. Data from these 37 participants was not included in the analysis. This study was approved by the Institutional Review Board at each participating center.

Procedures

Participants traveled to one of three regional sites (Georgetown University, University of California, Los Angeles [UCLA]), or University of Wisconsin-Madison) for an overnight stay in a General Clinical Research Center. The psychophysiology protocol took place during the following morning after a light breakfast with no caffeinated beverages.

Electrocardiographic (ECG) electrodes were placed on the left and right shoulders, and in the left lower quadrant. The participant was seated, and a keypad for responding to the stress tasks was secured in a comfortable position relative to the dominant hand. The protocol order was as follows: seated baseline (11 minutes); psychological stress task 1 (mental arithmetic or Stroop task—6 minutes); recovery 1 (6 minutes); psychological stress task 2 (mental arithmetic or Stroop task—6 minutes); recovery 2 (6 minutes). Task order was counterbalanced. Participants were instructed to remain silent throughout the procedures.

Cognitive Stressors

Mental Arithmetic

A computer-administered mental arithmetic task (21) was utilized. The task presented addition or subtraction problems that were adjusted in level of difficulty based on participants' performance.

TABLE 1. Sample Characteristics

Variable	*n*	Mean ± SD
Age	436	58.31 ± 11.43
Body mass index	436	29.56 ± 6.53
Diseases altering cardiac autonomic function		
High blood pressure	140	N/A
Heart disease	46	
Circulation problems	29	
TIA or stroke	18	
Depression	85	
Diabetes	48	
Medications altering cardiac autonomic function		
β blockers	57	N/A
AV node blockers	4	
Anticholinergic	22	
Sympathomimetic	20	
Have any of the diseases/take any medications listed above		
Yes	327	
No	109	
Sex		
Male	207	N/A
Female	229	
Menopausal status (women)		
Premenopausal	54	
Perimenopausal	15	
Postmenopausal	157	
Smoking		
Never	235	N/A
Smoker	47	
Ex-smoker	154	
Exercise/physical activity (hours/week)		
Vigorous	436	0.95 ± 2.74
Moderate	436	2.75 ± 5.51
Light	436	1.59 ± 3.88

SD = standard deviation; TIA = transient ischemia attack; AV = atrioventricular.

Stroop Color-Word Task

In this computer-administered version of the Stroop task, a color name (blue, green, yellow, or red) was presented on a computer monitor in a color that was either congruent or incongruent with the name. The participants' task was to press a key on the keypad corresponding to the color in which the word was presented rather than the color name.

Acquisition and Processing of ECG Signals

Analog ECG signals were digitized at 500 Hz by a National Instruments A/D board and passed to a microcomputer for collection. The ECG waveform was submitted to an R-wave detection routine implemented by proprietary event detection software, resulting in an RR interval series. Errors in marking of R waves were corrected interactively following established procedures (22,23). HR was calculated based on 58.75-second and 60-second epochs; the epoch length was adjusted to cover the entire recovery period.

Assessment of Recovery

HR data were averaged on a minute-by-minute basis for the Math and the Stroop tasks and associated recovery periods. Mean baseline HR was assessed as an average of minutes 5 to 10. The averaging was performed to obtain a stable estimate of HR response and to improve the reliability of our findings (24).

HRR was evaluated, using the three different methods reported in studies that measure recovery (20,25,26). The first method assessed the amount of

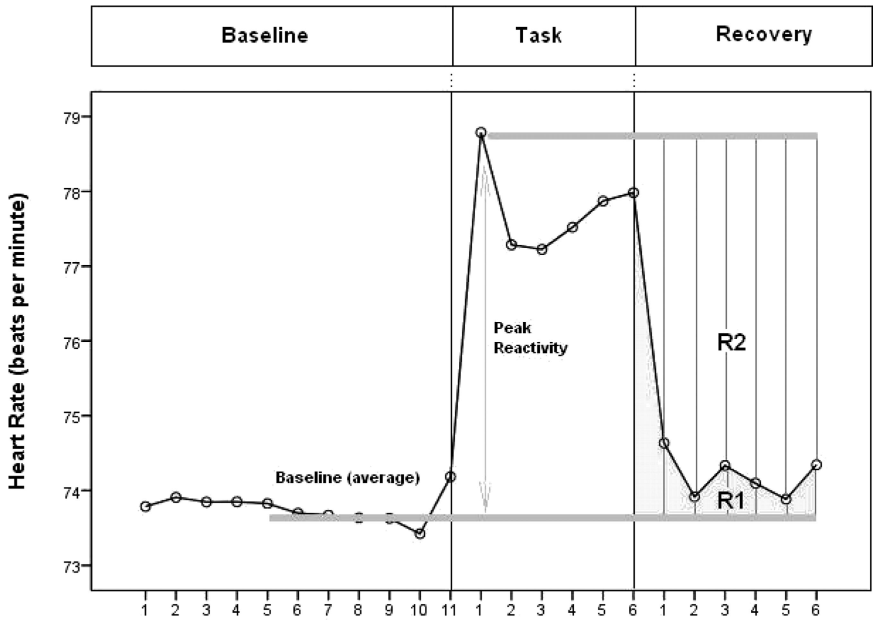

Figure 1. Computation of the area under the curve.

HR change, operationalized as the difference between the averaged reactivity and the averaged recovery period (20). The second method computed the time required for HR to recover by 50%, 75% (26), or 100% (25). Finally, we computed HRR as area under the curve (AUC), as illustrated by Figure 1 (26), and operationalized as the ratio of R2/(R1 + R2). Following this formulation, a greater ratio reflects faster recovery.

Statistical Analysis

All analyses were conducted, using SPSS 17 (SPSS Inc., 2009, Chicago, Illinois).

Replicating the study by Steptoe et al. (20), we categorized age into five groups according to the established MIDUS guidelines (32–44, 45–54, 55–64, 65–74, and 75–84 years old), and HR values were averaged across the baseline and stress, and recovery periods. Repeated-measures analysis of variance was then conducted with age as the independent variable. Unlike Steptoe et al. (20), we did not include education in the model, because all but three of our participants graduated from high school and therefore fell into the "high education" category.

Time to recovery was also analyzed, using multiple linear regression with age and the confounders predicting the seven recovery levels as a categorical variable (corresponding to the 6 minutes of the recovery period and the additional 7th category for those participants who never met the specified recovery criteria). As time to recovery was assessed using three different criteria (50%, 75%, and 100%), we report the results of three different analyses.

A final analysis of HRR AUC also was conducted, using multiple linear regression. All the analyses controlled for the effects of the medical, demographic, and life-style factors known to affect cardiovascular functioning. To account for the effects of disease conditions and medications that can influence cardiac autonomic control, a dummy variable classifying each participant as either having or not having disease conditions/taking medications was entered in the analysis. This ordinal variable was created, using classification guidelines from the CARDIA study (27). Three dummy variables classifying participants' smoking status were created; two of them (current smoker and ex-smoker) were entered in the model, whereas the third one (never smoked) was used as a reference category. Menopausal status was classified as pre-, peri-, and postmenopausal; postmenopausal and perimenopausal status variables were entered in the analysis; the premenopausal status variable served as a reference. Three types of exercise/physical activity were evaluated separately in MIDUS II: The participants reported how many hours per week they spent performing vigorous, moderate, and light physical activity or exercise. Therefore, we created three continuous exercise/physical activity variables for the present analysis; the participants may or may not have had scores on each of these three variables, depending on the responses provided. Finally, we controlled for the participants' sex and body mass index.

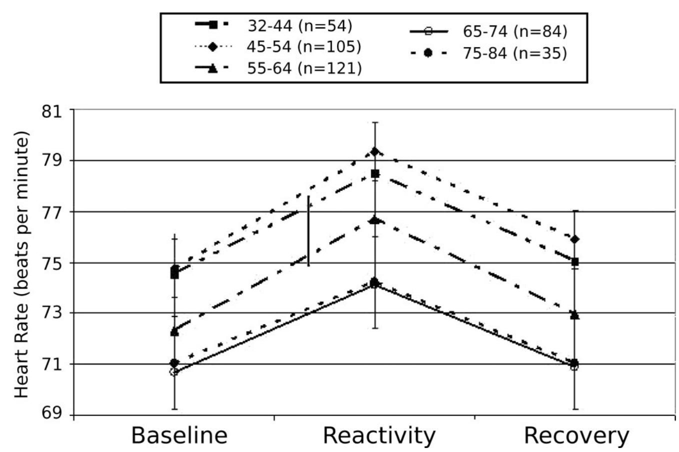

Figure 2. Heart rate values for the baseline, reactivity, and recovery periods for the five age groups (means and standard errors; adjusted for the effects of the covariates).

RESULTS

Repeated-Measures Analysis

The repeated-measures analysis of variance demonstrated no age effect on the HR change across the baseline, reactivity, and recovery periods ($F(8,401) = 1.738$, $p = .104$). Figure 2 depicts mean HR changes for the five age groups adjusted for the effects of the covariates.

Time to Recovery

Table 2 presents the results of analyses of time to 50%, 75%, and 100% HRR. Like the repeated-measures analysis, there was no significant effect of age on the time to recovery as assessed in this way.

TABLE 2. Age and HRR

Predictors	Predicted Variable															
	50% HRR				75% HRR				100% HRR				HRR AUC			
	UnStd. β	Std. Error	Std. β	p	UnStd. Beta	Std. Error	β	p	UnStd. β	Std. Error	Beta	p	UnStd. Beta	Std. Error	β	p
Age	−0.009	0.008	−0.072	.243	−0.012	0.011	−0.067	.273	−0.021	0.014	−0.092	.129	0.002	0.001	0.083	.173
Disease/medications	0.044	0.175	0.013	.802	0.016	0.264	0.003	.953	−0.139	0.325	−0.022	.670	0.004	0.028	0.007	.897
BMI	−0.002	0.011	−0.009	.861	−0.014	0.017	0.043	.412	−0.031	0.021	−0.077	.136	0.001	0.002	0.019	.715
Sex	0.014	0.238	0.005	.952	−0.305	0.36	−0.071	.397	−1.077	0.442	−0.202	.015	0.061	0.038	0.136	.103
Menopausal status (women)[a]																
peri- menopausal	−0.098	0.43	−0.013	.819	−0.309	0.65	−0.027	.635	0.527	0.798	0.036	.509	0.003	0.068	0.002	.970
post-menopausal	0.051	0.257	0.017	.844	0.166	0.389	0.037	.671	0.324	0.478	0.058	.498	−0.025	0.041	−0.052	.545
Smoking status[b]																
Current smoker	0.435	0.238	0.096	.068	0.478	0.359	0.07	.184	0.276	0.441	0.032	.532	−0.102	0.038	−0.142	.007
Ex-smoker	0.013	0.160	0.004	.936	−0.194	0.242	−0.044	.422	−0.332	0.296	−0.060	.263	0.003	0.025	0.007	.901
Vigorous exercise (hrs/week)	−0.014	0.026	−0.027	.598	−0.035	0.039	−0.046	.378	−0.027	0.048	−0.029	.575	0.003	0.004	0.040	.441
Moderate exercise (hrs/week)	0.001	0.013	0.003	.949	−0.016	0.020	−0.043	.413	−0.014	0.024	−0.030	.559	0.001	0.002	0.017	.741
Light exercise (hrs/week)	0.031	0.018	0.086	.091	0.009	0.027	0.017	.743	−0.041	0.033	−0.062	.218	−0.002	0.003	−0.036	.471

HRR = heart rate recovery; AUC = area under the curve; BMI = body mass index.

[a] Menopausal status was coded as a dummy variable: three categories (pre-, peri-, and postmenopausal; men coded as 0 on all the three categories), "premenopausal" is used a reference category.

[b] Smoking status was coded as a dummy variable: three categories (never smoked, current smoker, ex-smoker), "never smoked" is used as a reference category.

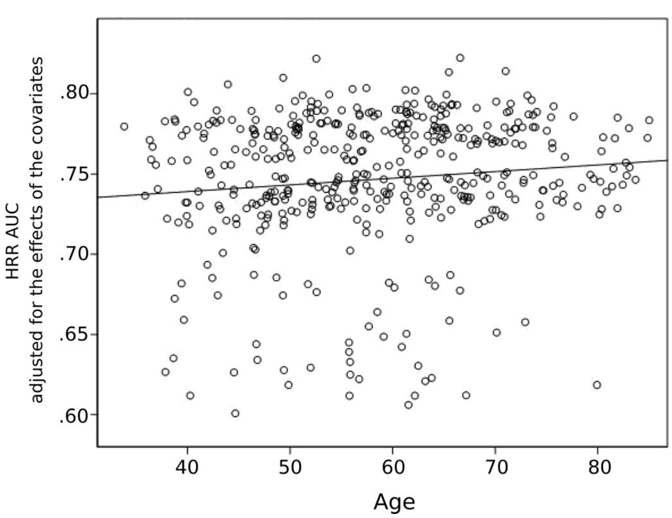

Figure 3. Age and heart rate recovery area under the curve (*HRR AUC*) (adjusted for the effects of the covariates).

Area Under the Curve

Analyses for AUC appear in Table 2. As the table shows, and as Figure 3 illustrates, there was no significant effect of age on the HRR AUC.

DISCUSSION

In the current investigation, HRR from cognitive challenge was preserved with age as measured by all three recovery assessment methods. To the best of our knowledge, only Steptoe et al. (20) have previously investigated the relationship between age and HRR from cognitive challenge. They conducted a repeated-measures analysis on the average HR during baseline, three cognitive tasks, and three recovery periods, and found that greater age was associated with slower recovery (20). However, certain methodological features of their analysis may have contributed to this finding. Rather than collect data on a relatively continuous set of age categories, Steptoe et al. compared 65 to 80 years old to 27 to 42 years old. In addition, their sample size (n = 158) was considerably smaller than ours. Using a larger sample with a broader range of age categories (32–44, 45–54, 55–64, 65–74, and 75–84 years old), we reproduced their repeated-measures analytic approach but found no effect of age on HRR.

Analysis of the mean value of HRR does not reflect the dynamics of recovery, which may provide important insights concerning the functioning of the cardiovascular system. For example, the same amount of HR change may occur either immediately after stressor termination, or require a prolonged period of recovery, which in the current study was 6 minutes. To address this possibility, we measured HRR in 1-minute epochs and analyzed the occurrence of HRR at 50%, 75%, and 100% levels. Moreover, we also conducted combined analysis of the amount and speed HRR by computing AUC (25,26). Neither HRR measured as time to recovery nor AUC was associated with age. The combination of the comprehensive evaluation of recovery, employing three different analytic approaches, and the large data set that included both male and female participants of diverse age range provide confidence in our finding that HRR from cognitive challenge is preserved across the age spectrum.

This finding contrasts with evidence showing that age is related to slower recovery from exercise and may derive from the different physiology of the two responses. HR is the product of both sympathetic and parasympathetic cardiac control. In the case of exercise challenge, the initial HR response is driven primarily by parasympathetic withdrawal but as exercise progresses, the HR-increasing contribution of the sympathetic nervous system increases dramatically. In the case of psychological challenge, the initial HR response also is driven by parasympathetic withdrawal but the sympathetic contribution to the HR reactivity is smaller than that observed in exercise studies (28,29). The relatively greater sympathetic contribution to the HR response to exercise may lead to greater residual sympathetic activation at the termination of the stressor, thus slowing HR recovery. Because aging is associated with increased sympathetic cardiac control both at rest and in response to stress (3,4), HR in older participants may take longer to recover after exercise.

Studies of RR interval variability reveal that cardiac parasympathetic modulation decreases with age (30,31), but no studies have examined the role of age on recovery of parasympathetic control after cognitive challenge. HRR from cognitive challenge may possibly be preserved in older participants because the restoration of parasympathetic HR modulation may also be preserved with age. Investigation of the age-related differences in the recovery of parasympathetic and sympathetic cardiac control, however, is beyond the scope of the present study, and should be addressed in future research.

It is also possible that the preservation of the HRR after cognitive challenge with age may be the product of psychological factors. For example, cognitive challenge, in contrast to exercise, can lead to postchallenge rumination, which has consistently been shown to delay cardiovascular recovery from that challenge (32–34). Thus, Glynn et al. (34) compared the effects of mental re-creation of subjects' performance on mental arithmetic and exercise tasks on cardiovascular recovery, and found that rumination delayed cardiovascular recovery after the mental arithmetic task but not after exercise. Aging is associated with decreased rumination (35) and improved emotion regulation (36,37). Mood induction studies demonstrate that, compared with their younger counterparts, older adults are better able to restore their mood after watching films and listening to music that elicited negative emotions (38,39). Thus, we speculate that a reduction in the tendency to ruminate may buffer the age-associated deterioration of cardiovascular structure and function.

Our findings are limited by the cross-sectional nature of the present investigation as HRR preservation in older individuals may represent a cohort effect. The longitudinal follow-up is necessary to validate our results. Because MIDUS II lacked any rumination-related measures, we were unable to test the hypothesis that HRR is preserved in older adults because they engage in superior emotion regulation post cognitive stress.

To conclude, we found that HRR after cognitive challenge, measured comprehensively using three methods, was preserved with age. This finding remained after adjustment for several potential demographic, life-style, and medical confounders. Future research should explore the role that changes in emotion regulation with increasing age may play in HRR from cognitive challenge.

We thank the staff of the Clinical Research Centers at the University of Wisconsin-Madison, UCLA, and Georgetown University for their support in conducting this study. We thank the staff of the Clinical Research Centers at the University of Wisconsin-Madison, UCLA, and Georgetown University for their support in conducting this study. We also appreciate helpful advice of Ivy Chen, MST, who consulted on many important aspects of the statistical analysis for the present paper.

REFERENCES

1. Alexander KP, Newby LK, Armstrong PW, Cannon CP, Gibler WB, Rich MW, Van de Werf F, White HD, Weaver WD, Naylor MD, Gore JM, Krumholz HM, Ohman EM. Acute coronary care in the elderly, Part II—ST-segment-elevation myocardial infarction—a scientific statement for healthcare professionals from the American Heart Association Council on Clinical Cardiology—in collaboration with the Society of Geriatric Cardiology. Circulation 2007;115:2570–89.
2. Lakatta E. Age-associated cardiovascular changes in health: impact on cardiovascular disease in older persons. Heart Fail Rev 2002;7:29–49.
3. Kaye DM, Esler MD. Autonomic control of the aging heart. Neuromolecular Med 2008;10:179–86.
4. Esler M, Lambert G, Kaye D, Rumantir M, Hastings J, Seals DR. Influence of ageing on the sympathetic nervous system and adrenal medulla at rest and during stress. Biogerontology 2002;3:45–9.
5. Ferrari AU, Radaelli A, Centola M. Invited review: aging and the cardiovascular system. J Appl Physiol 2003;95:2591–7.
6. Cole CR, Blackstone EH, Pashkow FJ, Snader CE, Lauer MS. Heart-rate recovery immediately after exercise as a predictor of mortality. N Engl J Med 1999;341:1351–7.
7. Antelmi I, Chuang EY, Grupi CJ, Latorre Mdo, Mansur AJ. Heart rate recovery after treadmill electrocardiographic exercise stress test and 24-hour heart rate variability in healthy individuals. Arq Bras Cardiol 2008;90:380–5.
8. Hughes JW, York, Kaki M, Li, Qin, Freedland, Kenneth E, Carney, Robert M, Sheps, David S. Depressive symptoms predict heart rate recovery after exercise treadmill testing in patients with coronary artery disease: results from the psychophysiological investigations of myocardial ischemia study. Psychosom Med 2008;70:456–60.
9. Deschenes MR, Hillard MN, Wilson JA, Dubina MI, Eason MK. Effects of gender on physiological responses during submaximal exercise and recovery. Med Sci Sports Exerc 2006;38:1304–10.
10. Jae SY, Carnethon MR, Heffernan KS, Choi YH, Lee MK, Park WH, Fernhall B. Slow heart rate recovery after exercise is associated with carotid atherosclerosis. Atherosclerosis 2008;196:256–61.
11. Pitsavos CH, Chrysohoou C, Panagiotakos DB, Kokkinos P, Skoumas J, Papaioannou I, Michaelides AP, Singh S, Stefanadis CI. Exercise capacity and heart rate recovery as predictors of coronary heart disease events, in patients with heterozygous familial hypercholesterolemia. Atherosclerosis 2004;173:347–52.
12. Morshedi-Meibodi A, Larson MG, Levy D, O'Donnell CJ, Vasan RS. Heart rate recovery after treadmill exercise testing and risk of cardiovascular disease events (the Framingham Heart Study). Am J Cardiol 2002; 90:848–52.
13. Dewey FE, Freeman JV, Engel G, Oviedo R, Abrol N, Ahmed N, Myers J, Froelicher VF. Novel predictor of prognosis from exercise stress testing: heart rate variability response to the exercise treadmill test. Am Heart J 2007;153:281–8.
14. Cole CR, Foody JM, Blackstone EH, Lauer MS. Heart rate recovery after submaximal exercise testing as a predictor of mortality in a cardiovascularly healthy cohort. Ann Intern Med 2000;132:552–5.
15. Jouven X, Empana JP, Schwartz PJ, Desnos M, Courbon D, Ducimetiere P. Heart-rate profile during exercise as a predictor of sudden death. N Engl J Med 2005;352:1951–8.
16. Nishime EO, Cole CR, Blackstone EH, Pashkow FJ, Lauer MS. Heart rate recovery and treadmill exercise score as predictors of mortality in patients referred for exercise ECG. JAMA 2000;284:1392–8.

17. Heponiemi T, Elovainio M, Pulkki L, Puttonen S, Raitakari O, Keltikangas-Jarvinen L. Cardiac autonomic reactivity and recovery in predicting carotid atherosclerosis: the cardiovascular risk in young Finns study. Health Psychol 2007;26:13–21.
18. Moseley JV, Linden W. Predicting blood pressure and heart rate change with cardiovascular reactivity and recovery: results from 3-year and 10-year follow up. Psychosom Med 2006;68:833–43.
19. Stewart JC, Janicki DL, Kamarck TW. Cardiovascular reactivity to and recovery from psychological challenge as predictors of 3-year change in blood pressure. Health Psychol 2006;25:111–8.
20. Steptoe A, Kunz-Ebrecht SR, Wright C, Feldman PJ. Socioeconomic position and cardiovascular and neuroendocrine responses following cognitive challenge in old age. Biol Psychol 2005;69:149–66.
21. Turner JR, Hewitt JK, Morgan RK, Simes J, Carroll D, Kelly KA. Graded mental arithmetic as an active psychological challenge. Int J Psychophysiol 1986;3:307–9.
22. Dykes FD, Ahmann PA, Baldzer K, Carrigan TA, Kitney RI, Giddens DP. Breath amplitude modulation of heart rate variability in normal full term neonates. Pediatr Res 1986;20:301–8.
23. Berntson GG, Quigley KS, Lang JF, Boysen ST. An approach to artifact identification: application to heart period data. Psychophysiology 1990; 27:586–98.
24. Kamarck TW. For distinguished early career contribution to psychophysiology: SPR Award Address, 1991. Recent developments in the study of cardiovascular reactivity: contributions from psychometric theory and social psychology. Psychophysiology 1992;29:491–503.
25. Christenfeld N, Glynn LM, Gerin W. On the reliable assessment of cardiovascular recovery: an application of curve-fitting techniques. Psychophysiology 2000;37:543–50.
26. Kario K, Schwartz JE, Gerin W, Robayo N, Maceo E, Pickering TG. Psychological and physical stress-induced cardiovascular reactivity and diurnal blood pressure variation in women with different work shifts. Hypertens Res 2002;25:543–51.
27. Sloan RP, Huang MH, McCreath H, Sidney S, Liu K, Dale Williams O, Seeman T. Cardiac autonomic control and the effects of age, race, and sex: the CARDIA study. Auton Neurosci 2008;139:78–85.
28. Guyton AC, Hall JE. Textbook of Medical Physiology, 11th edition. Philadelphia: Elsevier; 2006.
29. Lahiri MK, Kannankeril PJ, Goldberger JJ. Assessment of autonomic function in cardiovascular disease. J Am Coll Cardiol 2008;51:1725–33.
30. Fukusaki C, Kawakubo K, Yamamoto Y. Assessment of the primary effect of aging on heart rate variability in humans. Clin Auton Res 2000;10:123–30.
31. Umetani K, Singer DH, McCraty R, Atkinson M. Twenty-four hour time domain heart rate variability and heart rate: relations to age and gender over nine decades. J Am Coll Cardiol 1998;31:593–601.
32. Gerin W, Davidson KW, Christenfeld NJ, Goyal T, Schwartz JE. The role of angry rumination and distraction in blood pressure recovery from emotional arousal. Psychosom Med 2006;68:64–72.
33. Key BL, Campbell TS, Bacon SL, Gerin W. The influence of trait and state rumination on cardiovascular recovery from a negative emotional stressor. J Behav Med 2008;31:237–48.
34. Glynn LM, Christenfeld N, Gerin W. The role of rumination in recovery from reactivity: vardiovascular consequences of emotional states. Psychosom Med 2002;64:714–26.
35. Phillips LH, Henry JD, Hosie JA, Milne AB. Age, anger regulation and well-being. Aging Ment Health 2006;10:250–6.
36. Gross JJ, Carstensen LL, Pasupathi M, Tsai J, Skorpen CG, Hsu AYC. Emotion and aging: experience, expression, and control. Psychol Aging 1997;12:590–9.
37. Mroczek DK, Kolarz CM. The effect of age on positive and negative affect: a developmental perspective on happiness. J Pers Soc Psychol 1998;75:1333–49.
38. Phillips LH, Henry JD, Hosie JA, Milne AB. Effective regulation of the experience and expression of negative affect in old age. J Gerontol B Psychol Sci Soc Sci 2008;63:P138–P145.
39. Kliegel M, Jager T, Phillips LH. Emotional development across adulthood: differential age-related emotional reactivity and emotion regulation in a negative mood induction procedure. Int J Aging Hum Dev 2007;64:217–44.