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## Heart Rate Recovery after Cognitive Challenge is Preserved with Age

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### Abstract

**Objectives**—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 following exposure to cognitive challenge (mental arithmetic and Stroop) was investigated in a sample of 436 participants aged 35–84 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 (AUC). The analyses were controlled for medical comorbidities and medications that influence HR, such as BMI, 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 vs. exercise stress, including any role for improved emotion regulation with greater age.

### Keywords

heart rate recovery; aging; autonomic nervous system; area under the curve; rumination

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## INTRODUCTION

Aging is strongly associated with elevated risk for cardiovascular morbidity and mortality. For example, the prevalence of coronary artery disease and hypertension rises significantly with age, while over 80% of cardiovascular deaths occur in people aged 65 or older (1). In an effort 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 response, which is indicative of decreased sensitivity to  $\beta$ -adrenergic stimulation (2,5). Moreover, the effects of age persist during the post-exercise recovery period, as older individuals recover considerably more slowly compared to 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). Indeed, 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 following 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 incidence of atherosclerosis at the 2-year follow-up assessment. Since delayed HRR from both exercise and cognitive challenge increases 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 27–80 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 participants had slower HRR compared to younger participants. In addition, those older participants who had lower education recovered more slowly compared to those older participants who had higher education. While suggestive, the reliance of these analyses on averaged scores rather than on a more complete post-stress 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 USA. 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 heart rate data were available for 436 participants. The age of these 207 male and 229 female participants ranged from 35 to 84 (mean = 58.26 +/- 11.46 years). Table 1 provides detailed information concerning demographics, BMI, 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 IRB at each participating center.

### Procedures

Participants traveled to one of three regional sites (Georgetown University, 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.

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.

**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 and 60-sec 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 5–10. The averaging was performed in order 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 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). Replicating Steptoe et al. (20), age was categorized into 5 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 ANOVA 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 3 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 7 recovery levels as a categorical variable (corresponding to the 6 minutes of the recovery period and the additional 7<sup>th</sup> category for those participants who never met the specified recovery criteria). As time to recovery was assessed using 3 different criteria (50%, 75% and 100%), we report the results of 3 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, while the third one (never smoked) was used as a reference category. Menopausal status was classified as pre-, peri- and post-menopausal; post-menopausal and peri-menopausal status variables were entered in the

analysis; the pre-menopausal 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 BMI.

## Results

**Repeated Measures Analysis**—The repeated measures ANOVA 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% HR recovery. Like the repeated measures analysis, there was no significant effect of age on the time to recovery as assessed in this way.

**Area under the Curve**—Analyses for area under the curve 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) has 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 65–80 year olds to 27–42 year olds. In addition, their sample size, 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 olds), 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 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 recovery in one 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 dataset that included both male and female participants of diverse age range provides 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 rises 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 indeed 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 by the 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 post-challenge 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 to 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 heart rate recovery 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 older adults because they engage in superior emotion regulation following cognitive stress.

To conclude, we found that HRR after cognitive challenge, measured comprehensively using 3 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 HR recovery from cognitive challenge.

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## Glossary

HR            heart rate

HRR	heart rate recovery
AUC	area under the curve
BMI	body mass index
ECG	electrocardiogram

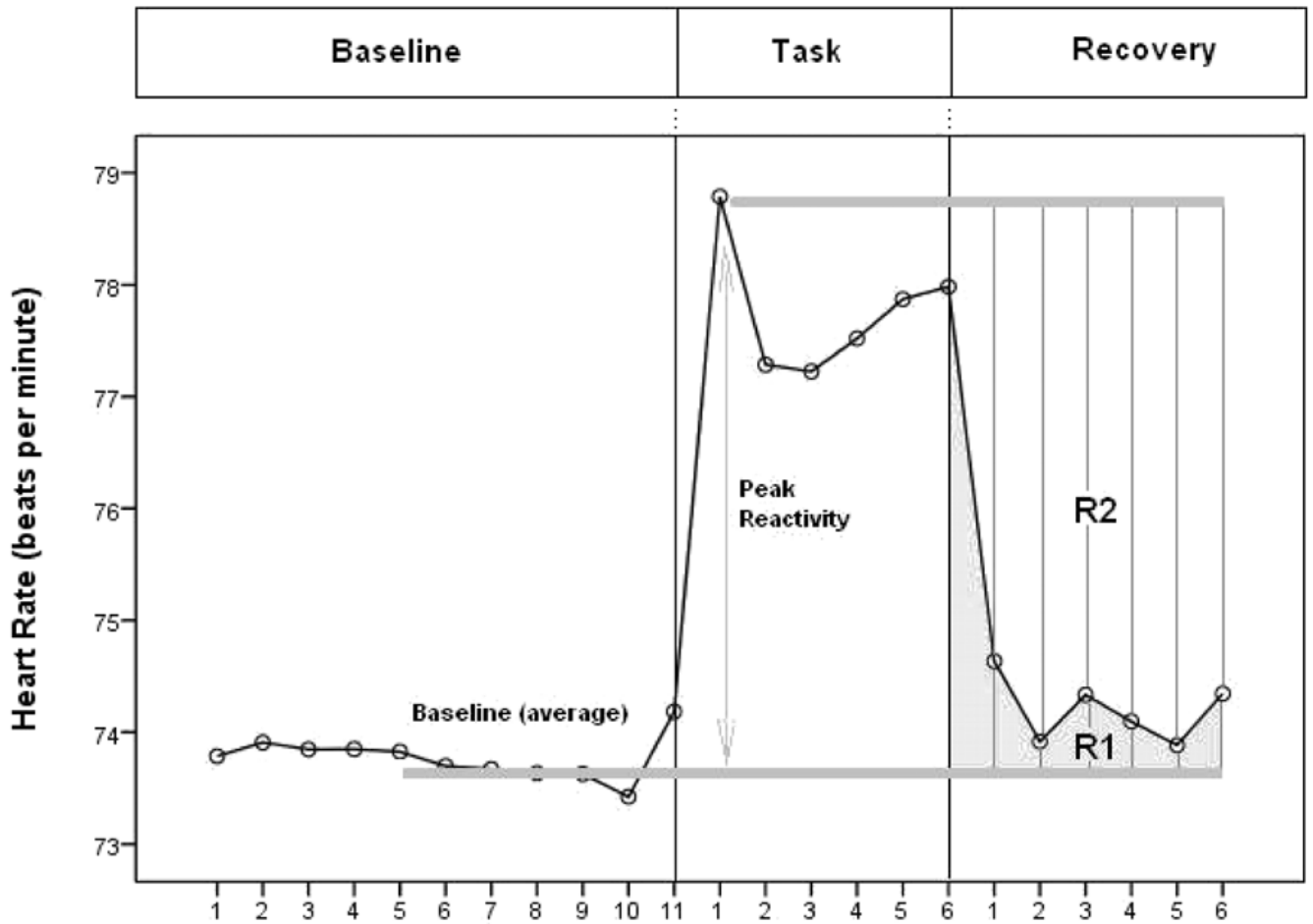
## References

- 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. [PubMed: 17502591]
- Lakatta E. Age-associated cardiovascular changes in health: impact on cardiovascular disease in older persons. *Heart Failure Review* 2002;7:29–49.
- Kaye D, Esler MD. Autonomic control of the aging heart. *NeuroMolecular Medicine* 2008;10:179–86. [PubMed: 18338270]
- Esler M, Lambert G, Kaye D, Rumantr 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. [PubMed: 12014841]
- Ferrari AU, Radaelli A, Centola M. Invited review: Aging and the cardiovascular system. *Journal of Applied Physiology* 2003;95:2591–7. [PubMed: 14600164]
- Cole CR, Blackstone EH, Pashkow FJ, Snader CE, Lauer MS. Heart-rate recovery immediately after exercise as a predictor of mortality. *New England Journal of Medicine* 1999;341:1351–7. [PubMed: 10536127]
- Antelmi I, Chuang EY, Grupi CJ, Latorre MdrRDdO, 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. [PubMed: 18592090]
- 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. *Psychosomatic Medicine* 2008;70:456–60. [PubMed: 18434491]
- Deschenes MHMN, Wilson JA, Dubina MI, Eason MK. Effects of gender on physiological responses during submaximal exercise and recovery. *Medicine and science in sports and exercise* 2006;38:1304–10. [PubMed: 16826028]
- 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. [PubMed: 17137583]
- 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. [PubMed: 15064112]
- 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). *American Journal of Cardiology* 2002;90 PII S0002-9149(02)02706-6.
- 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. *American Heart Journal* 2007;153:281–8. [PubMed: 17239690]
- 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. *Annals of Internal Medicine* 2000;132:552–5. [PubMed: 10744592]

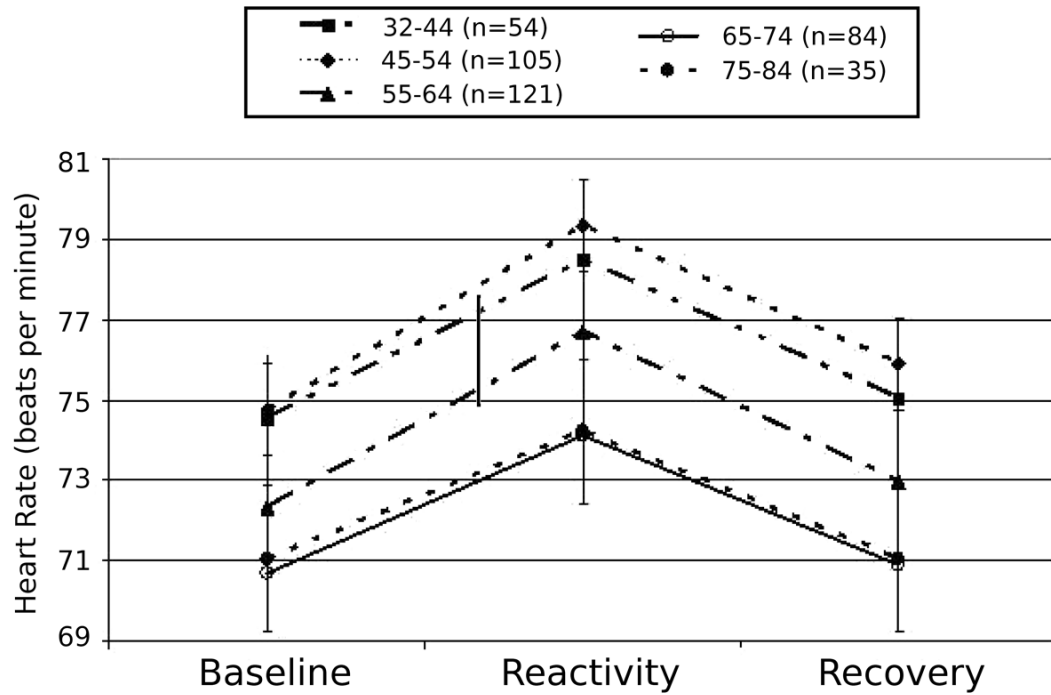
15. Jouven X, Empana JP, Schwartz PJ, Desnos M, Courbon D, Ducimetiere P. Heart-rate profile during exercise as a predictor of sudden death. *New England Journal of Medicine* 2005;352:1951–8. [PubMed: 15888695]
16. Nishime EO, Cole CR, Blackstone EH, Pashkow FJ, Lauer MS. Heart rate recovery and treadmill exercise score as predictors of mortality in patients referred for exercise ECG. *Jama-Journal of the American Medical Association* 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. [PubMed: 17209693]
18. Moseley JV, Linden. Wolfgang Predicting blood pressure and heart rate change with cardiovascular reactivity and recovery: Results from 3-year and 10-year follow up. *Psychosomatic medicine* 2006;68:833–43. [PubMed: 17132835]
19. Stewart JCJ, Denise L, Kamarck Thomas W. Cardiovascular reactivity to and recovery from psychological challenge as predictors of 3-year change in blood pressure. *Health Psychol* 2006;25:111–8. [PubMed: 16448304]
20. Steptoe A, Kunz-Ebrecht SR, Wright C, Feldman PJ. Socioeconomic position and cardiovascular and neuroendocrine responses following cognitive challenge in old age. *Biological Psychology* 2005;69:149–66. [PubMed: 15804543]
21. Turner JR, Hewitt JK, Morgan RK, Simes J, Carroll D, Kelly KA. Graded mental arithmetic as an active psychological challenge. *International Journal of Psychophysiology* 1986;3:307–9. [PubMed: 3754545]
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. *Pediatric Research* 1986;20:301–8. [PubMed: 3703619]
23. Berntson GG, Quigley KS, Lang JF, Boysen ST. An approach to artifact identification: Application to heart period data. *Psychophysiology* 1990;27:586–98. [PubMed: 2274622]
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. [PubMed: 1410179]
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. [PubMed: 10934913]
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. *Hypertension research* 2002;25:543–51. [PubMed: 12358139]
27. Sloan RP, Huang MH, McCreath H, Sidney S, Liu KA, Williams OD, Seeman T. Cardiac autonomic control and the effects of age, race, and sex: The CARDIA study. *Autonomic Neuroscience-Basic & Clinical* 2008;139:78–85.
28. Guyton ACaH, JE. *Textbook of Medical Physiology*. 11. Philadelphia, Pennsylvania: Elsevier Inc; 2006. p. 2006
29. Lahiri MK, Kannankeril PJ, Goldberger JJ. Assessment of autonomic function in cardiovascular disease. *Journal of the American College of Cardiology* 2008;51:1725–33. [PubMed: 18452777]
30. Fukusaki CKK, Yamamoto Y. Assessment of the primary effect of aging on heart rate variability in humans. *Clinical autonomic research* 2000;10:123–30. [PubMed: 10954070]
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. *Journal of the American College of Cardiology* 1998;31:593–601. [PubMed: 9502641]
32. Gerin WPD, Karina W PhD, Christenfeld Nicholas JS PhD, Goyal Tanya PhD, Schwartz Joseph E PhD. The role of angry rumination and distraction in blood pressure recovery from emotional arousal. *Psychosomatic medicine* 2006;68:64–72. [PubMed: 16449413]
33. Key BL, Campbell TS, Bacon SL, Gerin W. The influence of trait and state rumination on cardiovascular recovery from a negative emotional stressor. *Journal of Behavioral Medicine* 2008;31:237–48. [PubMed: 18350377]



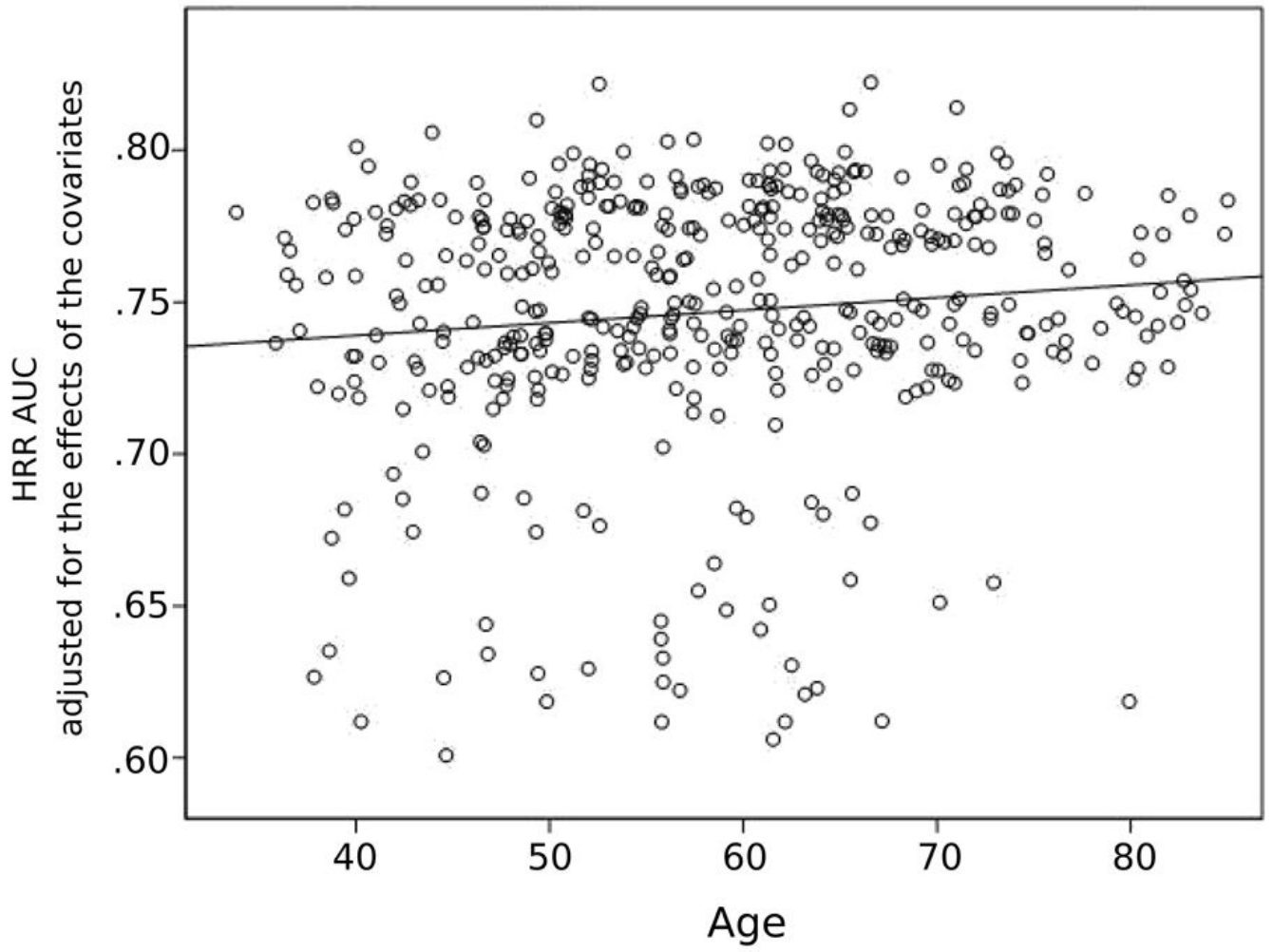
34. Glynn LM, Christenfeld N, Gerin W. The role of rumination in recovery from reactivity: Cardiovascular consequences of emotional states. *Psychosomatic Medicine* 2002;64:714–26. [PubMed: 12271102]
35. Phillips LH, Henry JD, Hosie JA, Milne AB. Age, anger regulation and well-being. *Aging & Mental Health* 2006;10:250–6. [PubMed: 16777652]
36. Gross JJ, Carstensen LL, Pasupathi M, Tsai J, Skorpen CG, Hsu AYC. Emotion and aging: Experience, expression, and control. *Psychology and Aging* 1997;12:590–9. [PubMed: 9416628]
37. Mroczek DK, Kolarz CM. The effect of age on positive and negative affect: A developmental perspective on happiness. *Journal of Personality and Social Psychology* 1998;75:1333–49. [PubMed: 9866191]
38. Phillips LH, Henry JD, Hosie JA, Milne AB. Effective regulation of the experience and expression of negative affect in old age. *Journals of Gerontology Series B-Psychological Sciences and Social Sciences* 2008;63:P138–P45.
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. *International Journal of Aging & Human Development* 2007;64:217–44. [PubMed: 17503687]



**Figure 1.**  
Computation of the Area Under the Curve.



**Figure 2.** HR values for the baseline, reactivity, and recovery periods for the 5 age groups (means and standard errors; adjusted for the effects of the covariates).



**Figure 3.**  
Age and HRR AUC (adjusted for the effects of the covariates).

**Table 1**

## Sample characteristics

Variable		N	Mean and SD
Age		436	58.26+/- 11.46
BMI		436	29.60+/- 6.56
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	Beta-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)	Pre-menopausal	54	
	Peri-menopausal	15	
	Post-menopausal	157	
Smoking	Never	235	N/A
	Smoker	47	
	Ex-smoker	154	
Exercise/physical activity (hours per week)	Vigorous	436	0.99+/-2.83
	Moderate	436	2.63+/-5.40
	Light	436	1.57+/- 3.85

Table 2

	Predicted variable															
	50% HRR				75% HRR				100% HRR				HRR AUC			
	UnStd. Beta	Std. Error	Std. Beta	p	UnStd. Beta	Std. Error	Std. Beta	p	UnStd. Beta	Std. Error	Std. Beta	p	UnStd. Beta	Std. Error	Std. Beta	p
Education	-.009	.008	-.072	.243	-.012	.011	-.067	.273	-.021	.014	-.092	.129	.002	.001	.083	.173
	.044	.175	.013	.802	.016	.264	.003	.953	-.139	.325	-.022	.670	.004	.028	.007	.897
	-.002	.011	-.009	.861	-.014	.017	.043	.412	-.031	.021	-.077	.136	.001	.002	.019	.715
	.014	.238	.005	.952	-.305	.360	-.071	.397	-.1077	.442	-.202	.015	.061	.038	.136	.103
Menopausal status (women) <sup>a</sup>	-.098	.430	-.013	.819	-.309	.650	-.027	.635	.527	.798	.036	.509	.003	.068	.002	.970
	.051	.257	.017	.844	.166	.389	.037	.671	.324	.478	.058	.498	-.025	.041	-.052	.545
Menopausal status <sup>b</sup>	.435	.238	.096	.068	.478	.359	.070	.184	.276	.441	.032	.532	-.102	.038	-.142	.007
	.013	.160	.004	.936	-.194	.242	-.044	.422	-.332	.296	-.060	.263	.003	.025	.007	.901
Exercise (hrs/week)	-.014	.026	-.027	.598	-.035	.039	-.046	.378	-.027	.048	-.029	.575	.003	.004	.040	.441
	.001	.013	.003	.949	-.016	.020	-.043	.413	-.014	.024	-.030	.559	.001	.002	.017	.741
Exercise (hrs/week)	.031	.018	.086	.091	.009	.027	.017	.743	-.041	.033	-.062	.218	-.002	.003	-.036	.471

Menopausal status was coded as a dummy variable: three categories (*pre-*, *peri-*, and *post-menopausal*; men coded as 0 on all the three categories), *pre-menopausal* is used as a reference category.

Exercise was coded as a dummy variable: three categories (*never smoked*, *current smoker*, *ex-smoker*), *never smoked* is used as a reference category.