

Aging or Disease? Cardiovascular Reactivity in Finnish Men Over the Middle Years

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Cardiovascular responses to psychological events may mediate the influence of stress on cardiovascular disease. In this study the authors asked whether cardiovascular responses to psychological challenge changed with age and whether such changes were intrinsic to aging or could be attributed to the influence of disease and medications. Cardiovascular reactivity to mental challenge was examined in 902 men ranging in age from 46 to 64 years who participated in the Kuopio Ischemic Heart Disease Risk Factor Study. A battery of 4 tasks was used to induce cardiovascular responses. Current disease status, age, and medication use were entered into hierarchical regression analyses to assess their relation with measures of cardiovascular reactivity. Age and hypertension contributed independent, approximately equal, but small amounts of variance in the cardiac and vascular reactivity indexes. Medications also influenced reactivity independently of age and disease. Performance on the tasks was more consistently altered by age than by disease or medication. Cardiac and vascular reactivity increased with increasing age and the presence of hypertension. The authors conclude that both age and disease state must be considered when examining cardiovascular reactivity as a risk factor for disease.

The amplitude of an individual's cardiovascular reactions to stress or challenge may be correlated with the subsequent development of cardiovascular disease. Controlling for standard medical risk factors, a number of studies have found that responsiveness to a challenge is correlated with the subsequent expression of cardiovascular disease (Keys et al., 1971; Manuck, 1994; Manuck, Olsson, Hjendahl, & Rehnqvist, 1992; Menkes et al., 1989; Wood, Sheps, Elveback, & Schiryer, 1984). Aging, a standard medical risk factor, is intimately related to cardiovascular disease both because of the high prevalence of these diseases in older adults and because these diseases develop slowly, at least over the middle and later years. How do age and reactivity

to psychological challenge interrelate such that both may be independent risk factors for the development of cardiovascular disease? Does aging intrinsically increase vulnerability to disease, or is age merely a convenient marker for slowly developing covert disease? Reactivity to a stressful challenge is the normal reaction of a healthy cardiovascular system; with advanced cardiovascular disease, reactivity to stress and exercise is impaired. If hyperreactivity to stress is a risk factor for disease, then we should assess this reactivity before cardiovascular disease, and perhaps aging acts to decrease this reactivity. Interestingly, there are some indications that measures of hostility (a trait related to reactivity; Suarez, Williams, Kuhn, Zimmerman, & Schanberg, 1991) taken at middle age are more predictive of heart disease than such measures taken from older patients (e.g., Williams et al., 1988). In short, the interrelations of aging and cardiovascular reactivity must be understood if we are to understand how both contribute to cardiovascular disease. This article contributes to this understanding by examining the separate and joint influences of aging and disease on the expression of cardiovascular reactions to psychological challenge across middle age.

The psychological events that induce cardiovascular reactivity have not been well characterized (e.g., J. R. Turner, Sherwood, & Light, 1992). Stress and attendant emotional reactions are generally considered to increase heart rate and blood pressure (e.g., Lazarus, 1966). Heart rate and blood pressure also increase, however, during physical and mental work (e.g., Jennings, 1986). Cardiovascular reactions are typically only weakly coupled to self-reports of either emotion or mental effort

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(Jennings, Lawrence, & Kasper, 1978; Öhman, 1987). Thus, a specific psychological source for cardiovascular reactivity is as yet not clearly defined. In the current research, cardiovascular reactions are elicited by asking study participants to perform challenging mental tasks. The tasks are not rated as highly stressful (Kamarck et al., 1992), but some have stressful elements. Reliable cardiovascular reactions appear to result from engaging participants in mental work sufficiently challenging to elicit affect related to moment-to-moment successes and failures on the tasks (Kamarck et al., 1992; Kamarck, Jennings, & Manuck, 1993).

Interpreting cardiovascular reactivity to our challenges thus requires a consideration of whether aging might directly change the challenge offered by a mental task or the affect related to success and failure. We could not infer an influence of age on cardiovascular reactivity if the age groups studied were given different challenges or showed different affects to success and failure. Turning first to emotion, we can ask whether transient affective responses to challenge are altered with age. Such responses might show some stability even in the face of possible changes in patterns of emotional adjustment and patterns of adjustment with age (e.g., Heckhausen & Schulz, 1995). Levenson, Carstensen, Friesen, and Ekman (1991) examined how age influenced physiological responses to emotion and noted the dearth of information on this topic (see Schulz, 1985). In their study, Levenson et al. (1991) found that participants in their 70s reported experiencing emotions as vividly as college-age study participants. Furthermore, facial expressions and physiological responses separated different emotions equally as well in both groups. Despite this, the older individuals had generally smaller physiological responses to the emotional induction than the younger persons. Levenson et al. (1991) concluded that emotions are clearly present and differentiated in older people. The diminished physiological responding may indicate a decrease in the linkage between emotion and biological response, but their study did not have a nonaffective control condition to determine whether all physiological responsivity was decreased or just that to emotion. Although there seems to be general agreement about a decrease in psychophysiological responsivity (even as assessed by self-report; Lawton, Kleban, & Dean, 1993) with age, self-report indexes of affect (e.g., hostility, anger expression) have not uniformly been shown to increase, decrease, or remain the same with age (Barefoot, Beckham, Haney, Siegler, & Lipkus, 1993; Carstensen & Turk-Charles, 1994; Lawton, Kleban, & Dean, 1993; Malatesta & Kalnok, 1984; Malatesta-Magai, Jonas, Shepard, & Culver, 1992). At present, on the basis of this evidence, we can reasonably assume that affect induced by similar challenges is experienced similarly across age groups.

In contrast, declines in performance with age on many mental tasks are well documented (see Salthouse, 1996, for a review; also Salthouse, 1985). With age, the same nominal mental task is likely to present an increasing level of challenge to individuals of increasing age.

The current research attempted to present comparable performance and affective challenges to individuals across the ages studied. This was done first by designing computerized tasks that adjusted difficulty to meet the performance level of the

participant. Task difficulty was titrated until the individual was successful on the task about 60% of the time. Thus, regardless of age, participants should be equivalently challenged and affectively involved by the task. Second, we hoped to minimize differences in performance skill and affective response by studying a relatively small age span (18 years). Third, extremes of affective response were avoided by neutral task presentation; the tasks were not accompanied by harassment, ego-involving instructions, or large monetary payoffs or losses. Thus, we sought to compare the cardiovascular reactivity of different age groups to a consistent performance challenge eliciting mild affect. Any differences in cardiovascular reactivity could then be attributed to age differences in psychophysiological responses to an engaging mental task and not to age differences in performance skill or affect.

From a physiological perspective, changes in the cardiovascular system with age are relatively well documented, but less is known about age-related changes in the system's reactivity. Increasing age is related to increases in blood pressure and little change (typically minor decrements) in heart rate and cardiac output (see Folkow & Svanborg, 1993; Kohn, 1977; Lakatta, 1985; Shock, 1977; Shock et al., 1984; Swine, 1992). Changes in resting cardiovascular physiology may be related to structural changes with age in the heart and vasculature, primarily an increased stiffness of both. Responsivity of the heart and vasculature to metabolic and mental requirements may be related in addition to age-related changes in the transduction of afferent and efferent messages via the nervous and endocrine systems. Changes in these systems are reviewed by Amenta (1993) and Folkow and Svanborg (1993). Age trends in cardiovascular responses to psychological challenges have not been widely studied, but the literature has been reviewed by Jennings and Yovetich (1991). The most agreed-on finding is that blood pressure reactions tend to increase with age, whereas heart rate reactions decrease. Blood pressure responses are primarily due to sympathetic nervous system activation (adrenergic responses), whereas heart rate is primarily controlled by the parasympathetic nervous system through the vagal nerve activating cholinergic receptors. Thus, interpreting existing age trends further to suggest that adrenergic responses increase with age but vagal responses decrease is tempting. Such an inference is not possible, however, given conflicting animal and human results on changes in adrenergic and cholinergic receptor sensitivities with age. Conceptually, if reactivity to stress is a risk factor, then risk might increase with age given increments in cardiac and vascular adrenergic activation with age and a decline in vagal restraint (e.g., De Meersman, 1993; Ingall, McLeod, & O'Brien, 1990; cf. Folkow & Svanborg, 1993).

The aim of this article is to present methods and descriptive results from a large sample of cardiovascular reactivity data collected in Kuopio, Finland, as part of a larger epidemiological study (Kuopio Ischemic Heart Disease Risk Factor Study, or KIHDS; Salonen, 1988). The descriptive question is asked, "How much of the variance between individuals in cardiovascular reactions to psychological challenges can be attributed to age, disease, and medication use?" By using a multiple regression analysis that sequentially adds the variable contributing the most unique variance to the overall model, we can assess whether

variance caused by age is better explained by presence of a disease (or vice versa). Medication effects are included to ensure that medication influences do not obscure a disease (or aging) effect and also to assess the impact of medication on reactivity in a community sample. We are also able to examine the performance levels achieved by participants on our mental challenge tasks. These measures are used primarily to ensure that apparent age differences are not due to performance skill, but the degree to which age and disease influence performance level is also of interest. Age was a cross-sectional variable; men were selected from four different age cohorts. At the time of cardiovascular reactivity testing, the men's ages were 46, 52, 58, or 64 years. Major influences of both aging and chronic disease are expected to occur in this age range; thus, the sample seemed optimal for comparing disease and aging influences on cardiovascular reactivity. We report cross-sectional differences in cardiac and vascular responses with age as defined by statistically derived combinations of reactions assessed with electrocardiography, impedance cardiography, and photoplethysmography. A measure of vagally controlled heart rate change is also included as a separate variable because of reports of the importance of maintained vagal function for reducing risk of myocardial infarction (see brief review in Jennings & McKnight, 1994).

Method

Sample

The volunteers for this study were participants in KIHD, which was designed to investigate previously unestablished risk factors for ischemic heart disease, carotid atherosclerosis, and related disease outcomes in a population-based sample of eastern Finnish men. The sampling cohort included all men born in the years 1926 to 1927, 1932 to 1933, 1938 to 1939, and 1944 to 1945 in the city and region of Kuopio, Finland. A total of 2,682 men (82.9% of those eligible) participated in the baseline KIHD examinations. The current data are from a cohort of 1,038 KIHD participants who completed a 4-year follow-up reevaluation between March 1991 and December 1993. Follow-up examinations were conducted on those men who had undergone ultrasonographic examination of the right and left carotid arteries at baseline. A total of 1,229 individuals were eligible for the follow-up study; of these 52 had died, were suffering severe illness, or had migrated from the region, and 139 could not be contacted or refused to participate. Thus, the follow-up study included 1,038 participants, or 84.4% of those eligible. Because of scheduling difficulties, only 902 of the 1,038 men participated in the cardiovascular reactivity testing described here.

Disease and Medication Measures

Medical history was obtained through a health history interview conducted by a nurse, and the diagnostic categories were coded. For purposes of this report, diseases were classified into nine categories:

1. Symptomatic coronary heart disease (previously diagnosed myocardial infarction, angina pectoris (diagnosed on the basis of Rose criterion, previous diagnosis of angina pectoris, use of angina medication, or history of angiography)
2. Other cardiovascular disease (cardiomyopathy, congestive heart failure, functional heart problem, claudication, or other heart disease)
3. Cardiac arrhythmia (previous diagnosis of cardiac arrhythmia)
4. Hypertension using World Health Organization criteria (systolic-

diastolic pressures equal to or greater than 165/90 mm Hg or current use of antihypertensive medication)

5. Cerebral stroke
6. Cardiac bypass (participants who had a cardiac bypass for relief of coronary heart disease (CHD) were classified separately so that surgical effects would not be confounded with the CHD category)
7. Respiratory disease (bronchitis, bronchial asthma, pneumoconiosis, and tuberculosis)
8. Diabetes (use of diet or medication to control diabetes or fasting glucose equal to or greater than 8 mmol/L)
9. Cancer.

Medications were brought to the testing session, and staff coded these using the Nordic ATC classification system. For purposes of this article, medication status was used only to control for whether the disease or its medical treatment altered cardiovascular reactivity. Thus, only the presence of medications treating classes of disease was coded. Specifically, medications were coded as alimentary (ATC code A), blood (code B), musculoskeletal (code M), nervous (code N), respiratory (code R), cardiac-antiarrhythmic (code C 01), cardiac-antihypertensive (code C 02), other cardiac (codes C 03-07), and other drug (codes D, G, H, J, P, S, and V).

A wide variety of biological, psychosocial, socioeconomic, and environmental factors was assessed as part of the KIHD follow-up examination, which consisted of 2 days of testing 1 week apart. Measures included cholesterol and lipoprotein levels, ultrasonographic assessment of carotid atherosclerosis, dietary habits, recreational physical activities, personality and behavioral characteristics, social support, ambulatory monitoring of blood pressure, Holter electrocardiogram monitor, and cognitive functioning, among others. These measures are the subject of other articles.

Procedure

Volunteers performed four computer-based cognitive and psychomotor tasks, each 9 min in length, designed to induce cardiovascular responses reliably. Three of the tasks make up the Pittsburgh Battery, and the fourth was a version of the Stroop Color-Word Test. These tasks have been shown to distinguish reliably between high and low cardiovascular responders when administered on repeated testing sessions (Kamarck et al., 1992, 1993). Each was preceded by a 9-min "baseline" period during which the volunteers performed simple color identifications (see Jennings, Kamarck, Stewart, Eddy, & Johnson, 1992). Task order was randomized with the constraint that the Stroop task was always presented last, because we anticipated large reactions to this task that might dissipate slowly. Completion of the battery generally required a session lasting approximately 2 hr.

Performance Tasks and Derived Scores

The Pittsburgh Battery is described in detail elsewhere (Kamarck et al., 1992; Kamarck, Jennings, Pogue-Geile, & Manuck, 1994). It is a computer-based test designed to maintain a constant level of challenge across a number of tasks. This is accomplished by adjusting task difficulty trial by trial while the task is being performed; a success rate of approximately 60% correct is targeted by the computer program. The tasks were designed so that performance would not require high literacy levels or specific cultural backgrounds. The Stroop Color-Word Test has a similar computer format and also adjusts the speed of the task based on the performance of the volunteer. The battery and each task are preceded by a brief set of instructions that includes practice items that must be completed before the task is performed.

The first task of the Pittsburgh Battery is the target task. The volunteer's task is to "shoot" a target that moves at different speeds across

the top of the computer screen. A "cannon" is centered at the bottom of the screen pointing up to where targets will pass. The volunteer must hit the target by timing the keypress because the cannon's aim could not be altered. A trial begins with a blank screen, and then the cannon appears; a fixed 4 s later, a target starts to cross the screen. During the anticipatory interval between cannon appearance and target appearance, a vagally induced slowing of heart rate is expected to occur (see review in Bohlin & Kjellberg, 1979). This transient slowing occurs in the context of an overall cardiovascular activation induced by the task. Approximately 50 targets are presented in the 9-min task. Feedback is provided in the form of points for target hits. Immediate visual feedback, a simulated explosion, is provided for hits as well. The percentage of target hits is evaluated after each set of 10 trials. Mean target speed (varying from 1 [*slow*] to 4 [*fast*] and defining difficulty level) is increased if the percentage of hits exceeds 60%.

The second task of the Pittsburgh Battery is the scanning task. This is a spatial memory task. A target item appears in the "sky" in one of four quadrants across the top of the screen. During the scanning period, from 1 to 12 targets (depending on the volunteer's skill level) can appear sequentially. The volunteer's task is to remember for 5 s the quadrant in which each sequential target appeared. At the end of 5 s, the sequence of quadrants in which targets appeared must be duplicated in order on a keypad with four keys corresponding to the four quadrants. Approximately 35 scanning sequences are presented during the 9-min task. Feedback is given in the form of points for items recalled in the correct order. After each set of six trials, the number of trials with perfect recall is evaluated. If 66% of the targets were recalled, then the number of targets is increased (difficulty level is defined by the number of targets from 1 to 12).

The third task of the Pittsburgh Battery is the tracking task. The volunteer's task is to propel an icon through a tortuous path (which varies in width depending on volunteer skill) using a computer joystick. The mapping between the joystick and the icon is reversed in the up-down direction (i.e., when the joystick is pushed upward, the icon moves downward and vice versa). The number of times the icon is propelled across the screen varies between 5 and 30 times among volunteers. Feedback is given in terms of points for time on the path and forward progress made. Immediate visual feedback and an unpleasant auditory tone occur when the icon leaves the path. After each path is completed, the percentage of time within the path is evaluated. If the percentage of time is greater than 60%, then difficulty level is increased by narrowing the path (scaled arbitrary pixel units).

The fourth task is a computer version of the Stroop Color-Word Test. A color name appears in the middle of the screen written in color: red, green, yellow, or blue. The participant must identify the color and ignore the color name presented. The color must be matched to color names presented on the bottom of the screen; the match determines which of four keys to press. The correct key must be pressed as quickly as possible. A distracting tape recording of color words is also presented acoustically during the task. The pause between color items becomes shorter as performance improves. Participant skill alters the number of trials considerably, but approximately 50 trials are presented within the 9-min task period. Feedback points are awarded on the basis of the number correct; the display also gives the correct answer briefly after each error. Percentage correct and the items completed (termed difficulty level for this task) were scored.

Test-Retest Reliability of the Reactivity Protocol

A substudy was completed to examine whether an individual's responses to the tasks were consistent across repeat testing: We expected to find, as in previous samples, that individuals would be consistent in their degree of responsiveness to the tasks. A sample of 29 participants

was asked to return for retesting from 8 to 12 months after their initial testing with the reactivity tasks. The sample was chosen from individuals tested during the prior year who had complete data and were in the immediate area of Kuopio. Otherwise, they shared the same characteristics as the overall sample. The data for 1 individual were not used because his blood pressure medication had been changed between testings, yielding a major change in his pressures.

Physiological Measures

Cardiovascular measures were taken throughout the session using the electrocardiogram, an automated blood pressure-measuring device (Dinamap), impedance cardiography, and a light-emitting diode-phototransistor vascular transducer (Jennings, Tahmouh, & Redmond, 1980). Electrocardiogram leads, used to assess heart rate, were placed in a modified lead II configuration that maximizes height of the R wave. The automated blood pressure device collected systolic, diastolic, and mean blood pressure every 90 s using an oscillatory technique. The vascular transducer assessed infrared light backscattered from the vascular bed using a laboratory fabricated light-emitting diode-phototransistor taped to the pad of the thumb with minimal contact pressure. The distance over which the pulse traveled was estimated by measuring the distance from the participant's thumbnail to midclavicle and from that point to the top of the sternum. Pulse wave velocity was then computed by dividing this total distance in meters by the time in seconds observed between the foot of the impedance cardiogram signal and the foot of the vascular signal from the thumb. The impedance cardiogram was collected using a Minnesota Impedance Cardiogram and spot electrodes using the placement recommended by Qu, Zhang, Webster, and Tompkins (1986). This placement was tested versus band electrodes by Boomsma, DeVries, and Orlebeke (1989). The average impedance signal was scored to identify the B point, maximal dz/dt , peak, and the O point. The measures were then used to compute pre-ejection period, left ventricular ejection time, and stroke volume using the Kubicek equation (see Sherwood et al., 1993). Cardiac output was then estimated by multiplying stroke volume by heart rate (specifically, heart rate in beats per minute \times stroke volume/1,000 to yield liters per minute). Total peripheral resistance was calculated by multiplying estimated mean arterial pressure by the estimated cardiac output (mean arterial pressure/cardiac output \times 80 to yield resistance units [dynes per second per centimeter⁻⁵]).

Scoring of Physiological Data

The scoring and measurement system is detailed by Debski, Zhang, Jennings, and Kamarck (1993). In brief, all continuous measures were digitized and then ensemble averaged using the R wave of the electrocardiogram to define the beginning of a 1-s window. Each window was combined point for point with other windows during the 30-s epoch. Points were then averaged so that a mean waveform was computed for the electrocardiogram, impedance cardiogram, and photovascular transducer signals. An operator checked these averages and examined beat-by-beat data as necessary, excluding artifactual data from averaging. A computer program marked R wave occurrence as well as onset and peak times for the impedance and peripheral vascular (photo) signal. These points, as well as the dichotic notch on the impedance signal, were checked by the operator and adjusted as necessary if the computer algorithm appeared incorrect. Records were scored by a single operator who had been shown in routine reliability checks between operators to make judgments with greater than 90% agreement. Measures described previously were then computed by the program and stored.

For purposes of data analysis, all measures were averaged across the baselines in the task battery to form a single baseline measure for each

variable. The 30-s epochs in each task were combined and averaged, forming a single value for each task in the battery. Change scores were then computed to assess the degree of cardiovascular response to each task and converted to a z score for each task (change score - mean change score for that task/the standard deviation of the change score). These standardized task scores were then averaged to form a "reactivity score" for each participant for each cardiovascular measure. These scores assessed each participant's relative responsiveness, adjusting for the differences between tasks in the average magnitude of cardiovascular response.

A special reactivity score was created from data in the target task. This was termed a "vagal reactivity" score because it measured a transient task- evoke response in heart rate shown in similar tasks to be under the control of the vagal (parasympathetic) nerve (Obrist, 1981). Heart rate values just before, during, and after the appearance of the target "spaceship" were averaged over trials. A change score was then created between the heart rates for the initial 2 s before target appearance and the 2 s surrounding the participant's response.

The final step in scoring the cardiovascular reactivity data was to reduce the multiple reactivity scores to two summary scores: factor scores representing "cardiac reactivity" and "vascular reactivity." Kamarck et al. (1994) used a confirmatory factor analytic approach to demonstrate that cardiovascular responses to mental stress can be statistically decomposed into two correlated dimensions: cardiac reactivity (primarily defined as task-induced changes in heart rate, systolic blood pressure, and preejection period) and vascular reactivity (primarily defined by task-induced changes in diastolic blood pressure and decreases in stroke volume). Table 1 provides the regression weights on the two factors for each of these parameters for the initial study as well as the current study. Data from the current study were subjected to a maximum-likelihood factor analysis, which again yielded a two-factor solution as the best fit for the data. The results were rotated to a target matrix (Procrustes rotation) using regression weights derived from samples described in the previous article as shown in Table 1, and factor scores were derived in the current sample based on this rotated solution. The cardiac and vascular factors in the current study accounted for 53% of the variance in the psychophysiological data and were correlated at $r = .51$.

Statistical Analysis

A multiple regression procedure was used (SAS General Linear Model, Type 1 Procedure; SAS Institute, Inc., 1985). The independent variables were age, presence or absence of each disease, and medication use. The primary dependent variables were assessed separately: the car-

diac factor score, the vascular factor score, and the vagal reactivity score; body mass index (BMI) was used as a covariate. Follow-up analyses on the reactivity scores for individual physiological variables were also performed. In these analyses, the baseline level of the variable was included as an additional covariate. The same analyses were also applied to the performance scores using difficulty levels as the dependent measure. Either age or the set of disease variables was entered first into analyses performed on each dependent reactivity score. Medication terms, interaction (multiplicative) terms of Age \times Disease, BMI, and mean baseline value of the dependent variable always followed the entry of disease or age. The percentage of variance accounted for was computed for each variable, contributing significantly to the prediction of the dependent variable. These percentages were then compared for the analyses forcing age into the regression first and disease into the regression first. Results are reported for variables for which F values indicated a significant contribution at $p < .05$ or less.

Results

The sample showed a distribution of diseases that increased modestly in frequency with age. Table 2 shows this distribution and the percentage in each age cohort showing each disease. The number and percentage of the cohort receiving medication for any disease state are also shown. Almost half of the sample, taken as a whole, reported a serious disease. This prevalence of disease provides an appropriate sample to compare disease and aging influences in the middle years. Table 3 shows the mean baseline levels and reactivity (task level less baseline) for each task and measure. The remainder of the physiological results focus on the influence of age and disease on the reactivity factors scores and the mean reactivity values derived by averaging z scores for each task across the four tasks.

Performance Results

The tasks were designed to present a consistent challenge to the participant, and thus the difficulty was adjusted based on performance while the participants were engaged in the task. This procedure is designed to maintain a stable level of physiological reactivity to challenge. Because the computer program actively controls the percentage correct, the best available measure of performance is that difficulty level on the task that the participant achieved during performance of the task. These difficulty levels for each task were analyzed to determine whether aging, disease, or medication might be influencing reactivity through an impact on performance ability.

Table 4 shows how age significantly ($df = 1$ and ≥ 759) influenced the difficulty level achieved in each of the tasks; age interacted with a disease state in the case of tracking and Stroop difficulty. Greater age was consistently associated with achieving less difficulty: less target speed in the target task, larger path width in the tracking task, fewer memory items in the scanning task, and fewer items completed in the Stroop task. The different tasks appeared to assess different aspects of performance because the performance difficulty on the Stroop and scanning tasks was correlated at only r ($df = 783$) = .43, and all other correlations were less than or equal to .10. The overall regression model, including age, diseases, their interactions, medications, and BMI, accounted for small to moderate amounts of variance in the performance scores: target = 5%, $F(29, 805)$

Table 1
Characteristics of the Confirmatory Factor Analysis Solution

| Variable | Regression weights | | Factor structure (correlations) | |
|-------------------|--------------------|-----------------|---------------------------------|-----------------|
| | Cardiac factor | Vascular factor | Cardiac factor | Vascular factor |
| Heart rate change | .576 | 0 | .49 | .27 |
| SBP change | .576 | .126 | .82 | .57 |
| DBP change | .173 | .420 | .75 | .74 |
| PEP change | -.811 | .440 | -.60 | .27 |
| SV change | -.116 | -.360 | .17 | -.29 |

Note. SBP = systolic blood pressure; DBP = diastolic blood pressure; PEP = preejection period; SV = stroke volume.

Table 2
Number of Individuals in Each Age Cohort Taking Medication or Reporting Disease

| Age (years) | n | Disease | On meds | CHD | CV-Oth | Arrhythmia | Stroke | Bypass | Hypertension | Respiratory | Cancer | Diabetes |
|-------------|-----|----------|---------|---------|---------|------------|--------|--------|--------------|-------------|--------|----------|
| 46 | 213 | 117 (55) | 46 (22) | 16 (7) | 19 (9) | 19 (9) | 3 (1) | 2 (1) | 84 (40) | 12 (6) | 1 (1) | 6 (3) |
| 52 | 220 | 129 (60) | 60 (27) | 36 (16) | 21 (10) | 36 (16) | 3 (1) | 4 (2) | 77 (35) | 13 (6) | 3 (1) | 10 (5) |
| 58 | 252 | 186 (75) | 80 (32) | 59 (24) | 44 (18) | 43 (17) | 8 (3) | 3 (1) | 117 (47) | 34 (14) | 7 (3) | 19 (8) |
| 64 | 217 | 168 (78) | 84 (39) | 82 (38) | 49 (23) | 42 (19) | 6 (3) | 5 (2) | 98 (45) | 34 (16) | 13 (6) | 8 (4) |

Note. Values in parentheses represent percentages. Disease = number reporting any of the diseases classified in the remaining columns; On meds = number receiving regular medications for disease; CHD = coronary heart disease; CV-Oth = other cardiovascular diseases not specifically classified.

= 1.6, $p = .03$; tracking = 7%, $F(29, 759) = 1.96$, $p = .002$; scanning = 10%, $F(29, 783) = 3.04$, $p < .0001$; and Stroop = 19%, $F(29, 758) = 6.19$, $p < .0001$.

Disease generally failed to relate significantly to performance when age was entered into the regression model first. A few diseases and medications did, however, consistently influence performance difficulty. For target performance, difficulty was lower with antihypertensive medications, $F(1, 805) = 5.5$. For tracking difficulty was higher for those with other cardiovascular disease (primarily heart failure), $F(1, 759) = 12.5$, but lower with respiratory medications, $F(1, 759) = 8.0$. For scanning, difficulty was higher for those taking either nervous system medications, $F(1, 783) = 4.3$, or antiarrhythmic drugs, $F(1, 783) = 4.8$. Lower difficulty was achieved on Stroop for those with coronary bypass, $F(1, 758) = 5.6$.

The significant relations among age, disease, and performance raised the possibility that performance differences might mediate any effects of age or disease on cardiovascular reactivity. Correlations between performance and cardiovascular reactivity indexes were, however, low, ranging from $-.06$ to $.14$. Because of the large sample, 10 of the 44 (11 difference scores by four tasks) indexes computed were statistically significant ($p < .05$). Correlations of difference scores with Stroop task performance were highest and the most numerous (5 of 11 computed were significant). To examine results with and without the possible influence of performance levels on degree of cardiovascular

reactivity, new standardized scores were created, residualizing each score from each task based on the regression of the performance on the score. The results reported next were essentially the same for residualized and nonresidualized standard scores. We report the results using the residualized scores.

Cardiovascular Reactivity

We now turn to the primary results, which address the issue of whether aging influences cardiovascular reaction when variance related to disease is removed from cardiovascular reactivity (controlling for performance and body mass). These results showed that aging consistently influenced cardiovascular reactivity and was minimally influenced by the prior extraction of variance as a result of disease: Entering aging first or disease first into the regression model in virtually all cases influenced the size and significance of the aging term minimally. Figure 1 illustrates the basic results using the cardiac and vascular factor scores, which summarized the reactivity to the psychological task battery: independent influences of aging and only one disease, hypertension, on reactivity. Table 5 provides the percentage of variance accounted for by predictor variables and includes the results for individual physiological response variables as well as for the summary factor scores. All results are taken from analyses in which disease variables were entered before aging variables unless stated otherwise.

Table 3
Mean Baseline and Reactivity Scores for the Different Tasks

| Variable | Baseline | Target | Tracking | Scanning | Stroop |
|-----------------------------|----------------|---------------|-----------------|----------------|-----------------|
| Heart rate ^a | 69.0 (11.0) | 0.80 (3.2) | 2.10 (3.50) | 3.30 (4.80) | 7.80 (6.10) |
| Systolic BP | 135.0 (16.0) | 7.80 (6.1) | 11.70 (7.60) | 9.20 (7.00) | 13.20 (8.60) |
| Diastolic BP | 82.0 (9.6) | 4.20 (4.1) | 7.50 (5.00) | 5.80 (4.90) | 7.60 (5.40) |
| PEP | 126.0 (16.0) | -5.20 (5.7) | -4.20 (5.30) | -5.10 (5.60) | -4.50 (6.30) |
| Cardiac output ^b | 6.4 (1.9) | 0.10 (0.8) | -0.10 (0.80) | 0.30 (0.90) | 0.10 (1.00) |
| TPR | 1403.0 (462.0) | 86.00 (357.0) | 176.00 (247.00) | 66.00 (324.00) | 119.00 (250.00) |
| PWV | 7.3 (1.0) | 0.04 (0.4) | 0.16 (0.44) | 0.17 (0.41) | 0.21 (0.50) |

Note. Values in parentheses represent standard deviations. BP = blood pressure assessed in millimeters of mercury; PEP = preejection period in milliseconds; TPR = total peripheral resistance in resistance units; PWV = pulse wave velocity in meters per second.

^a Beats per minute.

^b Liters per minute.

Table 4
Mean Performance Difficulty Scores by Age Group

| Variable | Age (years) | | | |
|---|--------------|--------------|--------------|-------------|
| | 46 | 52 | 58 | 64 |
| Target | | | | |
| Difficulty ^a (1 slow, 4 fast) | 2.0 (1.0) | 1.9 (0.9) | 1.8 (0.9) | 1.7 (0.8) |
| Tracking | | | | |
| Difficulty ^b (path width) | 19.0 (5.0) | 20.0 (6.0) | 22.0 (6.0) | 21.0 (6.0) |
| Scanning | | | | |
| Difficulty ^a (no. of memory items) | 4.6 (0.8) | 4.4 (0.7) | 4.2 (0.9) | 4.0 (0.8) |
| Stroop | | | | |
| Difficulty ^a (no. completed) | 119.0 (23.0) | 113.0 (26.0) | 101.0 (26.0) | 91.0 (22.0) |
| Tracking difficulty | | | | |
| Diabetic ^b | 17.0 (5.0) | 18.0 (5.0) | 23.0 (7.0) | 23.0 (4.0) |
| Nondiabetic | 19.0 (5.0) | 20.0 (6.0) | 22.0 (6.0) | 21.0 (6.0) |
| Stroop difficulty | | | | |
| Arrhythmic ^b | 110.0 (23.0) | 111.0 (24.0) | 101.0 (26.0) | 95.0 (22.0) |
| Nonarrhythmic | 120.0 (23.0) | 113.0 (27.0) | 102.0 (26.0) | 90.0 (22.0) |

Note. Values in parentheses represent standard deviations.

^a Means differ ($p < .01$). ^b Means differ ($p < .05$).

The top of Figure 1 illustrates the significant influences on the cardiac factor scores of age and hypertension. The F values for the regression term ($df = 1, 679$; degrees of freedom were reduced by missing data in variables used for factor scores) were 20.9 for age ($p < .0001$) and 15.4 for hypertension ($p < .0001$). Overall, the final regression model ($df = 29, 679$) accounted for 7% of the variance in the cardiac factor.

Figure 1 (bottom of figure) shows the significant influence on the vascular factor score of age and hypertension (also see Table 5). The F values for the regression terms ($df = 1, 679$) were 15.6 for age ($p < .0001$) and 10.7 for hypertension ($p < .0001$). Overall, the final regression model ($df = 29, 679$) accounted for 7% of the variance in the vascular factor score.

Figure 2 shows the significant influence on vagal reaction score of CHD and arrhythmia (also see Table 5). The F values for the regression term ($df = 1, 771$) were 3.9 for CHD ($p < .05$) and 5.5 for arrhythmia ($p < .05$). Overall, the final regression model accounted for 4% of the variance in the vagal reactivity scores.

The factor scores and vagal score provided the expected summary of the results of individual variables. Of note, the effects are significant but not large, and aging and disease effects are independent. Entering disease first does not eliminate aging effects; and age and disease do not interact (e.g., disease effects are not more prominent in the younger cohort). Table 5, which provides results for individual measures, can be summarized similarly. Features of interest in the table are (a) the relatively low and equal amounts of variance accounted for by age, dis-

ease, and medication variables, (b) the absence of Age \times Disease interactions (except for an Age \times CHD effect on preejection period), and (c) the minimal influence of some diseases. Given that physiological levels have been discussed as primary determinants of the size of reactivity scores, it is interesting that baseline levels contribute minimally to reactivity scores. In the case of stroke, diabetes, cardiac bypass, and other cardiac disease (primarily cardiomyopathy, heart failure), the factor scores failed to detect a difference found for individual variables. The mean differences corresponding to the statistically significant regression findings (as transformed back from z score units) are as follows: for stroke, those with the disease had a mean change in pulse wave velocity of $-.01$ m/s ($SD = .22$) relative to those without, $.15$ m/s ($SD = .29$); for other cardiac diseases, those with the disease had a mean heart rate change of 1.7 beats per minute ($SD = 2.0$), relative to those without this disease, who had changes of 2.3 beats per minute ($SD = 2.7$); for diabetes, those with the disease had a pulse wave velocity change of $.04$ m/s ($SD = .27$) relative to those without a change of $.15$ m/s ($SD = .38$); for cardiac bypass, those with bypass had a pulse wave velocity change of $-.07$ m/s ($SD = .27$) and a cardiac output change of $-.47$ l ($SD = .96$) relative to those without pulse wave velocity = $.15$ m/s ($SD = .38$), cardiac output = $.13$ l ($SD = .78$).

The differences in individual variables between age groups provide further context for the summary changes with age shown in Figure 1. Table 6 provides the means by age cohort for the variables showing a significant influence of age. Among the

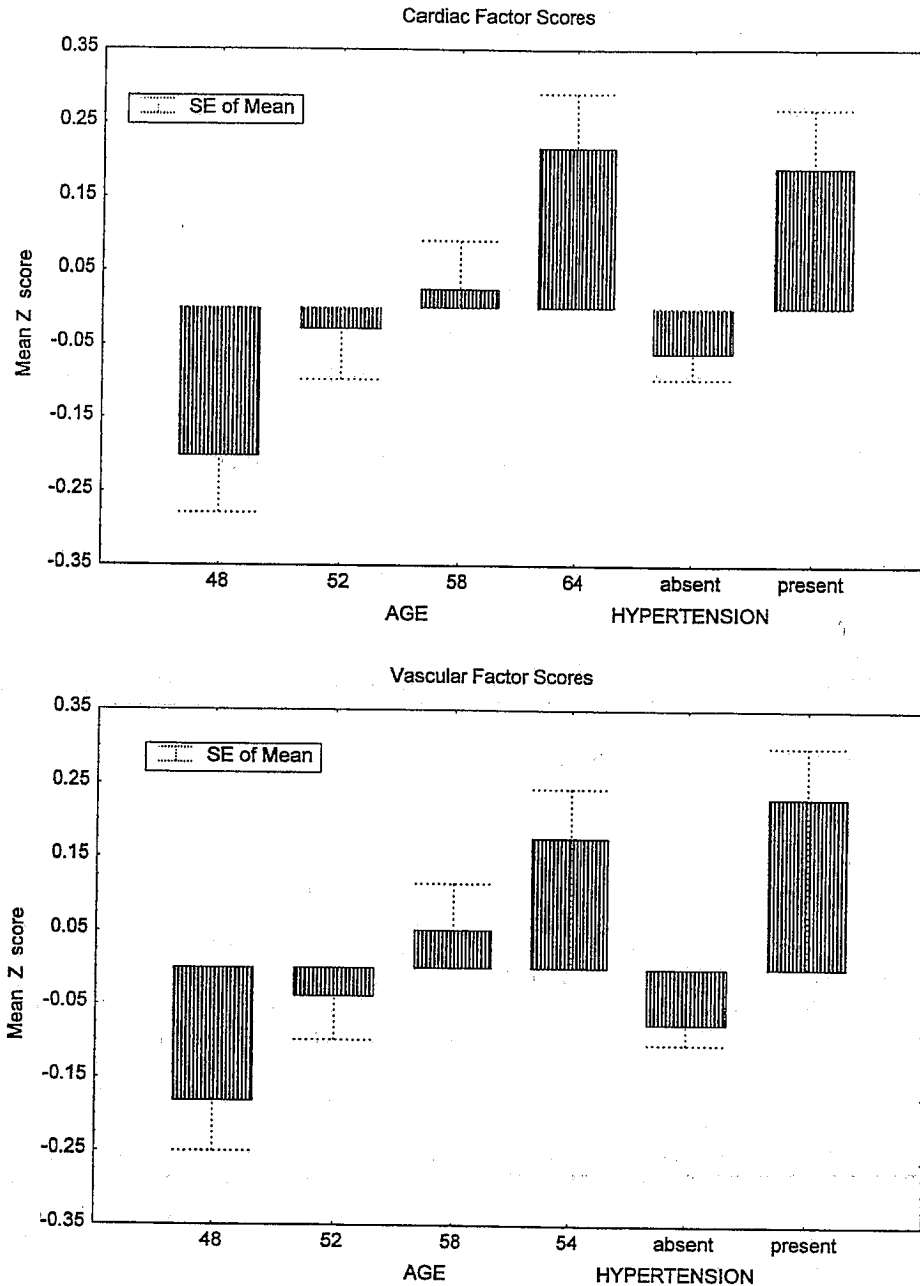


Figure 1. Age and disease variables showing a statistically significant contribution to the prediction of the cardiac reactivity factor score (top) and the vascular reactivity factor score (bottom).

older cohorts, psychological challenge elicits greater blood pressure change than in the younger cohorts. This enhanced reactivity is also seen in the peripheral blood vessels: Resistance to blood flow increases more to psychological challenge with age as do changes of the velocity of pulse wave transmission. The pumping force developed by the heart increases consistently in response to psychological challenge among participants with heart disease (a decrease in pre-ejection period corresponds to an increase in pumping force). In the absence of heart disease,

however, younger cohorts show a smaller increase in pumping force than older cohorts.

Stability of Physiological Levels and Reactivity

A final issue involves the extent to which the cardiovascular base levels and reactivity scores that were assessed are characteristic of an individual over time. Both physiological levels and reactivity are known to fluctuate normally as a result of everyday

Table 5
Percentage of Variance in Physiological Response to Challenge Accounted for by Age, Disease, and Medication Use (Diseases Entered First)

| Variable | HR | SBP | DBP | PEP | PWV | CO | TPR | Vagal | Card | Vasc |
|-------------------------|-----|-----|------------------|------------------|-----|-----|-----|-------|------|------|
| Age | | 4.5 | 4.1 | 0.9 | 1.3 | | 0.6 | | 2.9 | 2.1 |
| Medication ^a | | 1.7 | 1.1 | 0.5 | 1.8 | | | | 0.5 | |
| Basal level | | 1.8 | | | | 0.7 | 1.2 | | | |
| BMI | | | | | 0.7 | 0.8 | 1.3 | 0.8 | | 0.7 |
| CHD | | | 0.6 ^b | 0.8 ^c | | | | 0.5 | | |
| CV-Oth | 0.5 | | | | | | | | | |
| Arrhythmia | | | | | | | | 0.7 | | |
| Hypertension | | 3.4 | 3.6 | | | | | | 2.1 | 1.5 |
| Stroke | | | | | 0.8 | | | | | |
| Cardiac bypass | | | | | 0.5 | 0.8 | | | | |
| Respir | | | | | | | | — | | |
| Cancer | | | | | | | | | | |
| Diabetes | | | | | 0.5 | | | | | |
| Model | 4 | 13 | 12 | 5 | 8 | 6 | 7 | 4 | 7 | 7 |

Note. All entries reflect a significant contribution indicated by an *F* for entry significant at $p \leq .05$. Dash indicates significance with 0.5% of variance when entering age first. HR = heart rate; SBP = systolic blood pressure; DBP = diastolic blood pressure; PEP = preejection period; PWV = pulse wave velocity; CO = cardiac output; TPR = total peripheral resistance; Card = cardio factor score; Vasc = vascular factor score; BMI = body mass index; CHD = coronary heart disease; CV-Oth = other cardiovascular diseases not specifically classified; Respir = respiratory disease.

^a Medication differences for the different variables are accounted for by the following medication classes: total peripheral resistance nervous system medication; pulse wave velocity—antihypertensives and other cardiac (primarily β -blockers) and alimentary (primarily insulin) medications; preejection period—alimentary medications; SBP—other cardiac and alimentary medications; DBP—antiarrhythmic medication and nervous system medication; and cardiac score—antihypertensive medications.

^b Not significant entering age first.

^c Age \times CHD interaction; see Table 6 for mean results.

factors such as exercise and time of day. Nonetheless, under similar testing conditions over a period of a year or less, significant correlations should be observed if our measures are accurately assessing either levels or reactivity that characterizes a person. Table 7 shows the results for the subsample receiving the testing twice. Correlations are, with two exceptions, statistically significant. Correlations of reactivity for the more complex derived impedance measures were somewhat lower than those for directly measured variables such as systolic blood pressure.

Discussion

Aging Versus Disease?

The current results suggest that aging and disease have small but significant independent influences on responsiveness to psychological challenge within the cardiovascular system. When linear relationships between disease and reactivity are removed, aging continues to influence reactivity. Furthermore, age did not generally modulate the influence of disease, except in the case of a larger difference in preejection period change that was observed in the younger relative to the older participants with and without CHD. The conclusions are necessarily limited by our analytic approach and our sample. Our sample is geographically limited but covers the middle years during which aging and disease incidence are both influencing the cardiovascular system. We also studied age cross-sectionally rather than longitudinally; changes in reactivity as the same individuals age must be studied

separately. Our analytic approach considered independent linear effects of aging and disease. We cannot discount all possible relations, but the results do suggest that aging and disease effects are separable. In a number of cases, age and disease had opposing effects, an unlikely result if changes apparently resulting from age are in fact due to disease. Most obviously, in participants with diabetes or stroke, pulse wave velocity changes were less than in those without these diseases. Pulse wave velocity responses, however, uniformly increased with age. Age and disease both contribute to changes in cardiovascular reactivity during middle age.

The research was designed to assess cardiovascular reactivity to the challenge of performing a task well. The challenge was standardized by adjusting task difficulty to the skill of the participant. This also served to maintain a consistent level of challenge across age groups. We found, however, that the age groups did perform at different levels of difficulty. These difficulty levels were only minimally correlated with the degree of reactivity. Nonetheless, we controlled our analyses for performance task difficulty. Thus, we believe that the observed differences in reactivity with age are not due to differences in performance skill associated with age. Similarly, control of the challenge and use of neutral instructions were designed to minimize differences between age groups in affective responses to the task. Unfortunately, we were not able to have observational or detailed self-report measures of affect in this sample. In prior samples (Kamarck et al., 1992), however, self-reports of affect have sug-

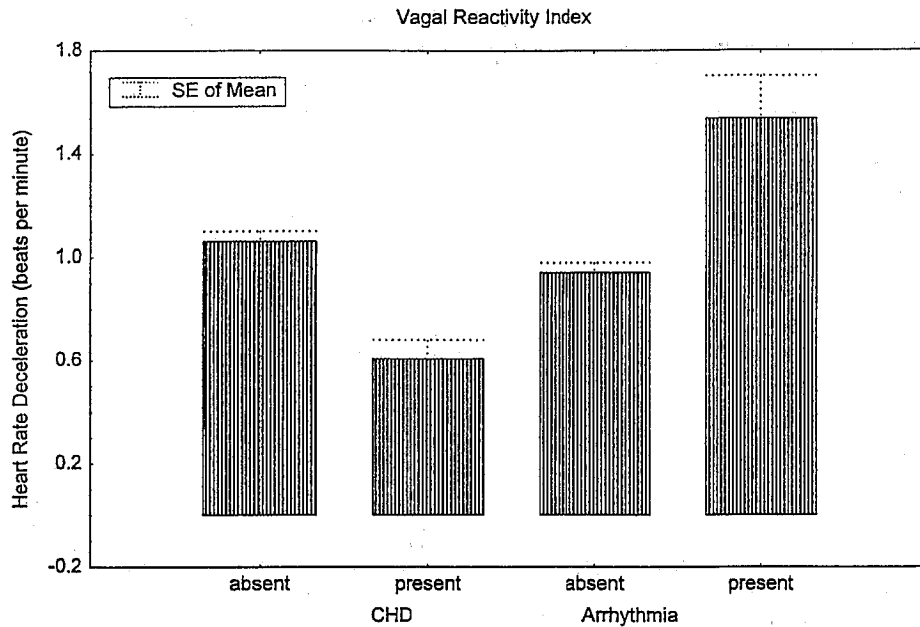


Figure 2. Age and disease variable showing a statistically significant contribution to the prediction of the vagal reactivity score. CHD = coronary heart disease.

gested that these tasks do not induce strong or variable affect. In summary, age groups seem to differ in cardiovascular responding to a consistent performance challenge. Levenson et al. (1991) found a decrease with age in psychophysiological responsivity to emotional inductions in the presence of no difference as a result of age in self-reports of affect. They speculated that the decrease in psychophysiological responsivity might be specific to affective stimuli. This interpretation may deserve further study in that we found increases, rather than decreases, with age in measures of reactivity of the vasculature to mini-

mally affective events. (Levenson et al., 1991, did not collect these vascular measures.)

Aging, Disease, and Reactivity

Interpretation of reactivity changes with age and disease is complex. Chronic or structural changes in the cardiovascular system resulting from age are known to change the level of, for example, blood pressure. Such long-term adjustments associated with aging could indirectly modify cardiovascular reactivity by

Table 6
Cardiovascular Reactivity Over the Middle Years (Also Showing Differential Responsivity of Preejection Period in Those Reporting CHD)

| Variable | Age (years) | | | |
|-----------------------|--------------|---------------|---------------|--------------|
| | 46 | 52 | 58 | 64 |
| Change in | | | | |
| Systolic BP | 8.8 (5.7) | 10.5 (5.7) | 11.2 (6.1) | 12.1 (5.7) |
| Diastolic BP | 5.6 (4.1) | 5.9 (3.4) | 6.6 (3.7) | 7.5 (3.9) |
| Pulse wave velocity | 10.1 (35.3) | 14.6 (34.4) | 17.4 (35.6) | 18.4 (32.2) |
| Peripheral resistance | 77.0 (154.0) | 113.0 (201.0) | 107.0 (171.0) | 173.0 (52.0) |
| CHD present | | | | |
| Preejection period | -4.4 (4.6) | -5.1 (4.8) | -4.9 (4.4) | -5.1 (4.5) |
| CHD absent | | | | |
| Preejection period | -3.4 (3.6) | -3.1 (4.5) | -4.2 (3.8) | -6.2 (4.6) |

Note. All entries are changes from baseline. Heart rate is expressed in beats per minute; systolic and diastolic BP in millimeters of mercury; cardiac output in liters per minute; peripheral resistance in peripheral resistance units; pulse wave velocity in millimeters per second; preejection period in milliseconds. BP = blood pressure; CHD = coronary heart disease.

Table 7
Stability of Physiological Levels and Changes

| Variable ^a | Levels | | | Changes (z score units) | | |
|-----------------------|---------|---------|-----|-------------------------|--------|-----------|
| | Mean 1 | Mean 2 | r | Mean 1 | Mean 2 | r |
| Heart rate | 69.8 | 70.0 | .55 | -.24 | .02 | .64 |
| Systolic BP | 132.5 | 130.9 | .79 | -.11 | .30 | .65 |
| Diastolic BP | 79.4 | 78.4 | .68 | -.10 | .00 | .60 |
| Preejection | 127.0 | 126.0 | .79 | .07 | .07 | .55 |
| Stroke volume | 97.0 | 100.0 | .82 | -.01 | .16 | .41 |
| Cardiac output | 6.5 | 6.8 | .85 | -.06 | .17 | .43 |
| Pulse wave velocity | 7.6 | 7.2 | .56 | .03 | .06 | .66 |
| Peripheral resistance | 1,376.0 | 1,266.0 | .75 | -.04 | -.15 | -.01 (ns) |
| Cardiac factor | | | | -.11 | .21 | .69 |
| Vascular factor | | | | -.05 | .05 | .58 |
| Vagal score | | | | .00 | -.24 | .25 (ns) |

Note. $n = 28$. All correlations are significant at $p < .05$ or less except as indicated. In all cases z scores are scaled to overall sample; values are the z scores summed across changes from the four tasks. The subsample deviated slightly from the overall z score for the sample ($z = 0.0$ by definition). BP = blood pressure.

^a Measurement scale for levels as in prior tables.

changing the basal condition on which the processes inducing reactions act. Alternatively, aging or disease could directly alter the psychological, neural, or receptor processes that contribute to the cardiovascular response to a psychological challenge.

Aging seems to decrease cardiac-pump function (heart rate and cardiac output) but to enhance vascular responses (blood pressure and peripheral resistance; e.g., Folkow & Svanborg, 1993; Lakatta, 1983, 1985; Schwartz, Gibb, & Tran, 1991). Our resting values of cardiovascular variables are consistent with this description. Reactivity of the cardiovascular system could be constrained by these changes in basal function with age. For example, increases in vascular reactivity could be due to a stiffening of the vasculature with age with compensatory changes in cardiac force. That is, given the same neural activation in response to the task, older individuals with stiffer vasculatures might show the observed increased responsiveness relative to younger individuals. Constriction of stiffer vessels would have a greater effect on peripheral resistance and pulse wave velocity than the constriction of less stiff vessels. Increased pressure changes could also result from the structural changes in the blood vessels (cf. Lakatta, 1990). Our data, however, do not directly support such a dependency between basal state and amount of reactivity. The amount of cardiovascular reactivity should be related to the level of baseline variables (as differentially influenced by age) if this is a significant factor in the amount of change observed. In fact, baseline measures contributed minimally to the significant predictors of reactivity; the only significant relation emerged for change in cardiac output (see Jennings & Yovetich, 1991, for an elaboration of this point). A second concern with the baseline hypothesis arises from the changes in preejection period with age. The increase in preejection period response (greater shortening) with age cannot be explained by increased peripheral resistance, a change that should lengthen rather than shorten preejection period (Metzger, Chough, Kroetz, & Leonard, 1970). Rather, it seems to support a greater response to sympathetic activation with

aging. Admittedly, our current measures are rather gross, separating structural changes from changes in sympathetic function to determine their relative potency in the aging process will require controlled experimental studies (e.g., Smulyan, Csermely, Mookherjee, & Warner, 1983). At present, however, the current results do not support a major role for changes in basal state in the interpretation of changes in cardiovascular reactivity with aging and disease.

If we discount indirect effects on reactivity caused by the influence of aging and disease on basal function, the alternative is that processes directly inducing the cardiovascular reactivity are altered by aging and disease. We have already discussed the low likelihood that age differences in affect or performance skill would account for our results.

Neural and receptor changes cannot be differentiated on the basis of our results, but we can examine patterns of change that would be broadly consistent with activation of cardiac and vascular sympathetics and of the vagus. Responsivity changes were all in the direction expected by increases in sympathetic activation, with age-pressor responses increased, pulse wave velocity change increased, peripheral resistance increased more with age, and preejection period showing greater decreases with age. Eisdorfer (1968; Eisdorfer, Nowlin, & Wilkie, 1970) some time ago suggested that sympathetic arousal increased with age, but the literature remains somewhat equivocal on this point (Folkow & Svanborg, 1993; Amenta, 1993; Jennings & Yovetich, 1991; Benetos et al., 1993; Hiremath, Pershe, Hoffman, & Blaschke, 1989; N. Turner, Houck, & Roberts, 1990). We separated cardiac and vascular reactivity factors based on the correlational structure of both the current data and prior data sets (Kamarck et al., 1994). These factors are modestly correlated but generally reflect our conceptual view as supported by the correlational structure that the heart and vasculature are altered by separable mechanisms; most notably, neuroendocrine influences differentially influencing β -adrenergic receptors (cardiac) and α -adrenergic receptors (vascular). Both cardiac and vascu-

lar reactivity factor scores increased with age and hypertension. Lakatta (1990; see also Avolio et al., 1983) reviewed evidence suggesting that aging influences stiffness of the vascular wall independently of the similar functional effects induced by atherosclerosis. Salonen and Salonen (1994) showed that resting systolic blood pressure and pulse pressure are increased in persons with atherosclerotic lesions. Our current findings are consistent with this concept; they show independent disease and aging influences on blood pressure and the cardiac and vascular factors. The inference of increasing sympathetic activation with age is consistent with our findings but cannot be made with certainty without better measures of changes in the structure of the vasculature with age and without consistent data on sympathetic α - and β -receptor changes with aging.

The lack of changes in vagally related variables, heart rate and the vagal score suggested stability across middle age in vagal function. Vagal responsivity was decreased in patients with CHD controlling for body mass. These results are consistent with the relation of vagal function to heart disease (see review in Jennings & McKnight, 1994; Malliani, Lombardi, Pagani, & Cerutti, 1994; Van Ravenswaaij-Arts, Kollée, Hopman, Stoeltinga, & van Geijn, 1993). Study participants with cardiac arrhythmia increased their cardiac output more in response to stress and also showed greater heart rate deceleration than the remaining participants. This is an unexpected combination of effects. A prior article failed to find arrhythmia related to cardiac reactivity (Follick et al., 1990).

Medication

Medications were included in the analyses to control for the presence of disease that was medicated. For example, a hypertensive treated with a β -blocker might show normotensive blood pressure and decreased heart rate. The drug-induced cardiac bradycardia could be mistaken for an aging effect if medication was not included in the analyses. The percentage of variance accounted for by medications was on a par with the variance accounted for by disease states and slightly less than that resulting from age. Medication influences on performance were similarly minimal. Antihypertensive and respiratory medications slightly impaired perceptual-motor performance, whereas antiarrhythmics and nervous system medications were associated with slightly better performance on a memory task (see Muldoon, Manuck, Shapiro, & Waldstein, 1991). The results suggest that interpretations of reactivity, particularly of vascular reactivity, must consider the influence of medications, particularly β -blockers, insulin, antiarrhythmics, and antianxiety medications.

Implications for "Reactivity"

Methodologically, the factors we examined may confound investigations directed at other issues. Among the factors studied, age showed the largest effects. The variance resulting from disease state and medications was surprisingly small. For example, the presence of respiratory disease or cancer did not contribute significantly to the variability in any of the measures, and heart rate reactions were not altered by any of the medications.

Age and disease, although showing statistically significant contributions, controlled little of the variance in the reactivity measures. Any factor controlling more than 10% of the variance would demonstrate an effect larger than that resulting from either age or disease in samples with age and disease profiles similar to those of the current sample.

In conclusion, the variability of cardiovascular responses among middle-aged men can largely be attributed to differences among individuals that were not examined in this report (e.g., personality traits, social factors, genetic background). Between the fourth and sixth decades of life, aging does contribute a significant amount to between-individual variability. This contribution is to both resting levels of cardiovascular functions and responsivity of cardiovascular variables to psychological challenge. Disease and medication influence differences between individuals in this age range, but this influence is usually equivalent to or generally less than the contribution of relative age. Hypertension and aging were associated with increased reactivity of the cardiovascular system, whereas other cardiovascular diseases were associated with lower reactivity of the cardiovascular system.

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