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Experiences of Demand and Control During Daily Life Are Predictors of Carotid Atherosclerotic Progression Among Healthy Men

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Objectives: The authors previously reported that individuals who rate their daily life as more demanding or less controllable by momentary electronic diary (ED) reports showed greater intima–medial thickness (IMT) by carotid ultrasonography. They now present prospective findings on this relation. ***Design.*** Three hundred thirty-five healthy individuals (ages 50–70 at study onset) completed ongoing ratings of activity and mood over a 6-day period, using ED assessments. ***Main Outcome Measures:*** Mean bilateral carotid artery IMT was measured at baseline and 36 months later. ***Results and Conclusion:*** Mean ratings of high demand and low control were significantly associated with IMT progression among men but not among women. These associations were not explained by traditional risk factors or by measures of occupational stress. Effects were partially accounted for by elevated ambulatory heart rates among those with low ratings of control. These data support the utility of ED-based measures for examining psychosocial risks in the prediction of cardiovascular disease progression.

Keywords: cardiovascular disease, atherosclerosis, ambulatory monitoring, ecological momentary assessment, job stress

A growing literature highlights characteristics of the job environment as potential correlates of cardiovascular disease risk. One of the most influential models in this area, the job strain model, specifies two workplace dimensions as most critical: psychological demand, on the one hand, and control or decision latitude, on the other. According to this model, those whose jobs are characterized as high in demands and low in control may be at elevated risk for disease (Karasek, 1979). The majority of studies in this literature, using both objective indicators and self-report ratings of the workplace, have demonstrated partial or full support for this hypothesis (Belkic, Landsbergis, Schnall, & Baker, 2004).

Whereas the job strain model adopts a concern for variables defined at the level of the organization, one may also characterize demand and control as dimensions of daily experience, the impact of which may not be limited to the workplace. Ecological momentary assessment (EMA) strategies are sampling techniques that can be used to assess self-reported experience in real time and in the natural environment (Stone & Shiffman, 1994; Stone, Shiffman, Atienza, & Nebeling, in press). Such strategies may be used to characterize perceptions of demand and control and their psychophysiological correlates across a range of settings during daily life.

We recently used EMA methods in a healthy sample of older adults who were also evaluated for subclinical cardiovascular disease via carotid ultrasonography (Kamarck et al., 2004). In this sample, higher average momentary ratings of activity demand and lower ratings of control were associated with concurrent measures of carotid intima–medial thickness (IMT), a marker of atherosclerosis. Carotid IMT measures are associated with pathologic and histologic measures of atherosclerosis in autopsy samples (e.g., Wong, Edelstein, Wollman, & Bond, 1993), and they are prospectively associated with the risk for cardiovascular events (myocardial infarction, stroke, sudden cardiac death), even among initially asymptomatic individuals (e.g., O'Leary, Polak, & Kronmal, 1999). In our study, observed associations among demand, control, and IMT were not limited to those who were employed at the time of the study, which supports our suspicion that the effects of demand and control are not confined to the workplace. Moreover, in contrast to the relations observed for EMA ratings, traditional questionnaire measures of job strain were not associated with extent of disease among employed individuals. Finally, we showed that the relation between measures of demand and atherosclerosis was partially accounted for (i.e., mediated) by the effects of daily activity demands on ambulatory blood pressure (ABP).

One of the limitations of our previous report involved the use of cross-sectional data. The influence of subclinical disease on daily experience cannot logically be ruled out as an explanation for such results. Third factors that may be difficult to control statistically,

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such as the influence of early life risk factors or unknown pleiotropic genes, could also explain such cross-sectional associations.

The participants in the Kamarck et al. (2004) study have now been followed up for 3 years, with repeat measures of carotid artery ultrasonography. These new data now permit us to examine correlates of 3-year carotid artery disease progression using a more powerful longitudinal or prospective design. A prospective design allows us to rule out the influence of reverse causality (the effects of disease on daily experience). Any third factors whose effects might be expected to be strongest earlier in life (and thus whose influence should be mediated by their effects on baseline levels of disease) also should not confound the findings when such a design is used. The purpose of the current report, then, is to extend the results of our original study, examining the association between daily ratings of demand and control and atherosclerotic progression with the use of a prospective design.

Method

Participants

Data from 335 adults from the Pittsburgh Healthy Heart Project were included in this study. The Pittsburgh Healthy Heart Project is an ongoing investigation examining biobehavioral predictors of subclinical cardiovascular disease progression in an asymptomatic, community-dwelling sample. The study was approved by the institutional review board at the University of Pittsburgh, and participants were paid $350 for completion of this portion of the research. Recruitment strategies included targeted mailings, radio and television spots, and posters on buses and at local businesses. Major inclusion criteria were age (50–70 years) and menopausal status (women were required to be peri- or postmenopausal, at least 6 months with no menstrual period, at time of enrollment), with the age range selected to capture a group at moderate risk for the development of subclinical disease. Participants were excluded if they reported a history of chronic medical disorders (including symptomatic cardiovascular disease), pharmacological treatment for hypertension or hypercholesterolemia in the past year, regular use of medication with autonomic effects, or excessive alcohol consumption (five or more drinks three or more times per week). People with diabetes who were on insulin were excluded, as were persons with clinic blood pressure greater than 180 mmHg systolic blood pressure (SBP) or 110 mmHg diastolic blood pressure (DBP). We also excluded participants whose arm circumference interfered with reliable microphone detection of Korotkoff sounds.

Individuals (n = 464) provided written consent to participate and were enrolled in the study. Of these, 13 were found to be ineligible during the initial data collection period, and an additional 69 dropped out during one of the subsequent visits. For this study, we also excluded from analyses those with fewer than 30 complete observations for either of the two ambulatory assessment periods (n = 34), those who began taking antihypertensive medications during the initial monitoring period (n = 7), and those who were missing one or more measures of baseline carotid ultrasound data (n = 4). As such, we initially reported that 337 individuals completed all of the baseline assessments relevant to these hypotheses (Kamarck et al., 2004). Baseline carotid data from 3 additional individuals became available subsequent to these initial analyses, yielding a total sample size of 340 with complete data at baseline. Follow-up data from 5 participants, however, were missing (2 participants dropped out, 1 was unable to be contacted, 1 had unscorable carotid data, and 1 was excluded because of a carotid endarterectomy), leaving a sample of 335 on which prospective analyses could be conducted. Sample characteristics are described in Table 1.

Measures and Procedures

Overview. Following informed consent, baseline data collection for each participant involved 11 visits scheduled over the course of 5 months, including a medical screening visit, 7 visits pertaining to training and feedback for ambulatory monitoring (3 days of daily monitoring occurred at 1 month and again at 4 months after the medical screening visit), 1 visit for laboratory cardiovascular measures, and 2 visits for ultrasound assessments, 1 of which involved carotid ultrasonography. Participants returned for their repeat carotid assessment approximately 3 years following their initial carotid ultrasound visit (Mdn = 35.7 months, range = 29.0–54.4). Daily monitoring occurred only at baseline, not at the 3-year follow-up point.

Cardiovascular risk factors. The medical screening visit included a medical history interview, blood pressure screening, and blood draw for risk factor assessment. American Heart Association guidelines (Perloff et al., 1993) were followed for clinic blood pressure measurement. Low-density lipoprotein (LDL) cholesterol was calculated from serum total cholesterol and high-density lipoprotein (HDL) values according to the Friedewald equation (Friedewald, Levy, & Frederickson, 1972). Fasting serum glucose was assayed via standard colorimetry, and insulin concentration was measured by radioimmunoassay (Kamarck et al., 2004). Body mass index was also assessed. Resting heart rate (HR) was measured during the laboratory visit. We assessed mean HR across four 10-min rest periods, using the same ambulatory monitor that was implemented in the field (see below).

During the medical screening visit, participants were also administered interview questions regarding cigarette smoking history, and they completed a health behavior questionnaire, which included the Paffenbarger Physical Activity Questionnaire (Paffenbarger, Wing, & Hyde, 1978) and items assessing alcohol use. To obtain an estimate of physical activity level, we converted and summed the number of blocks walked and stairs climbed per day, as reported on the Paffenbarger Physical Activity Questionnaire, to kilocalories per week. Current cigarette smoking was coded as a binary variable (0 = no, 1 = yes). Daily alcohol intake (grams per day) was computed according to the quantity–frequency method (Garg, Wagener, & Madans, 1993). This measure was log-transformed to reduce the influence of outlying cases.

Medical diagnoses and medication use. A medical history interview at baseline assessed current medical diagnoses and medication use. These were assessed again by telephone at 6, 18, and 30 months after study intake and in person during a separate visit at the 3-year follow-up. We scored medications in each class (antihypertensive, cholesterol-lowering drugs, diabetic medications, hormone replacement therapy) as present or absent (binary score), with a medication counted as present if it was reported at one or more follow-up points. Fourteen participants did not take part in the 3-year medical interview, so medication data in each

Table 1
Baseline Sample Characteristics, Pittsburgh Healthy Heart Project

	Men (*n* = 164, 49%)			Women (*n* = 171, 51%)		
Characteristic	*M*	*SD*	%	*M*	*SD*	%
Race/ethnicity						
White			86.0			83.6
Black			12.2			15.2
Asian			0.6			0.6
Hispanic			1.2			0.6
Age	60.0	5.0		60.0	4.4	
Education						
High school or less			15.9			33.9
Some college or trade school			22.0			26.9
College degree			29.9			17.0
Graduate degree			32.3			22.2
High blood pressure[a]			29.9			29.8
High cholesterol[b]			18.9			20.5
Lifetime smoking history			54.9			43.9
Current smoker			6.7			6.4
Daily alcohol use (ml)	9.2	11.8		3.8	6.5[c]	
High blood glucose[d]			7.3			4.1
Obese[e]			26.8			29.8
HRT user			—			50.6[f]
Baseline carotid IMT (mm)[g]	0.79	0.16		0.73	0.14	

Note. The dash indicates that data were not obtained because men were not prescribed hormone replacement treatment (HRT). IMT = intima–medial thickness.
[a] Screening blood pressure ≥ 140/90 mm Hg. [b] Low-density lipoprotein ≥ 160 mg/dl. [c] Data were missing for *n* = 1. [d] Blood glucose ≥ 126 mg/dl. [e] BMI ≥ 30 kg/m^2. [f] Data were missing for *n* = 2. [g] Range: men, 0.52–1.63; women, 0.53–1.53.

class were missing for those in this group who were medication free prior to the 3-year follow-up.

Demographic information. Occupational status was assessed at the initial visit and again, 1 month later, just prior to the completion of the Job Content Questionnaire (JCQ; Karasek, 1985). When comparing results for employed and nonemployed individuals, we used only the participants who were consistently employed or unemployed across these two assessments, and we excluded those with changing employment status (*n* = 31) or missing data (*n* = 1). For these analyses, we also excluded participants who said they were employed but had no specific workplace, as indicated by failure to endorse "work" location during any of the diary assessments (*n* = 12). The final sample sizes for analyses comparing employed and nonemployed groups were 151 and 140, respectively. The former group included those with full-time or part-time employment, and the latter group included homemakers, retirees, and laid-off workers. Race was coded as a binary variable (White, non-White), and educational attainment was scored as a continuous variable with four levels (Kamarck et al., 2004).

Job strain. The JCQ (Karasek, 1985) was administered at baseline to those participants who were employed at the time of assessment. Two subscales from the JCQ have been widely used in studies of occupational stress and health (Landsbergis, Schnall, Warren, Pickering, & Schwartz, 1994): Psychological Job Demands, a five-item scale that measures workload and intensity (e.g., "My job requires working very fast"), and Decision Latitude, a weighted sum of two subscales, Skill Discretion (six items; e.g., "My job requires a high level of skill") and Decision Authority (three items; e.g., "My job allows me to make a lot of decisions on my own"). Three-year test–retest reliabilities of .64 have been reported for each subscale (Schnall, Schwartz, Landsbergis, Warren, & Pickering, 1998).

ABP (1-month and 5-month visits). Approximately 1 month following the initial visit, participants were trained to use an automated, auscultatory ABP monitor (Accutracker DX, SunTech Medical, Raleigh, NC) along with a self-report electronic diary. After an initial day of practice, participants were instructed to wear the monitor and to carry the electronic diary during all waking hours over the following 3 days. The monitor took assessments of SBP, DBP, and HR every 45 min during this period. Approximately 4 months later, participants were retrained and sent out for an additional 3 days of ABP and diary monitoring using similar procedures. For data editing procedures, see Kamarck et al. (2004). For clinic as well as ABP assessments, we selected cuff sizes appropriate to arm circumference, in a manner consistent with recent guidelines (Perloff et al., 1993).

Electronic diary protocol and Diary of Ambulatory Behavioral States (DABS; Kamarck et al., 1998). Diary items were presented by electronic diary (PalmPilot Professional, Palm, Inc., Santa Clara, CA); responses were recorded with a stylus. Entries were scheduled at 45-min intervals following each ABP assessment during the waking day. The software used (invivodata, inc., Scotts Valley, CA) created a time and date stamp for each record, providing a check on compliance. For more detailed information about the electronic diary methods used in this study, see Kamarck et al. (in press).

The DABS is a self-report questionnaire designed for repeated assessment of determinants of cardiovascular activity in the ambulatory setting (Kamarck et al., 1998). We used a revised, 45-item version of the DABS for this study. A number of multi-item scales on the DABS were designed for the assessment of relevant psychosocial constructs. For the two scales of interest in this study, participants were asked to consider activities during the 10-min period prior to each ABP assessment. The three-item Task Demand scale (i.e., "Required working hard?" "Required working fast?" and "Juggling several tasks at once?") and the two-item Decisional Control scale (i.e., "Could change activity if you chose to?" and "Choice in scheduling this activity?") were based on the JCQ (Karasek, 1985) and were devised as momentary analogues to the Psychological Demands and Decision Latitude subscales, respectively. Participants responded to each of these items using a visual analogue scale with a bipolar response anchor (no, yes). Scores ranging from 0 to 10 were derived for each item and were averaged across items for each scale.

Four-month test–retest correlations of .73 and .72 were obtained for mean ratings of the Task Demand and Decisional Control subscales, respectively (Kamarck et al., 2004). Among employed participants ($n = 152$), mean task demand ratings drawn from periods at work were moderately associated with the Psychological Demands subscale from the JCQ, and mean Decisional Control ratings at work were associated with the JCQ Decision Latitude scale (Kamarck et al., 2004); such associations were significant and of comparable magnitude for both men and women. For additional information on the reliability and validity of these scales, see Kamarck et al. (1998, 2004).

In addition to the multi-item scales, the DABS contains a number of single-item ratings used to assess other determinants of cardiovascular activity. For example, during each assessment, participants rated their physical activity level on a 4-point scale (1 = *limited, e.g., writing,* 2 = *light, e.g., walking,* 3 = *moderate, e.g., jogging*, and 4 = *heavy, e.g., running*), and they were asked to indicate their current location ("home," "work," "vehicle," "outside," or "other").

Carotid ultrasound assessments. Approximately 2 months after the initial medical screening visit, participants attended an appointment with the ultrasound research laboratory affiliated with the project. We used a B-mode ultrasound scanner (Toshiba SSA-270A and SSA-140A, Toshiba American Medical Systems, Tustin, CA) to identify the borders of the intima and medial layers of the left and right carotid arteries, using the intima–lumen interface and the media–adventitial interface as markers. Distances between these interfaces were measured on digitized images across the distal 1 cm (far wall) of the common carotid artery, the carotid bulb, and the proximal 1 cm of the internal carotid. Baseline and follow-up carotid studies were read concurrently via the Automated Measurement System (Goreborg University, Gothenburg, Sweden), which features an edge detection algorithm that has been shown to reduce reader variability (Wendelhag, Liang, Gustavsson, & Wikstrand, 1997). Measures at each of the six locations (three segments from both the right and the left side) were averaged to create mean IMT. For assessing carotid IMT progression, we calculated an arithmetic difference score, subtracting mean IMT at baseline from mean 3-year IMT.

Data Analysis

General linear models were used to test the major hypotheses. A significance threshold of $p < .05$ was used throughout. Because the distribution for IMT change was positively skewed, we applied a logarithmic transformation to this variable in all models. For models testing the interaction between demand and control, we examined the cross-product of demand and control after adjusting for the main effects of each. Because Demand × Control interaction effects have sometimes been tested via specific contrasts between individuals in the high demand/low control quadrant and those in the remainder of the sample (Landsbergis et al., 1994), we ran follow-up analyses using such methods as well. For these latter analyses, we identified Demand × Control quadrants using dichotomized variables defined on the basis of median splits across each of these two measures.

For analyses testing mediation, we used a product of coefficients test, described by MacKinnon (2002; MacKinnon, Lockwood, Hoffman, West, & Sheets, 2002). This test assesses the indirect effect of a mediating variable as the product of two regression coefficients, one linking the explanatory variable and the mediator, and the other linking the mediator and the dependent variable. The resulting product is divided by its standard error and tested for significance against a cumulative frequency distribution for this parameter, derived as part of a simulation study (MacKinnon, 2002).

Results

IMT Change

The sample as a whole showed a significant degree of carotid atherosclerotic progression, as expected, over the 3-year follow-up period. Median annualized IMT progression was 0.02 mm averaged across the common carotids, internal carotids, and bulb (0.027 for men, $SD = 0.16$; 0.017 for women, $SD = 0.12$), with a median progression rate of 0.01 mm/year when the common carotids were examined separately (0.011 for men, 0.013 for women). Changes of this magnitude are within the range shown for a normative multisite sample (Chambless et al., 2002).

Correlates of IMT

After adjustment for age and sex, baseline IMT was associated with HDL cholesterol (partial $r = -.11$, $n = 335$, $p = .05$), body mass index ($r = .15$, $n = 335$, $p = .007$), waist circumference ($r = .17$, $n = 335$, $p = .002$), clinic SBP ($r = .12$, $n = 335$, $p = .02$), ambulatory SBP ($r = .27$, $n = 335$, $p = .0001$), and ambulatory DBP ($r = .16$, $n = 335$, $p = .004$). Three-year IMT was associated with similar predictors (LDL cholesterol, $r = .11$, $n = 335$, $p = .05$; body mass index, $r = .12$, $n = 335$, $p = .04$; waist circumference, $r = .14$, $n = 335$, $p = .01$; and ambulatory SBP, $r = .25$, $n = 335$, $p = .0001$, and DBP, $r = .14$, $n = 335$, $p = .008$).

Correlates of IMT Change

Demographic correlates of IMT progression were examined. There were significant effects of sex, age-adjusted $F(1, 332) = 10.19$, $p = .0015$, $R^2 = .03$, modified by a significant Age × Sex interaction, $F(1, 331) = 8.02$, $p = .0049$, $R^2 = .02$. Significant increases in rate of progression with age were shown for men only, $F(1, 162) = 4.82$, $p = .03$, $R^2 = .03$, not for women, $F(1, 169) = 3.36$, $p = .07$, inverse association, $R^2 = .02$. The effects of age and sex and their interaction were used as covariates in all subsequent models when relevant. There were no effects of race or education on 3-year IMT progression.

None of the risk factors associated with baseline or follow-up IMT were significantly associated with 3-year IMT change. Of the cardiovascular risk factors assessed in this study, only reported alcohol use at baseline was associated with IMT change, $F(1, 329) = 4.48$, $p = .04$, $R^2 = .01$. Baseline IMT was associated with IMT change in unadjusted analyses ($r = .11$, $p = .04$), but neither baseline IMT nor the interval between baseline and follow-up assessments was significantly associated with extent of IMT change after adjustment for demographic covariates (ps = .17 and .61, respectively).

Although the sample was free of cardiovascular medications at baseline by design, a number of individuals were prescribed cardiovascular drugs during follow-up. Eighteen percent of the sample (66 of 323) reported taking cholesterol-lowering medications at some point during the follow-up interval, and 20% (68 of 323) reported taking antihypertensive drugs. Thirty-one percent (100 of 325) were taking one or both of these medications. Three percent (10 of 321) were on drugs (e.g., insulin, metformin) for diabetes. Medication use (examined separately within each medication type and also in the aggregate for those with nonmissing data) was not significantly associated either with 3-year IMT progression (average $p = .46$) or with mean ratings of daily demand or control (average $p = .68$). A slight majority of the women were on hormone replacement therapy at baseline (50.1%) and during the follow-up (1998–2003; 54%). HRT use among women was not associated with 3-year IMT progression ($p = .15$).

Demand and Control Effects on IMT Progression

As hypothesized, individuals who rated their daily life as generally more demanding showed significantly greater 3-year IMT progression: effects of demand, $F(1, 330) = 4.88$, $p = .03$, $n = 335$, $R^2 = .01$. Similarly, individuals with lower average diary ratings of control showed significantly larger 3-year changes in IMT: in a separate model, effects of control, $F(1, 330) = 4.80$, $p = .03$, $R^2 = .01$.[1] These two effects appeared to be interrelated; when they were entered in the same model, neither term was significant (ps = .14 and .15, respectively; univariate correlation between mean demand and control, $r = -.43$, $p < .0001$). The interaction between demand and control on IMT change also was not significant when calculated as a cross-product of demand and control ($p = .65$) or as a contrast comparing the high demand/low control quadrant with the rest of the sample ($p = .27$).

Sex Differences in the Relation Between Demand and Control and IMT Progression

Associations involving demand and control were significant among men only, not among women: Sex × Demand interaction, $F(1, 329) = 5.06$, $p = .03$, $R^2 = .01$; Sex × Control interaction, $F(1, 329) = 3.72$, $p = .05$, $R^2 = .01$. For men ($n = 164$), $F(1, 161) = 8.62$, $p = .004$, $R^2 = .05$, for demand; $F(1, 161) = 7.23$, $p = .008$, $R^2 = .04$, for control, inverse association; for women ($n = 171$), $F(1,168) = 0.00$, $p = .99$, for demand; $F(1, 168) = 0.17$, $p = .68$, for control. When both demand and control were entered simultaneously in the model, neither term met criteria for significance, which suggests substantial overlap between these two variables for men, as in the sample as a whole: demand effects for men, $F(1, 160) = 3.82$, $p = .05$, $R^2 = .02$; control effects for men, $F(1, 160) = 2.48$, $p = .12$, $R^2 = .01$. Figures 1 and 2 illustrate the patterns of results, by quartile, among the men.

Because ratings of demand were potentially confounded by physical activity (correlation between mean ratings of demand and mean ratings of physical activity during monitoring period, $r = .18$, $p = .001$), we reran the results after adjustment for mean physical activity ratings over the monitoring period. Associations involving demand and IMT change were still significant following this adjustment: demand effects for men, $F(1, 160) = 5.98$, $p = .02$, $R^2 = .04$. Associations involving demand and control were not altered by statistical adjustment for baseline alcohol consumption, the only standard cardiovascular risk factor that was associated with IMT change in this study (among men, the significance value for demand was .004 before adjustment and .005 after adjustment for alcohol consumption; the significance value for control was .008 before and .012 after adjustment). Finally, employment status did not significantly moderate the effects of task demand or task control on IMT progression in the sample as a whole (for interaction, ps = .24 and .79 for demand and control, respectively) or among the men separately (ps = .33 and .24 for demand and control, respectively).

Demand and Control Effects in Work and Nonwork Settings

Among employed participants ($n = 151$), activities at work were rated as higher in demand and lower in control compared with activities in nonwork settings: for demand, $t(150) = 14.43$, $p < .0001$ (Ms = 5.62 for work vs. 4.05 for home; $d = 0.98$); for control, $t(150) = -7.49$, $p < .0001$ (Ms = 6.72 for work vs. 8.23 for home; $d = 0.95$). Despite these mean differences, ratings of demand and control were moderately correlated across settings (demand ratings correlated .72 across work and nonwork settings, and control ratings correlated .47; each associated with $p < .0001$).

Among employed men ($n = 88$), there were no apparent differences in the magnitude of association between demand and control ratings, on the one hand, and IMT change, on the other, as a function of the setting from which such ratings were derived: for work-related ratings, demand, $F(1, 85) = 6.97$, $p = .01$, $R^2 = .08$; for nonwork-related ratings, demand, $F(1, 85) = 6.62$, $p = .01$, partial $R^2 = .07$. In this subsample, ratings of control were significant neither inside nor outside of the workplace: for work-related ratings, $F(1, 85) = 0.11$, $p = .74$; for nonwork-related ratings, $F(1, 85) = 0.90$, $p = .35$.

Global Ratings of Job Demand and Control and IMT Progression

There were no significant associations between questionnaire ratings on the Psychological Demands or Decision Latitude sub-

[1] The Demand and Control scales were two of the five measures of psychosocial stress included in the ambulatory diary (the DABS). None of the other three scales, Social Conflict, Negative Affect, and Arousal, was significantly associated with 3-year IMT change in this sample.

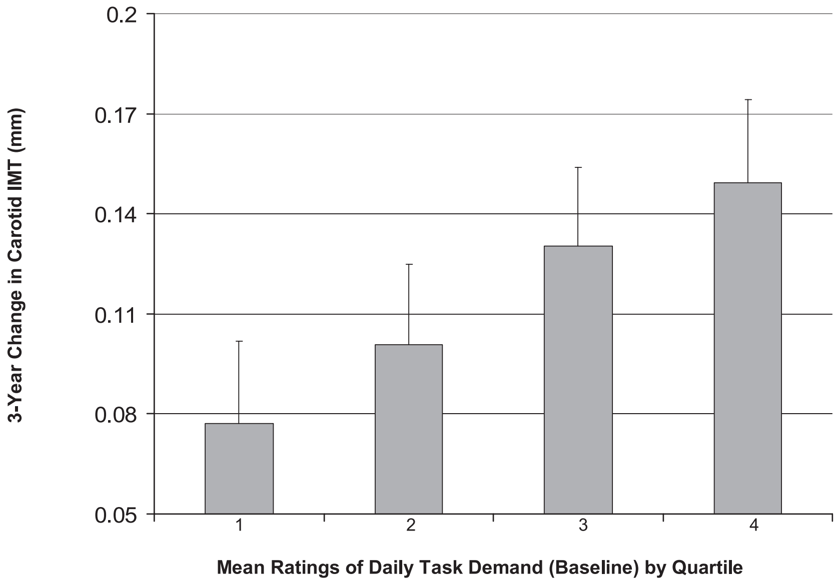

Figure 1. Association between mean (+*SE*) diary ratings of task demand and 3-year changes in carotid artery intima–medial thickness (IMT) among men ($n = 164$).

scales from the JCQ and 3-year IMT change (for employed men and women, $p = .61$ for Psychological Demands, $p = .62$ for Decision Latitude; for employed men only, $p = .20$ for Psychological Demands, $p = .54$ for Decision Latitude). The interaction between psychological demands and decision latitude on IMT progression was not significant ($p = .96$), nor was the specific contrast comparing IMT progression for the high demand/low control quadrant with the rest of the sample ($p = .88$).

Mechanisms Potentially Accounting for the Relations Between Demand, Control, and IMT Progression

There were no significant associations between baseline ambulatory SBP or DBP and carotid disease progression. The relation between baseline ambulatory HR and carotid disease progression was significant, however, $F(1, 330) = 10.73$, $p = .001$, $R^2 = .03$, and these effects did not differ by sex (no significant Sex ×

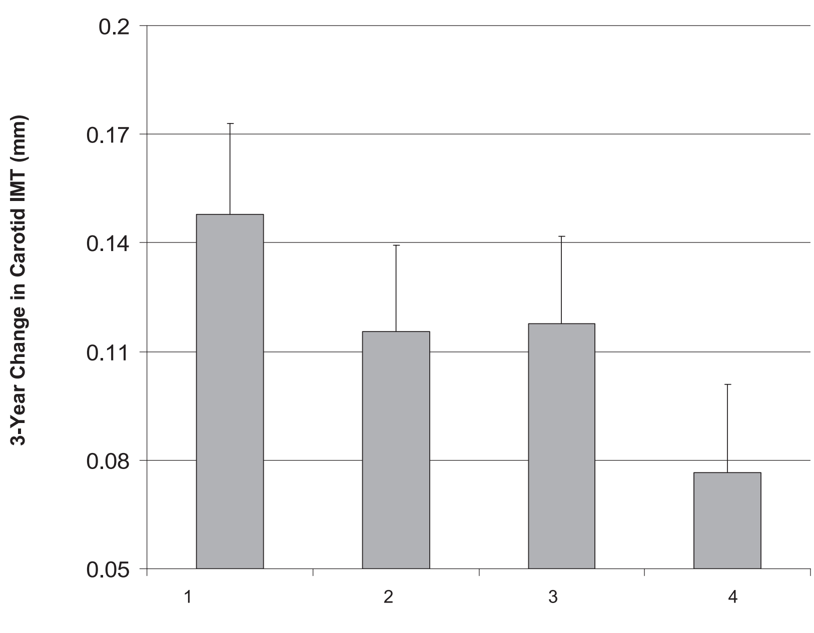

Figure 2. Association between mean (+*SE*) diary ratings of decisional control and 3-year changes in carotid artery intima–medial thickness (IMT) among men ($n = 164$).

Ambulatory HR interaction, $p = .64$). We examined whether such associations could be accounted for by resting HR measures taken in the laboratory (after adjustment for age and sex, ambulatory and laboratory HR were correlated $r = .73$, $p < .0001$). It is interesting that these associations could not be accounted for by laboratory HR alone: After adjustment for resting HR along with other covariates, the effect was largely unchanged and still significant, $F(1, 329) = 12.34$, $p = .0005$, $R^2 = .04$, which suggests that these HR effects were unique to the ambulatory setting.

Whereas mean ratings of task demand were not associated with ambulatory HR (in sex- and age-adjusted analyses, $p = .41$; in men only, $p = .96$), mean daily ratings of task control showed significant inverse associations with ambulatory HR in the sample as a whole, $F(1, 331) = 7.51$, $p = .007$, $R^2 = .02$, as well as among the men, $F(1, 161) = 6.89$, $p = .01$, $R^2 = .04$; the Sex $\times$ Control interaction effect was not significant ($p = .44$).

We examined the possibility that the relation between daily ratings of task demand and decisional control, on the one hand, and carotid disease progression, on the other, could be explained, in part, by ambulatory HR among men. In a model that included age and mean task control, we added the measure of mean daytime ambulatory HR. The effects associated with task control were reduced but were still significant after we adjusted for ambulatory HR: before adjustment, $F(1, 161) = 7.23$, $B = -.021$, $p = .008$, $r = -.21$; after adjustment, $F(1, 160) = 5.03$, $B = -.017$, $p = .03$, $r = -.17$. The indirect effect (MacKinnon et al., 2002) of control on IMT through ambulatory HR was significant ($z' = 1.68$, $p < .01$). This finding suggests that the association between decisional control and subclinical disease may be partially but not fully accounted for by the relation between decisional control and daytime ambulatory HR.

Discussion

We have previously shown that diary ratings of demand and control during daily life are associated cross-sectionally with carotid artery IMT, a marker of atherosclerosis. In the present report, we demonstrate that these associations persisted in prospective analyses examining 3-year changes in IMT. These effects were significant only among men. We were unable to resolve whether findings were due primarily to higher levels of perceived demand or to lower levels of perceived control.

Our results suggest that associations between daily experiences of demand or control and atherosclerotic progression among men may not be attributed solely to job strain. For example, the effects persisted even when measures of demand derived from settings outside of the workplace (e.g., home) were examined. Further research is needed examining the relation between daily psychosocial stress and atherosclerotic progression.

Daytime ambulatory HR partially mediated the relation between perceptions of daily decisional control and disease progression in men. Such results are also consistent with previous data suggesting that resting HR is positively associated with risk for cardiovascular disease and mortality (Beere, Glagov, & Zarins, 1992; Mensink & Hoffmeister, 1997; Perski, Olsson, & Landou, 1992). Previous evidence supports the association between HR variability and disease risk; HR variability is a correlate of resting HR and a marker of parasympathetic function (Tsuji et al., 1996). Excessive sympathetic nervous system (SNS) activation is also a plausible mediator of the effects shown in this study, as the SNS has been implicated in a number of mechanisms of relevance to atherosclerosis, including endothelial function (Hijmering et al., 2002), platelet activation (Larsson, Hjemdahl, Olsson, Egberg, & Hornstra, 1989), and vascular remodeling (e.g., Biaggioni, 2003). Our data (e.g., the failure to demonstrate associations with baseline ABP) are inconsistent with a hypothesized role for the SNS in accounting for the relation with demand and control, but it is possible that more frequent monitoring over the course of the follow-up period would be necessary to demonstrate such effects. It is interesting that relations with ambulatory HR persisted even after adjustment for laboratory-assessed resting HR, as such effects specifically implicate the role of daily activities and stressors as correlates of autonomic dysfunction and cardiovascular risk.

The relation between demand or control and atherosclerotic progression was significant only for men in this sample; such results parallel the findings from previous literature suggesting that job strain tends to be a stronger correlate of health among men (Pickering, 1997; Siegrist, 2002). It is possible that men are more sensitive than are women to health effects associated with performance demands arising inside and outside of the workplace. Such a speculation is consistent with the finding that men appear to show larger blood pressure responses to performance stressors in a laboratory setting (e.g., (Stoney, Davis, & Matthews, 1987).

Less consistent with this interpretation is the fact that there were no significant sex differences when we examined cross-sectional associations involving demand, control, and baseline IMT in our earlier report from this sample (Kamarck et al., 2004). Because the rate of 3-year disease progression was slower for women than for men (and the variance associated with progression was also smaller in this group), another interpretation of the sex differences observed in this study is that they may reflect group differences in the power to detect associations with IMT progression in this sample. We continue to follow this sample and will report on the results of additional follow-up data when they are available. Further research is needed examining sex differences in the effects of psychosocial stressors on cardiovascular health (e.g., Orth-Gomer et al., 2000).

We found no relation between cardiovascular medication use and carotid IMT progression. Whereas this appears to be inconsistent with previous research (Blankenhorn et al., 1993; Furberg et al., 1994), this was not a randomized clinical trial, so prescribed medication use was confounded with initial disease risk. We also found no relation between the use of hormone replacement therapy and carotid atherosclerotic progression. These results are consistent with the most recent randomized clinical trial data from the Heart and Estrogen/Progestin Replacement Study (Byington et al., 2002), which suggest that hormone replacement therapy has no effect on 4-year carotid IMT changes.

There were significant associations between biological risk factors and IMT in cross-sectional analyses, although such factors were not associated with our measures of disease progression. We speculate that the relative stability of risk factors over time, the relatively brief (3-year) follow-up, and the relative health of the sample might have contributed to our failure to detect independent associations between traditional risk factors and the progression of disease. Because cross-sectional analyses reflect variance in IMT accumulating over the course of a lifetime (rather than during a relatively brief follow-up period), risk factor associations in cross-sectional studies involving these measures sometimes have been found to be stronger than those in longitudinal reports (Chambless et al., 2002). It is possible that the effects of our psychosocial measures, conversely, may be relatively specific to this period of the life span, accounting for the retention of these effects in the prospective analysis. We are continuing to follow this group, with the expectation that associations involving both traditional and nontraditional risk factors will become more robust with time.

This sample was older than many who have participated in previous investigations examining job strain and cardiovascular health, and the majority of the sample was unemployed, which restricted our ability to compare the findings with the previous literature. The findings should be replicated with a younger, employed sample. This was a relatively select group, in that they were somewhat older yet healthy. Such characteristics reduce the confounding effects of medication use and clinical disease on self-reported stress, but they also reduce the representativeness of the sample. Finally, the effects we observed were not specifically hypothesized in the design of this study, and we cannot rule out the possibility that they may be due to chance. Arguing in favor of a substantive interpretation of these results is the fact that we have shown a pattern of significant results involving these diary measures of demand and control across a variety of outcome measures in the current investigation (Kamarck et al., 2005). Even more convincing, however, would be a direct replication of these findings in another sample.

Despite these limitations, this study contributes to the growing literature suggesting that psychosocial processes may be correlates or triggers of subclinical cardiovascular disease. This is the first study, to our knowledge, that has used real-time, real-world EMA measures of psychosocial risk in the prediction of cardiovascular disease progression. Our data support the utility of such an approach and the incremental value of EMA data over global questionnaire and laboratory assessments. In conjunction with our initial cross-sectional findings, these data suggest that the experience of high demand and low control activities during daily life may be linked with disease risk, especially for men, and, contrary to the emphasis of the job strain literature, some of our results suggest that such effects are relatively independent of the setting (work vs. nonwork) in which these activities occur. The significant findings with respect to ambulatory HR help us to understand some of the biological mechanisms that may link daily experiences with disease risk and further support the importance of examining individuals in the context of their natural environment. Finally, the prospective design of this study enhances our confidence that the effects observed cannot be attributed to the impact of subclinical disease and its correlates on the experience of daily stress. Future research should replicate and extend these findings and further investigate the biological mechanisms that may contribute to such processes. Future work may also examine the implications of these methods and findings for early intervention in individuals at risk for cardiovascular disease.

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