The Relationship of Chronic and Momentary Work Stress to Cardiac Reactivity in Female Managers: Feasibility of a Smart Phone–Assisted Assessment System

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Objectives: To evaluate a wireless smart phone–assisted (SPA) system that assesses ongoing heart rate (HR) and HR-triggered participant reports of momentary stress when HR is elevated during daily life. This SPA system was used to determine the independent and interactive roles of chronic and momentary work stress on HR reactivity among female managers. **Methods:** A sample of 40 female managers reported their chronic work stress and wore the SPA system during a regular workday. They provided multiple reports of their momentary stress, both when triggered by increased HR and at random times. Relationships among chronic stress, momentary stress, and HR were analyzed with hierarchical linear modeling. **Results:** Both chronic work stress (b = 0.08, standard error [SE] = 0.03, p = .003) and momentary work stress (b = 1.25, SE = 0.62, p = .052) independently predicted greater HR reactivity, adjusting for baseline HR, age, smoking, caffeine, alcohol use, and momentary physical activity levels. More importantly, chronic and momentary stress significantly interacted (b = 1.00, SE = 0.04, p = .036); high momentary stress predicted elevated HR only in the context of high chronic stress. **Conclusions:** Female managers who experience chronic work stress displayed elevated cardiac reactivity during momentary stress at work. The joint assessment of chronic stress and momentary stress and their relationship to physiological functioning during work clarifies the potential health risks associated with work stress. Moreover, this wireless SPA system captures the immediate subjective context of individuals when physiological arousal occurs, which may lead to tailored stress management programs in the workplace.
Key words: work stress, momentary stress, female manager, cardiac reactivity, wireless sensor technology, smart phone.

BPM = beats per minute; **HR** = heart rate; **SPA** = smart phone assisted.

INTRODUCTION

A long-standing literature documents links between chronic stress, as indexed by stressful life events or stressful environments, and mental and physical health problems (1–3). Similarly, there is a large literature on the physiological effects of acute stress, which is typically tested in the laboratory, but can also be assessed during daily life using ecological momentary assessment or experience sampling (4). Although studies of either chronic or acute stress have been mainstays of psychosomatic research, an unanswered question is how chronic and acute stresses operate together. Are they independent in their physiological effects, or do they interact, with the experience of chronic stress, either augmenting or attenuating the effects of acute stress?

Allostatic load theory (5,6) posits that continuous exposures to short-term stressors may, over time, result in a resetting of the body's allostasis, resulting in allostatic load or overload. This is characterized by sustained activation of the physiological stress defense system, and the long-term effects are system failure, development of disease, and accelerated aging and death. Studies have begun to examine the interaction of chronic and acute stress, and although it is possible that early or chronic stress creates resilience, rendering a person less vulnerable to acute stress (7), research more commonly supports the allostatic load theory, in that chronic stress augments the effects of acute stress exposures. For example, stressful family environments create vulnerabilities for health problems in adulthood following acute stressors (8), and a history of trauma exposure increases the risk of developing posttraumatic stress disorder after an acute trauma (9).

Occupational or work stress has been of particular interest in psychosomatic medicine, but most of this research has examined only chronic work stress, operationalized by constructs such as effort-reward imbalance or perceived work demand and control. Findings from such research, however, are somewhat inconsistent; some studies show positive relationships between work stress and poor cardiovascular health (e.g., Ref. 10), whereas others fail to show this association (e.g., Ref. 11). This inconsistency suggests the need to consider other variables in concert with chronic work stress. One study found that the experience of elevated daily demands, as measured by ecological momentary assessment, was more predictive than chronic occupational stress of the progression of carotid artery atherosclerosis (12). However, instead of viewing acute and chronic stress as independent factors, acute work stress might interact with chronic work stress, resulting in particularly maladaptive outcomes. For example, one study of 43 men found that baseline occupational stress predicted greater cortisol reactivity to the Trier stress test in the laboratory, suggesting that chronic work stress augments the effects of acute stress (13).

Research needs to obtain ecologically valid assessments of momentary work stress and the physiological reactions accompanying it. Although laboratory stress research allows researchers to control stressor exposure and obtain a large panel of physiological data, such studies have questionable ecological validity (14). Experience sampling or momentary assessment approaches have greater ecological validity, but such approaches—as currently conducted—do not automatically link physiological triggers to subjective or behavioral measures. Typically, participant reports occur at either random or researcher-predetermined times. In some studies, self-reports are initiated by the participants themselves when they experience some situation or symptom, such as when engaging in certain social interactions (15). The latter

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approach, unfortunately, depends on the attention, memory, and motivation of the participant, which introduces substantial variability into the method.

Ideally, participant reports can be triggered by physiological alterations such as heart rate (HR) or blood pressure changes, independently of participant's attention or memory. Fahrenberg and colleagues (16) have termed this approach "interactive assessment," and it has been used primarily in medicine, such as early warning systems for cardiac patients having ambulatory monitoring, but such interactive assessment has only rarely been conducted in psychological or psychosomatic research. Myrtek and colleagues (17,18) developed the Freiburg Monitoring System to assess HR elevations associated with mental states (rather than metabolic demands due to physical activity), and this system prompts participants to provide subjective data at defined HR increases. These authors have found that there is a relatively low correlation between mental stress and cardiac elevations in daily life. Similar methods have been used in an attempt to understand the emotional reactions of patients with borderline personality disorder (19). The technology used in such studies can be cumbersome, however, requiring participants to carry a small computer that is attached to the physiological sensing system and onto which self-reports can be provided. Fortunately, there has been rapid development of technology to assess subjective and physiological responses in the real world (20,21). In particular, wireless sensors integrated with smart phone text messages can link one's physiological activity to the momentary assessment of subjective reports, using technologies that are increasingly available to people in their daily lives.

This study had three aims. First, we sought to introduce and demonstrate the feasibility of a wireless smart phone system that concurrently assesses both cardiac activity and subjective reports during daily life, including reports that are triggered by HR increases. Second, we sought to demonstrate the potential value of this system by examining the relationships of chronic and momentary stress to HR during daily life. We tested the hypotheses that elevations in both chronic and momentary work stress would independently predict increased HR at work (Hypothesis 1), and that these two types of stress would interact, with momentary work stress having the greatest relationship with HR reactivity among women with higher chronic work stress (Hypothesis 2). Third, research on work stress has often examined samples of either employees in lower skill ("blue collar") positions or men in supervisory positions; thus, we examined an understudied and potentially highly stressed population: women in managerial positions (22).

METHODS

Participants

We studied 40 healthy female managers 25 to 45 years of age working in the private or public sectors in Sweden. Potential participants were identified by approaching the human resources departments of several organizations, including Sweden's largest pharmacy chain and municipal agencies. We excluded women with self-reported current pharmacological treatment, cardiovascular disease, or mental illness. The sample of women were in upper management (59%), middle management (36%), or project management (5%); almost all (92.5%) had at least a college education and had been in their current positions from 1 to 10 years (mean [M] = 3 years). Most (87.5%) were married or partnered, and 65% had children younger than 18 years. See Table 1 for additional descriptive data for the sample.

Procedures

The protocol was approved by the institutional review board of Uppsala University, and data collection ran from November 2010 through March 2012. Employers provided the research team with the names of all female managers in the targeted age range. Potential participants were e-mailed a study invitation, and those who replied were sent a description of the study and a screening form to obtain demographic information, health, and work history. Interested participants who met the study criteria were met at their workplace between 8:00 and 10:00 AM, where the study was described, and participants provided written consent. Participants were informed that the goal of the study was to assess their HR and self-reported stress at various times during the day, they would receive an unspecified number of text questions on the phone during the day, and they should respond immediately and then return to their usual activities. To avoid bias, participants were not informed about any links between their own HR and phone activation. Participants completed a baseline questionnaire that included items about their chronic work stress. A wireless HR sensor was attached to the participant's chest, the quality of the HR signal was visually verified, and the participant was trained to use the phone to answer survey questions. Participants then sat quietly for 30 minutes, during which baseline HR was recorded (and there were no phone activations), after which the formal recording period began, and participants engaged in their normal work day.

We programmed the system to monitor HR continuously and send the stress rating questions to the phone at both HR-triggered and random times over the subsequent approximately 6-hour work period. To avoid excessive work disruption, we limited the system to a maximum of 14 subjective (phone) assessments for each participant during the recording period. On up to 11 occasions during the workday, the system prompted for stress ratings on the smart phone when the participant's ongoing HR increased at least 20% from her baseline HR (i.e., the mean HR from the initial 30-minute resting period). The system tracked HR based on consecutive beats during the recording period, and when the interbeat intervals of each of at least three consecutive beats were at least 20% shorter (i.e., higher HR) than during baseline, the phone activated for subjective ratings. The 20% elevation in HR was chosen by the research team from both pilot testing (described below) and from our knowledge of HR reactivity from various types of laboratory stressors; it was thought to be a large enough acceleration criterion that would identify times of substantial psychological stress, but not so high as to occur rarely. We also chose a criterion that would indicate episodes of greater

TABLE 1. Descriptive Statistics for the Study Sample (n = 40)

	M (SD)	*n* (%)
Baseline variables		
Age	36.03 (4.81)	
Current smoker		4 (10)
Caffeine consumption (1–4)	2.00 (0.30)	
Alcohol use (1–100)	12.95 (15.89)	
Chronic work stress (1–100)	69.86 (15.71)	
Baseline HR, BPM	77.08 (10.86)	
Momentary variables		
Random HR, BPM	78.13 (12.91)	
Triggered HR, BPM	94.77 (12.34)	
HR-triggered stress rating (1–6)	2.37 (1.04)	
Random stress rating (1–6)	2.10 (0.93)	
Physical activity (% of assessments)	6.96 (8.08)	

HR = heart rate; BPM = beats per minute; M = mean; SD = standard deviation.
Momentary variables were averaged over the assessments within participants and then averaged over participants in the sample.
See text for descriptions of categories or rating scales.

tachycardia—and presumably greater stress—than has been found using an "additional heart rate" algorithm that has not been consistently related to subjective state (17). In addition to these HR-triggered reports, the system was activated at three random times during the day to obtain HR and self-reports at times not triggered by increased cardiac activity. After each assessment (whether HR-triggered or random), the system was locked out for the next 10 minutes, during which, no data were collected. After 10 minutes, the system was reactivated and monitoring of HR continued. At the end of the work day, participants removed and returned the equipment (HR sensors, phone), and the HR and stress rating data were downloaded from the phone for analysis.

Smart Phone–Assisted Assessment System

The system that we developed consists of a wireless HR monitor and smart phone. The Zephyr HxM BT Heart Rate Monitor uses a strap mounted around the chest, thus freeing participants' hands. According to the manufacturer, the HR monitor is accurate to within 1 beat per minute (BPM). This monitor supports a Bluetooth serial port communication interface, which has 115,200 baud low-level transmission rate; HR is sampled continuously at a frequency of 1 Hz. The phone connects wirelessly to the sensor and stores and transmits data. We used the Nokia 5530 smart phone, which supports BlueTooth v2.0 with A2DP and Wi-Fi 802.11 b/g. This phone is equipped with a 434-MHz ARM 11 microprocessor and has an internal storage capacity around 70 MB with 128 MB SRAM. We used the Java RecordStore API to collect the data from HR monitor to be stored in the smart phone memory. The question responses were also stored in the phone.

We conducted an initial pilot test of the system, including its ability to track HR, trigger the phone to present survey questions under both elevated HR and control conditions, and differentiate among types of stressors in both HR and subjective stress ratings (23). We studied 10 student volunteers in the laboratory and had them engage in a series of activities: relaxation, mental stress (serial subtractions), walking, and more vigorous stepping, all while wearing the HR monitor and carrying the phone. Participants were prompted to respond on their phone to several questions about their stress and activities when their HR increased at least 20% above baseline as well as at random times. Analyses confirmed that HR significantly differed among the different stress conditions, with HR increasing from relaxation, to mental stress, to walking, and to exercise. Ratings of subjective stress also differentiated the conditions in the same pattern. We found that mental stress elicited at least a 20% increase in HR for most participants. Thus, this pilot study supported both the feasibility and validity of the system and offered support for the use of the 20% HR acceleration criterion.

Measures

Health-Related Covariates

At baseline, participants provided information about whether they are a current smoker (yes/no), their typical caffeine intake (cups of coffee or tea per day, coded from "zero cups" = 1 to "more than 6" = 4), and how often they drink alcohol (rated on a 1- to 100-point scale).

Chronic Work Stress

At baseline, participants rated four items about "your typical work day" on a 100-point scale: a) "Overall, how stressful is your work?"; b) "How intense is your work?"; c) "Do you have regular opportunities to recover during work?" (reverse scored); and d) "How often do you receive breaks during your work?" (reverse scored). As expected, the items all correlated with each other (Cronbach α = .73) and were composited into a single index of chronic work stress.

Momentary Work Stress

This was assessed multiple times during the work day, when triggered by HR acceleration and at random times. This item appeared on the phone: "How stressed are you?" and participants answered on the number pad on a 6-point scale (1 = *not at all*, 6 = *extremely*). The stress question is related to other measures, as hypothesized (24).

Activity Level

To account for momentary physical activity level in our analyses (e.g., the extent to which HR increases were driven by physical activity at work), we asked respondents at each sampling moment which of six possible activities they were engaged in. We dummy coded walking as "1" and the other sedentary activities (e.g., sitting at a desk, on the phone, with a client, at a meeting) as "0" to control for the effect of momentary physical activity.

Heart Rate

Baseline HR was recorded as the mean value during the 30-minute rest period at the start of the work day. Momentary HR was recorded as the immediate value (mean of 3 beats) when the smart phone was prompted for subjective stress response.

Data Analysis

We used hierarchical linear modeling (HLM) (25), which is ideal for these data because we had multiple assessments of HR and momentary work stress nested within people. HLM also estimates slopes (e.g., the within-person association between momentary work stress and HR reactivity) and intercepts (e.g., average HR reactivity), even with variable number of data points per person. All HLM analyses included random error terms and estimated fixed effects with robust standard errors (SEs); all significance tests were two tailed.

First, we ran a model accounting for baseline HR but with no Level 1 (within-person) predictors. This initial model established one's HR reactivity at work, assessed as HR at a particular sampling moment controlling for one's baseline (resting) HR (a Level 2, or between-person variable). Second, we entered momentary work stress as a predictor at Level 1; this model tested the association of momentary work stress with HR reactivity at work (Hypothesis 1). Next, to control for the effects of health-related covariates known to affect HR (age, smoking, caffeine, alcohol), we entered each of these covariates as predictors at Level 2, and we entered momentary physical activity (i.e., walking versus sedentary activity) at each sampling moment at Level 1.

The moderating association of chronic work stress on the association between momentary work stress and HR reactivity (Hypothesis 2) was modeled as a cross-level interaction (Level 2 chronic work stress × Level 1 momentary work stress), with both chronic and momentary work stresses included as main effects. We entered momentary work stress as a predictor at Level 1, chronic work stress at Level 2, and a chronic work stress × momentary work stress interaction term. Both momentary work stress and chronic work stress were centered around their means before conducting this analysis; chronic stress was grand-mean centered, whereas momentary stress was group-mean centered. Finally, to test whether the interaction remained robust after controlling for potential health-related confounds, we entered each of the health-related covariates as predictors at Level 2 and the covariate of momentary physical activity at Level 1.

RESULTS

Preliminary Descriptive Analyses

For 36 (90%) of the 40 participants, the recording period lasted the participant's full workday, averaging almost 6 hours after the instructions and baseline recording (M = 5.6 hours; range, 4.0–7.3 hours). For these 36 participants, there was a mean of 12.7 activations of the phone (range, 6–14); 20 of the participants had the maximum of 14 activations, and the remainder had somewhat fewer activations due to having fewer episodes of elevated HR. There were four participants for whom the recording period was truncated due to technical problems (e.g., HR monitor disconnect); their recordings ranged from 1.3 to 2.6 hours, and they provided from 4 to 11 samples. We retained these four participants in analyses because the data they provided during the recording period were valid and because our analytic method accounts for missing data. For the entire sample, all phone activations were responded to appropriately, with no missing self-report data.

As shown in Table 1, the sample's mean (standard deviation [SD]) chronic work stress rating was 69.86 (15.71) on a 1- to 100-point scale. The mean (SD) momentary stress rating during HR-triggered assessments (averaged over the multiple assessments within each participant) was 2.37 (1.04) on a 1- to 6-point scale, which was significantly higher than each participant's momentary stress ratings during random assessments (M [SD] = 2.10 [0.93], paired $t(39) = 2.14$, $p = .038$). The mean (SD) within-person HR during the HR-triggered assessments was 94.77 (12.34) BPM, which was, as expected, substantially higher than the mean within-person HR at random times (M [SD] = 78.13 [12.91], paired $t(39) = 12.88$, $p < .001$). Chronic work stress correlated positively but only moderately ($r = 0.46$, $p = .005$) with the average of each person's momentary stress ratings.

As shown in Model 1 of Table 2, baseline (resting) HR strongly predicted momentary HR (both HR-triggered and random), as assessed throughout the work day. The intercept in Model 1 of 9.97 can be interpreted as the predicted increase in HR that a person has at work from their own resting baseline HR.

Independent Associations of Momentary and Chronic Work Stress With HR Reactivity

We first tested the links between momentary work stress and HR reactivity at times of stress assessment, controlling for baseline HR. As shown in Model 2 of Table 2, momentary work stress was significantly associated with HR reactivity at work. Furthermore, when health-related covariates (age, smoking, caffeine, and alcohol use) and momentary physical activity were included in the model, the effect of momentary work stress on HR reactivity remained significant ($b = 0.94$, SE = 0.38, $t = 2.48$, $p = .018$).

To test whether chronic stress uniquely predicted HR reactivity, above and beyond the association of momentary work stress with HR reactivity, we added chronic stress as a predictor in an HLM model at Level 2 (person-level), along with momentary work stress as a predictor at Level 1. As shown in Model 3 of Table 2, chronic stress significantly predicted HR reactivity ($b = 0.08$, SE = 0.03, $t = 2.84$, $p = .007$), independent of the association of momentary work stress with HR reactivity ($b = 1.23$, SE = 0.62, $t = 1.99$, $p = .053$). When entering chronic work stress and momentary work stress along with the health-related covariates and physical activity, the association of chronic work stress with HR reactivity remained significant ($b = 0.08$, SE = 0.03, $t = 3.12$, $p = .003$), as did the association of momentary stress with HR reactivity ($b = 1.25$, SE = 0.62, $t = 2.01$, $p = .052$).

Moderation by Chronic Work Stress of the Association of Momentary Work Stress With HR Reactivity

We next tested whether the association of momentary work stress with HR reactivity was especially pronounced among those high in chronic work stress. As shown in Model 4 of Table 2, we found a significant two-way (cross-level) interaction between chronic work stress and momentary work stress predicting HR reactivity at work. As shown in Figure 1, those women who were relatively low in chronic work stress showed no association between momentary work stress and HR reactivity; however, those high in chronic work stress showed a strong association between momentary stress and HR reactivity. In other words, those women high in chronic stress were physiologically much more reactive to their own momentary stress at work compared with those low in chronic stress. Furthermore, when health-related covariates (age, smoking, caffeine, and alcohol use) and momentary physical activity were included in the model, the chronic work stress × momentary work stress interaction remained significant ($b = 1.00$, SE = 0.04, $t = 2.18$, $p = .036$).

Finally, we explored whether the different types of managers varied on any of the analyses above. We created a dummy code representing "0" for middle and project managers and "1"

TABLE 2. Hierarchical Linear Models Predicting HR Reactivity at Work From Chronic Work Stress, Momentary Work Stress, and Their Interaction

Model/Fixed Effect	Coefficient (SE)	*t* Ratio	P
Model 1 (initial model with only baseline HR as predictor)			
Intercept (average HR reactivity at work)	9.97 (3.36)	2.79	.005
Baseline HR	1.05 (0.04)	24.93	<.001
Model 2 (effect of momentary stress)			
Intercept (average HR reactivity at work)	8.09 (3.50)	2.31	.027
Baseline HR	1.04 (0.04)	24.95	<.001
Momentary work stress	0.97 (0.41)	2.38	.022
Model 3 (independent effects of chronic and momentary stress)			
Intercept (average HR reactivity at work)	0.77 (2.88)	3.74	<.001
Baseline HR	1.04 (0.04)	28.43	<.001
Chronic work stress	0.08 (0.03)	2.84	.007
Momentary work stress	1.23 (0.62)	1.99	.053
Model 4 (moderation of momentary stress by chronic stress)			
Intercept (average HR reactivity at work)	10.63 (2.86)	3.72	<.001
Baseline HR	1.04 (0.04)	28.66	<.001
Chronic work stress	0.08 (0.03)	2.85	.007
Momentary work stress	0.91 (0.62)	1.47	.147
Chronic work stress × momentary work stress	0.08 (0.04)	2.03	.049

HR = heart rate; SE = standard error.

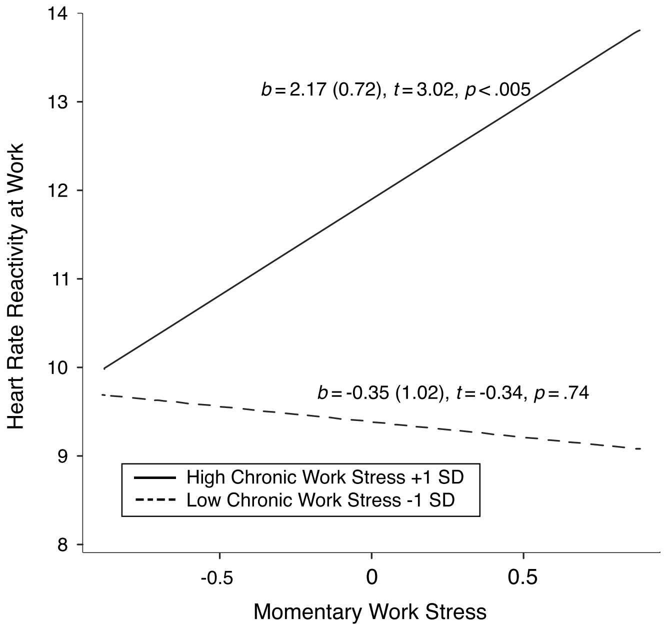

Figure 1. Participants' momentary work stress predicting HR reactivity at work (momentary HR at work, controlling for baseline HR), as moderated by chronic work stress, with high and low values of chronic work stress plotted at +1 and −1 SD from the mean, respectively. SD = standard deviation.

representing upper managers. Manager type was not significantly related to baseline HR or HR reactivity (p values > .40), nor did manager type moderate the association between momentary work stress and HR reactivity (p = .62), or between chronic work stress and HR reactivity (p = .14)

DISCUSSION

This feasibility study has potential implications for theory, research methods, and practice or policy. First, the results advance theory by suggesting that knowledge of either chronic stress or acute stress alone is insufficient in understanding cardiovascular reactivity. Instead, elevated chronic stress seems to set the stage for heightened physiological reactions under conditions of elevated acute or momentary stress. Second, this study advances research methods in that we have developed a highly portable system that uses smart phones to permit the assessment of real-time subjective states when triggered by a person's own physiological reactions in the field. Finally, this work has practical implications in that it highlights the substantial subjective and physiological stress conditions experienced by women in management positions.

Both chronic and acute or momentary stresses were related to cardiac reactivity at work, independently as well as in combination. Consistent with other research (26), women with higher self-reported chronic work stress had greater HR across the workday. In addition, ratings of momentary stress during the day were positively associated with HR measured concurrently, which is consistent with the well-known association between subjective stress and cardiovascular reactivity. Most importantly, however, both chronic and momentary work stresses were synergistic. Among only women who reported relatively high levels of chronic work stress was momentary stress linked with greater HR reactivity. In contrast, women with relatively low chronic levels of work stress did not show an association between momentary stress and HR reactivity. High chronic stress seems to set the stage for negative cardiovascular effects of acute stress, whereas low chronic work stress buffers the effects of acute stress.

This finding has substantial implications for research and theoretical models of stress. Our understanding of stress effects seems to be incomplete if we focus on only chronic stress or acute stress, as is commonly done (10,27,28). Their combination seems to matter more, and people with elevated chronic stress seem to be at greater physiological risk for acute stress exposures than are those with lower chronic stress. This emerging picture highlights the importance of individual differences in risk or resilience for negative health effects of stress. As with risk factors for the development of posttraumatic disorders (9), chronic stress may be a vulnerability or risk factor for augmenting the effects of acute stressful events.

This study also demonstrates the feasibility and use of a novel assessment system that allows a person's physiological reactions to trigger the timing of subjective assessment. Unlike current experience sampling or momentary assessment methods, this system engages in a continuous assessment of a physiological signal (HR in this case) and prompts the participant to respond when the signal reaches a certain threshold. This is an important technical advance because most of the physiological indices of psychosomatic interest—HR, blood pressure, electrodermal activity, muscle tension, gastric activity, and skin temperature—are not readily noticed by people. The ability to continuously monitor such indices and have them trigger the participant to make reports—in real time in the field and in the absence of the researcher—permits the assessment of the participant's subjective state when such physiological arousal occurs. Furthermore, unlike earlier systems, this can now be done wirelessly using a device that most people in industrialized nations today carry—a smart phone. This technology could also be used to assess a range of other important measures, such as participant's behavioral activities, interpersonal context, and even location (e.g., using GPS technology in the phone). The ongoing development of both sensor technology and methods to assess contextual factors can spur the next generation of ecologically valid field research.

This study also sheds light on the experience of working women in positions of responsibility and authority. This rarely studied group has unique challenges and risks, including work-family balance, workplace discrimination, and increased risk of burnout. We found that most managerial women had HR elevations at work on multiple occasions throughout the day, independent of their current level of physical activity, and subjective stress was experienced routinely. Such findings suggest that management positions can be quite stressful for women, with potential mental and physical health implications (29,30), although future research is needed to see how these women differ from female employees who are not managers as well as male managers.

This research has several limitations. First, the results are naturalistic and provide only a snapshot of a complex set of processes. We do not know, for example, what was driving the HR reactivity or the subjective stress, such as whether the participant was engaged in solitary mental challenges, evaluative threats, or interpersonal conflicts. Not only might these contexts differ in the intensity of their cardiovascular consequences, but the clinical ramifications, such as the need for and type of intervention, might also differ. Also, we controlled for baseline or typical use of various substances (smoking, alcohol, caffeine), but we did not assess the use of these substances during the recording period, and any such use might have influenced both HR and subjective stress ratings. Although we controlled for momentary physical activity, as reported by the participants, it would have been ideal to assess activity objectively, such as with actigraphy.

Second, we assessed only HR and a single subjective measure of momentary stress. Additional physiological indicators and a more comprehensive assessment of a participant's subjective experience would provide a much better understanding of stress at work. Third, our use of a 20% increase in HR for triggering momentary stress ratings proved to be successful, in that all participants had such elevations during the day and such elevations were related to increased momentary stress; yet we recognize that the 20% criterion needs further study. A different criterion might be more valid, or it might be wise to tailor the triggering parameters to the individual. Finally, studying healthy Swedish women in managerial positions at work is both unique and valuable, but the generalizability of such a sample is limited in many ways. Moreover, the sample was relatively small. Power analysis in multilevel modeling is challenging and an area of ongoing development because existing methods do not account for the improved reliability afforded by intensive repeated measures. However, we know that with our sample size, we had limited power to detect between-person differences. Based on Cohen's criteria for effects sizes, post hoc power analyses showed that we had very little power for detecting small effects (power = 0.10), modest power for medium effects (power = 0.49), and excellent power for large effects (power = 0.95) (31). Research with larger samples and in other settings is needed.

Despite these limitations, this study highlights the value of assessing both chronic and momentary stresses and demonstrates that women with elevated chronic work stress may have greater cardiovascular reactivity from acute stress experiences at work. Furthermore, this study suggests that new wireless technologies can track subtle physiological signals in daily life and alert the individual when physiological perturbations occur. This can be useful not only in psychosomatic research but also clinical practice, where such technology can easily be modified to educate people about their physiology in daily life and alert them to engage in corrective actions when unhealthy psychophysiological reactions occur.

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REFERENCES

1. Baum A, Garofalo JP, Yali AM. Socioeconomic status and chronic stress. Does stress account for SES effects on health? Ann N Y Acad Sci 1999;896: 131–44.
2. Dimsdale JE. Psychological stress and cardiovascular disease. J Am Coll Cardiol 2008;51:1237–46.
3. Dohrenwend BP. Inventorying stressful life events as risk factors for psychopathology: toward resolution of the problem of intracategory viability. Psychol Bull 2006;132:477–95.
4. Conner TS, Barrett LF. Trends in ambulatory self-report: the role of momentary experience in psychosomatic medicine. Psychosom Med 2012;74: 327–37.
5. Sterling P, Eyer J. Allostasis: a new paradigm to explain arousal pathology. In: Fisher S, Reason J, , editors. Handbook of Life Stress, Cognition, and Health. New York, NY: John Wiley & Sons; 1988:629–49.
6. McEwen BS. Protective and damaging effects of stress mediators. N Engl J Med 1998;338:171–9.
7. Tran V, Wiebe DJ, Fortenberry KT, Butler JM, Berg CA. Benefit finding, affective reactions to diabetes stress, and diabetes management among early adolescents. Health Psychol 2011;30:212–9.
8. Repetti RL, Taylor SE, Seeman TE. Risky families: family social environments and the mental and physical health of offspring. Psychol Bull 2002;128:330–66.
9. Gillespie CF, Phifer J, Bradley B, Ressler KJ. Risk and resilience: genetic and environmental influences on development of the stress response. Depress Anxiety 2009;26:984–92.
10. Kivimäki M, Head J, Ferrie JE, Brunner E, Marmot MG, Vahtera J, Shipley MJ. Why is evidence on job strain and coronary heart disease mixed? An illustration of measurement challenges in the Whitehall II study. Psychosom Med 2006;68:398–401.
11. Macleod J, Smith GD, Heslop P, Metcalfe C, Carroll D, Hart C. Psychological stress and cardiovascular disease: empirical demonstration of bias in a prospective observational study of Scottish men. BMJ 2002;324: 1247–51.
12. Kamarck TW, Shiffman S, Sutton-Tyrrell K, Muldoon MF, Tepper P. Daily psychological demands are associated with 6-year progression of carotid artery atherosclerosis: The Pittsburgh Health Heart Project. Psychosom Med 2012;74:432–9.
13. Wirtz PH, Ehlert U, Kottwitz MU, La Marca R, Semmer NK. Occupational role stress is associated with higher cortisol reactivity to acute stress. J Occup Health Psychol 2013;18:121–31.
14. Kirschbaum C, Pirke KM, Hellhammer DH. The 'Trier Social Stress Test—a tool for investigating psychobiological stress responses in a laboratory setting. Neuropsychobiology 1993;28:76–81.
15. Holt-Lunstad J, Uchino BN, Smith TW, Olson-Cerny C, Nealey-Moore JB. Social relationships and ambulatory blood pressure: structural and qualitative predictors of cardiovascular function during everyday social interactions. Health Psychol 2003;22:388–97.
16. Fahrenberg J, Myrtek M, Pawlik K, Perrez M. Ambulatory assessment—monitoring behavior in daily life settings. Eur J Psychol Assess 2007;23: 206–13.
17. Myrtek M. Heart and emotion: ambulatory monitoring studies in everyday life Cambridge, MA: Hogrefe & Huber Publishers; 2004.
18. Myrtek M, Aschenbrenner E, Brugner G. Emotions in everyday life. An ambulatory monitoring study with female students. Biol Psychol 2005;68:237–55.
19. Ebner-Priemer UW, Welch SS, Grossman P, Teisch T, Linehand MM, Bohus M. Psychophysiological ambulatory assessment of affective dysregulation in borderline personality disorder. Psychol Res 2007;150:265–75.
20. Prill T, Fahrenber J. New methods in ambulatory blood pressure monitoring: interactive monitoring and detection of posture and movment patterns. Behav Res Methods 2007;39:390–8.
21. Tuomisto MT, Terho T, Korhonen I, Lappalainen R, Tuomisto T, Laippala P, Turjanma V. Diurnal and weekly rhythms of health-related variables in home recordings for two months. Physiol Behav 2006;87:650–8.
22. Maki N, Moore S, Grunberg L, Greenberg E. The responses of male and female managers to workplace stress and downsizing. N Am J Psychol 2005;7:297–314.
23. Wang S, Shi W, Arnetz BB, Wiholm C. SPARTAN: a framework for smart phone assisted real-time healthcare network design. Collaborative Computing: Networking, Applications and Worksharing (CollaborateCom), 2010 6th International Conference on IEEE; 2010.
24. Arnetz BB. Techno-stress: a prospective psychophysiological study of the impact of a controlled stress-reduction program in advanced telecommunication systems design work. J Occup Environ Med 1996;38:53–65.

25. Raudenbush SW, Bryk AS, Cheong YF, Congdon R. HLM 6: hierarchical linear and nonlinear modeling. Lincolnwood, IL: Scientific Software International; 2004.
26. Hintsanen M, Elovainio M, Puttonen S, Kivimäki M, Koskinen T, Raitakari OT, Keltikangas-Järvinen L. Effort—reward imbalance, heart rate, and heart rate variability: the Cardiovascular Risk in Young Finns Study. Int J Behav Med 2007;14:202–12.
27. Chandola T, Britton A, Brunner E, Hemingway H, Malik M, Kimari M, Badrick E, Kivimaki M, Marmot M. Work stress and coronary heart disease: what are the mechanisms? Eur Heart J 2008;29:640–8.
28. Kuper H, Marmot M. Job strain, job demands, decision latitude, and risk of coronary heart disease within the Whitehall II study. J Epidemiol Community Health 2003;57:147–53.
29. Allesøe K, Hundrup YA, Thomsen JF, Osler M. Psychosocial work environment and risk of ischaemic heart disease in women: the Danish Nurse Cohort Study. Occup Environ Med 2010;67:318–22.
30. Xu W, Hang J, Cao T, Shi R, Zeng W, Deng Y, Gao W, Zhao Y, Guo L. Job stress and carotid intima-media thickness in Chinese workers. J Occup Health 2010;52:257–62.
31. Cohen J. A power primer. Psychol Bull 1992;112:155–9.