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ORIGINAL ARTICLE

Office workers with high effort–reward imbalance and overcommitment have greater decreases in heart rate variability over a 2-h working period

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Abstract
Purpose High levels of workplace psychosocial factors have been associated with adverse cardiovascular outcomes, possibly through the pathway of increasing autonomic arousal. The purpose of this study was to investigate whether the workplace psychosocial factors of effort–reward imbalance (ERI) and overcommitment were associated with greater decreases in heart rate variability (HRV) across a 2-h working period in a cohort of office workers performing their own work at their own workplaces.
Methods Measurements of HRV in 5-min time epochs across a 2-h morning or afternoon working period, as well as self-reports of ERI and overcommitment, were collected for 91 office workers.
Results There was a negative and significant ($p < 0.01$) ERI*time interaction for the standard deviation of the interval between normal heart beats (SDNN), the square root of the mean squared differences of successive normal heart beats (RMSSD), and the power in the high-frequency range of the heart rate signal (HF power), and a positive and significant ERI*time interaction for the ratio of power in the low-frequency range of the heart rate signal divided by the HF power (LF/HF ratio). There was a positive and significant overcommitment*time interaction for the LF/HF ratio ($p < 0.01$) in the morning, and a negative and significant overcommitment*time interaction for SDNN, RMSSD, and HF power ($p < 0.01$) in the afternoon.
Conclusions The results indicate that participants exposed to high levels of ERI and overcommitment exhibited a more adverse cardiovascular response (a greater decrease in HRV throughout the 2-h measurement period) compared to their colleagues with lower levels of these factors.

Keywords Psychosocial · Stress · Workplace · Heart rate variability · Autonomic control

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Introduction

Workplace psychosocial factors have been associated with adverse cardiovascular outcomes (Steptoe and Kivimäki 2012; Siegrist 2010). According to the effort–reward imbalance conceptual model (ERI), an imbalance in the workplace psychosocial factors of effort and reward (ERI) may cause an increase in worker's autonomic arousal (Siegrist

1996). Overcommitment, another component of the ERI model that describes an individual's pattern of coping with work demands, may modify the effect of ERI on autonomic arousal or may independently affect autonomic arousal (Siegrist et al. 2004). Increased autonomic arousal leads to a release of hormones and inflammatory cytokines that may cause endothelial dysfunction, decreased vasodilation, and, if repeated chronically, increased risk of cardiovascular disease (Poitras and Pyke 2013; Chandola et al. 2010; Siegrist 1996).

Autonomic arousal can be measured using heart rate variability (HRV). HRV, the beat-to-beat differences in heart rate over time, reflects the balance of sympathetic and parasympathetic nervous system activation (Thayer et al. 2012). During autonomic arousal, the sympathetic nervous system dominates over the parasympathetic nervous system, and this causes decreases in HRV (Thayer et al. 2012). Some commonly used measures of HRV include the power in the high-frequency range of the heart rate signal (HF power), which estimates parasympathetic influences; the ratio of power in the low-frequency range of the heart rate signal divided by HF power (LF/HF ratio), which estimates the relative balance of sympathetic to parasympathetic influence; the standard deviation of the interval between normal heart beats (SDNN), which is correlated with the total power of the heart rate signal; and the square root of the mean squared differences of successive normal heart beats (RMSSD) in the time domain, which is correlated with HF power (Task Force 1996). Decreased values of SDNN, RMSSD, and HF power, and increased values of the LF/HF ratio, indicate decreased HRV and therefore increased autonomic arousal and increased potential risk of cardiovascular disease.

Studies of the relationship between ERI and HRV have provided evidence that this workplace psychosocial factor can affect workers' autonomic arousals. Previous studies have reported that workers with high ERI had lower HRV compared to their colleagues during periods while participants were sitting quietly during work (Eller et al. 2011; Hintsanen et al. 2007) and over a workday (Uusitalo et al. 2011; Vrijkotte et al. 2000). The results of these studies, compiled in recent reviews, have indicated that increased ERI is associated with decreased HRV (Chandola et al. 2010; Jarczok et al. 2013).

Overcommitment has been shown in previous studies to affect autonomic arousal, although no previous study has demonstrated an association between overcommitment and HRV. Previous studies have demonstrated associations between overcommitment and some signs of autonomic arousal including a reduction in the dynamic range of cardiac sympathetic regulation as measured by heart pre-ejection period profiles (Vrijkotte et al. 2004) and reduced stress reactivity (Wirtz et al. 2008). However, the one previous study that investigated the effect of overcommitment on HRV did not observe an association (Vrijkotte et al. 2000).

Few studies have examined the relationship between ERI or overcommitment and changes in HRV during working periods. HRV follows daily circadian patterns (Vandewalle et al. 2007; Bonnemeier et al. 2003). However, it is unclear how the autonomic arousal associated with exposure to ERI or overcommitment may affect the daily circadian changes in HRV. Two studies that addressed this topic provided conflicting results. Loerbroks et al. (2010) reported a greater decrease in HRV over a workday for manufacturing workers with higher ERI, while Hanson et al. (2001) observed an increase in HRV over a workday for health professional and office clerk workers with higher ERI. If increased autonomic arousal among workers with higher levels of workplace psychosocial stress causes these workers to have greater decreases in HRV throughout a workday than their colleagues, this would indicate that they are at higher risk of developing adverse health outcomes.

In the current study, we measured the HRV patterns of office workers who reported different levels of ERI and overcommitment, while they performed their own computer-based work at their own workstations for approximately 2 h each. The office worker population may be at increased risk of developing adverse cardiovascular outcomes due to their workplace exposures such as sedentary work (van Uffelen et al. 2010). We hypothesized that workers with higher levels of ERI and overcommitment would have greater declines in HRV throughout the measurement period.

Methods

Study design

A repeated-measures study design was used with HRV parameters as the dependent variables and workplace psychosocial factors (ERI and overcommitment) and time as the independent variables. Heart rate measurements were recorded continuously while participants performed their own (mainly computer) work in their own workplaces for approximately 2 h. Participants were measured either in the morning or in the afternoon. Heart rate measurements were used to calculate HRV in 5-min time intervals (approximately 24 time points). ERI and overcommitment were assessed via a questionnaire administered before the heart rate measurements.

Study population

A total of 120 office workers were recruited to participate in the study. This study was part of the larger Predicting

Occupational biomechanics among OFfice workers (PROOF) study, which has been described previously (Bruno Garza et al. 2013; Eijckelhof et al. 2013). Workers were recruited to participate in the PROOF study based on their self-reported levels of reward and overcommitment assessed using the reward and overcommitment scales from the effort–reward imbalance questionnaire (Siegrist et al. 2004). Participants who responded to the screening questionnaire were separated into tertiles of reward and overcommitment, and those falling into the highest or lowest tertiles were recruited to participate in the study. Participants worked a minimum of 20 h a week at the VU University or the VU University Medical Center in Amsterdam, the Netherlands, used computers regularly during their workdays and were free from musculoskeletal disorders at the time of the measurement. Workers participating in this study reported working as secretary employees, supporting employees, and in other jobs such as doctoral student, researcher, administrator, or professor. This project was approved by the applicable institutional review boards for protection of human subjects, and all participants signed written consent forms before beginning the study.

Heart rate variability

A Polar heart rate monitor (Polar, Lake Success, NY, USA) recorded heart rate during the measurement. Heart rate data were analyzed using the Kubios HRV software (Kubios, Finland). Data were analyzed in 5-min intervals throughout the measurement period (approximately 24 intervals). Metrics calculated within each epoch included the square root of the mean of the sum of the squared differences between adjacent normal to normal intervals (RMSSD), the standard deviation of all normal to normal intervals over the entire period (SDNN), the high-frequency power (HF), and the ratio of the low-frequency to the high-frequency power (LF/HF ratio). In order to avoid the interference of artifacts, ECG recordings were checked using the "artifact correction" function in the Kubios software, and only sections that could be corrected using the "strong" option were included. If "very strong" artifact correction was required for a participant, then that participant was eliminated from the analysis because this correction caused significant differences in the output compared to the less strong corrections (data not shown).

Psychosocial factors

Participants completed a questionnaire determining their ERI using a 5-question effort subscale and an 11-question reward subscale, and overcommitment using a 6-question scale (Siegrist et al. 2004). Possible scores for effort could range from 5 (lowest effort) to 25 (highest effort), possible scores for reward could range from 11 (lowest reward) to 55 (highest reward), and possible scores for overcommitment could range from 0 (lowest overcommitment) to 18 (highest overcommitment). The sum scores of the effort and reward scales can be combined into an ERI ratio by using a correction factor that accounts for the uneven numbers of items (Siegrist et al. 2004). We used the following equation: ERI ratio = sum score effort scale/(sum score reward scale*5/11). Therefore, the ERI scores could range from 0.2 (lowest ERI) to 5 (highest ERI).

Potential confounders

The questionnaire filled out by participants on the day of their measurements also contained questions on age, gender, job title, and number of days exercise per week, which were considered potential confounders of the relationship between psychosocial factors and HRV.

Statistical analysis

Mixed effects linear regression models with participant ID as a random effect were used to test the hypothesis that workers with higher levels of ERI or overcommitment would have a greater decline in HRV. An autoregressive covariance structure was used to model the correlation between repeated measures. Separate models were run with each HRV parameter (RMSSD, SDNN, HF power, and LF/HF ratio) calculated during the working measurement period treated as outcome variables and the psychosocial variable (ERI or overcommitment, treated as continuous variables), time (5-min epoch 0–23, treated as a continuous variable), and the psychosocial*time interaction as independent variables. We were interested in the interaction term, which describes the change in HRV as the psychosocial variables and time increase. All HRV parameters were natural log-transformed so that they were normally distributed. Because we expected that there could be differences in HRV in the morning compared to the afternoon due to circadian rhythms, we performed stratified sub-analyses to analyze participants measured in the morning separately from participants measured in the afternoon. Age, gender, exercise, and job title were included in each model to control for potential confounding by these variables. All analyses were performed in SAS version 9.4 (Cary, NC). Significance was defined as two-tailed $p < 0.05$.

Results

Of the 120 participants recruited for this study, 91 had analyzable heart rate data (Table 1). Heart rate data from the other 29 participants were excluded because their data had

Table 1 Characteristics of the study population

Variable ($N = 91$)	Number or mean
Effort–reward imbalance (potential range 0.2–5)	0.52 (range 0.2–1.1)
Overcommitment (potential range 0–18)	7.6 (range 1–18)
Age (years)	44 (range 24–64)
Exercise (days/week)	3 (range 0–5)
Gender	
Male	26 (29 %)
Female	65 (71 %)
Time of day	
Morning	55 (60 %)
Afternoon	36 (40 %)
Job title	
Secretary employee	8 (9 %)
Other supporting employee	18 (20 %)
Other	65 (71 %)

too many uncorrectable artifacts. Of these 91 participants, 29 % were male, with a mean age of 44 years (range 24–64). Fifty-five participants were measured in the morning, and 36 participants were measured in the afternoon.

There was a significant ($p < 0.01$) ERI*time interaction for SDNN, RMSSD, HF power, and the LF/HF ratio during the measurement period for all participants combined. As the ERI*time interaction increased by one unit, there was a 0.8 % decrease in SDNN, a 1.3 % decrease in RMSSD, a 2.8 % decrease in HF power, and a 2.9 % increase in the LF/HF ratio (Table 2). There were no significant main effects of ERI in any models. There were significant ($p < 0.01$), positive main effects of time in each model. We did not observe any difference in these results when we stratified by time of day, and therefore, only the results for participants measured in the morning and in the afternoon combined are presented.

There was a significant overcommitment*time interaction for HF power ($p = 0.03$) and the LF/HF ratio ($p < 0.01$) during the measurement period across all participants combined. As the overcommitment*time interaction increased by one unit, there was a 0.1 % decrease in HF power and a 0.2 % increase in the LF/HF ratio (Table 3). There was no significant overcommitment*time interaction for SDNN or RMSSD. There were no significant main effects of overcommitment in any models. There were significant ($p < 0.01$), positive main effects of time in each model.

When we stratified the results by time, we observed differences in the effect of the overcommitment*time interaction for participants measured in the morning compared to in the afternoon (Tables 4, 5). In the morning, there was a significant ($p < 0.01$), positive overcommitment*time interaction for the LF/HF ratio, and a significant, positive main effect of time ($p < 0.01$). In the afternoon, there were significant ($p < 0.01$), negative overcommitment*time interactions for SDNN, RMSSD, and HF power, and a borderline-significant ($p = 0.06$) effect of the overcommitment*time interaction for the LF/HF ratio. There were significant ($p < 0.01$), positive main effects of time in each model.

Discussion

In this study, we observed a significant ERI*time interaction for SDNN, RMSSD, HF power, and the LF/HF ratio for participants measured in both the morning and the afternoon. We observed differences in the relationship between the overcommitment*time interaction and HRV depending on whether participants were measured in the morning or the afternoon. We observed a significant overcommitment*time interaction for the LF/HF ratio for participants measured in the morning, and a significant overcommitment*time interaction for SDNN, RMSSD, and HF power for participants measured in the afternoon. These results indicate that our study participants with higher ERI and overcommitment had a greater decrease in HRV throughout the 2-h working measurement period compared to their colleagues. We did not observe any main effects of ERI or overcommitment on HRV.

Our finding of a significant, negative association between the ERI*time interaction and HRV is in line with the results of the study by Loerbroks et al. (2010), who observed a negative and significant interaction between ERI and time for RMSSD. Our study provides additional evidence that the interaction of ERI and time also affects SDNN, HF power, and the LF/HF ratio and that the relationship between ERI and HRV holds among office workers along with manufacturing workers. Further, our study is the first to provide evidence of a relationship between overcommitment and HRV. This study contributes to the evidence provided in the reviews by Chandola et al. (2010) and Jarczok et al. (2013) that workplace psychosocial factors can affect workers' autonomic arousal.

Our findings that HRV decreases as exposure to ERI and time increase oppose an earlier finding by Hanson et al. (2001), who observed increases in HRV throughout the workday for workers with a high imbalance of effort and reward. The authors explained this result by hypothesizing that these individuals experienced withdrawal from their work at the end of the day. Based on our results, our participants did not exhibit this pattern of withdrawal. The participants in Hanson et al.'s study were health professionals and office clerks working at a 911 emergency line and drug rehabilitation center, who likely had jobs with different

Table 2 Beta coefficients, standard errors, and *p* values for the main effects of ERI*time, ERI, and time on ln(HRV) parameters

	ERI*time				ERI				Time			
	Beta coefficient[a]	Standard error	*p* value	Percent change[b]	Beta coefficient[a]	Standard error	*p* value	Percent change[b]	Beta coefficient[a]	Standard error	*p* value	Percent change[b]
SDNN												
Unadjusted	**−0.0079**	**0.0029**	**<0.01**	**−0.8**	−0.1703	0.1871	0.36	−15.7	**0.0054**	**0.0016**	**<0.01**	**0.5**
Adjusted[c]	**−0.0079**	**0.0029**	**<0.01**	**−0.8**	0.0552	0.1649	0.74	5.7	**0.0054**	**0.0016**	**<0.01**	**0.5**
RMSSD												
Unadjusted	**−0.0126**	**0.0032**	**<0.01**	**−1.3**	−0.2949	0.2204	0.18	−25.5	**0.0094**	**0.0018**	**<0.01**	**0.9**
Adjusted[c]	**−0.0126**	**0.0032**	**<0.01**	**−1.3**	−0.0530	0.2011	0.79	−5.2	**0.0094**	**0.0018**	**<0.01**	**0.9**
HF power												
Unadjusted	**−0.02782**	**0.0085**	**<0.01**	**−2.8**	−0.6116	0.4668	0.19	−45.8	**0.0201**	**0.0047**	**<0.01**	**2.0**
Adjusted[c]	**−0.0279**	**0.0085**	**<0.01**	**−2.8**	−0.0553	0.4233	0.90	−5.4	**0.0201**	**0.0047**	**<0.01**	**2.0**
LF/HF ratio												
Unadjusted	**0.0282**	**0.0092**	**<0.01**	**2.9**	0.5752	0.3215	0.07	77.7	**−0.0200**	**0.0051**	**<0.01**	**−2.0**
Adjusted[c]	**0.0282**	**0.0092**	**<0.01**	**2.9**	0.3832	0.3175	0.23	46.7	**−0.0200**	**0.0051**	**<0.01**	**−2.0**

Significant values are denoted by their bold formating

[a] A one unit change in ERI*time, ERI, or time corresponds to change in the ln(HRV) parameter by the amount of the beta coefficient

[b] Percent change in HRV parameter associated with a one unit increase in ERI*time, ERI, or time. Percent change is calculated as percentage (%) = [exp(beta coefficients) − 1] × 100

[c] Adjusted for age, gender, job title, and exercise

Table 3 Beta coefficients, standard errors, and *p* values for the main effects of overcommitment*time, overcommitment, and time on ln(HRV) parameters

	Overcommitment*time				Overcommitment				Time			
	Beta coefficient[a]	Standard error	*p* value	Percent change[b]	Beta coefficient[a]	Standard error	*p* value	Percent change[b]	Beta coefficient[a]	Standard error	*p* value	Percent change[b]
SDNN												
Unadjusted	−0.0003	0.0002	0.10	0.0	−0.0097	0.0120	0.42	−1.0	**0.0035**	**0.0015**	**0.02**	**0.4**
Adjusted[c]	−0.0003	0.0002	0.10	0.0	−0.0166	0.0103	0.11	−1.6	**0.0035**	**0.0015**	**0.02**	**0.4**
RMSSD												
Unadjusted	−0.0003	0.0002	0.09	0.0	−0.0148	0.0142	0.30	−1.5	**0.0055**	**0.0016**	**<0.01**	**0.6**
Adjusted[c]	−0.0003	0.0002	0.09	0.0	−0.0216	0.0126	0.09	−2.1	**0.0055**	**0.0016**	**<0.01**	**0.6**
HF power												
Unadjusted	**−0.0012**	**0.0005**	**0.03**	**−0.1**	−0.0262	0.0301	0.38	−2.6	**0.0143**	**0.0043**	**<0.01**	**1.4**
Adjusted[c]	**−0.0012**	**0.0005**	**0.03**	**−0.1**	−0.0438	0.0263	0.10	−4.3	**0.0143**	**0.0043**	**<0.01**	**1.4**
LF/HF ratio												
Unadjusted	**0.0019**	**0.0006**	**<0.01**	**0.2**	0.0035	0.0213	0.87	0.4	**−0.0197**	**0.0047**	**<0.01**	**−2.0**
Adjusted[c]	**0.0019**	**0.0006**	**<0.01**	**0.2**	0.0134	0.0206	0.51	1.3	**−0.0197**	**0.0047**	**<0.01**	**−2.0**

Significant values are denoted by their bold formating

[a] Adjusted for age, gender, job title, and exercise

[b] Percent change in HRV parameter associated with a one unit increase in overcommitment*time, overcommitment, or time. Percent change is calculated as percentage (%) = [exp(beta coefficients) – 1] × 100

[c] A one unit change in overcommitment*time, overcommitment, or time corresponds to change in the ln(HRV) parameter by the amount of the beta coefficient

Table 4 Morning: beta coefficients, standard errors, and *p* values for the main effects of overcommitment*time, overcommitment, and time on ln(HRV) parameters during the morning measurement period

	Overcommitment*time				Overcommitment				Time			
	Beta coefficient[a]	Standard error	*p* value	Percent change[b]	Beta coefficient[a]	Standard error	*p* value	Percent change[b]	Beta coefficient[a]	Standard error	*p* value	Percent change[b]
SDNN												
Unadjusted	0.0002	0.0002	0.34	0.0	−0.0106	0.0163	0.52	−1.1	0.0005	0.0019	0.80	0.1
Adjusted[c]	0.0002	0.0002	0.33	0.0	−0.0209	0.0131	0.11	−2.1	0.0005	0.0019	0.80	0.1
RMSSD												
Unadjusted	0.0001	0.0003	0.64	0.0	−0.0155	0.0181	0.39	−1.5	0.0026	0.0021	0.22	0.3
Adjusted[c]	0.0001	0.0003	0.63	0.0	−0.0251	0.0141	0.07	−2.5	0.0026	0.0021	0.22	0.3
HF power												
Unadjusted	−0.0003	0.0007	0.70	0.0	−0.0260	0.0384	0.50	−2.6	0.0088	0.0053	0.10	0.9
Adjusted[c]	−0.0002	0.0007	0.72	0.0	−0.0492	0.0304	0.11	−4.8	0.0087	0.0053	0.10	0.9
LF/HF ratio												
Unadjusted	**0.0021**	**0.0008**	**<0.01**	0.2	0.0043	0.0251	0.87	0.4	**−0.0182**	**0.0064**	**<0.01**	**−1.8**
Adjusted[c]	**0.0021**	**0.0008**	**<0.01**	0.2	0.0107	0.0235	0.49	1.1	**−0.0182**	**0.0064**	**<0.01**	**−1.8**

Significant values are denoted by their bold formating

[a] Adjusted for age, gender, job title, and exercise

[b] Percent change in HRV parameter associated with a one unit increase in overcommitment*time, overcommitment, or time. Percent change is calculated as percentage (%) = [exp(beta coefficients) − 1] × 100

[c] A one unit change in overcommitment*time, overcommitment, or time corresponds to change in the ln(HRV) parameter by the amount of the beta coefficient

Table 5 Afternoon: beta coefficients, standard errors, and *p* values for the main effects of overcommitment*time, overcommitment, and time on ln(HRV) parameters during the afternoon measurement period

	Overcommitment*time				Overcommitment				Time			
	Beta coefficient[a]	Standard error	*p* value	Percent change[b]	Beta coefficient[a]	Standard error	*p* value	Percent change[b]	Beta coefficient[a]	Standard error	*p* value	Percent change[b]
SDNN												
Unadjusted	**−0.0011**	**0.0003**	**<0.01**	−0.1	−0.0098	0.0177	0.58	−1.0	**0.0076**	**0.0024**	**<0.01**	**0.8**
Adjusted[c]	**−0.0011**	**0.0003**	**<0.01**	−0.1	−0.01111	0.0174	0.53	−1.1	**0.0076**	**0.0024**	**<0.01**	**0.8**
RMSSD												
Unadjusted	**−0.0010**	**0.0003**	**<0.01**	−0.1	−0.0159	0.0230	0.49	−1.6	**0.0095**	**0.0025**	**<0.01**	**1.0**
Adjusted[c]	**−0.0010**	**0.0003**	**<0.01**	−0.1	−0.0158	0.0243	0.52	−1.6	**0.0095**	**0.0025**	**<0.01**	**1.0**
HF power												
Unadjusted	**−0.0025**	**0.0009**	**<0.01**	−0.2	−0.0305	0.0488	0.53	−3.0	**0.0220**	**0.0072**	**<0.01**	**2.2**
Adjusted[c]	**−0.0025**	**0.0009**	**<0.01**	−0.2	−0.0369	0.0505	0.46	−3.6	**0.0220**	**0.0072**	**<0.01**	**2.2**
LF/HF ratio												
Unadjusted	0.0016	0.0009	0.06	0.2	0.0056	0.0378	0.88	0.6	**−0.0216**	**0.0070**	**<0.01**	**−2.1**
Adjusted[c]	0.0016	0.0009	0.06	0.2	0.0137	0.0412	0.74	1.4	**−0.0216**	**0.0070**	**<0.01**	**−2.1**

Significant values are denoted by their bold formating

[a] Adjusted for age, gender, job title, and exercise

[b] Percent change in HRV parameter associated with a one unit increase in overcommitment*time, overcommitment, or time. Percent change is calculated as percentage(%) = [exp(beta coefficients) − 1] × 100

[c] A one unit change in overcommitment*time, overcommitment, or time corresponds to change in the ln(HRV) parameter by the amount of the beta coefficient

roles and responsibilities than the office workers in the current study that could have caused them to withdraw from their work while workers in the current study did not. We only measured each participant for 2 h either in the morning or afternoon, so we cannot make conclusions regarding our workers' responses throughout the entire workday. However, in this study, we did not observe differences in our associations between the ERI*time interaction and HRV when we stratified our analyses by time of day. This indicates that our participants with high ERI had greater decreases in HRV compared to their colleagues regardless of the time of day that they were measured.

After adjusting for the ERI*time interaction, we did not observe any main effect of ERI on HRV. In our analyses, the main effects of ERI represent the effects of these factors on HRV when time is equal to zero, which corresponds to the beginning of our measurement period. This indicates that our participants did not have differences in their HRV parameters based on their ERI status at the beginning of the measurement period. Previous studies demonstrated that workers with high levels of ERI had decreased HRV during work periods compared to their colleagues (Uusitalo et al. 2011; Vrijkotte et al. 2000). However, the results of our study indicate that the difference may not be consistent throughout work periods: When workers with high ERI started working, their HRV parameters were no different from those of their colleagues, but as these workers remain exposed to ERI for longer their HRV parameters became significantly reduced. We should note that while the effects of the ERI*time interaction on HRV should not be affected by confounding because of the repeated measures of HRV over time, the main effects of ERI on HRV at the beginning of the measurement could be confounded. When we adjusted for confounders, our effects diminished. It was not our primary intention to investigate main effects in this study, and we did not measure all potential confounders that could affect the relationship. While we did not observe any association between ERI and HRV before or after adjusting for confounders, it is possible that an association could be observed in specific subgroups or after adjusting for residual confounders. For instance, workers with prior cardiovascular disease often have heightened HRV responses, so it is possible that restriction to that group might reveal a main effect of ERI on HRV. Also, participants with high ERI might have different jobs than those with high ERI that might be associated with other exposures that could affect HRV such as activity or posture. Although we considered job title to be a potential confounder in our analyses, most participants were classified as "other," and therefore, we had limited ability to evaluate the effect of job title on our analyses.

This is the first study to demonstrate that HRV decreases as overcommitment and time increase. This finding opposes an earlier finding by Vrijkotte et al. (2000), who did not observe an association between HRV and overcommitment. However, Vrijkotte et al. (2000) used a different, earlier measure of overcommitment that may have been less sensitive than the scale proposed by Siegrist et al. (2004). Based on the overcommitment component of the ERI conceptual model (Siegrist et al. 2004), workers with a high level of overcommitment are expected to experience continued exaggerated efforts that can increase autonomic arousal even in the absence of ERI. Therefore, our findings corroborate Siegrist et al.'s (2004) model as well as the results of previous studies that have demonstrated associations between overcommitment and autonomic arousal (Vrijkotte et al. 2004; Wirtz et al. 2008).

We observed that there were differences in the associations between the overcommitment*time interaction and HRV in the afternoon compared to the morning. There was only a significant effect of the overcommitment*time interaction on the LF/HF ratio for participants measured in the morning, while the overcommitment*time interaction was significantly associated with all HRV parameters (nearly significant for LF/HF ratio) in the afternoon. These results may indicate that the effect of overcommitment must accumulate throughout the workday before overcommitment can affect health. In support of this hypothesis, Steptoe et al. (2004) found an increase in cortisol levels among overcommitment individuals in the afternoon of a workday.

We observed significant, positive associations between time and HRV in many of our analyses. The combination of time and the ERI*time or overcommitment*time interaction terms describes the slope or rate of change of HRV throughout the measurement period. The positive effect of time on HRV indicates that the HRV for some participants in our study (the participants with low ERI or low overcommitment) actually increased throughout the measurement period. This result opposed the results reported by Loerbroks et al. (2010), who found a negative association between time and HRV after adjusting for ERI, the ERI*time interaction, and age. Hanson et al. (2001) did observe a positive association between time and HRV along with the positive association between the ERI*time interaction and HRV. Previous studies of the circadian patterns of HRV among workers have demonstrated that HRV tends to decline in the morning and then begins to increase again in the afternoon (e.g., Furlan et al. 2000; Cavallari et al. 2010). However, we observed positive associations between time and HRV among participants measured in both the morning and afternoon. Perhaps it is possible that having low ERI or overcommitment is protective—workers with low ERI or low overcommitment may actually have reduced autonomic arousal during the workday. However, we only measured participants in this study in either the morning or the afternoon, and do not have any whole day measurements of participants. Therefore, it is difficult to draw conclusions on patterns of HRV changes with time throughout the day based on the results of this study.

Although activation of the sympathetic nervous system can be beneficial in certain situations, repeated exposure to sympathetic nervous system activation can contribute to adverse cardiovascular and other health outcomes (Widmaier et al. 2006). The results of our study, in conjunction with other studies, indicate that workers exposed to high levels of workplace psychosocial factors may experience repeated sympathetic nervous system activation (as represented by decreased HRV), setting off a chain of responses that tax the cardiovascular and hormonal systems and can lead to endothelial dysfunction, decreased vasodilation, and, if repeated chronically, increased risk of disease (Poitras and Pyke 2013; Chandola et al. 2010; Siegrist 1996). The results of the current study indicate that this sympathetic activation increases as workers are exposed to workplace psychosocial factors for longer, putting these workers at higher risk of adverse health outcomes. The actual magnitude of increased risk from decreases in HRV over several hours as a result of exposure to workplace psychosocial factors is still unclear, but the results of this study are in line with the hypothesized mechanism.

Several strengths and limitations of this study should be noted. The repeated-measures design allowed us to control for within-person confounders when investigating the effects of the ERI*time and overcommitment*time interactions on HRV, which was the main goal of this study. However, we did not control for any time-varying factors, which could have affected the change in HRV over time. For instance, if participants with lower or higher ERI or overcommitment also had more activity or smoked cigarettes during the measurement period, these factors could have confounded our results because activity and cigarette smoking have been shown to affect HRV. However, our data represent the actual differences in HRV for workers with different levels of ERI and overcommitment, regardless of the mechanism by which ERI and overcommitment lead to changes in HRV. Other between-person confounders related to work or individuals could have affected our main effects results for ERI or overcommitment as discussed above, although it was not the primary intention of this study to investigate main effects. We only considered one model of workplace psychosocial factors in this study, the ERI model (Siegrist 1996; Siegrist et al. 2004). However, while other models of workplace psychosocial stress have also been proposed, previous studies indicated that factors from the ERI model were more strongly related to HRV than factors from other models (Loerbroks et al. 2010). We only measured participants for 2 h in only the morning or the afternoon of one workday. Therefore, we cannot make conclusions regarding patterns of HRV changes throughout an entire workday or for any time outside of the workday based on the results of this study. While we did check for differences in responses for participants measured in the morning compared to the afternoon, the morning and afternoon measurement start/end times were different for each participant, and therefore, the measurements were not aligned by time even within the morning/afternoon stratification. Finally, we have limited variability in our ERI scores, with few participants having high ERI scores. We cannot generalize our findings to participants with scores outside the range reported in this study.

In conclusion, in the current study we observed a greater decrease in HRV throughout a 2-h measurement period for participants with higher levels of ERI and overcommitment than their colleagues. Our results provide evidence in support of the hypothesis that exposure to workplace psychosocial factors can lead to increased autonomic arousal, which may help to explain the link between workplace psychosocial factors and adverse cardiovascular outcomes.

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Conflict of interest The authors declare that they have no conflict of interest.

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