

Original Scientific Paper

Effects of the physical work environment on physiological measures of stress

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Aims In this study we investigated the effects of the physical work environment on two physiological measures of the stress response.

Methods and results Circadian variations in vagally mediated heart rate variability (HRV) and the morning rise in cortisol were evaluated in 60 participants working in a government building either in a traditional (individual offices and old cubicles; $n=40$) or a modern workspace (individualized cubicles with improved views and lighting; $n=20$). Results revealed significant linear ($B = -1.03$; confidence interval: -1.05 to -1.01 , $P < 0.05$) and quadratic ($B = 1.001$; confidence interval: 1.0004 – 1.002 , $P < 0.05$) trends by office type interactions for indices of vagally mediated HRV. Individuals in the old office space had flatter slopes and thus less circadian variation including less HRV at night, and a larger rise in cortisol upon awakening compared with those in the new office space.

Conclusion These results indicate that physical features of the work environment may affect two aspects of the physiological stress response: circadian variations in HRV and the morning rise in cortisol. These findings have important social, economic, and public health implications for work environment risk factors on health. *Eur J Cardiovasc Prev Rehabil* 17:431–439 © 2010 The European Society of Cardiology

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Introduction

Recent research has suggested that stress at work is a major public health risk associated with cardiovascular morbidity [1–3]. In addition, stress at work is associated with substantial economic consequences, including increased absenteeism, increased worker turnover, decreased worker job satisfaction and associated decreases

in worker productivity [4,5]. Importantly, the physical characteristics of the work environment including noise, lighting, and ventilation have been linked to job satisfaction in office workers [6] and are therefore implicated in the effects of work-related stress on health. To date few studies have directly investigated the effects of the physical work environment on physiological health outcomes.

In this study, we measured two aspects of the physiological stress response: vagally mediated heart rate variability (HRV) and salivary cortisol, measures of the

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autonomic nervous system and the hormonal stress response, respectively. These measures were applied to workers in two different office settings.

Decreased vagally mediated HRV is an independent risk factor for morbidity and mortality [7]. In healthy individuals there is a prominent circadian variation in HRV such that there are significant increases during the night-time. We have shown that this increase in HRV during the night is blunted by acute stress and in conditions such as chronic alcoholism [8,9]. In addition, diurnal variations in activation of the hormonal stress response, as indexed by cortisol levels, have been associated with increased cardiovascular disease risk [10]. Finally, a recent report from the Whitehall Study has shown that work stress is associated with decreased vagally mediated HRV and a larger rise in morning cortisol [2]. In this study we therefore examined the effects of the physical work environment on diurnal variations in HRV and the morning rise in cortisol in workers in old or new office space. We hypothesized that improvement in physical work environment factors earlier shown to be associated with job satisfaction, such as natural lighting and views, noise/privacy and ventilation, would be associated with increased diurnal HRV variations and decreased morning rise in cortisol.

Methods

Participants

The study protocol was presented to the entire staff working in a single government facility in the Rocky Mountain region of the United States. Of the 200 workers in the facility, 60 (30%) agreed to participate. Participants were enrolled serially after receiving medical clearance, and were studied over a period of 17 months. Our sample consisted of 60 participants, of whom 40 were initially working in a traditional workspace and 20 were working in a modern workspace. Forty-seven participants agreed to participate in a second measurement day. Six of these 47 participants changed office type in between the first and the second measurement day (five from old to new; one from new to old). Table 1 shows the descriptive statistics of the total sample, split on type of office space in which participants were first measured. All participants were apparently healthy by medical examination and none were on medications that could potentially interfere with heart rate variability and cortisol levels. Pregnant women were excluded from the study.

Characteristics of the work performed

All workers were white-collar workers involved in real estate management for the government. This is generally sedentary work, requiring typical office-based activities, including substantial computer use, interpersonal interactions (face-to-face meetings of varied sizes and by

Table 1 Descriptive statistics

	Old office space (N=40)	New office space (N=20)
Person level		
Sex (female)	70.0%	65.0%
Ethnicity		
Caucasian	85.0%	65.0%
African-American	2.5%	10.0%
Hispanic/Latino	7.5%	20.0%
Asian/Pacific Islander	5.0%	0%
Marital status		
Single	22.5%	30.0%
Married	60.0%	45.0%
Divorced	17.5%	25.0%
Age	46.56 (10.51)	40.91 (11.14)
Months working in workspace	25.50 (23.66)	8.35 (6.44)
Physical fitness	3.68 (1.90)	3.60 (2.35)
Daily stress	2.04 (1.07)	1.72 (0.99)
Episode level		
MSD	22.65 (18.46)	22.98 (15.71)
nHF	24.34 (12.38)	23.07 (13.37)
Cortisol	476.56 (192.67)	416.29 (114.68)
Cigarette consumption	0.00 (0.05)	0.10 (0.31)
Alcohol consumption	0.02 (0.14)	0.00 (0.07)
Coffee consumption	0.25 (0.43)	0.26 (0.44)
Motility	0.07 (0.13)	0.05 (0.08)

MSD, mean of successive differences; nHF, normalized high frequency. Values are estimates (\pm SE).

telephone), moderate amounts of movement within the office environment, and less frequently, travel to other locations.

Physical characteristics of the office spaces

The study was performed in a federally owned building in the United States, which was undergoing serial renovations. This allowed us to measure participants in one geographical location with common external environmental conditions in older traditional office spaces and new renovated office spaces. Some conditions are the same in both new and old spaces, including the heating, ventilating and air conditioning system, ceiling height, and the distance from the window wall to the center of the building (the core). The salient differences between the two spaces are described in Table 2.

Assessment of subjective responses to physical characteristics of the office spaces

As part of the routine assessments of the workers, an anonymous survey was completed by workers in the old and the new office spaces. From this larger survey 11 questions related to the physical characteristics of the office space, which had earlier been shown to be associated with job satisfaction [6] were examined. These questions included satisfaction with numerous factors associated with noise/privacy, ventilation, and lighting and views (see Table 3). The response scales ranged from -3 (very dissatisfied) to +3 (very satisfied).

Procedures

All workers in the building were contacted concerning participation in the study. This study was approved by the

National Institute on Aging (MedStar) Institutional Review Board. Volunteers were solicited and gave written informed consent. After receiving consent a medical exam was scheduled. Those volunteers who were medically cleared for participation were scheduled for a 24-h ambulatory heart rate recording and diurnal cortisol assessment. Within 2 weeks, an experimenter fitted the ambulatory ECG device in the morning before the employees started their regular work activities and instructed them on the use of this device and on the use of a handheld computer that contained the hourly diary questions. Participants carried both electronic devices for 24 h. In addition, before the scheduled ECG recording day, participants were instructed on the cortisol assessment and

provided with five labelled Salivette tubes. The following morning both electronic devices and the cortisol tubes were collected by the experimenters. For those 47 participants who were measured on a second day, this same basic procedure was followed.

State measurements

Diary format

A Palm m100 handheld device (Palm Inc., Santa Clara, California, USA) was used for the hourly diary. Customized software (Pendragon Forms, version 3.1; Pendragon Software Corporation, Libertyville, Illinois, USA) was used to implement questions and to transfer responses from the handheld to MS-Access data format. For the hourly diary, an hourly tone (+ or -15 min) was set from 8:00 to 22:00 h on which participants were instructed to fill in the computerized questions. When the participants answered the first question of each entry of the log, the present time was stored to enable comparison between their responses and the cardiac measurements.

Daily stress and other (bio) behavioral variables

During the last 15 min of each hourly measurement period, until 22:00 h, the participants reported on the handheld computer to what extent they had felt stressed (not at all, some, a bit, much, very much). The participants also reported consumed units of tobacco, coffee, and alcohol (0, 1-2, 2-4, more than 4) in the preceding hour. In addition, participants rated their habitual physical activity using the University of Houston Nonexercise Questionnaire, a seven-point behaviorally anchored rating scale that has been shown to provide valid measures of habitual physical activity [11].

Cardiac activity

Ambulatory cardiac measures were acquired continuously by the VU-AMS device (version 4.6. TD-FPP, Vrije Universiteit, Amsterdam, the Netherlands). This device has been used extensively and details of its characteristics

Table 2 Physical characteristics of the old and new office spaces

	Old office space (N=40)	New office space (N=20)
Workstation layout	Located along the window wall	Located near the core
Accessibility of views	Ceiling-height solid partitions Furniture partitions > 64 inch No transparent windows	No ceiling-height solid partitions Furniture partitions < 64 inch transparent windows Open aisle along the window wall
Light levels on the work surface	325 lux	375 lux
Skylights	Not present	Present
Sound		
Sound masking	Not present	Present
Low-frequency background noise at 20 db	62 db	58 db
Quality	Marginally acceptable (low frequency rumble)	Neutral (good)
Measurements of CO ₂		
Temperature at three different height levels:	No differences	No differences
Volatile organic compounds (VOC), carbon monoxide (CO) and particulates	No differences	No differences
Relative humidity	17.4%	20%

Table 3 Differences in employee satisfaction between the office spaces

	Old (n=46)		New (n=22)		t	P	Questions
	M	SD	M	SD			
Temperature	0.20	1.869	0.64	1.620	0.948	0.347	How satisfied are you with the temperature in your workspace?
Noise level	0.09	1.736	0.32	2.079	0.482	0.632	How satisfied are you with the noise level in your office?
Sound privacy	-1.02	1.626	-1.14	1.699	0.268	0.789	How satisfied are you with your sound privacy?
Air quality	0.09	1.872	1.55	0.858	4.405	0.000	How satisfied are you with the air quality in your workspace?
Amount of light in own workspace	1.28	1.440	2.05	1.133	2.180	0.033	How satisfied are you with the amount of light in your workspace?
Distribution of light in own workspace	1.13	1.455	1.67	1.461	1.398	0.171	How satisfied are you with the distribution of light in your workspace?
Amount of daylight in own workspace?	-0.04	2.078	1.14	1.670	2.321	0.023	How satisfied are you with the amount of daylight in your workspace?
Visual comfort of the lighting	1.13	1.628	1.50	1.596	0.881	0.381	How satisfied are you with the visual comfort of the lighting
Access to a window view	-0.17	2.224	1.45	1.565	3.480	0.001	How satisfied are you with your access to a window view?
Overall building	1.26	1.639	1.45	1.224	0.492	0.624	How satisfied are you with the building overall?
Overall workspace	0.89	1.581	1.36	1.217	1.236	0.221	All things considered, how satisfied are you with your workspace?

have been published elsewhere [12]. Spectral analysis based upon an autoregressive technique using standard methods was used [13]. The autoregressive algorithm was applied to these data to obtain the high-frequency (0.15–0.40 Hz) (HF) component. The HF component is thought to reflect parasympathetic activity. The mean of the absolute successive difference (MSD) between normal-to-normal beats and normalized HF (0.15–0.40 Hz; nHF) for consecutive hourly periods were used as indices of vagal activity. The MSD is less affected by breathing and is therefore a suitable outcome measure in ambulatory studies [14]. Measures of HRV have been shown to be reliable and reproducible [15].

Cortisol measurements

Participants were provided with labeled Salivette tubes for collection of saliva to be used for the assessment of cortisol levels. They were instructed to collect saliva upon waking, 30 min after awakening, after arrival at work, mid-day, and in the evening before bedtime. Cortisol samples were analyzed with radioimmunoassay (Cortisol RIA kit TKC05; Siemens, Siemens Healthcare Diagnostics, Deerfield Illinois, USA). Results are given in µg/dl. The variation coefficient of the assay (CV%) was less than 8.5%.

Statistical analysis

Individual growth curve models were applied to estimate the effects of the office space, the biobehavioral variables and daily stress, aggregated per measurement day, on circadian variation in natural logarithm transformation of the MSD (lnMSD), nHF power, and cortisol [16,17]. The data collected in this study had a three-level hierarchical structure, with several daily measurements of biobehavioral variables, MSD, nHF, and cortisol nested within participants, and participants clustered within the office spaces.

The distribution of MSD was significantly skewed. This skewness was reduced by logarithmically transforming this variable. In the text, raw data (antilog) values are reported. All analyses were performed using the linear mixed model (MIXED) procedure in SPSS 14.0 (SPSS Inc., Chicago, Illinois, USA), with maximum likelihood estimation. We have earlier reported [12] the use of these statistical methods (multi-level regression models), where participants are treated as random effects, as a valid approach to studying participants in real-life situations, such as described here.

Results

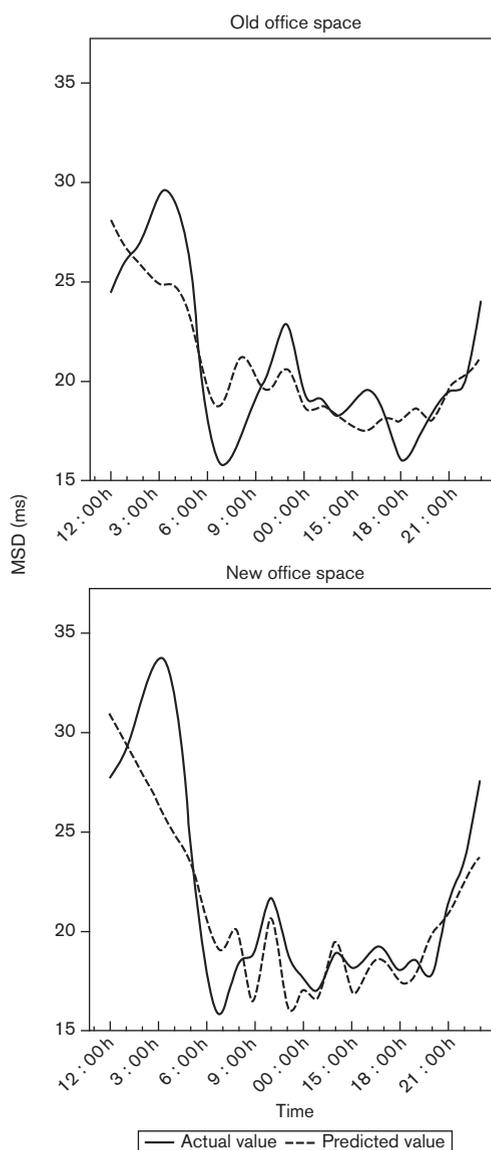
Descriptive statistics as a function of office type are presented in Table 1. The number of months working in the office space was the only variable that significantly differed between the office spaces [$t(58) = 4.55,$

$P < 0.05$]. We therefore controlled for time in office space in the statistical model.

Heart rate variability

Inspection of the graphs (see Fig. 1) suggested that the dependent HRV measures could best be described by a quadratic trend, with HRV highest during mid-night and lowest during the working hours as expected. The intraclass correlations showed that 61.56% of the variation in lnMSD and 47.40% of the variation in nHF was because of clustering of the measurements within participants and office spaces, providing strong evidence for a three-level hierarchical data structure.

Fig. 1



Estimated circadian heart rate variability curves mean of the absolute successive difference (MSD) by office space.

Effects on lnMSD

Results of the baseline growth curve model are presented in Table 4, which confirms that circadian lnMSD is best described by a quadratic trend (model 1). Office space and its interactions with the time variables were added as predictors to the model (model 2) resulting in a better fit based on the deviance test ($\chi^2 = 51.71$, d.f. = 5, $P < 0.01$). There was no main effect of office space on lnMSD. However, there was a significant difference between the office spaces in the circadian lnMSD curve which was indicated by a significant interaction between office space and a linear time trend [$B = -1.03$ (antilog value); confidence interval (CI): -1.05 to -1.01 , $P < 0.05$] and a significant interaction between office space and a quadratic time trend [$B = 1.001$ (antilog value); CI: $1.0004-1.002$, $P < 0.05$]. When controlling for the effects of biobehavioral variables, the interaction effects between the office spaces and the times variables remained significant (model 3). This model fitted the data best (comparing model 3 with model 2: $\chi^2 = 470.90$, d.f. = 9, $P < 0.001$). These interactions support statistically what is visible in Fig. 1, namely that in the new office space, in comparison with the old office space, HRV is higher during the night and lower during the working hours. Thus the HRV slope is less flat in the new space compared to the old space as shown by the difference between the highest lnMSD value and the lowest value being larger in the new space, compared to the old office space.

Effects on normalized high frequency

The nHF power was also best described by a quadratic trend (see also Table 5; model 1). When office space and its interactions with the time variables were added as predictors to the model (model 2), the model fit improved ($\chi^2 = 102.69$, d.f. = 5, $P < 0.001$). The circadian nHF curves were significantly different for the office spaces, indicated by a significant interaction between office space and a linear time trend ($B = -0.67$; CI: -1.08 to -0.26 , $P < 0.01$) and a significant interaction between office space and a quadratic time trend ($B = 0.028$; CI: $0.012-0.044$, $P < 0.01$). This pattern remained significant after controlling for the biobehavioral variables, which resulted in a better fitting model ($\chi^2 = 92.93$, d.f. = 9, $P < 0.001$). Thus, the nHF analyses yield very similar results as the lnMSD analyses.

Taken together, the HRV analyses showed that HRV was higher during the night-time and lower during the working hours in the new office space compared with the old space.

Cortisol

Results of the multilevel analysis of the cortisol data are presented in Table 6. Inspection of the graphs (see Fig. 2) suggested that the circadian cortisol curves could best be described by a cubic time trend, with cortisol highest

Table 4 Results of fitting a multilevel model for change on the lnMSD data

	Model 1	Model 2	Model 3
Dependent variable predictor	lnMSD	lnMSD	lnMSD
Fixed effects			
Intercept	3.286 (0.065)*	3.212 (0.079)*	4.275 (0.291)*
Time, linear slope	-0.075 (0.004)*	-0.065 (0.006)*	-0.038 (0.006)*
Time, quadratic slope	0.003 (0.0001)*	0.002 (0.0002)*	0.001 (0.0002)*
Office space		0.199 (0.130)	0.112 (0.131)
Time, linear × office space		-0.029 (0.009)*	-0.020 (0.010)*
Time, quadratic × office space		0.001 (0.0003)*	0.0007 (0.0003)*
Cigarette consumption			-0.099 (0.020)*
Alcohol consumption			-0.262 (0.075)*
Coffee consumption			0.016 (0.016)
Motility			-1.381 (0.086)*
Sex			0.386 (0.126)*
Age			-0.027 (0.006)*
Daily stress			-0.050 (0.035)
Months working at office space			0.002 (0.001)
Physical fitness			-0.029 (0.013)*
Variance components			
Repeated measures	0.142 (0.004)*	0.134 (0.004)*	0.118 (0.004)*
Intercept variance	0.277 (0.047)*	0.253 (0.045)*	0.212 (0.043)*
Intercept-slope covariance		0.0003 (0.0008)	0.001 (0.0008)*
Slope variance		0.0001 (0.0000)*	0.0001 (0.0000)*
Deviance	2236.89	2185.18	1714.28

The mixed model, or random effects model method of statistical analysis applied here and in Tables 5 and 6, was selected to address issues that arise when performing studies in real life situations, that is, issues related to missing data, unequal cells with respect to time or location, order of recruitment, order of repeated measures, seasonal effects, potential co-morbidities or medication use. Office space and individuals were included as higher level (random) effects and day of measurement and hours since waking, as repeated effects. All independent variables were centered on their grand mean. The units reported in the tables represent the change from the intercept (increase or decrease) associated with the effect of each variable. A sequence of three models was tested for each dependent variable: a baseline growth curve model containing only time variables (HRV: linear and quadratic time trends; cortisol: cubic time trend) served as a baseline model to assess the contribution of adding other predictor variables to the model. The main effects of interest office space and its interaction with time variables were added in a second model. Modelling variation of slopes across persons was applied to evaluate whether these variables had a random effect. Finally, biobehavioral variables, aggregated per measurement day were added to the model, to examine whether these could account for potential significant effects of the office space. Model 1: baseline growth level model with random intercept. In models 2 and 3 the intercept and the slope of time were allowed to vary between office spaces and individuals. lnMSD, natural logarithm transformation of the mean of successive differences (MSD). Values are estimates (\pm SE). lnMSD, natural logarithm transformation of the mean of successive differences. * $P < 0.05$.

30 min after waking. This was confirmed in a baseline growth curve model (model 1). In the second model office space and its interaction with the cubic time trend were entered into the model resulting in an overall better fitting model ($\chi^2 = 22.43$, d.f. = 2, $P < 0.001$). A significant main effect of office space was found ($B = -114.82$; CI: -224.79 to -4.85), with overall higher levels of cortisol in the old office space. The interaction of office

Table 5 Results of fitting a multilevel model for change on the nHF data

Dependent variable predictor	Model 1	Model 2	Model 3
	nHF	nHF	nHF
Fixed effects			
Intercept	34.043 (1.578)*	33.312 (1.727)*	41.775 (4.679)*
Time, linear slope	-2.191 (0.097)*	-1.967 (0.124)*	-1.739 (0.126)*
Time, quadratic slope	0.082 (0.004)*	0.072 (0.005)*	0.063 (0.005)*
Office space		2.372 (2.831)	2.639 (2.675)
Time, linear × office space		-0.670 (0.210)*	-0.658 (0.207)*
Time, quadratic × office space		0.028 (0.008)*	0.027 (0.008)*
Cigarette consumption			-1.664 (0.383)*
Alcohol consumption			-2.040 (1.396)
Coffee consumption			-0.068 (0.219)
Motility			-13.219 (1.841)*
Sex			-5.329 (2.023)*
Age			-0.132 (0.089)
Daily stress			0.914 (0.654)
Months working at workspace			0.012 (0.023)
Physical fitness			-0.312 (0.258)
Variance components			
Repeated measures	67.607 (2.073)*	62.408 (1.947)*	59.967 (1.87)*
Intercept variance	80.831 (13.919)*	119.701 (21.321)*	100.955 (18.724)*
Intercept-slope covariance		-2.248 (0.594)*	-2.075 (0.551)*
Slope variance		0.097 (0.023)*	0.099 (0.023)*
Deviance	15774.73	15672.04	15578.11

Model 1: baseline growth level model with random intercept. In models 2 and 3 the intercept and the slope of time were allowed to vary between office spaces and individuals. nHF, normalized high frequency power. Values are estimates (\pm SE). * $P < 0.05$.

Table 6 Results of fitting a multilevel model for change on the cortisol data

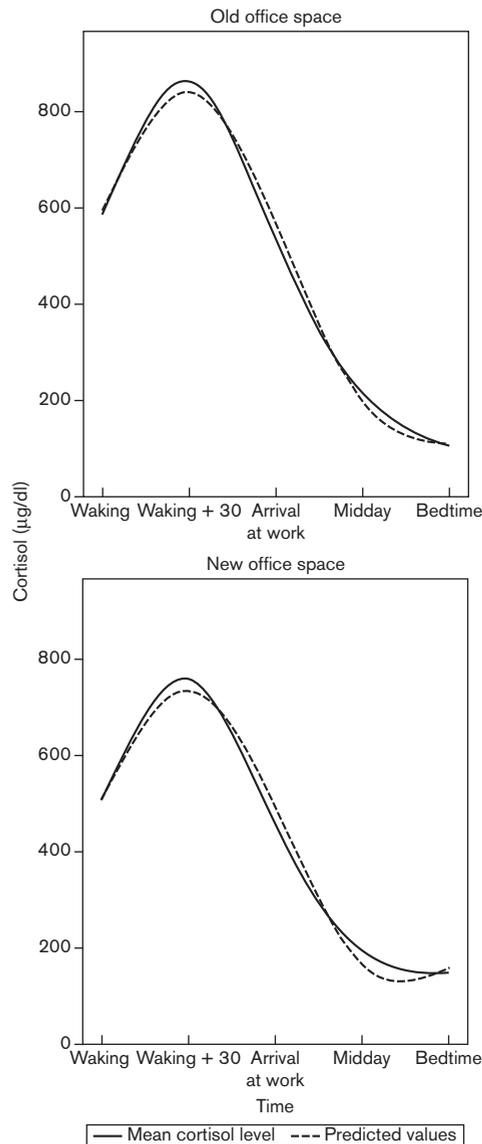
Dependent variable predictor	Model 1	Model 2	Model 3
	Cortisol	Cortisol	Cortisol
Fixed effects			
Intercept	565.54 (32.06)*	603.56 (42.02)*	652.47 (122.84)*
Time, linear slope	632.55 (68.51)*	632.44 (66.40)*	613.67 (67.14)*
Time, quadratic slope	-457.14 (43.33)*	-456.53 (41.87)*	-444.35 (42.25)*
Time, cubic slope	67.92 (7.12)*	67.01 (6.88)*	65.06 (6.95)*
Office space		-114.82 (55.16)*	-102.43 (57.66) ^($P=0.080$)
Time, cubic × office space		2.39 (1.14)*	2.49 (1.16)*
Cigarette consumption			4.28 (15.48)
Alcohol consumption			74.50 (48.25)
Coffee consumption			-15.90 (8.30) ^($P=0.062$)
Motility			-193.62 (235.98)
Sex			-5.01 (44.76)
Age			-0.92 (2.10)
Daily stress			-13.29 (27.94)
Months working at office space			1.48 (1.20)
Physical fitness			-5.21 (10.08)
Variance components			
Repeated measures	59262.31 (4560.46)*	55264.71 (4429.52)*	54116.84 (4455.87)*
Intercept variance	16363.20 (4973.52)*	39218.10 (11694.72)*	38657.58 (12095.75)*
Intercept-slope covariance		-6440.03 (3138.72)*	-6779.82 (3181.23)*
Slope variance		1068.81 (983.48)*	1190.68 (980.26)
Deviance	5620.02	5597.60	5395.68

Values are estimates (\pm SE). Model 1: baseline growth level model with random intercept. In models 2 and 3 the intercept and the slope of time were allowed to vary between office spaces and individuals. * $P < 0.05$.

space with the cubic time trend was also significant ($B = 2.39$; CI: 0.12–4.66). Preplanned t -tests showed statistically higher cortisol levels at 30 min after awakening in participants working in the old office space ($M = 871.07 \mu\text{g/dl}$, $SD = 362.50$) versus participants working in the new office space [$M = 756.64 \mu\text{g/dl}$, $SD = 286.47$, $t(80) = 1.41$, $P = 0.04$, one-tailed]. Controlling for biobehavioral variables in the third model resulted in a better fitting model ($\chi^2 = 202.27$, d.f. = 9,

$P < 0.001$), yet only caffeine intake had a – marginally-significant negative effect on overall cortisol levels ($P = 0.062$, two-tailed). The main effect of office space was slightly reduced and became a statistical trend ($P = 0.080$, two-tailed), but the interaction between office space and the cubic time trend remained significant. These results suggest that the morning rise in cortisol is greater in the old office space compared with the new office space.

Fig. 2



Estimated diurnal cortisol curves by office space.

Discussion

The results of this study provide important new evidence for the effects of the physical work environment on work-related stress. This study for the first time links the physical work environment to altered physiological aspects of the stress response. We found that old office space, characterized by poorer lighting and air quality compared with the new office space, was associated with less vagally mediated HRV at night and a higher morning cortisol rise. The pattern of relatively lower night-time and higher daytime vagally mediated HRV observed in individuals in the old office space was opposite to the expected typical healthy pattern, in which HRV should be higher at night and lower during working hours.

Together these findings indicate greater activation of both the autonomic and hormonal stress response in individuals in old office space, and a shift towards a more vagally mediated, lower stress hormone responsive state in individuals in the new office space.

Numerous studies have now reported that work stress is associated with increased risk of coronary heart disease [18,19]. In a prospective study based on the Whitehall II study Chandola *et al.* (2008) [2] found that work stress was associated with lower vagally mediated HRV and a greater morning rise in cortisol unrelated to other health behaviors. Thus, these authors suggested that work stress had direct effects on autonomic and endocrine responses that were not mediated through health behaviors.

In this study we found that the physical characteristics of the work place had effects on these same autonomic and endocrine responses, and that these effects were also not mediated by health-related behaviors such as smoking, physical fitness, alcohol or caffeine consumption. Specifically, we found that persons working in the older office space, which was characterized by poorer subjective air quality and lighting features such as less daylight and less access to window views, had a decreased diurnal variation in HRV, including less HRV at night, as well as a larger morning rise in cortisol. These are the same physiological responses identified by Chandola *et al.* [2] as intermediate mechanisms for the relationship between work stress and coronary heart disease. Importantly our findings were independent of any difference reported by individuals in the two office spaces in perceived stress. In fact, the HRV effects were greatest during the night when no self-reports were possible. Thus, our study suggests that the physical work environment may affect at least some of the underlying physiological factors associated with the negative health effects of increased work stress without the individuals being consciously aware of a stressful experience.

We have earlier shown that stress and worry during the day can have effects on both daytime and night-time cardiac activity [12,20]. These night-time effects included increased HR and decreased HRV. Moreover, we hypothesized that these night-time effects were occurring outside of conscious awareness and that these may represent a major source of stress-related cardiac activity that goes unreported. In this study we were able to identify that physical workspace, as a whole, may account for at least some of these unreported stress effects of the work environment. In addition the effects on HRV in this study were of the same magnitude as we earlier found to be associated with reported stress and worry (approximately 1 ms) even though in this study there were no significant differences in reported stress between the two office types.

Although in this study we did not address the individual features of the two workspaces that might account for these effects, there were distinct differences between them, which together could account for these differences. These include lighting/views, acoustics, and perceived air quality. These features have been reported to be associated with worker satisfaction in other studies [6]. To evaluate the contribution of such specific features of the work environment to worker satisfaction, Veitch *et al.* (2007) [6] developed and applied a set of standardized measurement tools for the assessment of workers' perceptions of their work environment. Three primary factors were identified, which were associated with workers' perceptions of satisfaction with their workplace. These factors were privacy/acoustics, ventilation/temperature, and lighting/views.

In this study, workers in the new office space reported greater satisfaction in the air quality, amount of daylight and access to window views compared with those in the older office space. Light levels and views of nature have both been associated with better health outcomes and lower depressive symptomatology in hospital settings [21], and could contribute to a shift in stress response systems [22]. The difference of 50 lux on the work surfaces measured in the two office spaces is within the perceivable range and could contribute to differential physiological responses in the two spaces. Although airflow and ventilation were not measurably different in the two spaces, workers in this study reported more satisfaction with air quality in the new compared with the old office space. An additional feature that distinguishes the two workspaces is the considerable amount of low-frequency noise in the old compared with the new space. Low-frequency mechanical noise has been linked to increased occupant discomfort [23], and noise levels in general have been associated with activation of the stress response and worse health outcomes in a variety of settings [24]. Together these features corresponded to physical differences between the two office spaces, although the two spaces were both within established limits for safety and comfort. Thus, although both spaces were within acceptable limits, it is possible that subtle differences in architectural features of workspaces could have a significant effect on health outcomes.

To rule out whether the difference in number of months' workers had spent in the two types of office space could have contributed to the observed effects, we controlled for time in office space and found that this variable was not a significant contributor in the models. Furthermore, we allowed participants habituation time (at least 8 weeks) in the new space to minimize any potential acute effects of the move.

More work is needed to identify the specific physical characteristics of the work place, which can impact health and consequent related aspects of work behavior such as

absenteeism, worker turnover, worker job satisfaction, and worker productivity. However the clear association we report here between overall workplace physical environment and physiological measures of the stress response, which are known to be intermediate mechanisms in stress-related illnesses, points to the importance of the physical work environment on health. This study suggests some features of the physical work environment that should be considered for future study, and provides sensitive objective outcome measures that could be used in subsequent research to address this relatively overlooked factor contributing to workplace stress, with important social, economic, and public health impact on workers.

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