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Occupational determinants of heart rate variability

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Abstract ***Objectives:*** Analysis of HRV has been suggested as a way to study the effects of work-related stresses on cardiovascular autonomic regulation. The aim of this study was to evaluate the use of HRV in the investigation of work-related stressors. ***Methods:*** Cross-sectional data from an ongoing cohort study were used to analyse the relationship of the potential workplace stressors of job-strain, noise and shift work, with HRV. Mean HRV values during sleep and work were calculated in 135 24-h EKG recordings. ***Results:*** Shift workers displayed significantly decreased SDNNi levels during sleep, compared with those of the daytime workers (adjusted least square mean values: 69.3 and 85.8 ms, respectively, $P < 0.05$). Compared with the control group reporting low job demands and high work control (mean: 73.2), we found significantly elevated %LF means during work adjusted for sleep in the low demands, low control group (77.9, $P < 0.01$), high demands, high control group (77.7, $P < 0.05$) and high demands, low control group (77.7, $P < 0.05$). Workers reporting a high noise level compared with a low work noise level also displayed an elevated adjusted mean %LF during work (78.0 and 75.3 respectively, $P < 0.06$). ***Conclusions:*** The finding of a decreased SDNNi level during sleep in shift workers compared with day workers indicated a less favourable cardiovascular autonomic regulation, which may explain in part the excess cardiovascular disease risk in shift workers. The elevated %LF during work in employees exposed to high job strain or high noise levels indicated a direct shift in the autonomic cardiac balance towards sympathetic dominance. We concluded that the analysis of HRV may provide a useful tool in the study of the physiological effects of work-related stresses.

Key words Heart rate variability · Shift work · Job strain · Workplace noise

Abbreviations *HRV* Heart rate variability · *%LF* Low frequency power (0.04–0.15 Hz) in normalised units (Low frequency power/High frequency + low frequency power) · *log(HF)* Power in the high frequency range (0.15–0.40 Hz) in logarithmic units · *Log(LF)* Power in the low frequency range (0.05–015 Hz) in logarithmic units · *SDNNi* Mean of the standard deviations of all NN intervals for all 5-min segments of the entire recording, in milliseconds · *HF* high frequency · *LF* low frequency

Introduction

Heart rate variability has become the accepted term to denote variations in both instantaneous heart rate and RR interval (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology 1996). Since the publication of studies establishing HRV as a strong and independent predictor of mortality after acute myocardial infarction (Kleiger et al. 1987; Malik et al. 1989; Bigger Jr. et al. 1992; Rovere et al. 1998), analysis of HRV has frequently been used in a clinical setting (Steenland et al. 1997). However, outside of the clinical setting, assessment of HRV can also be used as a non-invasive tool for predicting cardiovascular morbidity and mortality in healthy subjects (Dekker et al. 1997; Tsuji et al. 1994, 1996; Huikiri et al. 1998). Tsuji reported a hazard ratio of 1.47 for new cardiac events (95% confidence interval

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of 1.16 to 1.86) for a 1-standard deviation decrement in a popular HRV measurement (SDNNi).

Fluctuations in cardiac sympathetic and parasympathetic outflow cause a significant part of the beat-to-beat fluctuation in heart rate. Analysis of HRV could therefore be used as a tool to assess cardiac autonomic control. Variations in heart rate can be evaluated in time and frequency domain. Spectral analysis in the frequency domain enables a crude separation between vagal and sympathetic cardiac control to be made. Fluctuating efferent vagal activity is the major contributor to HF HRV (Malliani et al. 1991; Pomeranz et al. 1985). There is still some disagreement about interpretation of the LF HRV component. Some authors consider it as a marker of sympathetic modulations (Malliani et al. 1991; Pagani et al. 1997), while others adhere to the view that it reflects fluctuations in both sympathetic and vagal activity (Akselrod et al. 1981; Houle and Billman 1999).

During the past decade, HRV analysis has been proposed as a non-invasive technique for the assessment of job-related cardiovascular stressors (Kristal-Boneh et al. 1995). Up till now, there has been published only a very limited number of studies in which the relationship between working conditions and HRV is described. Work by Pagani et al. (1991) demonstrated a relationship between exposure to a psychological stressor (computer-controlled mental task, or a stressful interview) and the LF component of HRV. So far, no studies using a more general scoring of overall workplace stressors have been found. In this investigation we used the cross-sectional data of an ongoing cohort study designed to examine the effects of shift work on the cardiovascular risk profile. The influence of the workplace stressors noise, job strain, physical activity, and shift work on heart rate and HRV was investigated. We calculated 24-h mean heart rate and HRV values, and mean values during sleep and work, from all 5-min heart rate and HRV readings in the 24-h recording. Means during sleep and work were analysed, to differentiate between more acute and longer term effects. Means during work, corrected for values during sleep, were used as estimates of the direct effects of the indicated amount of workplace-related stressors on heart rate and HRV.

Methods

Population

All subjects participated in an ongoing cohort study of 396 shift workers and daytime controls. The participants worked in the integrated circuit manufacturing industry, waste incinerator plants, or in hospitals. The main objective of the cohort study was to determine the influence of shift work for 1 year, on cardiovascular risk factors. The ethical committee of Wageningen University approved the study, that implied that all respondents gave written informed consent before being included. Inclusion criteria were:

- Starting in a new job
- Working at least 32 h a week
- Expecting to work next year in the same job
- Not using medication, nor having had previous hospitalisation for cardiovascular disease
- Having no insurmountable objections to shift work (see Measurements)
- Being aged between 18 and 55 years

This study refers to the 155 members of the cohort who underwent an initial 24 h Holter recording covering a standard daytime working day. Of the recordings, 20 could not be used for this study (incomplete recordings due to non-compliance, skin irritation, technical failure, unexpected changes in the work schedule; two persons had an excessive number of premature beats). This left us with 135 complete and analysable recordings.

Data collection

Measurements were performed between 1 week and 2 months after the start of a new job.

24 h Holter recordings

The participants were submitted to a 24-h Holter recording, starting at the beginning of a morning shift (for the shift workers) or day shift (for the day workers). A trained research nurse prepared the Holter recorder. All subjects were instructed to note down the start and finish times of sleep, work, meals, leisure, physical activities and other possibly relevant events or activities. These diaries were later coded from a list of standard activities. The sleeping period was defined as the time 1 h after going to sleep until 1 h before getting up, as recorded in the diary.

Personal and work characteristics

All participants received a questionnaire which they were asked to complete, and return by mail, Unclear or missing answers were verified by telephone. Most questions were close-ended and came from standardised questionnaires.

Personal characteristics: In the questionnaire, education level was coded in seven levels, from primary to university education. In the final analysis these levels were reduced to categories: lower, intermediate and higher education. Physical activity indices for work, sport and leisure time were assessed as described by Baecke et al. (1982). Leisure time, physical activity and sports scores were combined into an overall leisure time physical activity score. Though current (type, quantity) and past (type, years, and quantity) smoking habits were queried, in the final analysis only the smoking status (non-smoker, current smoker, or ex-smoker) was used.

Current job title and job history: The questionnaire asked for details about the current job, including company, department, and shift work schedule. If in doubt concerning this schedule status on the employment form, we verified the data with the occupational health service or the human resources department of the employing firm. All jobs were coded for social status and job content. A total of nine different job titles were coded. In this study we defined shift work as ''working in an alternating work pattern, including nights''. Shift timetables were coded as forward rotating (nights-afternoons-mornings, advancing schedule) or backward rotating (mornings-afternoons-nights, delaying schedule). We coded rotation as fast, when at most, three consecutive night shifts were worked. Five consecutive night shifts at most, in a row were coded as medium rotation. Irregular shift schedules, often made each month after consultation with all workers involved, were coded as irregular. Information on all previous jobs including title, employer, starting and ending dates and shift work status was requested.

Workplace noise: Workplace noise was assessed using a question developed by Ising (1997): ''Please indicate the level of noise which matches best with the noise level at your workplace: (1) refrigerator; (2) typewriter; (3) electric lawnmower; (4) electric drill; (5) road drill''. Because of small numbers, especially in the higher

categories, we combined the two lowest noise classifications [both estimated as 55 dB(A)], into a low-level category, and the highest three noise levels [estimated as 75, 90 and 100 dB(A)] into a high noise category.

Job strain: The amount of job strain was assessed using the Dutch version of the "job demands, decision latitude and social support" questionnaire (Karasek 1979). The mean of the highest and lowest scores was selected as the cut-off point between high and low job strain.

HRV assessment

The 24-h Holter recordings were analysed with a Marquette Series 8000 Holter Analyser by an experienced Holter analyst. The onset-Q instants of all beats were determined with the CCTOC Marquette Holter research software module. The resulting inter-beat interval series were down-loaded from the Holter analyser, and further analysed on a personal computer as described by Janssen and Swenne (1992).

The complete recording was split into 5-minute segments. Only segments with 5% or less of missing values (due to a noisy ECG) were used. Heart rate and HRV parameters were computed for each segment. The 24-h and the mean values during sleep and work were obtained by averaging.

For the normal beats, SDNNi was calculated as standard deviation during a 5-min reference period, with the exclusion of all segments with more than 5% of missing values.

We adopted the mean HRV readings during sleep as individual reference values, because they are the least influenced by day to day differences in work and leisure time activities (Bernardi et al. 1996). The 24-h mean values were included to differentiate between changes in overall mean level or changes in mean value during sleep that were compensated for during another time of day.

The algorithm used for spectral analysis has been described elsewhere (Bootsma et al. 1994). Briefly, intervals were normalised to the duration of the mean interval. Then, linear trend removal, and 10% left and right tapering was done. After padding the data with zeros to the nearest power of two, we computed the power density spectrum by means of a Fast Fourier algorithm. We calculated the spectral powers within two frequency bands: LF (0.05–0.15 Hz a marker of fluctuations in either sympathetic, or sympathetic plus vagal activity) and HF (0.15–0.40 Hz a marker of vagal activity. (Malliani et al. 1991). The spectral components were calculated both as absolute units and as normalised units (the latter by dividing LF and HF by their sum, and multiplying this by 100).

Data analysis

Because of the skewed within- and between-subject distribution of the HF and LF spectral HRV components, we log-transformed these parameters before carrying out any averaging. Standard methods were used for descriptive analysis and linear regression. Least square mean values, calculated with SAS proc GLM [(SAS Institute (1989)], are shown to enable comparison of mean values between subgroups, adjusted for covariates. Least square means are the values of class or subclass means that are expected for a balanced design involving the class variable with all covariates at their mean values. Differences between categories and significance levels are identical to the differences and P values from analysis of covariance. Visual inspection of the residual values of the regression models was performed to affirm that the linear model was appropriate.

Results

Our study group consisted of 113 male and 22 female subjects; mean ± SD age 30.8 ± 7.5 years. Table 1 summarises the main work-related population characteristics, smoking habits and education level.

Table 1 Population characteristics

n	135
Age (years)	30.8 (7.5)[a]
Leisure time physical activity (score)	5.45 (1.37)[a]
Work time physical activity (score)	2.75 (0.54)[a]
Smoking	
Never	41.7%
Ex	22.0%
Current	36.4%
Education level	
Lower	26.2%
Intermediate	46.9%
Higher	26.9%
Work schedule	
Daytime only	23.7%
Working in shifts	76.3%
According to shift schedule:	
Fast forward	17.8%
Fast backward	8.9%
Medium backward	41.5%
Irregular	8.1%
Job strain categories	
Low demands, high control	39.3%
Low demands, low control	28.9%
High demands, high control	17.8%
High demands, low control	14.1%
Occupational noise level	
Low (Refrigerator/typewriter)	53%
High (Lawnmower/Elec. drill)	47%

[a] Mean (standard deviation)

In Table 2 the least square mean values and regression coefficients for heart rate and HRV during sleep are presented, together with the least square mean values for potential confounders (gender, age, smoking status, leisure time physical activity). Very few of the occupational factors did show a relationship with heart rate or HRV during sleep. Only for SDNNi were decreased values found in shift workers (−19%, $P = 0.04$) and for the high demands, high control group (−17% compared with the low demands, high control group, $P = 0.05$).

The adjusted least square mean values and regression coefficients of heart rate and HRV during work are given in Table 3. Compared with regression equations for the mean values during sleep, the relationships for smoking and gender are similar. Significant differences were found for shift workers compared with day workers, in heart rate (+6%, $P = 0.02$), SDNNi (−15%, $P = 0.03$) and %LF (+7%, $P = 0.03$). Also a significantly elevated heart rate was found for the high demands, low control group (+6%, $P = 0.05$) and increased levels of %LF for the low demands, low control (+6%, $P = 0.02$) and high demands, high control groups (+7%, $P = 0.01$), all compared with the low demands, high control group.

The least square means and regression coefficients during work, adjusted for age, gender, smoking status, leisure time physical activity and for mean values during

Table 2 Least square mean values and regression coefficients of mean heart rate variability parameters during sleep. Multiple linear regression analysis results: class variables presented as least square mean values adjusted for the other factors in the table. Standard error on estimate in brackets. *%LF* normalised low frequency power variability, *SDNNi* mean standard deviation of all 5 min intervals, *Log(HF)* power in the high frequency range (0.15–0.40 Hz) in logarithmic units, *Log(LF)* power in the low frequency range (0.05–015 Hz) in logarithmic units

	Heart rate (beats/min)	SDNNi (ms)	%LF	Log(LF) [log(s^2)]	Log(HF) [log(s^2)]
Gender					
Female[a]	68.2 (1.8)	64.1 (6.4)	54.1 (3.2)	−3.095 (62)	−3.186 (90)
Male	58.2 (1.0)***	91.0 (3.6)***	52.2 (1.8)	−2.918 (35)*	−2.961 (50)*
Smoking					
Never[a]	60.4 (1.4)	91.2 (5.1)	53.1 (2.5)	−2.889 (49)	−2.959 (71)
Ex	64.0 (1.6)*	77.4 (5.7)*	57.0 (2.8)	−2.956 (55)	−3.097 (80)
Current	65.3 (1.4)**	64.0 (5.2)***	49.3 (2.6)	−3.174 (50)***	−3.164 (73)*
Job strain categories					
Low demands, high control[a]	62.4 (1.4)	83.0 (5.2)	52.6 (2.6)	−2.991 (0.051)	−3.046 (0.073)
Low demands, low control	63.5 (1.6)	76.5 (6.0)	54.1 (3.0)	−3.001 (0.058)	−3.089 (0.084)
High demands, high control	65.4 (1.7)	68.7 (6.3)*	56.5 (3.1)	−3.032 (0.061)	−3.162 (0.088)
High demands, low control	61.6 (1.9)	82.0 (7.1)	49.5 (3.5)	−3.000 (0.068)	−2.997 (0.099)
Work schedule					
Day shifts only[a]	62.7 (1.8)	85.8 (6.7)	51.9 (3.3)	−2.959 (0.064)	−3.002 (0.093)
Working in rotating shifts	63.8 (1.1)	69.3 (4.0)*	54.4 (2.0)	−3.053 (0.039)	−3.145 (0.056)
Work place noise					
Low level noise[a]	64.1 (1.2)	80.8 (4.2)	52.9 (2.1)	−2.959 (0.041)	−3.022 (0.059)
High level noise	62.4 (1.4)	74.3 (5.2)	53.4 (2.6)	−3.053 (0.050)	−3.125 (0.073)
Age (per 10 years)$^+$	1.91 (0.95)*	−9.9 (3.5)**	8.2 (1.7)	−26 (34)	−203 (49)***
Leisure time physical activity (per 1 SD increase)$^+$	−1.24 (0.67)	2.2 (2.5)	−0.4 (1.2)	−26 (24)	−19 (34)
Physical activity during work (per 1 SD increase)$^+$	0.5 (0.9)	5.8 (3.3)	−0.8 (1.6)	0.031 (0.032)	0.048 (0.046)

[a] Reference classification for P values of category variables

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$

sleep are given in Table 4. As expected, due to a decrease of the between-person variation, lower standard errors of the estimates can be observed. The relationships between gender, and smoking, with heart rate and HRV that were present in the regression equation without adjustment for mean values during sleep, have disappeared. Elevated heart rate levels are present in the high demands, low control group (+7%, $P = 0.01$). The %LF is elevated for the low demands low control group (+6%, $P = 0.005$), the high demands, high control (+6%, $P = 0.01$) and the high demands, low control groups (+6%, $P = 0.03$). The high noise group displays an elevated %LF (+4%, $P = 0.06$) and increased LOG(LF) (+3%, $P = 0.02$). For the shift workers only

Table 3 Least square mean values and regression coefficients of mean heart rate variability parameters during work. Multiple linear regression analysis results adjusted for gender, age, smoking status and leisure time physical activity. Class variables presented as least square mean values. Standard error on estimate in brackets. *%LF* normalised low frequency power variability, *SDNNi* mean standard deviation of all 5 min intervals, *Log(HF)* power in the high frequency range (0.15–0.40 Hz) in logarithmic units, *Log(LF)* power in the low frequency range (0.05–015Hz) in logarithmic units

	Heart rate (beats/min)	SDNNi (ms)	%LF	Log(LF) [log(s^2)]	Log(HF) [log(s^2)]
Job strain categories					
Low demands, high control[a]	84.3 (1.6)	72.0 (3.6)	73.3 (1.5)	−2.668 (0.037)	−3.159 (0.057)
Low demands, low control	85.2 (1.8)	70.0 (4.0)	77.8 (1.7)*	−2.647 (0.041)	−3.243 (0.063)
High demands, high control	86.5 (1.9)	64.3 (4.2)	78.6 (1.8)*	−2.665 (0.044)	−3.267 (0.067)
High demands, low control	89.2 (2.1)*	73.0 (4.7)	76.0 (2.0)	−2.579 (0.049)	−3.113 (0.074)
Work schedule					
Day shifts only[a]	83.6 (2.0)	75.5 (4.3)	74.0 (1.8)	−2.623 (0.045)	−3.121 (0.069)
Working in rotating shifts	89.0 (1.2)*	64.2 (2.7)*	78.9 (1.1)*	−2.657 (0.028)	−3.270 (0.043)
Work place noise					
Low level noise[a]	86.9 (1.3)	68.1 (2.9)	75.4 (1.2)	−2.665 (0.030)	−3.194 (0.046)
High level noise	85.6 (1.6)	71.6 (3.4)	77.5 (1.5)	−2.614 (0.036)	−3.196 (0.055)
Physical activity during work (per 1 SD increase)	2.57 (1.02)	−3.5 (2.2)	−0.3 (0.9)	−0.026 (0.023)	−0.015 (0.035)

[a] Reference classification for P values of category variables

*$P < 0.05$

Table 4 Least square mean values and regression coefficients of mean heart rate variability parameters during work corrected for mean values during sleep. Multiple linear regression analysis results adjusted for gender, age, smoking status and leisure time physical activity. Class variables presented as least square mean values. Standard error on estimate in brackets. *%LF* normalised low frequency power variability, *SDNNi* mean standard deviation of all 5 min intervals, *Log(HF)* power in the high frequency range (0.15–0.40 Hz) in logarithmic units, *Log(LF)* power in the low frequency range (0.05–015 Hz) in logarithmic units

	Heart rate (beats/min)	SDNNi (ms)	%LF	Log(LF) [log(s^2)]	Log(HF) [log(s^2)]
Job strain categories					
Low demands, high control[a]	82.6 (1.4)	72.7 (3.1)	73.2 (1.3)	−2.657 (0.032)	−3.143 (0.043)
Low demands, low control	83.3 (1.6)	71.7 (3.6)	77.9 (1.5)**	−2.635 (0.037)	−3.224 (0.050)
High demands, high control	83.1 (1.8)	68.9 (3.8)	77.7 (1.6)*	−2.658 (0.038)	−3.224 (0.053)
High demands, low control	88.1 (1.9)*	72.5 (4.2)	77.7 (1.7)*	−2.562 (0.043)	−3.134 (0.059)
Work schedule					
Day shifts only[a]	82.0 (1.8)	72.9 (4.0)	75.1 (1.6)	−2.629 (0.041)	−3.155 (0.055)
Working in rotating shifts	86.6 (1.1)*	69.9 (2.5)	78.1 (1.0)	−2.627 (0.025)	−3.208 (0.034)
Work place noise					
Low level noise[a]	84.5 (1.2)	69.2 (2.5)	75.3 (1.0)	−2.669 (0.026)	−3.195 (0.035)
High level noise	84.1 (1.4)	73.6 (3.1)	78.0 (1.3)	−2.587 (0.032)*	−3.167 (0.044)
Physical activity during work (per 1 SD increase)	2.11 (0.89)*	−6.2 (2.0)**	0.15 (0.81)	−0.043 (0.020)*	−0.050 (0.028)

[a] Reference classification for P values of category variables

*$P < 0.05$, **$P < 0.01$

the mean heart rate was elevated compared with the day workers. A significant negative correlation was found between physical activity during work and SDNNi and LOG(LF).

No relationship was found between heart rate or HRV and social support or education, during sleep, work or 24-h means, nor did the inclusion of these factors in the regression model lead to an appreciable change of any of the other coefficients.

Discussion

In summary, in this study, indications have been found of a decreased HRV during sleep for people working in shifts, but not for any of the other recorded workplace stressors. For the mean HRV values during work, corrected for mean values during sleep, the results indicated a relationship of specific indicators of HRV with workplace noise, job strain and physical activity at work, but not with shift work.

Error in the measurement of HRV was expected to be small and non differential. The presented means were calculated from a recording over several hours. Since the data were based on average mean values over several hours of recordings, the influence of an outlying 5-min interval was small. Besides, the EKGs were coded by an experienced Holter analyst who was unaware of the condition of the respondent.

From other studies, the within-person day to day variation of HRV measurements were low (intra-class correlation of SDNNi between two recordings between 18 and 65 days apart: 0.9) (Kleiger et al. 1991). Error could have arisen if the use of the Holter recorder had induced changes of behaviour in the respondents during the measurements, for example a decline in physical activity because the respondents were not allowed to take a shower during the measurements, or poorer sleep quality due to the annoyance of carrying the Holter recorder. Error in sleep time as coded in the diary could lead to bias of the mean values during sleep. The exclusion of data within a1 h time window from the coded start to end of sleep, for the calculation of the mean values during sleep, ensured that bias due to imprecision of the coded sleep time was not very likely.

Quantification of the amount of noise, job strain and physical activity at work was done by questionnaire. Systematic differences in reporting between different occupational groups could be present. We assume that this bias is most likely to have caused a reduction of the reported correlations, although we cannot completely rule out the possibility of inflation of the reported effects. Another source of bias could have been the selection of workers most fit for particular jobs, or the selective drop out of workers not able to adapt to their working conditions. This selection of workers, often referred to as the healthy worker effect, could have reduced or eliminated possible adverse health effects of job-related, unhealthy work conditions.

We considered gender, age, smoking and leisure time physical activity to be confounding factors in this study. Inclusion in the regression model of other possible confounders that we had considered such as education level and social support, did not change the reported relationships.

Obviously heart rate and the level of HRV are the result of interaction between the neurocardiac regulatory system and external and internal stimuli. The calculation of mean heart rate and HRV values during sleep was done to minimise bias due to differences between individuals, in their response to external stimuli. Nevertheless, differences in sleep quality or lag effects of activities before sleep (alcohol consumption, smoking, strenuous physical activity) could have biased the sleep

time mean values. Adjustment of the HRV values during work for the mean levels during sleep was performed to remove between-person variations in baseline HRV levels. This should enable a less biased estimate to be made of the direct effect on HRV, of occupational circumstances.

In the next section, the different occupational factors reported in this paper will be considered in correlation with HRV. In all sections we will first deal with the mean HRV levels during sleep. Next the results regarding the mean values during work, adjusted for the mean values during sleep, will be discussed.

Workplace noise

Ising et al. (1997) reported a significantly elevated risk of myocardial infarction with increasing workplace noise category (electric lawnmower: RR 1.4; electric drill: RR 2.0; road drill: RR 3.8). A possible pathway of this increased risk could be via increased sympathetic stimulation, due to the exposure to high levels of the noise. One might hypothesise that this might lead to a less favourable cardiac regulation after chronic exposure to workplace noise. In this study no changes of heart rate, nor of HRV during sleep were found. Because of the relative short time between the measurements and the start of new employment (between 1 week and 2 months) it is not clear from the current investigation if the absence of an effect is due to limitations of the study because of too few observations, a relative short exposure time, or the absence of a long-term effect of exposure to high workplace noise levels. When looking at the acute effects of workplace noise on HRV, taking the sleep time mean corrected values during work, we found increased %LF and LOG(LF) in the high noise group. This might indicate that exposure to high levels of noise caused a shift in cardiovascular regulation towards sympathetic dominance.

Shift work

There is strong evidence of an elevated cardiovascular disease risk among shift workers (Knutsson et al. 1986; Kristensen 1989; Kawachi et al. 1995; Tenkanen et al. 1997; Knutsson et al. 1999). Changes in neural cardiovascular control could be in the causal pathway of this elevated risk. In this study only workers who started a new job within the past 2 months were included. Among the shift workers, a significantly decreased SDNNi during sleep as well as during work time was found, compared with that of daytime workers. One might hypothesise that this was caused by a disturbance of the circadian rhythm of cardiac neural regulation, for example by increased sympathetic activity at a time when the cardiovascular system anticipated rest. Another explanation could be a poorer sleep quality for shift workers compared with that of the day workers. There is some evidence of decreased HRV in individuals with sleep problems (Bonnet and Arand 1998). However, due to the cross-sectional design of this study, we cannot rule out that the reported results were caused by selection effects of the respondents, or that the observations might be due to adaptation to irregular working hours. The analysis of the HRV levels during sleep, adjusted for the mean values during sleep, did not show significant differences between shift and day workers. This might indicate similar levels of job stress in shift and daytime jobs, when adjusted for the other workplace-related stressors included in this study.

Job strain

The evidence available so far is equivocal regarding the presence of an elevated cardiovascular disease risk in high strain jobs (high job demands in combination with low work control) (Steenland et al. 1997). No studies regarding long term effects on HRV, from working in a high strain job were found. Analysing the mean HRV levels during sleep, we found a decreased SDNNi in the high demands, high control group compared with the low demands, high control participants. This could indicate a less favourable cardiac regulation for the high demands of the high control group. However, because of the cross-sectional design of this study, it cannot be ruled out that this effect was caused by self-selection of the workers enrolled in this group. Those who favour high strain jobs might react differently to workplace stressors from workers who prefer low stress employment. However it could also be a reflection of a true effect of working in a high demands, high control job towards less favourable cardiac control. One might hypothesise that workers in the high demands, high control group, frequently found in managerial positions, could have been more often occupied with their work outside the normal working hours. This might have led to a shift in cardiovascular regulation towards sympathetic dominance during sleep, possibly due to a poorer sleep quality. Because all workers started a new job within the previous 2 months, the reported effect might also have been due to a more difficult adaptation to a new job with high demands and high control, an effect which might subside after several months.

When looking at the effects of job strain on HRV during work, corrected for mean values during sleep, we observed decreased values of %LF for the low demands, high control group compared with the other groups, thus indicating a shift in cardiovascular regulation towards sympathetic dominance, in the other groups. Due to the correction of the means at work for individual mean values during sleep, the probability of bias due to selection of respondents is low, because most of the between-person variation has been removed. Therefore, the regression coefficients for the mean values during work are likely to reflect a rapid change due to the conditions during work, suggestive of a direct

relationship between job strain and neural cardiac regulation. In the literature only a few studies were found dealing with stress and HRV. Of the investigations published so far that reported on the influences of short-term stressful situations, that of Sloan et al. (1996), recorded an elevated heart rate and decreased very LF, LF and HF power in subjects during exposure to mental stress. In this study no influence was found on the LF / HF ratio. Myrtek et al. (1996) reported lower SDNNi during increased mental load but did not differentiate between LF and HF components. In contrast, our data showed an increased level of %LF during work, and none on SDNNi, for workers reporting high job strain. Whether this was due to the different nature of the investigated stressors, the different time frame of exposure, or just a chance finding warrants further study. Further research is needed to investigate the contribution of specific frequency components, although our data indicated an increase of the LF/HF ratio, which suggested a shift in cardiovascular regulation towards sympathetic dominance. One might hypothesise that exposure to workplace conditions, related to sympathetic dominance in cardiovascular regulation might lead to adverse effects, comparable to those caused by exposure to stress, such as increased frequency of cardiac arrhythmias (Stamler et al. 1992; Sgoifo et al. 1997).

Physical activity at work

No relationship was found between physical activity at work, and heart rate and HRV during sleep. No other studies were found reporting a relationship between physical activity at work and HRV. This is in contrast to the study of Mølgaard, Sørensen et al. (1991) which reported a positive correlation between the level of leisure time physical activity and SDNNi, primarily due to increases in the HF component. The relatively short interval (from 1 week to 2 months) between the start of the current job and the measurements, or a rather low contrast between the high and low physically active jobs, could possibly explain the lack of a significant effect.

For the mean values during work, adjusted for the mean values during sleep, an inverse relationship was observed between SDNNi and Log (LF), and physical activity during work. The assumption is that the increased heart rate during physical activity was the most probable cause of these correlations. This was confirmed by including in the regression model, the mean heart rate during work. The reported regression coefficients decreased from −6.2 to −2.4 ($P = 0.12$) for SDNNi and from −0.043 to −0.33 ($P = 0.10$) when mean heart rate during work was included.

Conclusion

Despite the 1 week and 2 months time delay between the start of the current job and the measurements, we found significant lower HRV levels in the shift workers compared to the day workers, and for the high demands, high control group. These differences could be caused by the differences in the occupational factors themselves, but due to the cross-sectional design of the study we cannot rule out that the effect is caused by selection of the workers in the different groups. Nevertheless, the decreased SDNNi level in shift workers may be related to a less favourable cardiovascular regulation and could possibly explain part of the increased cardiovascular morbidity and mortality among shift workers. Further study is needed to investigate long-term effects of chronic exposure to working conditions and less favourable effects on cardiovascular regulation.

The %LF present in the variability of the heart rate, measured as mean values during work, corrected for the mean values during sleep shows a relationship with the work-related stressors job strain and workplace noise. Therefore we conclude that analysis of HRV can be used for measuring the effects of work-related stressors. One might hypothesise that the chronic disturbance of the autonomic cardiac balance towards sympathetic dominance might be a factor contributing to an elevated cardiovascular disease risk due to exposure to workplace stressors. However, further research is needed to investigate the health effects of a long-term shift in cardiovascular neural regulation towards sympathetic dominance.

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