

Heart Rate Variability in Occupational Health —A Systematic Review

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Abstract: This systematic review evaluates and summarizes the evidence of association between work-related factors and heart rate variability (HRV) in workers. We reviewed English articles indexed in MEDLINE under the key words: work, worker, occupational, industrial, and heart rate variability. Studies were included if one or more of the dependent variables was one of the time- or frequency-domain indexes of HRV [standard deviation of all normal-to-normal (NN) intervals (SDNN), mean of the 5-min standard deviations of NN intervals calculated over several hours (SDNN index), the root mean squared differences of successive NN intervals (RMSSD), integrated spectral powers of high (HF, > 0.15 Hz) and low frequency (LF, 0.04–0.15 Hz) HRV, and the LF/HF ratio] as recommended by the European Society of Cardiology and the North American Society of Pacing Electrophysiology. Physical and chemical work environments (i.e. exposure to occupational toxicants and hazardous environments), psychosocial workload (i.e. job stressors), and working time (i.e. shift work) had been examined and identified as having associations with low HF power. These findings may indicate that research into parasympathetic nervous system activity should be focused to protect cardiovascular health at work. We also propose the use of very low and ultralow frequency HRV components in autonomic research for workers' health.

Key words: Physical and chemical work environment, Psychosocial workload, Shift work, Fatigue, Cardiovascular disease, Autonomic nervous system, HRV

Background

Cardiovascular disease (CVD) is the leading cause of mortality and morbidity in industrialized countries¹⁾. In a working population, occupational factors are believed to pose a threat to workers' cardiovascular health. Substantial research has shown that adverse physical and psychosocial work environments and working conditions, such as shift work and excessive workload, are related to CVD. To examine the acute and chronic effects of such work-related factors on the cardiovascular system, cardiac autonomic nervous system activity during work and rest has been assessed by heart rate variability (HRV).

Heart rhythm is recorded by electrocardiography. The measured signal shows a series of waves that present electrical events in the four chambers and the conduction

pathways within the heart. The time interval between consecutive R waves that correspond to the contraction of the ventricles is called the RR interval (RRI). HRV is a time series of RRIs that fluctuate beat by beat in healthy humans because of time-to-time changes in activities of sympathetic and parasympathetic nerves innervating to the sinus node.

HRV is generated in part by periodic inputs of both respiration and blood pressure variability into the medullary cardiovascular centers²⁾. These periodic modulations are clearly identified within the power spectrum of HRV as peaks at the respiratory frequency (≈ 0.25 Hz) and at the frequency of the well-known Mayer wave (0.1 Hz) in blood pressure variability^{1, 3)}.

Heart rate increases and decreases during inspiration and expiration, respectively. This is mainly caused by the physiological fact that parasympathetic output from the cardiovascular center is inhibited during inspiration⁴⁾. Respiratory rhythm during rest is about 0.25 Hz. Therefore,

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the amplitude of variations in HRV related to respiration (i.e. respiratory sinus arrhythmia) is considered to reflect the fluctuation in tonic parasympathetic input, and the integrated spectral power of high frequency (HF, > 0.15 Hz) HRV is used as an index of the level of parasympathetic activity⁵⁾. The Mayer wave is a 10-s oscillation of blood pressure. The wave is mediated mainly by the sympathetic nervous system. The wave elicits a 10-s oscillation in HRV by modulating both sympathetic and parasympathetic nerve activities via baroreceptors. As a result, low-frequency (LF, 0.04–0.15 Hz) power of HRV reflects both sympathetic and parasympathetic activity and the LF/HF ratio is considered to mirror sympathovagal balance⁵⁾. Therefore, the frequency analysis of HRV is able to provide results that are more easily interpretable in terms of physiological regulation. To standardize physiological and clinical studies, short-term recordings of 5 min under physiologically stable conditions are recommended for HRV frequency-domain methods⁵⁾. For long-term (> 5 min) recordings, the frequency analysis should be performed in 5-min segments or over the total 24-h record⁵⁾. The HF and LF components of power spectral density obtained from the entire 24-h record are not different from the mean HF and LF components obtained from 5-min segments over the entire 24-h period.

For descriptive statistical methods, several time-domain measures are recommended by the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (Task Force)⁵⁾. The measures for overall variation include the standard deviation of all normal-to-normal (NN) intervals (SDNN) and the HRV triangular index, which is the number of NN intervals divided by the number of NN intervals within the modal bin of the NN interval histogram. The mean of the 5-min standard deviations of NN intervals calculated over several hours (SDNN index) is the measure of variation due to cycles shorter than 5 min. The measure of variation due to cycles longer than 5 min is the standard deviation of the average NN interval calculated over 5 min (SDANN). The estimates for short-term variation are the root mean squared differences of successive NN intervals (RMSSD).

Low HRV has been utilized in clinical studies of patients with CVD to predict a variety of cardiovascular outcomes⁵⁾, and in healthy populations' all cause and cardiac mortality^{6–8)}, as well as new onset of hypertension⁹⁾. Low HF power of the HRV spectrum is also a risk for mortality in patients, who have had myocardial infarction^{10–12)} and who have coronary artery disease¹³⁾ or congestive heart failure^{14, 15)}.

The goal of this paper was to review studies of HRV concerning occupational health. Given the functional utility of HRV analysis, it may inform us of the autonomic

effects of many factors at the workplace, such as work environments, workloads, and working time. The information quantified by HRV may help to determine effective strategies for health assessment and promotion at work and also future research needs. This systematic review included only studies which used one or more of the above mentioned indices of HRV, which are recommended by the Task Force⁵⁾, as a dependent variable.

Methods

We conducted a systematic review of all English articles using MEDLINE (Ovid, Pubmed) to identify all observational studies assessing the association between work and HRV. Key words used for the computer searches were: work, worker, occupational, industrial, and heart rate variability. Studies were included in our review if one or more of the dependent variables was one of the time- or frequency-domain indexes of HRV recommended by the Task Force⁵⁾, as mentioned in the Background. Studies in which participants were not workers (subjects without occupational exposure) were not included. Forty-six studies published from 1994 to July 2007 were included in the review. Sample sizes of these studies ranged from 6 to 2,197, with a median of 51.5. It is notable that only 2 of 46 studies (4%) utilized longitudinal study designs. Factors of occupational exposure were classified as a) physical and chemical work environment, b) psychosocial workload, or c) working time. Table 1 presents a summary of the studies reviewed.

Results

Physical and chemical work environment Particulate matter

Magari *et al.*¹⁶⁾ found that mean RRI and SDNN on workdays decreased with increase in a 4-h moving average of fine particle (particulate matter with a mean aerodynamic diameter $\leq 2.5 \mu\text{m}$, PM_{2.5}) concentration after controlling for time of day, age, and urinary nicotine levels in male boilermakers and a pipe fitter. Lead and vanadium concentrations as a component of PM_{2.5} were positively associated with the SDNN index during work in the male boilermakers after controlling for mean RRI, age, and smoking status¹⁷⁾.

Exposure to high levels of PM_{2.5}, mainly from welding fume was significantly associated with reduced mean RRI, SDNN, RMSSD, and HF and LF components on workdays in the male boilermakers after controlling for time of day and time-varying activities¹⁸⁾. The responses were greater in subjects with a high CVD risk profile than in subjects with a low CVD risk profile.

Particles of motor vehicle origin, as an occupational

Table 1. Studies of industrial environment and heart rate variability in workers

First author, year	Population	N (men/women or total)	Duration of recording	Condition at recording	Data length for analysis	Comparison	Outcome						
							Mean RRI	SDNN (TP)	SDNNI	RMSSD	HF	LF	LF/HF
<i>Physical and chemical work environment</i>													
<i>Particular matter</i>													
Magari <i>et al.</i> 2001 ¹⁶⁾	boilermakers and a pipe fitter	33/0	24 h x 2 d	workday	every 5 min	PM _{2.5}	↓	↓	-	-	-	-	-
Magari <i>et al.</i> 2002 ¹⁷⁾	boilermaker construction workers	39/0	8–10 h	workday	every 5 min	PM _{2.5}	n.s.	-	↑	-	-	-	-
Chen <i>et al.</i> 2006 ¹⁸⁾	boilermakers	10/0	24 h	workday	every 5 min	PM _{2.5}	↓	↓	-	↓	↓	↓	n.s.
Riediker <i>et al.</i> 2004 ¹⁹⁾	highway patrol troopers	9/0	20 min	resting in the morning on workday	last 10 min	PM _{2.5}	↑	↑	-	-	-	-	-
Riediker <i>et al.</i> 2004 ²⁰⁾	highway patrol troopers	9/0	20 min	resting in the morning on workday	last 10 min	PM _{2.5}	↑	↑	-	-	↑	n.s.	↓
<i>Carbon disulfide</i>													
Borkiewicz <i>et al.</i> 1997 ²¹⁾	a. workers at a chemical fibre plant b*. healthy workers	a. 152/0 b. 93/0	512 points	resting in the morning after the night rest	512 points	a vs. b	↓	(↓)	-	-	↓	↓	n.s.
Jhun <i>et al.</i> 2003 ²²⁾	a. workers with carbon disulfide poisoning b*. healthy workers	a. 71/0 b. 127/0	3 min	resting	3 min	a vs. b	n.s.	(↓)	-	-	n.s.	↓	-
<i>Lead</i>													
Murata <i>et al.</i> 1995 ²³⁾	a. glass workers b*. textile workers	a. 0/36 b. 0/15	300 points	resting	300 points	a vs. b	n.s.	-	-	-	-	-	↓
Gajek <i>et al.</i> 2004 ²⁴⁾	a. copper foundry workers b*. healthy workers	a. 22/0 b. 13/0	24 h	daytime after at least 20 min rest and night (0400–0415)	15 min x 2 sessions	a vs. b	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Böckelmann <i>et al.</i> 2002 ²⁵⁾	a. lead-exposed workers b*. healthy workers	a. 109/0 b. 27/0	-	resting, psychometric strain test (number memory test), and recovery periods in the morning	-	a vs. b at baseline baseline vs. 4 yr later	n.s.	(n.s.)	-	-	n.s.	n.s.	-
<i>Manganese</i>													
Barrington <i>et al.</i> 1998 ²⁶⁾	a. manganese alloy workers b*. healthy workers or published normals	a. 8 b. 8 or 274	24 h	-	24 h	a vs. b	↓	n.s.	-	↓	↓	↓	↓
<i>Smoking</i>													
Kobayashi <i>et al.</i> 2005 ²⁷⁾	taxi drivers	20/0	18 h	workday (0800–0200)	every 5 min	smoking	-	-	-	-	n.s.	-	↑
<i>Electromagnetic field</i>													
Borkiewicz <i>et al.</i> 1996 ²⁸⁾	a. workers on AM broadcast stations b*. workers of radio link stations	a. 71 b. 22	512 points	resting in the morning	512 points	a vs. b	↑	n.s.	-	-	n.s.	n.s.	n.s.
Wilén <i>et al.</i> 2007 ²⁹⁾	a. radiofrequency operators b*. healthy workers	a. 18/17 b. 14/23	24 h	workday	every 1 h	a vs. b	-	(↑)	-	-	n.s.	↑	-
Borkiewicz <i>et al.</i> 2006 ³⁰⁾	a. switchyard substations b*. radio link stations	a. 63/0 b. 42/0	512 points	resting in the morning	512 points	a vs. b	n.s.	↓	-	-	n.s.	n.s.	n.s.
<i>Vibration</i>													
Lasker and Harada, 1999 ³¹⁾	a. chainsaw operators and tunnel construction workers with hand-arm vibration syndrome b*. healthy workers	a. 21/0 b. 10/0	2 min	resting	2 min	a vs. b	n.s.	n.s.	-	-	↓	↓	-
Lasker <i>et al.</i> 1997 ³²⁾	a. patients with hand-arm vibration syndrome with VWF b. patients with hand-arm vibration syndrome without VWF c*. healthy workers	a. 16/0 b. 13/0 c. 12/0	4 min	supine deep breathing before and after psychological test	2 min x 2 sessions	b vs. c	n.s.	↓	-	↓	-	-	-
Sakakibara <i>et al.</i> 2002 ³³⁾	a. patients with VWF b*. healthy workers	a. 21/0 b. 17/0	50 min	resting, cold water immersion, and recovery	128 s x 8 sessions	a vs. b	↑	-	-	-	n.s.	↑	↑
<i>Cold environment</i>													
Borkiewicz <i>et al.</i> 2006 ³⁴⁾	cold storage workers	63/39	512 points	resting in the morning	512 points	cold microclimate	n.s.	n.s.	-	-	n.s.	n.s.	n.s.

First author, year	Population	N (men/women or total)	Duration of recording	Condition at recording	Data length for analysis	Comparison	Outcome						
							Mean RRI	SDNN (TP)	SDNNI	RMSSD	HF	LF	LF/HF
Psychosocial workload													
<i>Job strain</i>													
Collins <i>et al.</i> 2005 ³⁶⁾	day workers	36/0	24 h × 2 d	workday and the next rest day	every 5 min	job strain	↓	-	-	-	↓	-	↑
van Amelsvoort <i>et al.</i> 2000 ³⁷⁾	workers in the integrated circuit manufacturing industry, waste incinerator plants, or in hospitals	135	24 h	morning or day shift	every 5 min	job strain	↑	n.s.	-	-	n.s.	↑	-
Riese <i>et al.</i> 2004 ³⁸⁾	nurses	0/159	24 h × 2 d	the third morning shift (0730–1615) and rest day	every 30 s	job strain	n.s.	-	-	n.s.	-	-	-
Kang <i>et al.</i> 2004 ³⁹⁾	workers employed in the ship-building industry aged over 40	167/0	5 min	resting	5 min	job stress	-	n.s.	-	-	n.s.	n.s.	n.s.
Kageyama <i>et al.</i> 1998 ⁴⁰⁾	white collar workers	223/0	5 min	supine and standing rest during late morning or early afternoon	3 and 2 min	job stress	n.s.	-	-	-	n.s.	n.s.	-
Vrijotte <i>et al.</i> 2000 ⁴²⁾	white collar workers	109/0	24 h × 3 d	2 workdays and a rest day	every 30 s	work stress	↓	-	-	↓	-	-	-
<i>Employment</i>													
Hemingway <i>et al.</i> 2005 ⁴³⁾	clerical civil servants	2,197/0	5 min	resting	5 min	employment grade	↓	↓	-	-	↓	↓	-
<i>Organizational injustice</i>													
Elovainio <i>et al.</i> 2006 ⁴⁵⁾	workers in long term care homes	0/57	5 min	resting	5 min	injustice	-	-	-	-	↓	-	-
<i>White-collar office work for hypertensive</i>													
Kobayashi <i>et al.</i> 2001 ⁴⁶⁾	white-collar workers	22/0	24 h	workday	512 points (every 30 min)	hypertension	n.s.	-	-	-	↓	↓	↑
<i>Fatigue</i>													
Pichot <i>et al.</i> 2002 ⁴⁷⁾	a. garbage collectors b*. healthy sedentary workers	a. 6/0 b. 8/0	4 h × 8 d	nocturnal sleeping (0000–0400) on workday	every 256 points	a vs. b	↓	n.s.	n.s.	↓	↓	↓	n.s.
Watanabe <i>et al.</i> 2002 ⁴⁸⁾	workers of an electric instrument corporation	52/0	5 min	resting in the morning	5 min	vital exhaustion	-	-	-	-	↓	n.s.	↓
Sasaki <i>et al.</i> 1999 ⁴⁹⁾	engineers	188/0	3 min	resting in the afternoon on workday	3 min	working hours	-	-	-	-	-	-	n.s.
Sasaki <i>et al.</i> 1999 ⁵⁰⁾	engineers	147/0	3 min	resting in the afternoon on workday	3 min	working hours	n.s.	-	-	-	-	-	n.s.
Karita <i>et al.</i> 2006 ⁵¹⁾	information service workers	413/0	10 min	resting	last 150 points	subjective symptoms	-	-	-	-	↓	n.s.	n.s.
Aasa <i>et al.</i> 2006 ⁵²⁾	ambulance personnel	24/2	24 h × 3 d	24-h shift (1700–1700) and the next two rest days	(mean values of 1 h intervals)	health complaints	n.s.	-	-	-	↓	↑	-
<i>Train driving</i>													
Myrtek <i>et al.</i> 1994 ⁵³⁾	train drivers	23/0	1,387 min	workday	every 1 min	speed	↑	-	-	↓	-	-	-
Working time													
<i>Night shift work</i>													
Ito <i>et al.</i> 2001 ⁵⁴⁾	nursing staff	0/10	24 h × 2 d	a. day shift (0800–1700) b. night shift (2140–0840)	512 s (each hour)	a vs. b	n.s.	-	-	-	n.s.	n.s.	n.s.
Freitas <i>et al.</i> 1997 ⁵⁵⁾	oil refinery security workers	12/0	24 h × 2 d	a. day shift (0600–1400) b. night shift (2200–0600)	512 points (each hour)	a vs. b	n.s.	n.s.	-	-	n.s.	n.s.	n.s.
Adams <i>et al.</i> 1998 ⁵⁶⁾	emergency physician	8/4	24 h	1500–1700, the middle of night shift (2300–0700), and after the shift	2 h × 3 sessions	night work	↓	↓	-	-	↓	-	↑
Ishii <i>et al.</i> 2005 ⁵⁷⁾	a. shift nurses b*. non-shift nurses	0/91	300 points	resting in the evening (1700–1900) following day work	300 points	a vs. b	n.s.	-	-	-	↓	-	↑
Murata <i>et al.</i> 2005 ⁵⁸⁾	a. shift workers b*. day workers	a. 153/0 b. 87/0	300 points	resting in the morning (0800–1200) of day shift or rest day	100 points with minimum SD	a vs. b	n.s.	-	-	-	n.s.	↓	n.s.
Ha <i>et al.</i> 2001 ⁵⁹⁾	a firm manufacturing diapers and feminine hygienic materials	134/0	5 min × 3 sessions	resting on the second or third day of the 3-day period of morning, afternoon, and night shift	middle 3 min × 3 sessions	shift work	-	-	-	-	↓	↓	-

First author, year	Population	N (men/women or total)	Duration of recording	Condition at recording	Data length for analysis	Comparison	Outcome						
							Mean RRI	SDNN (TP)	SDNNI	RMSSD	HF	LF	LF/HF
van Amelsvoort <i>et al.</i> 2000 ³⁷⁾	a. shift workers b*. day workers (all workers in the integrated circuit manufacturing industry, waste incinerator plants, or in hospitals)	a. 102 b. 32	24 h	morning or day shift	every 5 min	a vs. b	↓	↓	-	-	n.s.	n.s.	-
van Amelsvoort <i>et al.</i> 2001 ⁶⁰⁾	a. shift workers b*. day workers (all workers in the integrated circuit manufacturing industry or waste incinerator plants)	a. 67/8 b. 29/3	24 h × 2 d	morning or day shift at baseline and 1 yr later	every 5 min	a vs. b at baseline baseline vs. 1 yr later	↓ ↑	-	↓ n.s.	-	↓ n.s.	↓ n.s.	-
Mitani <i>et al.</i> 2006 ⁶¹⁾	ambulance personnel	9/0	24 h × 2 d	24-h shift (0900-0900) and rest day	every 5 min	24-h work	n.s.	-	-	-	↓	-	↑
Takeyama <i>et al.</i> 2005 ⁶²⁾	firefighters	12/0	24 h	24-h shift	every 5 min	24-h work (0500-0700)	↓	-	-	-	n.s.	-	↑
Sato <i>et al.</i> 2001 ⁶³⁾	long distance truck drivers	6/0	14.8-93.5 h	workday	every 2 min	24-h work (0000-1200)	-	-	-	-	-	-	↓

↑, ↓ indicate increase or decrease (statistically significant at $p < 0.05$). n.s. indicates no change ($p \geq 0.05$). -, data is not provided. *, unexposed workers; vwf, vibration-induced white finger; PM_{2.5}, particulate matter with a mean aerodynamic diameter $\leq 2.5 \mu\text{m}$; RRI, RR interval; SDNN, standard deviation of normal-to-normal (NN) intervals; TP, total power; SDNNI, SDNN index; RMSSD, root mean squared differences of successive NN intervals; HF, high frequency ($> 0.15 \text{ Hz}$); LF, low frequency (0.04–0.15, 0.01–0.15, 0.02–0.15, or 0.05–0.15 Hz).

source of PM_{2.5}, were not associated with a decrease in HRV. Riediker *et al.*^{19, 20)} reported an association between in-vehicle PM_{2.5} during work and HRV at rest on the next morning in non-smoking male highway patrol troopers. The PM_{2.5} was significantly positively associated with mean RRI, SDNN, and the HF component, and negatively associated with the LF/HF ratio²⁰⁾. Among sources of in-vehicle PM_{2.5}, the “speed-change” factor was dominated by copper, sulfur, and aldehydes were significantly associated with mean RRI and SDNN¹⁹⁾.

Carbon disulfide

In male workers at chemical fiber plants who worked under conditions of continuous exposure to carbon disulfide (CS₂), mean RRI, total power (TP) of HRV power spectral density, the normalized HF component (HF as a percentage of TP), the normalized LF component (LF as a percentage of TP), and the normalized very low frequency (VLF, 0.0033–0.04 Hz) component (VLF as a percentage of TP) during rest were significantly lower than those in age-matched, unexposed, healthy male controls²¹⁾. In retired male workers with CS₂ poisoning, the LF component and TP during rest were significantly lower than those of age-matched control subjects who had no history of organic-solvent exposure and CVD²²⁾.

Lead

The LF/HF ratio during rest was significantly lower in female glass workers exposed to lead (mean blood lead concentration: 556 $\mu\text{g/l}$) than in female textile workers unexposed to lead (mean blood lead concentration: 63 $\mu\text{g/l}$)²³⁾. In contrast, Gajak *et al.*²⁴⁾ did not find a significant difference in the LF/HF ratio, assessed in 15-min RRIs during rest in the daytime and at night, between

male copper foundry workers (mean blood lead concentration: 410 $\mu\text{g/l}$) and age-matched healthy male controls (mean blood lead concentration: 36 $\mu\text{g/l}$). Among the subjects exposed to lead, a negative correlation was found between the lead concentration and the ratio of nighttime HF to daytime HF²⁴⁾. In a longitudinal study that examined the effect of 4 yr of lead exposure on HRV²⁵⁾, mean blood lead levels of lead-exposed workers increased from 390 $\mu\text{g/l}$ to 430 $\mu\text{g/l}$ over 4 yr. Mean RRI and HF component during rest, the psychometric strain test (number memory test), and recovery conditions in the morning were significantly lower than the initial values in the follow-up investigation 4 yr later.

Manganese

Mean RRI, RMSSD, and HF and LF components in manganese alloy workers were significantly smaller than in healthy controls while the LF/HF ratio was significantly larger in the workers than in the controls, although whether RRIs were collected on workdays or rest days was not specified²⁶⁾.

Smoking

The LF/HF ratio significantly increased immediately after smoking at night in taxi drivers²⁷⁾. Smoking caused acute effects on HRV under their ordinary work conditions²⁷⁾.

Electromagnetic field

A statistically significant negative correlation was found between the maximum exposure level of electromagnetic field (EMF) intensity and the HF component during rest in workers occupationally exposed to medium frequency (0.7–1.5 MHz) EMF, although some frequen-

cy-domain parameters of HRV (HF and LF components, TP, and LF/HF ratio) did not differ between exposed (radiofrequency exposure: 113.3 Vh/m/d) and unexposed workers (radiofrequency exposure: 0 Vh/m/d)²⁸. In contrast, TP and the VLF component among operators of radiofrequency (RF) plastic sealers (mean electric field strength: 88 V/m) during the nighttime were significantly increased when compared with a control group²⁹. One study found that the relative risk of decreased SDNN (SDNN < 27 ms) during rest was significantly higher in workers of switchyard substations who were occupationally exposed to 50 Hz EMF (EMF exposure: 0.2–15.2 kVh/m/d) when compared with unexposed workers (EMF exposure: 0 kVh/m/d)³⁰. The VLF component was significantly higher in the exposed group and was accompanied by a significant increase in arterial blood pressure which was correlated with the exposure level³⁰.

Vibration

Laskar *et al.* reported that workers with hand-arm vibration syndrome showed significantly decreased HF and LF components during rest³¹ and significantly decreased SDNN and RMSSD during rest after a psychological test when compared with the healthy controls³². Among operators with vibration-induced white finger, the LF/HF ratio increased significantly during immersion of the hand in cold water at 10°C, but did not increase in healthy controls³³.

Cold environment

Any selected HRV parameters (SDNN and HF, LF, and VLF components) during rest in the morning did not differ between workers who were chronically exposed to different microclimate conditions (–26 to 20°C)³⁴.

Psychosocial workload

Job strain

Work stress is usually defined as job strain according to the model of Karasek *et al.*³⁵. The relationship between job strain and 5-min HRV over 48 h, a work day and a rest day, was examined in subjects covering a wide range of occupations in a range of industry sectors³⁶. Subjects in high-strain jobs held positions such as letter carrier, laborer, printer, quality technician, and tele/data communications, while subjects in low-strain jobs held positions such as teacher, business agent, retirement specialist, and buyer. Job strain and low decision latitude were associated with decreases in the HF component. Job strain was also associated with increases in the LF/HF ratio during working hours³⁶. Among daytime and shift workers, van Amelsvoort *et al.*³⁷ found a significantly elevated normalized LF component during work in the low demands and low control group, high demands and

high control group, and high demands and low control group when compared with a group reporting low job demands and high work control after controlling for age, gender, smoking status, leisure time physical activity, and mean values during sleep. Three studies have been performed on a homogeneous group of healthy workers: one reported no effect of job strain by itself or in interaction with social support on 30-s HRV (RMSSD) over 24 h on a workday and a rest day in female nurses³⁸; the second did not find significant differences in parameters of 5-min HRV (SDNN, HF, LF, and VLF components, TP, and LF/HF ratio) during rest between high- and low-strain groups in male workers employed in the shipbuilding industry³⁹; and the third found that subjects who complained of poor sleep quality, which is associated with job stress, exhibited a reduced HF component during standing rest, although job stressors were not correlated with HRV in male workers employed by a private company⁴⁰.

When chronic work stress was defined according to Siegrist's model of effort-reward imbalance⁴¹ as (a) high imbalance, a combination of high effort and low reward at work, or (b) high overcommitment, an exhaustive work-related coping style indexing the inability to unwind, high imbalance was associated with a lower RMSSD during work, leisure time, and sleep on workdays and a rest day in middle-aged white-collar workers working at the same computer company⁴².

Employment

Among healthy clerical civil servants working in the London offices of 20 departments, low employment grade was associated with low HRV (SDNN, and HF and LF components) during rest after controlling for age⁴³.

Organizational injustice

Organizational justice for women working in long-term care homes was measured using the scale of Moorman⁴⁴. The low perceived justice group showed an 80% excess risk of reduction in the HF component during rest when compared with the high perceived justice group⁴⁵.

White-collar office work for hypertensive

The LF/HF ratio during work of white-collar workers with hypertension was significantly higher than that of normotensives⁴⁶. As a result, LF/HF during 24 h including a workday of hypertensives was significantly higher than that of normotensives⁴⁶.

Fatigue

One study examined the effects of cumulative fatigue on HRV. The HRV of six garbage collectors was measured twice a week during three consecutive weeks of work, and during the following week of rest⁴⁷. During

the weeks of work, there was a significant progressive decrease in mean RRI, RMSSD, and the HF and LF components, while there was an increase, although not significant, in the LF/HF ratio during nocturnal sleeping. In the resting period, there were significant recoveries in mean RRI, RMSSD, and the HF and LF components of HRV during nocturnal sleeping⁴⁷.

Another study examined the effects of overtime and frequent business trips on 5-min HRV during rest in the morning in healthy male workers and found that the HF component was lower in the high vital exhaustion group⁴⁸. Sasaki *et al.* reported increases in the LF/HF ratio during rest and the fatigue (drowsiness, dullness, and feeling of local physical abnormality) complaint rate with increase in working hours, but there were no differences among short (working hours: 53.1 h/wk), medium (working hours: 60.0 h/wk), and long (working hours: 67.1 h/wk) working hour groups⁴⁹, and they did not find significant relationships between working hours and mean RRI or the LF/HF ratio during rest in engineers⁵⁰.

The HF component during rest was lower in workers with symptoms such as dullness, fatigue, backache, diarrhea, sleep disorders, and irritation than in those without these symptoms and was negatively associated with the presence of any these symptoms once a week or more frequently⁵¹. Mean HF and LF components during a 24-h shift and on the next two work-free days significantly differed between ambulance personnel with many health complaints and few health complaints⁵². The subjects with many health complaints showed lower HF and higher LF components with less circadian variation during both the work and the work-free days⁵².

Train driving

In train drivers, RMSSD decreased during driving when compared with that during sleep, while it increased a little during standing⁵³.

Working time

Night-shift work

The within-individual effects of night-shift work on HRV have been examined. Two studies^{54, 55} compared 24-h HRV between day (working from 0800 to 1700 or from 0600 to 1400) and night (working from 2140 to 0840 or from 2200 to 0600) shifts. All selected HRV parameters in frequency-domain (TP, HF and LF components, and LF/HF ratio) during the awake, work, and sleep periods were not statistically different between shifts. The LF/HF ratio was lower in the sleeping period and higher in the waking and working periods of workers on both shifts^{54, 55}, and the HF component was higher during the sleeping period and lower in the waking and working periods of workers on both shifts^{54, 55}. Among emergency

physicians, post-night shift (0700–1500) values for mean RRI, SDNN, and the HF component were significantly higher than both pre- (1500–2300) and mid-night shift (2300–0700) values⁵⁶. The LF/HF ratio during post-night shift was significantly lower than the pre- and mid-night shift values⁵⁶.

The LF/HF ratio and the HF component during rest in the evening following day work were significantly larger and smaller, respectively, in nurses working shifts compared to nurses who were not⁵⁷. Shift workers displayed significantly decreased RRI during work and SDNN during sleep at night on the morning shift day, compared with those of the daytime workers³⁷. One study reported that among male shift workers, who were employed at a copper-smelting plant, mean RRI, HF component, and LF/HF ratio during rest in the morning on the day shift or work-free days were not different from those of day workers⁵⁸.

The HF and LF components during rest showed decreasing trends in accordance with increase in shift work duration⁵⁹. In a longitudinal study, one year changes in HRV were measured in shift workers who started a new job⁶⁰. The HF and LF components on the morning or day shift decreased after 1 yr, but those changes were not different from changes in day workers⁶⁰.

24-h shift work

One study found differences in HRV between 24-h shift workdays and work-free days. The circadian rhythms of the LF/HF ratio and normalized HF component of 5-min RRIs were disturbed on a 24-h shift workday, while the rhythm was well preserved on the next work-free day⁶¹. Although the mean value of the LF/HF ratio and normalized HF component differed significantly between the waking and sleeping times on the work-free day, they did not differ on the workday⁶¹. In firefighters, the LF/HF ratio of 5-min RRIs during night duty was significantly higher in workers who had to wake up from 0500 to 0700 than in workers who had to wake up from 0315 to 0515⁶². In long-distance truck drivers, during a workday including long distance driving, the LF/HF ratio during 0000–1200 was significantly lower than during 1600–2400⁶³.

Discussion

Physical and chemical work environment

Particulate matter

Particulate air pollution with PM_{2.5} is associated with several adverse health outcomes, particularly death and hospital admissions from cardiopulmonary disease^{64–66}. Although the mechanisms responsible for the cardiac mor-

bidity and mortality associated with particulate air pollution have not been fully elucidated, adverse effects on HRV in response to occupational exposure to PM_{2.5} have been demonstrated^{16, 18}). Welding fume, which has a rich content of ultrafine particles (diameter $\leq 0.1 \mu\text{m}$) and transition metals, as an occupational source of PM_{2.5} emerged as having an unfavorable influence on HRV¹⁸). However, some studies found the positive influences on HRV^{17, 19, 20}), indicating that the mechanisms of the effects of PM_{2.5} on the autonomic system might depend on the characteristics of the content of PM_{2.5}, such as substance and diameter.

Carbon disulfide

CS₂ is reported to have a toxic effect on the cardiovascular and autonomic nervous systems^{67, 68}). Studies on the effects of occupational exposure to CS₂ on HRV^{21, 22}) found adverse changes in HRV. The changes last after the termination of the exposure²²). These adverse effects on the autonomic nervous system can partly explain the fact that chronic exposure to CS₂ increases the mortality rate from myocardial infarction above that of the general population^{69, 70}).

Lead

Lead exerts toxic effects. Long-term exposure may cause complex neurobehavioral and neuroendocrine abnormalities. Lead inhibits neuronal conduction in the nervous systems, which use dopamine, noradrenaline, serotonin, or acetylcholine as neurotransmitters. In the peripheral nervous system, lead inhibits neurotransmission at the level of autonomic system synapses and neuro-muscle junction⁷¹). Studies of HRV^{24, 25}) show that the HF component or the LF/HF ratio was reduced by occupational exposure to lead, indicating that lead damages the vagal nerve more than other cardiac nerves, supporting the hypothesis that lead-induced neuronal alterations are mainly present in long neurons, which have more binding sites, than short ones⁷¹).

Manganese

Manganese is an essential element for humans. However, overexposure to manganese causes irreversible neuromotor damage as in Parkinson's disease. Reduced nerve conduction velocities in manganese-exposed workers were reported in the motor fibers of the median and peroneal nerves⁷²). HRV in manganese alloy workers was significantly different from healthy controls²⁶), indicating that the autonomic nerve function might also be altered by manganese exposure. Occupational exposure to manganese may influence autonomic nerves and have neurotoxic effects.

Smoking

Smoking acutely increases sympathetic activities and increases plasma catecholamine levels^{73, 74}). This has been recognized as a major mechanism of CVD in smokers. An increase in the LF/HF ratio immediately after smoking in taxi drivers²⁷) indicates that sympathomimetic and parasympatho-withdrawal responses to smoking may play additional roles in increasing cardiac risk and partly explain the high incidence and hospitalization rate of CVD among taxi drivers^{75, 76}).

Electromagnetic field

The possible influence of electromagnetic fields on the circulatory and nervous systems has been a subject of research for many years, as in theory the autonomic system may be affected by the electric impulses generated by an external EMF. Since the circulatory and nervous systems are composed of electrically excitable tissues, it is plausible that they can be stimulated by EMF. However, studies of HRV have not found clear effects of occupational exposure to EMF on the HF and LF components²⁸⁻³⁰). This might be due to the level of exposure in the occupational settings, which did not exceed admissible values. Wilen *et al.*²⁹) indicated that an increase in TP and the VLF component of exposed workers might be associated with increased parasympathetic activity due to an adaptation of the thermoregulatory system and cardiac modulation to long-term low-level thermal exposure in RF operators²⁹).

Vibration

Prolonged vibration exposure can cause vibration-induced white finger, which is one of the most common types of hand-arm vibration syndrome found among operators of hand-held vibratory tools. The blanching attacks are induced by pathological vasospasm of the finger, usually following exposure of the whole body to cold conditions in winter⁷⁷). Such enhanced vasospastic response to cold is considered to result from an exaggerated central sympathetic vasoconstrictor reflex and local changes in the digital vessels⁷⁸). This explanation is supported by the increase seen in the LF/HF ratio during immersion of the hand of workers with white finger in cold water³³). Workers with hand-arm vibration syndrome showed decreased HF and LF components during rest when compared with healthy workers³¹). In addition, SDNN and RMSSD decreased in workers with hand-arm vibration syndrome without vibration-induced white finger³²). Hand-transmitted vibration may also cause persistent damage to nerves and blood vessels in the upper limbs or the higher centers of the autonomic nervous system.

Cold environment

One of the health hazards of cold exposure is hypertension⁷⁹. Blood pressure is higher in winter than in summer because of the increase in peripheral resistance at lower environmental temperatures⁸⁰, and this may be one of the mechanisms underlying the higher mortality from CVD in winter. Long-term occupational exposure to cold environment increases blood pressure in male workers working in cold areas more than once per day⁷⁹. Borkiewicz *et al.*³⁴) also found higher blood pressure in workers with exposure to ambient temperatures varying from 0 to 10°C for 8 h/d than in workers with exposure to ambient temperatures between 10°C and 14°C for 8 h/d. However, the chronic effect of occupational exposure to a cold microclimate on HRV was not significant, indicating that HRV might not be a sensitive marker for capturing the adverse effects of exposure to a cold environment on the cardiovascular system.

Heat and organic solvents

There is a possibility that occupational exposure to heat and some organic solvents, such as n-hexane, xylene, and toluene, effect the cardiovascular system. It has been reported that the additional stimulus of a heated environment during exercise increased sympathetic activity during exercise⁸¹. Murata *et al.* found a decreased coefficient of variation for the high-frequency component (0.15–0.3 Hz) of HRV in workers exposed to n-hexane, xylene, and toluene⁸². These studies were not included in this review because either the participants were not workers or the dependent variables were not the indices of HRV recommended by the Task Force⁵. Parameters of HRV recommended by the Task Force⁵) might be able to detect adverse changes in the cardiovascular systems of workers with occupational exposure to heat and the organic solvents.

Psychosocial workload

Job strain

Work stress relates to the elevation of blood pressure and self-perceived psychological stress and is an independent risk factor of CVD. When subjects consisted of workers from different positions or working conditions, adverse effects on HRV associated with work strain were observed^{36, 37}), while in a homogeneous group of healthy workers, HRV was not associated with work strain^{38–40}).

Employment

Low employment grade was associated with adverse changes in HRV⁴³). Part of this association is explained by behavioral factors such as smoking, and part by psychosocial factors. In the context of a working population, low job control predicts coronary incidence and may

mediate the relationship between low employment grade and adverse changes in HRV.

Organizational injustice

The influence of justice at work on employee health has been gaining attention recently. It has been reported that there is an association between justice at work and employee health⁸³). However, the pathways and mechanisms underlying this association are not clear. An increased risk of reduction in the HF component was reported for workers self-reporting low perceived justice⁴⁵), indicating that organizational injustice is a risk factor of adverse effects on the cardiovascular system.

White-collar office work for hypertensive

Hypertension is one of the risk factors of CVD. The LF/HF ratio during work of hypertensives was significantly higher than that of normotensive subjects⁴⁶), suggesting that hypertension enhances the response of HRV to workload and that workload contributes to the progression of CVD in hypertensives.

Fatigue

Excess fatigue has attracted a great deal of attention as one of the major occupational health problems, especially in Japan. Two studies clearly showed an association between cumulative or excess fatigue and adverse changes in HRV^{47, 63}). When the fatigue complaint rate did not differ, the LF/HF ratio during rest also did not differ between workers with short, medium, and long working hours and relationships between working hours and mean RRI or the LF/HF ratio during rest were not statistically significant⁵⁰). Symptoms were associated with adverse changes in HRV^{51, 52}). It has been assumed that exhaustion is related to autonomic nervous dysfunction in patient populations. Workers with excess fatigue or intense subjective symptoms might also show objective signs of sympathovagal imbalance.

Train driving

Train driving contains physical and mental workload components⁵³). Decreased RMSSD during train driving⁵³) indicates that physical or mental workload during train driving may cause adverse effects on HRV.

Working time

Night shift work

Several studies have shown altered circadian rhythms of HRV in night shift workers^{54–56}). The circadian pattern of HRV and cardiac autonomic activity seem to be predominantly related to the level of physical activity or sleep (supine) and wakefulness (standing), and remains independent of the night-day cycle^{54, 55}). The altered cir-

cadian rhythm of HRV during night shift work may last and cause adverse changes in HRV even on a day without a night shift^{37, 57}). Furthermore, the longer the night shift work duration is, the smaller the HF and LF components are^{59, 60}). These results may explain positive associations between night shift work and CVD^{84–86}), and between the duration of night shift work and the risk of CVD⁸⁷).

24-h shift work

Twenty-four-hour shift work can also disturb the circadian rhythm of HRV^{61–63}) as the autonomic system associates with wake-sleep and activity-rest rhythms⁸⁸). As shown for night shift workers, a disturbed circadian rhythm of HRV could increase CVD risk. Sato *et al.*⁶³) found that the LF/HF ratio was lower in the morning than at midnight in 24-h shift truck drivers, suggesting that parasympathetic nervous system activities are more dominant than sympathetic nervous system activities in the morning after midnight work, and that this situation might cause drowsiness during driving in the morning.

Future directions

As CVD can be caused by a number of occupational factors, HRV has been examined in workers from a wide range of occupations. HRV is a useful tool for revealing adverse effects on the cardiovascular system in the occupational setting. Nevertheless, to get a clear and deeper understanding of the effects of work-related factors on HRV, it might be better to consider the following points in the future studies.

For short-term recordings, only four studies controlled or measured the breathing rhythm during the recording of RRI of resting workers. Since respiration potentially influences the HF component⁵), breathing rhythm should be measured or controlled when HRV is measured in a controlled circumstance. This would permit identification and exclusion of participants with breathing rhythms outside the HF range.

For long-term recordings, frequency analysis has been performed in 5-min segments, and mean HF and LF components were evaluated in most studies where continuous recording over several hours was performed on workdays or rest days. In frequency analysis of the total record of continuous recordings over several hours, the lower frequency components, i.e. VLF (0.0033–0.04 Hz) and ultralow frequency (ULF, < 0.0033 Hz) components can also be evaluated. These components have not been examined in previous studies concerning occupational health and they might become promising markers according to Bigger *et al.*¹⁰) who demonstrated decreases in the VLF and ULF components as better predictors of all-cause mortality in post-infarction patients. However, it is

noted that HRV at frequencies lower than $10^{-3.5}$ ($\approx 3.16 \times 10^{-4}$) Hz (a period > 1 h) are strongly influenced by behavioral factors such as physical activity, sleep-wake cycle, and circadian and ultradian rhythms. Therefore, the ULF component should be examined controlling for behavioral factors. Another approach to adjust for the effects of behavioral factors is to change the frequency divisions of the Task Force⁵) and evaluate a “new” VLF ($10^{-3.5}$ –0.04 Hz) component suggested by Aoyagi *et al.*⁸⁹). Figure 1 depicts the representative power spectral densities of a healthy young man and an elderly man during waking with normal daily activities. Power for the young man at frequencies higher than $10^{-3.5}$ Hz is higher than that for the elderly man, which might be related to the deterioration of the cardiovascular system due to aging. This implies that the “new” VLF component might be sensitive to undesirable changes in the cardiovascular system. Also, the division of VLF and ULF components at 0.0033 Hz, as suggested by the Task Force⁵), is arbitrary.

Finally, the literature on the effects of work-related factors on HRV is predominantly based on cross-sectional studies. To deduce chronic effects on the autonomic system and the causal relationships between the hypothesized exposures and HRV, longitudinal research is highly recommended.

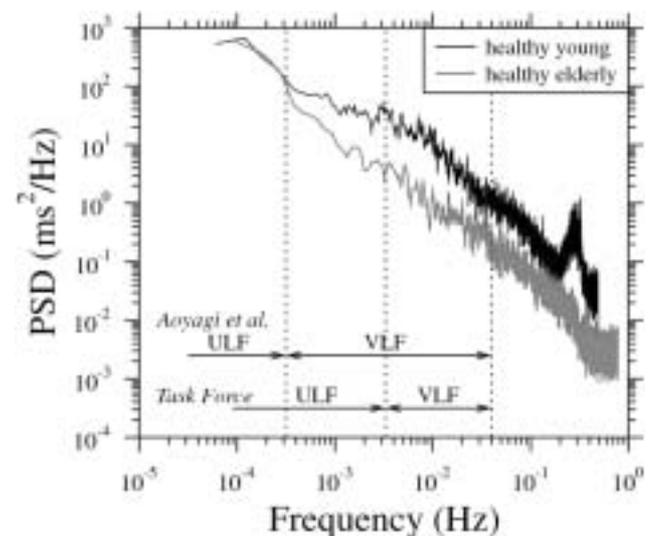


Fig. 1. Examples of power spectral density (PSD) of long-term heart rate variability calculated using a fast Fourier transform during waking with normal daily activity for a healthy young man and a healthy elderly man. Vertical dotted lines indicate boundary frequencies of the very low (VLF) and ultralow frequency (ULF) bands defined in the Task Force report⁵) or suggested by Aoyagi *et al.*⁸⁹).

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