

Heart rate variability and occupational stress—systematic review

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Abstract: The aim of this systematic review was to explore studies regarding association between occupational stress and heart rate variability (HRV) during work. We searched PubMed, Web of Science, Scopus, Cinahl and PsycINFO for peer-reviewed articles published in English between January 2005 and September 2017. A total of 10 articles met the inclusion criteria. The included articles were analyzed in terms of study design, study population, assessment of occupational stress and HRV, and the study limitations. Among the studies there were cross-sectional (n=9) studies and one longitudinal study design. Sample size varied from 19 to 653 participants and both females and males were included. The most common assessment methods of occupational stress were the Job Content Questionnaire (JCQ) and the Effort-Reward Imbalance (ERI) questionnaire. HRV was assessed using 24 h or longer Holter ECG or HR monitoring and analyzed mostly using standard time-domain and frequency-domain parameters. The main finding was that heightened occupational stress was found associated with lowered HRV, specifically with reduced parasympathetic activation. Reduced parasympathetic activation was seen as decreases in RMSSD and HF power, and increase in LF/HF ratio. The assessment and analysis methods of occupational stress and HRV were diverse.

Key words: Occupational health, Occupational stress, Heart rate variability, Autonomic nervous system, Work

Introduction

Long-term stress has become one of the most prevalent health risks in the contemporary society¹. After Hans Selye's² pioneering definition of stress as “*the non-specific response of the body to any demand for change*” various definitions have emerged. Generally, stress implies a harmful long-term imbalance between the individual's

resources and the environmental demands³. Consequently, occupational or work-related stress can be defined as a pattern of reactions that occurs when workers are presented with work demands that are not matched to their knowledge, skills or abilities, and which challenge their ability to cope³.

There is plethora of occupational stress models and theories. Among the two most widely used occupational stress theories are Siegrist's Effort-Reward imbalance (ERI)⁴ and Karasek's High Demand-Low Control Theory⁵. The ERI model states that work-related stress depends upon a reciprocal relationship between efforts and

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rewards at work: working hard without receiving adequate appreciation or being treated fairly causes a stressful imbalance⁶). In Karasek's model, workplace stress is a function of how demanding a person's job is and how much control (discretion, authority or decision latitude etc.) the person has over their own responsibilities. This creates four kinds of job characteristics: passive, active, low strain and high strain⁵).

Long-term occupational stress has been associated with a number of ill-health outcomes such as cardiovascular diseases⁷), musculoskeletal disorders, particularly back problems⁸) and neck-shoulder-arm-wrist-hand problems⁹). In addition, a close relationship between chronic stress, depression, inflammation, and disorders including obesity, diabetes, arthritis, skin diseases, infectious diseases, and sleep disorders has been found. What is more, the potential outcomes of stress at work are diverse and do not only pertain to health but also cause absenteeism from work and thus, financial losses^{1, 10}).

Physiologically, a stressful situation triggers a cascade of stress hormones and autonomic nervous system (ANS) acceleration resulting in muscle tension and enhanced performance: this short-term "fight-or-flight" response evolved as a survival mechanism, enabling people to react quickly to life-threatening situations. However, a long-term activation of the stress-response system and the subsequent overexposure to cortisol and other stress hormones can disrupt almost any body processes via subsequent increases in blood pressure, blood supply to active muscles, muscle strength, and cell metabolism¹¹).

Heart rate variability (HRV) is commonly used tool to assess ANS activity. HRV implies the normal variation in the time intervals between consecutive heart beats (R-R intervals). Thus it reflects the balance of the cardiovascular system controlled by the sympathetic and parasympathetic parts of the ANS. Stress has been found related to increased low frequency HRV power (expressed in normalized units)¹²) reflecting increase in sympathetic stimulation¹³). On the other hand, parasympathetic activation increases HRV¹³). Therefore, changes related to psychophysiological strain and recovery of the ANS can be evaluated by HRV analyses. Several analysis parameters and recommendations for performing HRV analysis have been proposed¹²). The analysis methods of HRV can be divided into time-domain, frequency-domain and nonlinear methods. The most commonly used analysis parameters of HRV used in occupational health studies are summarized in Table 1.

It is commonly known that ageing decreases HRV^{14, 15}). In addition, there are many individual factors affecting

HRV such as gender^{14, 15}), health^{13, 16, 17}), physical fitness¹⁸) and heredity^{19–21}). Moreover, it is known that breathing patterns effect HRV through parasympathetic input¹²).

The current technology for the registration of HRV allows reliable long-term (24–48 h) data collection at work, in leisure-time activities and during sleep^{22, 23}). Physiological indicators of occupational stress would be useful in occupational health services with respect to early prevention of detrimental long-term stress effects. The information obtained by HRV may help in planning strategies for health assessment and promotion at work. Many of the studies on HRV have been conducted in laboratory conditions with healthy subjects. However, less is known about the association between occupational stress and HRV measured in real working life settings. Therefore, the aim of this systematic review was to examine previous studies regarding the association between occupational stress and HRV during work, in real life setting.

Methods

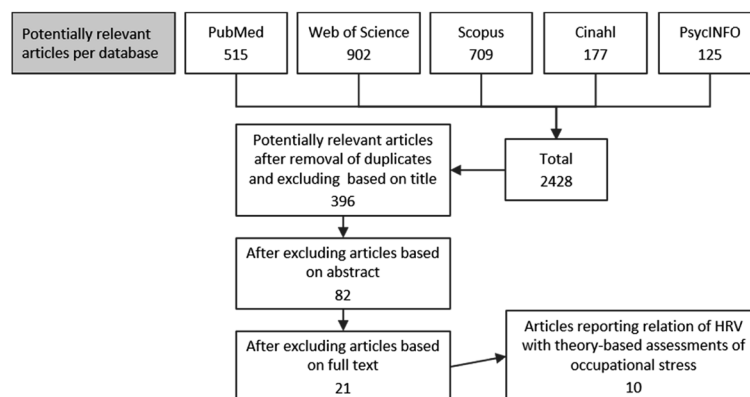
PubMed, Web of Science, Scopus, Cinahl and PsycINFO databases were searched for available literature from the January 2005 to September 2017. The used search terms were "stress", "strain", "work", "job", "occupational", "mental work load", "heart rate variability", "heart rate variation", "heart rate", "heart beat variability", "heart beat variation" and "RR variation". In addition, in PubMed, the used MeSH search terms were "Stress", "Physiological", "Work", "Workload" and "Heart Rate". The used search terms and search strategy were designed with an information specialist from the Library of the University of Eastern Finland.

The search process and its results in different phases are depicted as a flow chart (Fig. 1).

On the first phase of the selection, the authors (S J-P, SS, MT) scanned first all the resulting titles and then the abstracts to exclude articles that were clearly out of scope. Duplicate articles were then removed. On the second phase, based on the full text reading, the articles focusing on occupational stress among working age population (19–64 yr) and HRV measured beat-to-beat during work were included. In addition, the selected studies had to be written in English, had to be peer reviewed and published during 2005–2017. Articles using laboratory settings and focusing on post-traumatic conditions, heat exposure, over trained athletes, or patient populations (e.g., cardiovascular diseases, depression or stroke patients) were excluded. The authors independently assessed the titles, the abstracts and full texts, any

Table 1. Description of commonly used time-domain, frequency-domain and nonlinear HRV parameters based on the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (1996)¹²⁾

HRV Parameter	(units)	Description
Time-domain parameters		
Mean HR	(bpm)	Mean heart rate
Mean RR	(ms)	Mean of the selected beat-to-beat RR interval series, inversely proportional to mean heart rate
SDNN	(ms)	Standard deviation of all normal RR (normal-to-normal intervals, NN) intervals, the square root of variance (demonstrates overall HRV)
SDNNindex	(ms)	Mean of the standard deviations of all NN intervals for all 5-min segments of the entire recording
SDANN	(ms)	Standard deviation of the averages of NN intervals in all 5-min segments of the entire recording
RMSSD	(ms)	The square root of the mean of the squares of differences between consecutive RR intervals (describes short-term variations)
pNN50	(%)	Number of consecutive NN interval pairs differing more than 50 ms (NN50) divided by the total number of NN intervals
Frequency-domain parameters		
VLF power	(ms ²)	Very low-frequency power (frequency range 0–0.04 Hz)
LF power	(ms ²)	Low-frequency power (frequency range 0.04–0.15 Hz)
LF power	(%)	Percentage of LF power represent the relative power in proportion to the total power, LF power/Total power × 100%
LF power	(n.u.)	LF power in normalized units (n.u.) represent the relative power in proportion to the total power minus the power of the VLF component, LF power/ (Total power – VLF power)
HF power	(ms ²)	High-frequency power (frequency range 0.15–0.4 Hz) (synchronous with respiration)
HF power	(%)	Percentage of HF power represent the relative power in proportion to the total power, HF power/Total power × 100%
HF power	(n.u.)	HF power in normalized units (n.u.) represent the relative power in proportion to the total power minus the power of the VLF component, HF power/ (Total power – VLF power)
LF/HF	-	LF/HF power ratio (estimates sympatho-vagal balance)
Nonlinear parameters		
SampEn	-	Sample entropy of RR interval time series

**Fig. 1. The search process and selection of articles in different phases.**

disagreements were discussed and resolved by consensus.

Among the resulting articles ($n=21$)^{24–44}, ten studies focused on occupational stress and HRV^{25–30, 34, 37, 40, 43}, five studies focused on occupational stress and changes in shift schedule^{33, 35, 36, 39, 42}, five studies examined the association of HRV and working hours/changes in shift schedule^{24, 31, 32, 38, 44}, and one study investigated the effect of physical work environment on occupational stress mea-

sured by HRV⁴¹. In nine studies only subjective assessment of stress response was used^{31–33, 37–41, 43}. However, for further analysis only those studies that included theory-based assessments of occupational stress were selected^{24–30, 34–36, 42, 44}. In addition, in Aasa *et al.*²⁴ and Wong *et al.*⁴⁴ theory-based assessment of occupational stress was used (in Aasa *et al.* the demand-control-support questionnaire^{5, 45} and the Stress-Energy Questionnaire (SEQ)⁴⁶);

in Wong *et al.* the Sources of Occupational Stress Survey (SOSS)⁴⁷⁾, but the association between HRV and stress was not tested. Thus, these were excluded from the final analyses. Consequently, the final set of articles (n=10) was then evaluated using the following criteria: Study design (cross-sectional, longitudinal); Study population (sample size, gender, occupation); Assessment of occupational stress; Assessment of HRV; Limitations of the studies.

Results

A total of 10 articles^{25–30, 34–36, 42)} met the inclusion criteria. A summary of the selected studies (study design, study population and assessment of occupational stress) is presented in Table 2.

Study designs

Nine studies were cross-sectional (i.e., study with measurements during single point in time)^{26–30, 34–36, 42)} and only one was carried out with longitudinal study design with a one year follow-up²⁵⁾.

Study populations

The sample size varied between 19⁴²⁾ and 653²⁶⁾ participants. The mean of the sample size was 179 (median 73 participants). Six studies examined both females and males and four only males^{26–28, 34)}.

The mean age of the study population was reported in seven studies^{25, 26, 29, 34–36, 42)}. Mean age ranged from 29 yr³⁴⁾ to 47 yr²⁶⁾ (mean age was 41, based on the information from those seven studies).

In two studies the subjects were nurses or other hospital workers^{25, 42)} and in one study physicians³⁰⁾. Other examined occupational groups were factory workers²⁶⁾, media workers³⁵⁾, workers in consumer goods production³⁴⁾, workers in airplane manufacturing³⁶⁾, white-collar workers²⁹⁾ and “employed”^{27, 28)}.

Assessment of occupational stress

The most commonly used assessment methods of occupational stress were the Job Content Questionnaire (JCQ)^{5, 48)} and the Effort-Reward Imbalance (ERI) questionnaire⁴⁹⁾. The JCQ was used in four studies^{27, 28, 30, 34)}, ERI was used in two studies^{29, 42)} and both JCQ and ERI in two studies^{25, 36)}. In addition, the Job Stress Questionnaire (JSQ)^{50, 51)} and the Occupational Stress Questionnaire (OSQ)^{52, 53)}, were used in single studies^{26, 35)}.

Assessment of HRV

Measurements and HRV analysis parameters used in the studies are summarized in Table 3. HRV was recorded using a Holter electrocardiogram (ECG) device in seven studies^{25–28, 30, 35, 36)}. The recording length in these studies varied from one to two full days (24–48 h). Sampling rate of the ECG was reported in two studies: 200 Hz in Hernández-Gaytan *et al.*³⁰⁾ and 400 Hz in Loerbroks *et al.*³⁶⁾. In the rest of the studies this information was not reported. HRV was recorded using a 36-h HR monitoring periods (including both work and leisure or sleep time) in one study⁴²⁾. Shorter HR monitoring periods (2–12 h) during work were utilized in one study²⁹⁾. In addition, one study assessed HRV only from short (5–10 min) resting periods³⁴⁾. Polar HR monitors were used in 2 out of 3 studies utilizing HR monitoring.

HRV was characterized using 1–6 different HRV parameters, that can be divided into time-domain, frequency-domain and nonlinear parameters as described in Table 1. One or more time-domain parameters were used in eight studies and frequency-domain parameters in seven studies. In five studies, both time and frequency-domain HRV parameters were used. Only one study used nonlinear HRV parameters⁴²⁾. The most commonly used time-domain HRV parameters were RMSSD (used in five studies), SDNN (five studies), and mean RR or HR (three studies). The most commonly used frequency-domain parameters were HF power in absolute or normalized units (six studies), LF power in absolute or normalized units (four studies) and LF/HF ratio (five studies). Regarding nonlinear parameters, SampEn was used in Uusitalo *et al.*⁴²⁾.

HRV was analyzed using altogether seven different freely or commercially available analysis programs. The single studies used Kubios HRV software²⁹⁾, Century 2000 ECG software³⁵⁾, Firstbeat PRO software⁴²⁾, Holter Plus III software³⁰⁾, Marquette 12SI ECG analysis program²⁸⁾, MemCalc/BP Analyzer software³⁴⁾ and Syne Tec software²⁶⁾. In one study, HRV analysis was performed using in-house algorithms²⁷⁾. In two studies^{25, 36)} the used HRV analysis programs were not reported.

Five studies explicitly reported of using the recommendations of Task Force in their measurements and analyses^{25, 28, 30, 36, 42)}. In three studies^{26, 27, 29)}, Task Force recommendations were referenced in text, but they did not explicitly state if these recommendations were followed or not. Moreover, the Task Force recommendations were not mentioned in two studies^{34, 35)}. The respiratory rate was taken into account in one study³⁴⁾ as recommended by the Task Force. In addition, the effect of breathing patterns on

Table 2. Study characteristics of the 10 articles included in the review in alphabetical order

Study, yr (origin)	Study design	Number of participants (occupation), gender and age (yr)	Assessment of occupational stress (definition of occupational stress)
Borchini <i>et al.</i> 2015 (Italy) ²⁵⁾	Longitudinal study design; two measurements with one-year interval	n=36 (nurses) 6 males, 30 females Mean age 39	JCQ ^{a)} (<i>workplace stress is a function of how demanding a person's job is and how much control; discretion, authority or decision latitude etc. the person has over their own responsibilities</i>) ERI ^{b)} (<i>Mismatch between effort (intrinsic or extrinsic) and rewards (money, esteem, career opportunities) will lead to stressful experiences</i>)
Clays <i>et al.</i> 2011 (Belgium) ²⁶⁾	Cross-sectional study	n=653 (factory workers) All males Mean age 47 ± 4.3 (range 40–55)	JSQ ^{c)} ; A measure of job stressors Work stressor index: a computed scale based on five items; Mostly external work stressors: general satisfaction at work, responsibilities at work, imposed work pace, difficult professional relations (with superiors, colleagues or subordinates) and complaints about physical work conditions (noise, light, heat or tobacco smoke)
Collins <i>et al.</i> 2005 (USA) ²⁷⁾	Cross-sectional study	n=36 (employed men) All males Age range 35–59	JCQ ^{a)} (<i>See corresponding definition above</i>)
Collins and Karasek 2010 (USA) ²⁸⁾	Cross-sectional study	n=36 (employed men) All males Age range 35–59	JCQ ^{a)} (<i>See corresponding definition above</i>)
Garza <i>et al.</i> 2015 (Netherlands) ²⁹⁾	Cross-sectional study	n=91 (white-collar workers) 26 males, 65 females Mean age 44 (range 24–64)	ERI ^{b)} (<i>See corresponding definition above</i>)
Hernandez-Gaytan <i>et al.</i> 2013 (Mexico) ³⁰⁾	Cross-sectional study	n=54 (resident doctors) 36 males, 18 females Age range 23–36	JCQ ^{a)} (<i>See corresponding definition above</i>)
Lee <i>et al.</i> 2010 (South Korea) ³⁴⁾	Cross-sectional study	n=140 (workers in consumer goods production) all males Mean age 29 (range 25–44)	JCQ ^{a)} (<i>See corresponding definition above</i>)
Lindholm <i>et al.</i> 2009 (Finland) ³⁵⁾	Cross-sectional study	n=132 (media workers, shift work) 63 males, 69 females Mean age 43 ± 10 (range 25–62)	OSQ ^{d)} (<i>The characteristics of the demand–control balance at work</i>)
Loerbroks <i>et al.</i> 2010 (Germany) ³⁶⁾	Cross-sectional study	n= 591 (workers in airplane manufacturing) 520 males, 71 females Mean age of groups 26, 40, 50 and 56	JCQ ^{a)} (<i>See corresponding definition above</i>) ERI ^{b)} (<i>See corresponding definition above</i>)
Uusitalo <i>et al.</i> 2011 (Finland) ⁴²⁾	Cross-sectional study	n=19 (hospital workers) 1 males, 18 females Mean age 42 (range 24–57)	ERI ^{b)} (<i>See corresponding definition above</i>) VAS-assessment of emotions of stress, irritation and satisfaction; A self-rating of the stress response on a 10-cm scale without graduation

^{a)} JCQ: The Job Content Questionnaire^{5, 47)}, ^{b)} ERI: The Effort-Reward Imbalance questionnaire⁴⁸⁾, ^{c)} JSQ: Job Stress Questionnaire^{49, 50)}, ^{d)} OSQ: Occupational Stress Questionnaire^{51, 52)}.

HRV was recognized in two studies^{36, 42)}, but it was not measured or controlled.

Associations between occupational stress and HRV

A summary of the changes in HRV parameters with respect to occupational stress is presented in Table 4. The

most commonly used measure of stress, the JCQ, was used in six studies^{25, 27, 28, 30, 34, 36)}. In five studies^{25–28, 30)}, occupational stress was associated with reduced HRV. More specifically, in Clays *et al.*²⁶⁾ and Collins *et al.*²⁷⁾, stress was associated with reduced parasympathetic activation (i.e. decreased HF power), whereas in Collins

Table 3. Descriptions of measurements of HRV and outcomes

Study, yr (origin)	Measurement of HRV and analysed samples	Comparisons made	Results	Mean RR Mean HR	SDNN SDANN SDNN _{index}	RMSSD pNN50	LF/HF		Test used (adjustments made)
							LF (ms ²)	HF (ms ²)	
Borechini <i>et al.</i> 2015 (Italy)	2 × 24 h Holter ECG: 1) working day 2) resting day Entire 24 h recording analysed	JCQ:		HR n.s.	SDNN↓ ¹	RMSSD n.s.	-	-	ANCOVA (age and smoking status)
		a) prolonged high strain	a vs. b vs. c (progressive change from a to c)	HR n.s.	SDNN _{index} ↓ ¹	pNN50 n.s.			
		b) recent high strain c) stable low strain	a vs. c		SDANN n.s. SDNN↓ ^{1,2} SDNN _{index} ↓ ^{1,2} SDANN↓ ¹	RMSSD n.s. pNN50 n.s.			
Clays <i>et al.</i> 2011 (Belgium)	24 h Holter ECG (working day), entire 24 h recording analysed	JSQ:	High vs. low JSQ score (a)	HR↑	SDNN n.s.	pNN50 n.s.	LF n.s.	LF/HF↑	Pearson correlation
		a) Total JSQ score b) Work stressor index	High vs. low stressor score (b)	HR↑	SDNN n.s.	pNN50↓	LF n.s.	LF/HF↑	
Collins <i>et al.</i> 2005 (USA)	2 × 24 h Holter ECG (workday + rest day), analysed in 5-min epochs	JCQ:	Effects of a-d		SDNN↓ ^{c,d}	-	HF↓ ^{a,c}	LH/HF↑ ^b	Repeated measures mixed model (age and education)
		a) High strain							
		b) High strain – work							
		c) Low control d) High demands							
Collins and Karasek 2010 (USA)	2 × 24 h Holter ECG (workday + rest day), analysed in 5-min epochs	JCQ:	b vs. c and a vs. c	-	-	-	HF vari- ance↓	-	Repeated measures ANOVA (age)
		a) Exhausted							
		b) High strain c) Low strain							
Garza <i>et al.</i> 2015 (Netherlands)	2 h HR monitoring (Polar) during work, analysed in 5-min epochs	ERI:	Effects of a & b	-	SDNN↓ ^a	RMSSD↓ ^a	HF↓ ^{a,b}	LH/HF↑ ^{a,b}	Repeated measures mixed model (age, gender, exercise and job title)
		a) High ERI b) Over-commitment							
Hernandez-Gaytan <i>et al.</i> 2013 (Mexico)	24 h Holter ECG (24 h workshift), entire 24 h recording analysed	JCQ:	a, b and c vs. d	-	SDNN n.s.	-	LF↓ ^{a,c}	LF/HF↓ ^a	Linear mixed model (gender, age and BMI)
		a) High strain	Effect of low job decision latitude (low control)		SDNN n.s.		LF↓	LF/HF↓	
		b) Active							
		c) Passive d) Low strain							

Table 3 Continued.

Study, yr (origin)	Measurement of HRV and analysed samples	Comparisons made	Results	Mean RR Mean HR	SDNN SDANN SDNN _{index}	RMSSD pNN50	LF (ms ²) HF (ms ²)	LF/HF LF (%) HF (%) SampEn	Test used (adjustments made)
Lee <i>et al.</i> 2010 (South Korea)	3 × 5-min resting HR measurements (LRR-03, GMS Co.) after different shifts (morning, afternoon, night)	JCQ: a) High strain b) Active c) Passive d) Low strain	a vs. c (within shortest seniority workers)	-	-	-	LF↑ HF n.s.	LF/HF n.s.	ANOVA with Duncan's post hoc test (duration of employment and age)
Lindholm <i>et al.</i> 2009 (Finland)	24 h Holter ECG (workday and following leisure time/night), analysed in 1h epochs	OSQ fro demand-control balance: a) Job control b) Job demand	Low/intermediate vs. high control High vs. intermediate/low demand	-	-	RMSSD↓ RMSSD n.s.	- -	- -	Repeated measures ANOVA
Loerbroeks <i>et al.</i> 2010 (Germany)	24 h Holter ECG (workday and following leisure time/night), analysed at work, leisure and sleep periods for age groups 1) 17–34 yr 2) 35–44 yr 3) 45–54 yr 4) 55–65 yr	a) Job strain index from JCQ b) Effort-reward imbalance ratio (ERI)	High vs. low strain (a) High vs. low ERI (b)	-	-	RMSSD n.s. RMSSD↓ ²⁾ (during work and leisure time)	- -	- -	Regression analysis (gender, activity, smoking, alcohol)
Uusitalo <i>et al.</i> 2011 (Finland)	2 × 36 h HR monitoring (Polar) (night before, workday and following leisure time/night) for two workdays during same working period, analysed as averages over 1) daytime, 2) work time, and 3) night time	ERI: Effort at work	High vs. low effort	RR n.s.	SDNN↓ ^{1,2)}	RMSSD↓ ^{1,2)}	LF↓ ^{1,2)} HF n.s.	SampEn n.s.	Spearman correlation

↑, ↓ indicate increase or decrease (statistical significant at $p < 0.05$), n.s. indicates no change ($p \geq 0.05$), – indicates data is not provided. For example, if in comparison a vs. b parameter X↑, it means that X was higher in situation a compared to situation b. Superscripts refer to specific measurement groups or analysis samples (numerical superscripts) and to specific occupational stress comparison (alphabet superscripts).

Table 4. Summary of main results of the studies regarding associations between occupational stress and HRV

Authors	Main results
Borchini <i>et al.</i> 2015 (Italy)	Occupational stress lowered time-domain HRV parameters
Clays <i>et al.</i> 2011 (Belgium)	Occupational stress was associated with reduced parasympathetic activation
Collins <i>et al.</i> 2005 (USA)	Occupational stress/job strain was associated with reduced parasympathetic activation
Collins and Karasek 2010 (USA)	Occupational stress/job strain was associated with reduced cardiac vagal variance
Garza <i>et al.</i> 2015 (Netherlands)	Occupational stress was associated with lowered HRV, mainly caused by reduced parasympathetic activation
Hernández-Gaytan <i>et al.</i> 2013 (Mexico)	Job strain and low job control were associated with lowered LF power of HRV
Lee <i>et al.</i> 2010 (South Korea)	Occupational stress was associated with higher LF power in the group of workers with short duration of employment
Lindholm <i>et al.</i> 2009 (Finland)	Low job control was associated with reduced parasympathetic activation
Loerbroeks <i>et al.</i> 2010 (Germany)	Occupational stress was associated with reduced parasympathetic activation among 35–44-yr-old workers
Uusitalo <i>et al.</i> 2011 (Finland)	Occupational stress was associated with reduced parasympathetic activation

and Karasek²⁸), association with reduced cardiac vagal variance was found. Borchini *et al.*²⁵ found association between occupational stress and time-domain HRV parameter SDNN during working day. In Hernández-Gaytan *et al.*³⁰, occupational stress was associated with lowered LF power (as well as lowered LF/HF ratio), whereas interestingly, Lee *et al.*³⁴ found the opposite (i.e. LF power was increased in relation to occupational stress in the group of workers with short duration of employment).

In Loerbroeks *et al.*³⁶, no relation between occupational stress and HRV was found when measured by JCQ, but a reduced parasympathetic activation (i.e. lowered RMSSD) among 35–44-yr-old workers was associated with occupational stress when measured with ERI. In addition, ERI was used in Garza *et al.*²⁹ and Uusitalo *et al.*⁴² and occupational stress was found associated with reduced parasympathetic activation (i.e. lowered RMSSD and HF power). Lindholm *et al.*³⁵ who measured occupational stress with OSQ, found that low job control was associated with reduced parasympathetic activation (i.e. lowered RMSSD).

A summary of the associations between occupational stress and HRV in all the studies is presented in Table 4.

Limitations of the studies

The most common limitations mentioned in the studies were small sample size^{25, 30, 34, 42} and cross-sectional study design^{26–30, 34–36, 42}. In two studies, generalization of the results was seen limited, because there was an imbalance between men and women in the study group^{30, 36}. Further, five studies recognized that they were not able to control potential confounding factors in real-world study settings^{28–30, 34, 42} such as smoking or physical activity.

Discussion

The aim of this systematic review was to examine the literature concerning the association of occupational stress and heart rate variability during work, among working-age population. Ten articles met the inclusion criteria.

The main finding was that heightened occupational stress was found associated with lowered HRV, specifically with reduced parasympathetic activation. Reduced parasympathetic activation was seen as decreases in RMSSD and HF power, and increase in LF/HF ratio. Lowered HRV with respect to occupational stress was observed in 8 studies^{25–27, 29, 30, 35, 36, 42}. In two studies^{28, 34}, this association was not detected.

Assessment of occupational stress

Our systematic review showed somewhat diversity in assessing occupational stress in the studies. As summarized by O'Connor & Ferguson⁵⁴, there are different approaches in occupational stress assessment: 1) The stimulus-based approach, i.e. the assessment of job stressors. The basic assumption is that stress from the environment asserts demands on an individual without any mediating psychological processes: the greater the strain, the larger the reaction. The assessment methods using this approach include the ERI and the JCQ, the most commonly used questionnaires in the reviewed studies. 2) The response-based approach, i.e. the assessment of the workers' strain—psychological or physiological—to job stressors such as work overload, time pressure, excess responsibility, role conflict. This approach mainly considers stress in terms of the general reaction to the stressors. Strictly speaking, the latter approach—although commonly used—is not compatible with the actual definition of occupational

stress (a disproportional relationship between individual's resources and work demands).

Assessment of HRV

Our systematic review showed the association between HRV and occupational stress. In addition, it showed the diversity of measurement methods of HRV in the studies. Occupational stress was associated with lowered HRV, specifically with reduced parasympathetic activation. The most common HRV parameters reflecting parasympathetic activation were RMSSD and HF power. In addition, LF/HF ratio was frequently used for evaluating sympatho-vagal balance. However, the comparison of HRV findings is challenging, because of high variety of used HRV parameters, measurement devices and methods, as well as diversity of study designs.

The guidelines for measurement, physiological interpretation and clinical use of HRV are given in Task Force²⁾. Ten studies either reported of using these guidelines or at least referenced the guidelines in text, whereas two studies did not mention the guidelines.

In the reviewed studies, a wide range of HRV parameters recommended by the Task Force were used, but number of HRV parameters used in individual studies varied from one single parameter to 6 different parameters. The most commonly used time-domain parameters were mean HR, SDNN and RMSSD; where mean HR is known to reflect physical activity and sympatho-vagal balance, SDNN reflects overall HRV and RMSSD reflects mainly parasympathetic activation of ANS. The most commonly used frequency-domain parameters were LF power, HF power and their ratio (LF/HF). HF power reflects parasympathetic activation through the physiological influence of respiration, known as respiratory sinus arrhythmia (RSA). LF power reflects both sympathetic and parasympathetic activation, but common understanding is that sympathetic and baroreceptor activity play big role in the generation of this frequency component. LF/HF ratio is a commonly used index of sympatho-vagal balance.

Nonlinear analysis methods were utilized in only one reviewed study⁴²⁾, where sample entropy was used. Despite almost complete disuse of nonlinear analysis methods among the reviewed studies, the use of these methods is becoming more and more common as they have evidenced to reveal useful additional information about HRV characteristics in different applications and patient groups, see for example^{55–57)}.

The physiological influence of respiration on heart beat intervals, i.e. the respiratory sinus arrhythmia forms

one of the two main oscillatory components of HRV. In HRV spectrum, RSA is observed as power component in the HF band with center frequency equal to respiratory rate¹²⁾. The HF band is typically defined as 0.15–0.4 Hz frequency band, which is expected to include normal human breathing rate. However, during exercise the respiratory rate easily exceeds the 0.4 Hz limit reaching even close to 1 Hz (60 breaths per min) in intense exercise. On the other hand, in case of slow breathing the respiratory rate can easily drop below the 0.15 Hz, in which case the RSA component starts to overlap with the LF component. If possible, the HF band should be extended to include the observed respiratory frequency, which is not however trivial in case of slow breathing. Among the reviewed studies, the respiratory rate was taken into account in one study³⁴⁾ as recommended by the Task Force. In addition, the effect of breathing patterns on HRV was recognized in two studies^{36, 42)}, but it was not measured or controlled. Overall, respiratory rate influences HRV⁵⁸⁾ and should (if possible) be taken into account in HRV analysis and when interpreting the results.

In addition, it should be noted that HRV analysis should always be performed on normal-to-normal beat interval data. Ectopic beats or other artefacts such as missed, extra or misaligned beat detections can cause significant alterations into HRV analysis parameters, and thus, any such aberrant beats should be corrected prior to HRV analysis^{59, 60)}. In addition, very low frequency changes such as slow increases or decreases in heart rate can have a significant influence on certain HRV measures (for example on SDNN reflecting overall HRV), which can be considered as bias when performing short-term HRV analyses assuming stationarity. In these cases, it may be advisable to remove the trend prior to HRV analysis⁶¹⁾.

ECG recording for HRV assessment was carried out in seven of the reviewed studies, whereas HR monitors (mainly Polar) were utilized in rest of the studies. The ECG recording should be preferred over HR monitoring due to two reasons. First, the origin of abnormal beat intervals can be verified from the ECG data and possible ectopic beats or other arrhythmic events can be identified. Secondly, an estimate of respiratory rate can be extracted from the ECG (i.e. ECG derived respiration, EDR)^{62, 63)}. Currently several easy-to-use, wearable and relatively inexpensive ECG devices exist on the market, which are designed for long-term recordings. In addition, continuous optical pulse wave measurement devices have become popular, but their accuracy for HRV assessment in long-term recordings is still a challenge.

It is noteworthy, that only one study was performed with a longitudinal study design²⁵). As the key advantage of the longitudinal studies is the ability to show the patterns of a variable over time, this indeed would be a recommended approach in occupational stress-HRV studies to learn about cause-and-effect relationships. In addition, the dispersion of HRV and occupational stress assessment methods makes the comparison of the studies difficult. Instead of a big picture, a fragmented puzzle emerges. Therefore, more unified assessment methods and longitudinal study settings are called for.

Many of the studies on HRV have been performed in laboratory conditions and less in real working life settings. When compared to short-term (laboratory) measurements, long-term (24 h or more) HRV monitoring enables assessment of stress and recovery patterns during normal working and leisure time as well as during sleep. However, HRV measurements obtained in actual working conditions often involve unidentified confounding factors that can never be controlled completely, which need to be taken into account when interpreting the study results. For example, physical activity is known to decrease HRV, and thus, the physical activity of workers should be controlled or measured along with HRV to avoid HRV data misinterpretations. In addition, the effects of the confounding factors would be reduced, for example through using subjective methods such as questionnaires, and with the longitudinal study settings. Despite of the challenges, the information of work load and recovery obtained by HRV would be useful in the early identification and prevention of stress, for example in occupational health care.

Conclusions

This systematic review showed that occupational stress is associated with lowered HRV, specifically with reduced parasympathetic activation. Thus, analysis of HRV can be used as an informative marker for physiological impacts of workplace stressors. In addition, this systematic review showed the diversity of assessing occupational stress or measuring of HRV in the studies. Consequently, the utilizing of stress theories/models and valid stress indicators would improve the comparability of results. Further, more unified HRV assessment and analysis methods, as well as longitudinal study settings, are called for.

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