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Perceived Mental Stress and Reactions in Heart Rate Variability—A Pilot Study Among Employees of an Electronics Company

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In this study perceived mental stress during occupational work was compared to heart rate variability (HRV) using a traditional questionnaire and a novel wristop heart rate monitor with related software. The aim was to find HRV parameters useful for mental stress detection. We found the highest correlation between perceived mental stress with the differences between the values of triangular interpolation of rythm-to-rythm (RR) interval histogram (TINN) and the root mean square of differences of successive RR intervals (RMSSD) obtained in the morning and during the workday ($r = -.73$ *and* $r = -.60$*, respectively). The analysis shows that as the RMSSD and TINN value differences increase from night to morning, the stress decreases.*

work stress   wristop computer   heart rate variability

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1. INTRODUCTION

The effects of work stress on health are well known [1] and they have been extensively studied [2]. Traditionally, work stress has been measured using subjective methods, such as questionnaires. Now, modern methods aim at more objective evaluation, especially for mental work stress. In this way novel methods can supplement traditional, subjective evaluation methods, especially with healthy subjects. Measuring and analysing individual workload is one aspect in work stress evaluation. The poor correlation between measured and perceived physical workload has been demonstrated [3]. According to the Finnish Occupational Safety Act §25 (738/2002)[1], employers are required to evaluate their employees' mental stress objectively. This motivates the development of reliable and practical methods for evaluation of occupational stress.

One new option for measuring stress at work is a wristop computer [4]. These computers collect heart rate (HR) beat-by-beat with high sampling frequency enabling the calculation of heart rate variability (HRV) parameters. HRV is an objective measure of individual differences in regulated emotional response, particularly as it relates to mental stress [5]. Since recent advances in electronics integration, it is now possible to make long-term HR recordings digitally. HRV recordings have been used to study the autonomic nervous system in clinical research studies [6], and now with the development of cost-effective wristop computers, the HRV analysis area has expanded to cover everyday life situations. HRV seems to be an effective method for studying work-related stressors [7, 8]. HRV, which is known as a noninvasive measure for cardiovascular autonomic regulation [9], also offers opportunities to study, among others, associations between psychological processes and physiological reactions [10, 11]. HR measures autonomic cardiovascular activity, especially the physiological aspect of emotions and HRV expresses the balance of the regulation of the sympathetic and parasympathetic nervous systems [11]. Cardiac autonomic modulation during provocative stress shows similar physiological responses in young and old adults [12].

HR varies during different activities and postures [13] and according to age and gender [14, 15]. The most often used HRV parameters in earlier studies have been spectral parameters such as low-frequency (LF) power, high-frequency (HF) power and LF/HF ratio (Table 1). LF is connected with the heart's parasympathetic and sympathetic activity [16]. Elevated LF during a workday is associated with high work stress [7]. HF is connected with respiratory frequency [17]. LF is higher in men and HF is higher in women [15, 18]. Stress decreases HF and increases LF and LF/HF [19]. In Bilan's study LF was highest in the morning, HF was highest at night and LF/HF was lowest at night [20].

LF decreases ~40 min after falling asleep [17]. According to Hall, Vasko, Buysse, et al. acute stress alters HRV during sleeping [21]. Age is associated with HF and LF power. LF has a highly significant correlation with age, while women over 50 years old have higher LF values than women under 30 [22]. HRV, except LF/HF, is age dependent in both genders [23]. HRV has been studied less among healthy people than among cardiovascular or diabetes patients [24]. Therefore there is a need for research among healthy people.

The root mean square of differences between successive rhythm-to-rhythm (RR) intervals (RMSSD) describes short-term HR variations. A low value indicates high stress. Ramaekers, Ector, Demyttenaere, et al. [25] emphasize that a higher expression of negative emotions is related to higher vagal tone. TINN, baseline width of the RR interval histogram evaluated with triangular interpolation [26], describes total variations of HR. A low value indicates high stress.

The aim of this study was to find HRV parameters associated with perceived mental work stress. Thirty volunteers working in an electronics

[1] The Finnish Occupational Safety Act, Ministry of Social Affairs and Health, http://www.finlex.fi/en/laki/kaannokset/2002/en20020738

TABLE 1. Descriptions and Interpretations of Statistical, Geometric, Nonlinear and Spectral Heart Rate Variability Measures

Measure	Description and Interpretation
Statistical measures	
MeanRR (s)	Mean of the selected rhythm-to-rhythm (RR) interval series
MeanHR (beats/min)	HR measures autonomic cardiovascular activity, including physical activity and mental activity
RMSSD (ms)	The root mean square of differences of successive RR intervals, describes short-term variations. Low value indicates high stress.
Geometric measures	
TINN (ms)	Baseline width of the RR interval histogram evaluated with triangular interpolation. TINN describes total variations of HR. Low value indicates high stress.
Nonlinear measures	
SD1 (ms)	The standard deviation of the Poincaré plot perpendicular to the line-of-identity, describes short-term variability caused by respiratory sinus arrhythmia [31]. Low value indicates high stress.
SD2 (ms)	The standard deviation of the Poincaré plot along the line-of-identity, describes long-term variability [31]. Low value indicates high stress.
Spectral measures	
Power LF and HF (n.u.)	The powers of LF and HF frequency bands in normalized units (n.u.). LF demonstrates both sympathetic and vagal activation. HF component is synchronous with respiration and is modulated by the vagal tone [37]. High LF indicates high stress and high HF indicates low stress.
LF/HF	LF/HF ratio describes ratio of LF and HF frequency band powers.

company participated in the study. Each participant was asked to fill in a traditional questionnaire about perceived mental stress and to keep a diary during the recording day. The participants' HR was recorded using wristop computers.

2. METHODS

2.1. Study Group

In the present study, 30 volunteers (15 males and 15 females) responded to the questionnaire concerning stress and work ability and kept a diary, while their HR was continuously monitored for 24 hrs. Inclusion criteria were completing the questionnaire, keeping a diary and monitoring HR for morning, workday and night periods. Twelve persons fulfilled all the necessary criteria. Some values were missing; as a result we obtained 30 workday, 20 morning and 19 night HR data sets.

The age of the subjects ranged from 24 to 62 years (M = 40, SD 8.8). They were working in an electronics company in assembly work (n = 11) and in clerical work (n = 19). Out of the 12 persons with HRV data obtained in the morning, during the workday and at night, 3 were working in assembly work and 9 in clerical work. The clerical work consisted of general office work, e.g., visual display work, handling orders, relaying phone calls, billing, customer contacts, project planning and management. The assembly work consisted of assembling and testing small electronic devices. The mean HR was 77 beats/min. The medical history of the participants examined by an occupational health service indicated they were all healthy. The participants were not taking any medication known to affect cardiovascular function during the measuring period.

2.2. Methods

Beat-to-beat HR was recorded with a HR wristop monitor (Suunto T6, Suunto Ltd., Finland). HR monitoring started at the beginning of the morning of the workday or at the beginning of the workday and ended after the night. The average length of the HR recordings of all participants was 19 hrs. The average lengths of different periods were 0.58 hrs for the morning, 8.23 hrs for the workday and 5.57 hrs for the night. The morning period started when the subjects woke up and ended when they left for work. The workday started when the subjects arrived at work and ended on leaving work. The night period started when the subjects fell asleep and ended when they woke up. The evening between the workday and the night was excluded from the analysis because of the wide variation in the subjects' activities. In addition to the values of HRV parameters during the three periods of the day, we defined the differences between each period. The idea of this differential method was to diminish a wide dispersion of parameter values arising from interindividual differences.

A single survey item was used to assess perceived mental stress, which was elicited on a visual analog scale (from 0—*very little stress* to 10—*very high stress*) during the workday. Subjects who answered 6 or more were considered stressed. The periods studied were formed on the basis of the information written in the subjects' study diaries. The same diary data was also used to verify significant variations in HRV.

2.3. HRV Analysis

Data processing was based on Virtanen's research [27]. All the most commonly used time- and frequency-domain parameters of HRV were calculated and the parameters mostly associated with perceived mental stress were reported. RR interval segments were processed recognizing ectopic beats. RR intervals were processed with a Matlab program that checked intervals for abnormalities and, if necessary, interpolated new values or removed abnormal intervals. After pre-processing the RR interval segments were analysed with scientific HRV analysis software (Biosignal Analysis and Medical Imaging Group, Department of Physics, University of Kuopio, Finland) [28]. This software produces all the most commonly used HRV parameters according to the guidelines given in Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology [29]. The HRV parameters used in this study are briefly described in Table 1.

The software used in the HRV analysis calculated all commonly used time and frequency-domain parameters and nonlinear Poincaré plots. The following parameters were considered: mean RR interval (MeanRR), RMSSD, triangular interpolation of RR interval histogram (TINN), LF power in normalized units, HF power in normalized units, LF/HF ratio and Poincaré plot standard deviations (SD1 and SD2). The frequency domain parameters were extracted from a spectrum estimate calculated using the fast Fourier transform. Prior to spectrum estimation the RR interval time series was transformed to evenly sampled series by using 4-Hz cubic spline interpolation. The LF and HF frequency bands were set at 0.04–0.15 and 0.15–0.40 Hz respectively. The LF and HF powers in normalized units were obtained by dividing the absolute powers of the components by the total power within 0.04–0.5 Hz and multiplying by 100.

The RMSSD parameter evaluates the differences between successive RR intervals, and thus describes short-term variability. The TINN parameter is a geometric measure of the baseline width of the RR interval histogram evaluated through triangular interpolation. Thus, TINN describes the total variation of the RR series [27]. Typically TINN values are different for men and women [30]. The standard deviation of the Poincaré plot perpendicular to the line-of-identity (SD1) describes short-term variability caused by respiratory sinus arrhythmia [31] and the standard deviation of the Poincaré plot along the line-of-identity (SD2) describes long-term variability [31].

2.4. Statistical Analysis

Normality of distributions of HRV parameters was tested with Shapiro-Wilk's test. Due to the skewed distributions, values of continuous variables were expressed as medians (*Md*) and ranges. Spearman's correlation coefficient was used to test the associations of HRV parameters with perceived stress. Associations between perceived stress and the differences of HRV parameters during the workday, morning and night were also tested with Spearman's correlation. Differences in HRV parameters between morning and night and between workday and night were tested with the Wilcoxon test. The sample size was too small to compare women and men. Statistical analyses were performed with SPSS for Windows, version 14.0.

3. RESULTS

In our study 16 subjects (*Md* 6, range: 0–9) reported mental stress in the questionnaire. The lowest and the highest mean RR, RMSSD, HF, SD1 and SD2 values were respectively in the morning and at night. LF and LF/HF values were highest in the morning and lowest at night. TINN values were lowest in the morning and highest during the workday (Table 2).

Table 3 presents Spearman's correlation coefficients between perceived mental stress and the HRV parameters, and the workday–morning, workday–night and night–morning differences in HRV parameters. The highest but negative correlations were found between perceived mental stress and the difference between workday and morning values of RMSSD, TINN and SD1 (r = –.60, –.73 and –.60 respectively).

Figure 1 shows that perceived stress is usually higher when RMSSD is higher in the morning than during the workday. The same trend is

TABLE 2. Medians (*Md*) and Ranges of the Heart Rate Variability Parameters in the Morning, During the Workday and at Night

	Morning (n = 20)		Workday (n = 30)		Night (n = 19)			
Parameters	*Md*	Range	*Md*	Range	*Md*	Range	p_1	p_2
MeanHR (beats/min)	83	68–114	77	64–97	64	47–80	.002	<.001
MeanRR (s)	0.7	0.5–0.9	0.8	0.6–0.9	0.9	0.8–1.3	.002	<.001
RMSSD (ms)	23.6	5.9–52.1	27.6	8.8–44.5	39.8	7.6–94.5	.002	.007
TINN (ms)	300	155–610	407	240–695	405	150–680	.071	.587
LF (n.u.)	88.3	65.4–94.7	84	66.3–91.8	71.6	47.4–52.6	.003	<.001
HF (n.u.)	11.7	5.3–34.6	16.0	8.2–33.7	28.4	12.4–52.6	.003	<.001
LF/HF (%)	7.6	1.9–17.7	5.3	2.0–11.2	2.5	0.9–7.1	.003	<.001
SD1 (ms)	17.0	4.3–37.2	19.9	6.3–31.8	28.5	5.5–67.3	.002	.007
SD2 (ms)	127.6	57.5–198.6	132.3	82.9–247.9	151.4	89.0–270.9	.071	.376

Notes. Differences between morning and night (p_1) and between workday and night (p_2) were tested with the Wilcoxon test; n.u.—normalized units; for an explanation of the other symbols, see Table 1.

TABLE 3. Spearmann Correlation Coefficients (*r*) Between Perceived Mental Stress and the Heart Rate Variability (HRV) Workday Parameters and Between Mental Stress and Workday–Morning, Workday–Night and Night–Morning Differences in HRV Indices

	Perceived Mental Stress					
	Morning (n = 20)	Workday (n = 30)	Night (n = 19)	Workday–Morning (n = 12)	Workday–Night (n = 19)	Night–Morning (n = 12)
Parameters	r (p)	r (p)	r (p)	r (p)	r (p)	r (p)
MeanRR (s)	.07 (.77)	–.03 (.86)	.19 (.44)	–.46 (.14)	–.41 (.08)	.28 (.37)
RMSSD (ms)	.11 (.66)	.06 (.76)	.20 (.41)	–.60 (.04)	–.42 (.07)	.31 (.32)
TINN (ms)	.48 (.03)	.38 (.04)	.44 (.06)	–.73 (.01)	–.39 (.10)	–.12 (.70)
LF(n.u.)	.30 (.20)	.10 (.60)	.14 (.56)	–.03 (.91)	.02 (.92)	–.32 (.32)
HF(n.u.)	–.30 (.20)	–.10 (.60)	–.14 (.56)	.03 (.91)	–.02 (.92)	.32 (.32)
LF/HF (%)	.30 (.20)	.10 (.60)	.14 (.56)	–.17 (.59)	.26 (.29)	–.23 (.48)
SD1 (ms)	.11 (.66)	.04 (.83)	.20 (.41)	–.60 (.04)	–.42 (.07)	.31 (.32)
SD2 (ms)	.16 (.50)	.26 (.16)	.40 (.09)	–.21 (.50)	–.46 (.05)	.32 (.31)

Notes. Statistical significance (p) of correlations is given in parentheses; n.u.—normalized units; for an explanation of the other symbols, see Table 1.

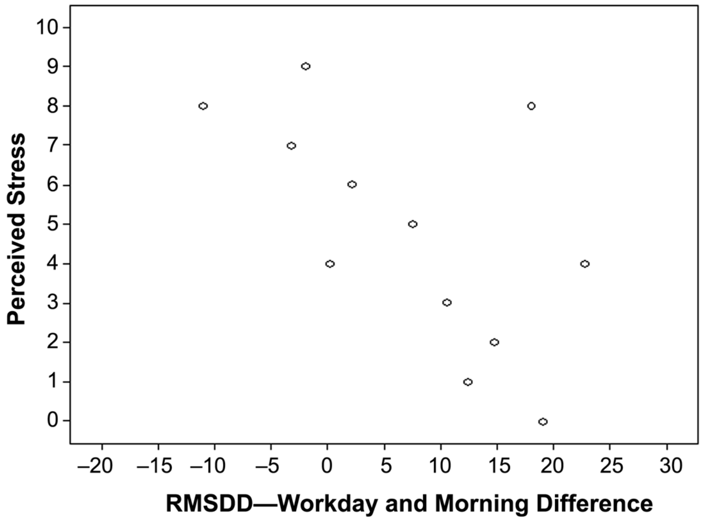

Figure 1. Association of the difference between workday and morning values in root mean square of differences of successive rhythm-to-rhythm intervals (RMSSD) with perceived mental stress (n = 12).

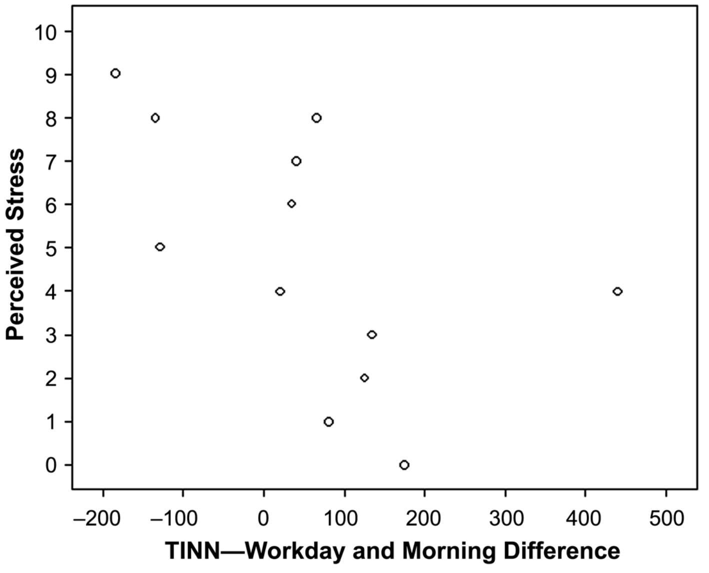

Figure 2. Association of the difference between workday and morning values in TINN with perceived mental stress (n = 12). *Notes.* TINN—triangular interpolation of rhythm-to-rhythm interval histogram.

shown in Figure 2 between perceived stress and TINN. The result that low workday RMSSD correlates with increased stress is further verified by the fact that average night RMSSD is high, which can be assumed to be a low stress period.

4. DISCUSSION

The main finding of the present study is an association between perceived stress and certain HRV parameters. Our study showed that HRV parameters describing mental stress, i.e., RMSSD, TINN and HF were lowest in the morning. These low morning values suggest the subjects' perceived stress was high in the morning. On the other hand, these values were highest at night, which suggests the subjects' relaxation and low mental stress. The values of LF and LF/HF, which were the highest in the morning and the lowest at night, are also indicative of high mental stress in the morning and low at night.

As expected, mean RR, RMSSD, HF, SD1 and SD2 values were the lowest during the morning and the highest during the night. The lowest TINN values were found during the morning. The highest LF and LF/HF values were during the morning, as predicted by other studies [19, 20, 32]. The highest HF values were during the night, which is consistent with previous studies [20, 33].

There are some limitations to the present study. We did not measure respiration, because in many HRV studies respiratory sinus arrhythmia was ignored [35]. HF does not accurately mirror vagal effects on the heart when there are changes in respiratory frequency [10]. For example, physical activity, which is associated with an accentuation of vagal activity [36] may affect HRV. The results should be interpreted with caution due to the small sample size and the recording of only a single day. The analysis may not have any direct applicability to HRV estimated from data collected under clinical or laboratory conditions. Variation of resting HR was not considered while interpreting the HRV results. The analyses presented reported relationships with the important classes of HRV measures based on statistical, geometric, nonlinear and spectral measures. Therefore, we cannot know for certain that a wristop computer measures stress induced during measurement and not accumulated stress from prior events.

Despite some limitations, there are considerable strengths in this study. The implications of this work go beyond the use within work period analysis of HRV. A continuous HR recording makes it possible to identify those periods of work which are most stressful and hence possible targets for ergonomics interventions. Furthermore, because our results are based on data collected with a compact wristop computer, continuous RMSSD monitoring can be integrated into the wristop. The data for this study were gathered using long-lasting and multiple measurements in combination with new variables to quantify HR. The use of long-term measurement intervals in occupational setting is pioneering with a simple wearable device. HRV values were measured during the morning, the workday and at night. The recommended segment length for short-term HRV analysis is 5 min [29]. In our study, the analysis was on average 0.58 hrs for the morning, 8.23 hrs for the workday and 5.57 hrs for the night. The data were carefully analysed. Several HRV parameters were calculated and the differences between values obtained in the morning, during the workday and at night were studied. We analysed more HRV parameters and our measurements were significantly longer compared to earlier studies. We believe that our research will help to clarify the use of HRV parameters for the evaluation of mental stress. We also proposed some specific ways to establish baselines for each individual over fairly long periods as a means to personalize derivation of HRV scores.

The applications of our results, like HRV analysis software, may help occupational health services and safety managers to evaluate mental stress at workplaces according to occupational safety acts. According to these results, we can say that a properly calibrated wristop device could give relatively accurate estimates of a person's stress basing on HRV values for a test period. However, the results also suggest that we should not abandon traditional questionnaires when studying mental work stress. The analyses described in this paper could also be integrated as part of wristop computer software including personal calibration data and all the necessary user parameters. Such an integrated analysis tool could prove to be a useful tool for occupational health services wishing to monitor people's stress levels. The cross-sectional design of this study limited insight into the dynamics of the relation between perceived mental stress and HRV parameters. Further investigations should concentrate on measuring longer periods including both work and leisure time.

In conclusion, no single parameter seems to correlate with perceived stress. Instead, differences between workday and morning values of TINN, RMSSD and SD1 variables correlate well with perceived mental stress. From this result we can conclude that we can make good estimates of workday stress if we compare the values of these parameters between workday and morning measurements. However, while correlations are promising with HRV parameters and mental stress, a more extensive study with a larger study population would improve result reliability. Continuous HR recordings enable us to identify those periods of work which are most stressful and hence optimal targets for ergonomics interventions. We should not abandon subjective methods; the methods are mutually complementary and both subjective and objective methods give valuable information.

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