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Changes in heart rate variability during working and non-working nights

Promjene u varijabilitetu srčane aktivnosti tijekom radnih i neradnih noći

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Summary

The aim of this study was to compare levels and patterns of heart rate variability during working night shifts and the same period of non-working nights. Eight nurses from the Surgical Department of Zadar Hospital, aged 25-33, participated in this study. The study included continuous recordings of cardiac activity during 10 hours of night-shift working (9.00 pm – 7.00 am) and during the equivalent non-working night periods.

As expected, the analyses showed differences in the levels of cardiac activity between working and non-working nights. Non-working nights were characterised by longer R-R intervals, higher variability indices and greater parasympathetic effects on cardiac activity, while their patterns of changes and spectral compositions were rather similar to those obtained during working nights.

The obtained results showed the supremacy of the circadian pattern of changes, i.e. parasympathetic prevalence, during both working and non-working nights. Parasympathetic prevalence during night shift working seemed inappropriate since normal working implies sympathetic activity. This is particularly true for the periods between 4.00 and 6.00 am, when various parameters indicated almost the same level of arousal during working and non-working nights. Certainly, the lack of sympathetic activity and parasympathetic dominance during working nights represents a discrepancy between the work requirements and the momentary capabilities of the organism to meet them. Due to this, it represents a major source of stress in night-shift working.

Key words: heart rate variability, shift working, circadian pattern, sympathetic and vagal modulation of cardiac activity

Sažetak

Cilj ovoga istraživanja bio je usporediti razine i obrasce varijabiliteta srčane aktivnosti tijekom noćne smjene i ekvivalentnog neradnog razdoblja noći. U ispitivanju je sudjelovalo osam medicinskih sestara s Odjela za kirurgiju, Opće bolnice Zadar. Dob ispitanica kretala se u rasponu od 25 do 33 godine. Ispitivanje je uključivalo kontinuirano registriranje srčane aktivnosti tijekom 10-satnog razdoblja noćne smjene (21.00 – 07.00 sati) i tijekom ekvivalentnog neradnog razdoblja.

U skladu s očekivanjem, analize su pokazale razlike u razinama srčane aktivnosti između radnog i neradnog razdoblja. Pri tome su tijekom neradnih razdoblja utvrđene veće prosječne vrijednosti i veći varijabilitet R-R intervala, odnosno naglašeniji učinak parasimpatičke regulacije srčane aktivnosti. S druge strane, obrasci promjena i spektralne kompozicije srčane aktivnosti bile su slične tijekom dvaju ispitivanih razdoblja.

Dobiveni rezultati ukazali su na izraženost cirkadijurnog obrasca promjena, odnosno parasimpatičku prevalenciju tijekom radnih i neradnih noćnih razdoblja. S obzirom da normalan rad zahtjeva aktivnost simpatičkog dijela autonomnog živčanog sustava, indikativna je parasimpatička prevalencija u srčanoj regulaciji tijekom radnog noćnog razdoblja. Navedeno se prvenstveno odnosi na razdoblja od 04.00 do 06.00 sati za koje su utvrđene iste razine parametara varijabiliteta srčane aktivnosti. Općenito se može kazati da parasimpatička dominacija tijekom radnih noći ukazuje na različitost među radnim zahtjevima i trenutnim mogućnostima organizma da ih zadovolji, što predstavlja glavni izvor stresa kod noćnog rada.

Ključne riječi: varijabilitet srčane aktivnosti, rad u smjenama, cirkadijurni obrazac, simpatička i parasimpatička regulacija srčane aktivnosti

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Introduction

The recording and analysis of heart rate variability (HRV) is a rather simple non-invasive technique for the evaluation of various aspects of cardiovascular activity, including its autonomic modulation. While time-domain parameters of the cardiac R-R intervals give a good indication of cardiac reactions to physical and/or mental load, their spectral analysis enables the separation of vagal and sympathetic control of cardiac activity. Respiratory rhythm effects on HRV (0.15 – 0.4 Hz) are generally considered as a marker of vagal modulation.[1-3] The physiological interpretation of low frequency spectral component (LF, 0.04 – 0.15 Hz) is more controversial. Some authors consider it as a marker of sympathetic modulation of HRV, since it has been shown that many factors which enhance sympathetic activity, such as tilt, upright posture, mental/emotional stress, physical exercise, induced hypertension etc., cause an increase in low frequency power range.[4-6] On the other hand, there is some evidence suggesting that low frequency power reflects changes in both autonomic subsystems, sympathetic and parasympathetic.[7] Nevertheless, the LF component is considered as a surrogate measure of sympathetic cardiovascular modulation.[8] However, since the majority of psychophysiological conditions imply a reciprocal relationship between the sympathetic and vagal activity, so called normalized units (HFn.u. and LFn.u.), which represent the relative value of each of the two spectral powers in relation to total power, may provide an insight in relative contributions of the vagal and sympathetic effects on HRV.[9,10] It should be noted though, that LFn.u. and HFn.u. components should be considered only as the markers of predominantly sympathetic and vagal modulation of heart rate variability, rather than their single markers, because the neural regulation of cardiac activity is affected by interaction of both autonomic branches.[6]

Since performance during night working follows the circadian pattern of changes,[11] the study of sympathetic and vagal contributions to cardiac activity modulation, autonomic cardiac modulation during night work would give a new insight to how the organism copes with the disturbed circadian rhythm. Reduced performance during night-working shifts may be explained by the fact that many bodily systems function at their lowest capabilities at night. Working thus in rotating shift systems causes a mismatch between the endogenous circadian timing system and the exogenous timers, with consequent disturbances in the normal psycho-physiological circadian rhythms.[12] One of the rea-sons for pointing out that night-shift working is an important stressor, per se, might be due to the rigidity of circadian changes added by the discre-pancy between the required (by work) and available sympathetic and parasympathetic activity. Working in night shifts, may therefore represent an extra stress, so called circadian stress,[13] as it requires a significant involvement of sympathetic control of bodily functions, when normally parasympathetic activity prevails.

Some studies, with continuous measures of HRV during night shift, were directed toward studying of interactions between the circadian and activity-non-activity (sleep-wake) cycles.[14-17] Generally, HRV indices differentiated between working and non-working, as well sleep and awake periods, with the highest sympathetic dominance during the work periods, with no clear difference between day and night shifts.[14,16,17] It was concluded, therefore, that HRV is largely affected by the level of activity rather than the time of the day. Some other results, however, showed an important effect of the circadian cycle on HRV modulation during night-shift work. Furlan and his co-workers[15] obtained relative dominance of vagal modulation on HRV with a simultaneous decrease in the sympathetic cardiac modulation in night working shifts, when compared to morning and afternoon working periods.

It could be argued that if the night work efficiency is to be maintained at the daily level, the level and patterns of changes of cardiac activity during night working shifts should be similar to those during daily work. This would mean that the level of activity has a major role in the modulation of HRV, *via* the autonomic nervous system. If the circadian changes have the main effects on the cardiac activity modulation during night-working shifts, and during non-working nights, their patterns of changes should be similar (but not necessarily the levels). However, most of the previous studies did not report on differences in HRV patterns between working and non-working nights.

The aim of this study, therefore, was to compare the levels and patterns of cardiac activity modulation during working and non-working nights, which could help in the understanding of the sympathetic-vagal prevalence in cases of disturbed circadian cycles.

Method

Participants

Eight shift-working female nurses, aged 25 – 33 years, from the Surgical Department of Zadar General Hospital, voluntarily participated in the study. They worked in three shifts, known as *fast forward rotating shift system*, which consisted of two successive working days in each of the three shifts (morning, afternoon and night shift), followed by a day off.

Procedure and material

The procedure included continuous recordings of cardiac R-R intervals throughout the second working night in the night-shift (21.00 pm – 07.00 am) and the same period during a non-working night, which mostly consisted of sleeping. The recordings of R-R intervals (in ms) were done by the use of three ECG chest electrodes connected to *the Four Channel Data Logger* (90 x 50 x 15 mm) which was worn on a special belt by the subject. Four subjects started the procedure before their regular night shifts at 9.00 pm, and four of them at the same time before non-working nights. Each subject had the second block of recordings within seven days. The *Data Loggers* had a built-in *event maker*, which was used by the subjects to mark various events, such as the beginning and end of shifts, meal taking, going to bed etc. Collected data were transferred from the *Data Loggers*, via *the Data Logging System,* to the PC for further analyses.

Results

The Statistica v.6. programme packages were used for hour-to-hour analyses of R-R intervals, where the means, standard deviations and RMSSD indices were obtained, as well as for time series analyses of five-minute periods.

For the comparisons of various parameters a two-way ANOVA was used together with the Greenhouse-Geisser adjustment. The analysis showed significant differences between the means of R-R intervals during working and non-working night periods, as well as their significant increase from 9.00 pm to 05.00 am, and a decrease after that in both situations (Figure 1).

RMSSD parameter (the mean of absolute differences between successive R-R intervals) during night shifts had an increasing trend, similar to the mean of R-R intervals in the same situation, while their changes during non-working nights were without a significant trend (Figure 2.).

Spectral analysis (Fast Fourier Transform) was worked out separately for low (0.04 – 0.15 Hz) and for high (0.15 – 0.4 Hz) frequency bands over five-minute periods.

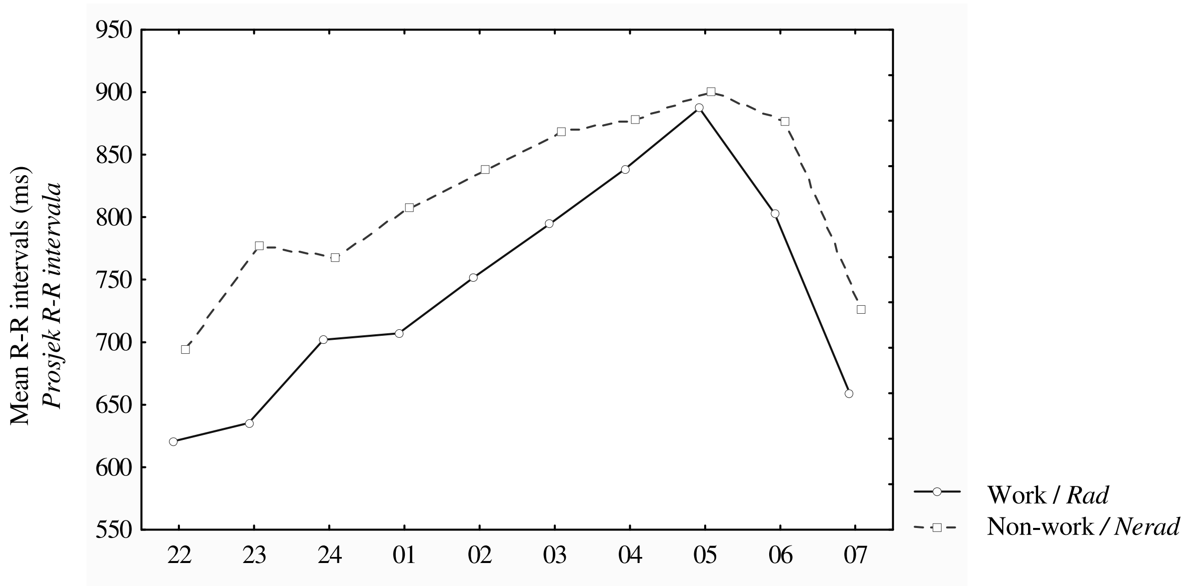

Figure 1. Mean R-R intervals during working and non-working night periods
Slika 1. Prosječne vrijednosti R-R intervala tijekom radnih i neradnih noćnih perioda

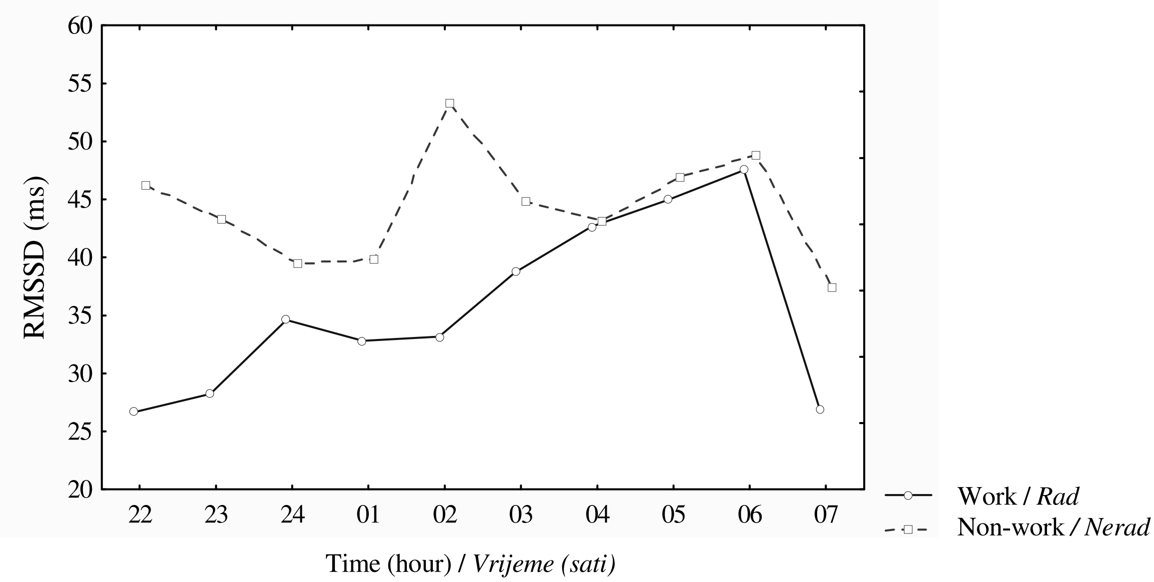

Figure 2. Levels of RMSSD parameter during working and non-working night periods
Slika 2. Razine RMSSD parametra tijekom radnih i neradnih noćnih perioda

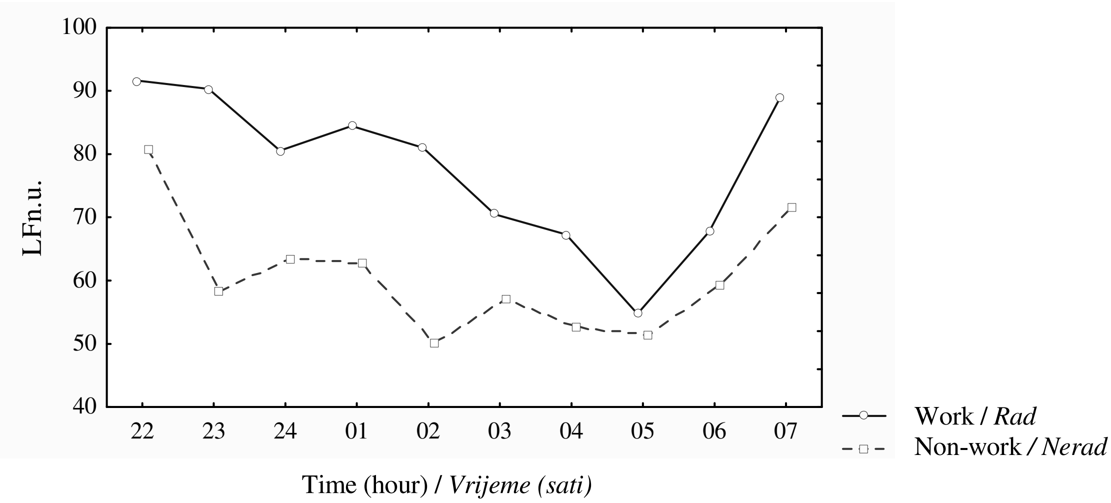

Figure 3. Changes in LFn.u. during working and non-working night periods
Slika 3. Promjene LFn.u. tijekom radnih i neradnih noćnih perioda

Working and non-working periods, as well as time at work, did not have significant effects on LF or HF compositions. Further analysis included their transformation into *so-called* normalized units, dividing them by the total spectral power (0.04 – 0.4 Hz) and multiplying them by 100. As can be seen in Figures 3 and 4, the power spectrum normalised units, during working and non-working nights, underwent significant changes in the course of time, and they also differed between themselves.

The similarity of patterns in cardiac activity modulations during working and non-working nights is also shown via correlations of cardiac parameters obtained in the two situations (Table 1), which ranged from .44 to .58 (df = 78, $p < .01$).

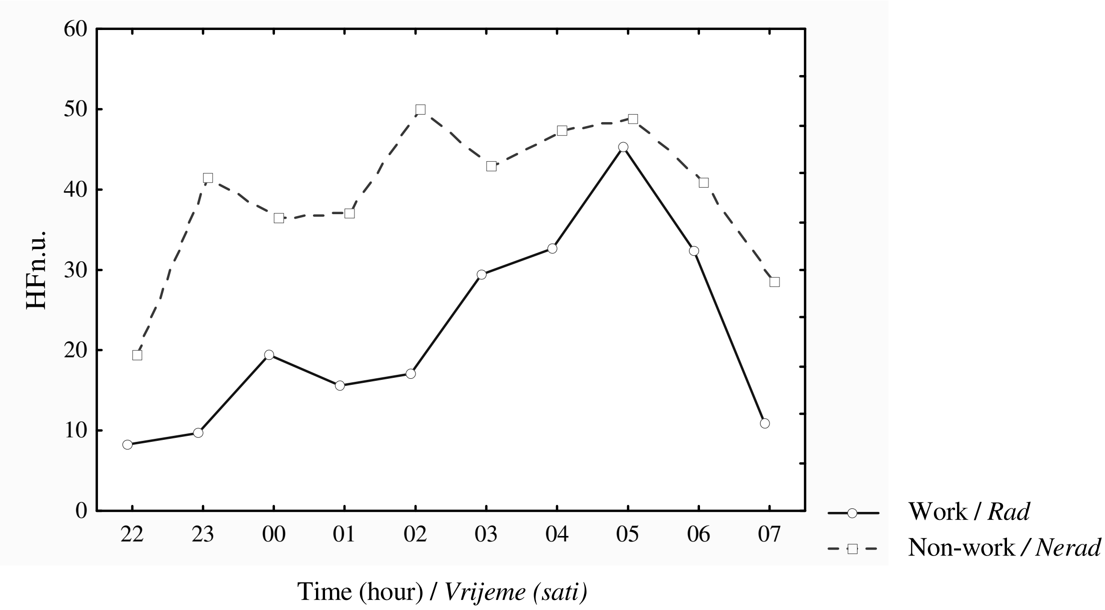

Figure 4. Changes in HFn.u. during working and non-working night periods
Slika 4. Promjene HFn.u. tijekom radnih i neradnih noćnih perioda

Table 1. Results of two-way analyses of variance: The effects of working – non-working nights on cardiac parameters
Tablica 1. Rezultati dvosmjernih analiza varijance: Učinci radnih i neradnih noćnih perioda na parametre srčane aktivnosti

Parameters / *parametri*	I	II	III
The mean of R-R intervals *Prosjek R-R intervala*	Work – non-work period *Vrijeme rada-nerada*	1/7	7.03*
	Time (h) *Vrijeme*	9/63	27.57**
	Interaction *Interakcija*	9/63	1.92
The mean of absolute differences between successive R-R intervals (RMSSD) *Prosjek potpune razlike između sukcesivnih R-R intervala (RMSSD)*	Work – non-work period *Vrijeme rada-nerada*	1/7	7.10*
	Time (h) *Vrijeme*	9/63	1.48
	Interaction *Interakcija*	9/63	1.02
Low frequency spectral component in normalized units (LFn.u.) *Niska frekvencija spektralne komponente kod normaliziranih jedinica (LFn.u.)*	Work – non-work period *Vrijeme rada-nerada*	1/7	12.07*
	Time (h) *Vrijeme*	9/63	6.26**
	Interaction *Interakcija*	9/63	2.53

p level — *p razina* — * < .05 ** < .01
I - Source of variation — *I – Izvor varijacije*
II - Degrees of freedom (df) — *II – Stupnjevi slobode*
III – F-ratio — *III – F-omjer*

Discussion

As expected, the mean R-R intervals were significantly higher during non-working periods in comparison with working periods, which complies with the results of some previous studies.[14-17] The difference between the two periods implies that R-R intervals were synchronised with the sleep-work cycle. On the other hand, there were obvious similarities in the pattern of changes of R-R intervals during the two periods (Figure 1), with an increase from 9.00 pm to 5.00 am, after which followed a decrease. Similarities are reflected in high correlations (r = .58), which suggests a significant influence of the circadian clock on cardiac activity, regardless of the physical activity differences of the subjects. Similar results were obtained in some previous studies,[18-21] pointing out the effects of circadian pattern of changes in heart rate, regardless of the differences in their general levels or the activity which caused them.

The RMSSD parameter was worked out because it is less influenced by changes in heart rate than standard deviation, for example. It is considered as HRV parameter which primarily reflects the vagal modulation of cardiac activity[8,10,21] The levels and changes in the RMSSD parameter during working and non-working periods were also different, as shown in Figure 2. During non-working periods from 10.00 pm to 6.00 am, the RMSSD parameter barely changed, apart from the jump at 2.00 am, while, at the same time, it almost linearly increased during working periods. The initial difference in the RMSSD parameter between working and non-working periods, which persisted until 3.00 am, was obviously due to the work effects on this parameter. After this, the RMSSD level was the same for three consecutive hours, most probably due to less activity during working periods, and an increase in vagal dominance at those hours of the night (circadian pattern). Interestingly, the maximum values for R-R intervals were obtained at 5.00 am, while the RMSSD had a peak at 6.00 am, which suggests a somewhat different control of their changes, or some kind of lagging of the changes in this parameter in comparison with R-R intervals.

The spectral analysis outcome shown *via* normalised units for the low frequency band (LFn.u.) represents the influence of sympathetic modulation on heart rate variability, which is different during working and non-working periods (Figure 3). Its gradual, almost linear decrease is obvious during the working period between 10.00 pm and 5.00 am, and a sudden rise after that, while no significant changes were observed during non-working periods.

The lowest value of sympathetic effects, reached at 5.00 am was similar to the value during sleeping non-working periods, i.e. the vagal dominance. Furthermore, normalised units for the high frequency band (HFn.u.), which reflect vagal effects on HRV modulation, showed an opposite pattern of changes to the LFn.u. which could have been expected (Figure IV).

While sympathetic modulation of cardiac activity was decreasing from 90% at 10.00 pm down to 55% at 5.00 am, at the same time, the parasympathetic influence increased from about 10 to 50%. At 5.00 am, the sympathetic and vagal contribution to cardiac activity control was relatively equal.

During non-working (sleeping) periods, however, the obtained results showed that sympathetic and vagal influences were rather stable and more or less equivalent between 11.00 pm and 5.00 am. Some hour-to-hour deviations were most probably due to different stages of sleep, as results of previous studies suggested.[22] As indicated by the vagal prevalence and RMSSD parameter, which reached some kind of peak at 2.00 am, it could be assumed that at the time the subjects were in the *delta wave* sleeping stage. An increase in sympathetic activity towards the end of sleeping period could be related to the REM phase and the awakening which followed.[23]

Generally speaking, the obtained results showed two main features. The first is a distinct difference in the general level of all the parameters during working and non-working periods, except between 4.00 and 6.00 hrs. The second feature is the similarity of various parameters in the early morning hours during working and non-working periods, which is the period of lowest arousal, highly dominated by the parasympathetic activity.

This early morning period is sometimes called the critical period, because of high numbers of various job-related mistakes and accidents due to sleepiness.[24]

Furlan et al.[15] suggested that lower values of cardiac sympathetic modulation indices during night work, compared to day work, might be related to the presence of sleepiness or diminished alertness which in turn could facilitate errors and accidents. On the other hand, van den Berg and his co-workers[25] failed to identify fatigue, drowsiness and/or sleepiness *via* HRV parameters, i.e. they could not differentiate *sleep deprivation* from *resting* conditions in awake and sleeping subjects. The differences in the results could be due to the differences in the procedures applied in the two studies. A review on shift work and productivity[11] clearly showed a decrease in performance during the night shift from 10.00 to 6.00 am, with its lowest point at 3.00 am, which, once again, stressed out the differences between night shifts and daily shifts.

It should be said that differences between the shifts in efficiency, safe behaviour etc, have their psychophysiological basis, part of which is autonomic regulation of cardiac activity. As the results of this study show, during the early morning of the night shift, cardiac parameter levels were similar to those obtained during sleep periods, pointing, thus, that the organism was not capable of working during this time. Since the use of pharmacodynamic stimulants would have adverse effects on the workers, some authors advocate external stimulation during this period, such as short breaks,[11] bright lighting,[26] face washing in cold water, etc.

Generally speaking, this study showed that two major factors are indirectly responsible for the level and pattern of changes of cardiac activity during night period. One of them is a pre-set circadian pattern of changes, which includes relatively low sympathetic and prominent vagal influences on cardiac activity, since the night period (sleeping) is the period of anabolic processes in the organism. The other factor is the activity (work) during the night period. As it is known, work requires extra energy, which can be mobilised by the sympathetic system, therefore, during night shift working the normal circadian sympatho-vagal balance is upset, and sympathetic influence becomes dominant for most of the night. Due to the lack of energy restoration processes during night work, the capacities of the organism seem to be exhausted by the early morning hours, when work supporting systems function at their lowest. As these results showed, there seems to be a compromising interference between the effects of the work energy requirements (sympathetic activity) and normal circadian changes (vagal dominance) on cardiac activity modulation. The effects of the former are dominant until the early morning hours, and the effects of the latter (most probably helped by exhaustion) are obvious during these hours.

Although the levels and patterns of cardiac activity were different during working and non-working nights, all the correlations between their respective parameters were significant. The top correlation was between the means of R-R intervals ($r = .58$; $p < 0.01$), suggesting prevalent circadian effects in both situations. Correlations between other parameters were somewhat smaller (from .44 to .46), but also significant, indicating thus the interfering effects of the circadian pattern and work on cardiac activity during night shifts.

Conclusion

Although the results showed differences in heart rate variability during working and non-working nights, at the same time they strongly suggest the supremacy of the circadian pattern of changes over the effects of work requirements. The obtained parasympathetic dominance during working nights represents a discrepancy between the work requirements of night shifts and the momentary capabilities of the organism to meet them.

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