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Shift work and psychophysiological changes

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Abstract: Shift work is considered a risk factor for health problems due to the continuous desynchronization and resynchronization of circadian rhythms. This study used heart rate measurement during sleep to determine whether shift work, and different length of this work, affects nonlinear aspects of cardiovascular dynamics, indicators of the autonomous nervous system, in healthy shift workers. The study included 48 healthy, premenopausal, female participants (nurses) divided in two groups of equal age and length of service. One group worked in a three-shift rotation system and the other (control) worked only the day shift. Cardiac activity (R-R intervals) was monitored continuously during sleep using the Data Logging System. Cardiac activity was recorded in both day and shift workers at night after the second consecutive day shift.

Results showed that shift workers with up to 10 years of service had higher values of correlation dimension than the equivalent group of day workers but shift workers with more than 10 years of service had lower values of correlation dimension than comparable groups of day workers. All shift workers, regardless of length of service, had significantly higher indices of determinism than day workers, but the index of determinism slightly enlarges with increased years of services. Generally, it seems that shift work has a negative impact on cardiovascular dynamics from the very beginning, and nonlinear parameters of cardiovascular dynamics can be potential predictors of future health problems.

Key words: shift work, cardiovascular dynamics, R-R interval, index of determinism, correlation dimension

INTRODUCTION

A continuous desynchronization of circadian rhythms, which accompanies shift work, especially night work, is considered the main factor that increases susceptibility to diseases of shift workers (Boivin et al., 2022; Ho et al., 2022; Khan et al., 2018; Knutsson, 2003). Numerous diseases and negative outcomes associated with shift work have been identified, so researchers from various fields are looking for predictors of disease in shift workers while they are still healthy. The R-R intervals are of particular interest in this context.

Parameters of cardiac dynamics (R-R intervals) are also affected by continuous desynchronization of circadian rhythms due to shift work, since they are markers of the functioning of the autonomous nervous system. A normal circadian rhythm of heart dynamics includes

sympathetic dominance on heart modulation during the daytime and parasympathetic dominance during the night (Tokić, 2016). Previous research showed that circadian rhythm of heart dynamic's regulation is disrupted in shift workers, they have generally increased sympathetic activity (Ishii et al., 2004, 2005), and increased sympathetic activity during sleep (van Amelsvoort et al., 2001). This type of heart dynamic's changes is considered potentially unfavorable for health (Dekker et al., 2000).

The majority of previous studies that compared cardiac dynamics of shift and day workers oriented only on linear parameters of cardiac dynamics (MeanHR, SDNN, RMSSD, LF, HF, LF/HF) (Karhula et al., 2014; Tenkanen et al., 1997; Watson et al., 2007; Winchell & Hoyt, 1996). Linear parameters are calculated based on the assumption that cardiac activity is linear and highly predictable, but research shows that this is not the case (Proroković, 2014), and the use of nonlinear cardiac dynamics parameters has some advantages related to the fact that cardiac dynamics is actually chaotic. Chaotic in this sense means that normal cardiac activity is somewhere in the middle between linear, predictable dynamic and total random dynamic that is completely unpredictable.

From the aspect of chaos theory, all healthy physiological systems demonstrate chaotic dynamics while pathological conditions are characterized either by completely random and unpredictable changes or by a significant increase in the linearity of the changes. Such "healthy" dynamics are in the middle of a continuum that has random, uncorrelated changes on one side and fully determined linear changes on the other (Goldberger, 1997, 2006). This type of dynamics makes physiological systems the most adaptable to external and internal changes and challenges, so using only linear parameters in the description of the dynamic system omits important information about the adaptability and responsiveness of the physiological system. Nonlinear parameters may be even better predictors of pathological changes than linear parameters (i.e., Bigger et al., 1996; de Sousa et al., 2006; Goldberger, 2006; Huikuri et al., 1998). Quantifying the chaos of a system includes measures of complexity (dimensionality) and measures of predictability (Heath, 2000). One of the commonly used nonlinear parameters indicating predictability is the ratio of determinism to recurrences, i.e., the determinism index (ID = %determinism / %recurrences). ID has the largest values for cyclic systems, the smallest for random, and a value in between for chaotic systems. Thus, a higher determinism index means that the future behavior of the system can be better predicted (Proroković, 2014). Among complexity measures, the most commonly used parameter is the correlation dimension (D2), defined as the number of independent variables required to describe system behavior. A higher value of the correlation dimension means a more complex system (Celebi et al., 2001).

Since it has been established that shift work causes short-term changes in the dynamics of the cardiovascular system, its cumulative effects may lead to irreversible changes in cardiac activity dynamics. Since dynamic systems, including cardiovascular, have a tendency for self-organization, short-term changes in dynamics do not usually have significant effects and the system returns to a stable state (Goldberger, 2006). However, it can be assumed that higher frequencies, intensity and exposure to specific stressors (in this case continuous desynchronization of circadian rhythms for shift work) can lead to quantitative and qualitative changes in general dynamics, which become a permanent feature of the system itself, i.e., their new stable (sick) state.

For this reason, the aim of this study was to investigate how different lengths of circadian rhythm desynchronization associated with

working in shifts alter the nonlinear aspect of cardiac dynamics (aspects of predictability and complexity). To overcome the usual methodological problems of previous researchers, this study included shift and day workers equally in terms of work tasks, gender, age, and length of service. Following previous research which emphasized that cardiac dynamics change first before disease becomes apparent (i.e. Dekker et al., 2000; Heitmann et al., 2010; Huikuri et al., 1998; RenuMadhavi & Ananth, 2012), only healthy, premenopausal subjects were included in the study. The period of deep sleep was used for analysis, as cardiac dynamics during this time without external distraction are considered the best indicator of baseline status/dynamics. Some previous studies on healthy individuals (Ivanov et al, 1999; Vandeput et al., 2012) found an increase in complexity and a decrease in determinism in rest and sleep phases compared with active phases during the day.

METHOD

Participants

The sample included only healthy, premenopausal nurses (N = 48), employees of two hospitals in Croatia, divided into two groups of equal job, age and length of service (24 nurses in each group). One group worked a three-shift rotation system, and the other only the morning shift. In the group of day workers only those nurses who had less than five years of past experience in working in shifts and who ended shift work at least two yours before research started were included in this study. Based on the length of service, the groups were divided into three comparable subgroups with eight participants: 1-10, 11-20 and 21-30 years of service.

Instrument and procedure

Continuous 24-hour monitoring of cardiac activity was made using a portable device for recording R-R intervals (ms) (three ECG chest electrodes connected to a four channel Data Logger, worn on the belt; resolution 1/1000s). For all respondents, the measurement was performed in the period when they worked two consecutive morning shifts (from 6/7 am to 14/15 pm). The data logging system was set on the first day at the end of shift (between 13 and 15 h), and taken off approximately 24h later, at the end of shift next morning. Participants were instructed to press an event maker button on the Data Logger for every important event during recording. i.e.,

Table 1 Descriptive parameters for age and length of service of day and shift workers

Category: length of service (yr)		Day worker (n = 24)		Shift workers (n = 24)	
		M	Sd	M	Sd
1-10	Age	29.40	5.53	28.90	2.57
	Years of service	6.88	3.14	6.33	2
11-20	Age	38.90	5.73	37.83	4.89
	Years of service	15.33	3.52	14.14	4.06
21-30	Age	47	2.65	45.75	2.92
	Years of service	25	4	24.25	2.76

meals, going to bed, getting up etc. For the purpose of this article, heart dynamics were analyzed during sleep (period between going to bed and getting up).

Analysis

The period of deep sleep in this study was taken as an indicator of basal cardiovascular dynamics. Time series of R-R intervals during sleep (the period between two events marked on the event maker – going to sleep and getting up) was divided into 400 R-R cycles on which the LF/HF ratio was calculated as an indicator of the depth of sleep. LF/HF is a linear parameter in which a lower value indicates a higher degree of parasympathetic modulatory effects on the dynamics of cardiac activity. Previous research showed that LF/HF ratio proved to be a suitable indicator for distinguishing sleep stages. Simultaneous recordings of EEG and ECG showed that changes in brain activity characterizing changes in sleep stages (from deep sleep to shallower sleep and waking) were due to arousal. Increased arousal has been shown to be associated with an increase in the power of the LF spectrum, i.e., the LF/HF ratio (McMillan, 2002).

Two successive periods with the lowest value of LF/HF ratio were identified as the target period, i.e., a period of deep sleep (800 R-R intervals, about 12 minutes). Kardum (2007) determined that one cycle of sleep lasts for approximately 90 minutes, of which about 18 minutes refers to a period of deep sleep. In this study, the target period of sleep lasted from 12-15 minutes, so it can be assumed that most of the deep sleep phase is embraced.

Statistica 12 (TIBCO Software Inc.), Data Plore, and Visual Recurrence Analysis (E. Kononov) programs were used for results analysis. Correlation dimensions were calculated in DataPlore, the visual recurrence analysis was used to calculate the ratio between % determinism and % recurrences; i.e., the index of determinism and the differences between groups were calculated in Statistica.

RESULTS

Upon identifying the period of deep sleep characterized by the lowest LF/HF ratio, consisting of 800 R-R intervals, all subsequent nonlinear analyses were conducted during this time window. Comparison of LF/HF values between shift and day workers revealed a significant impact of shift work on the LF/HF ratio (Figure 1), with shift workers displaying significantly lower levels of LF/HF ratio, especially in the oldest group ($F = 5.91$, $p = .021$; $M_{(day\ workers)} = 0.90$; $Sd = 0.80$; $M_{(shift\ workers)} = 0{,}39$, $Sd = 0.65$).

Analyses in nonlinear parameters (correlation dimension and index of determinism) were calculated with 2 (type of work) × 3 (length of service) ANOVA.

With regard to the correlation dimension as a measure of the complexity of cardiac dynamics, the ANOVA revealed a nearly significant interactive effect of type of work (shift/day) and length of service on the correlation dimension ($F = 2.79$, $p = .076$; $par.\eta 2 = 0.14$; Figure 2). Despite the lack of statistical significance at the 5% risk level, this finding remains noteworthy due to the large effect size and small sample size. The complexity of the cardiovascular system during deep sleep was found to be high for early-stage shift workers but declined in later-stage shift workers. Conversely, daily workers exhibited a high and relatively stable level of complexity in their cardiac dynamics during deep sleep, regardless of length of service.

Analysis of variance (ANOVA) demonstrated a statistically significant impact of work type on the index of determinism. The index

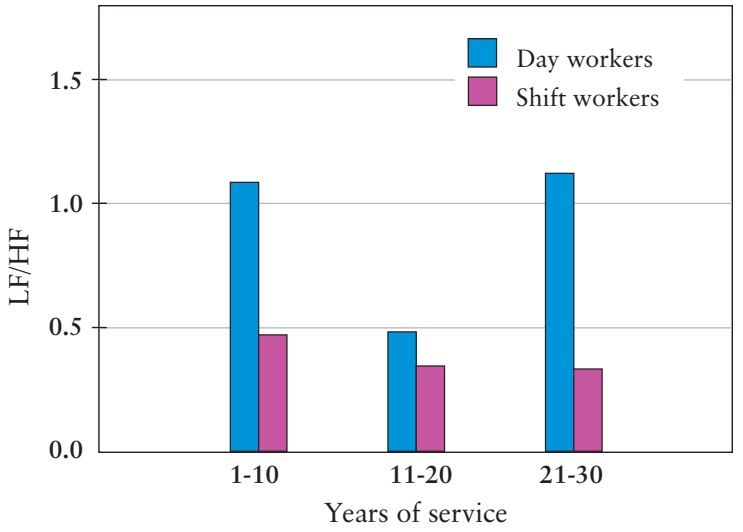

Figure 1 LF/HF ratio at day and shift workers during deep sleep

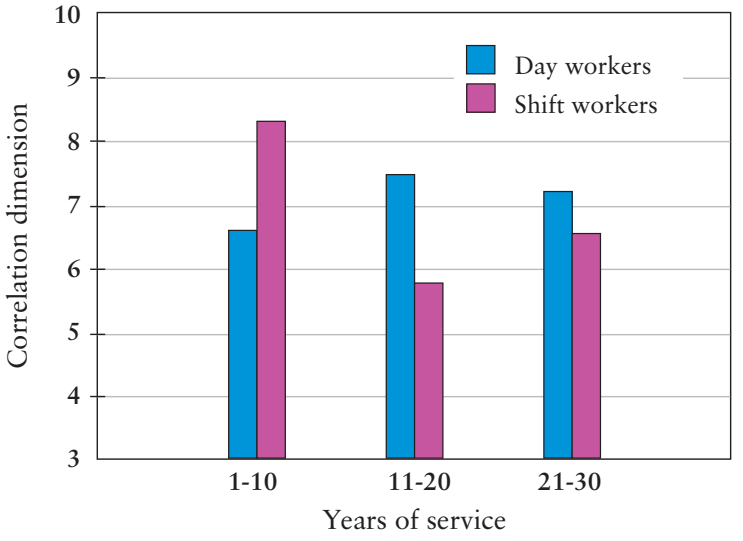

Figure 2 The relation between complexity of cardiovascular dynamics during sleep and types of work

of determinism values, as presented in Figure 3, revealed a notably higher level of predictability in cardiovascular dynamics during deep sleep for all three groups of shift workers, as compared to day workers ($F = 10.84$; $p = .002$; par.$\eta 2 = 0.25$).

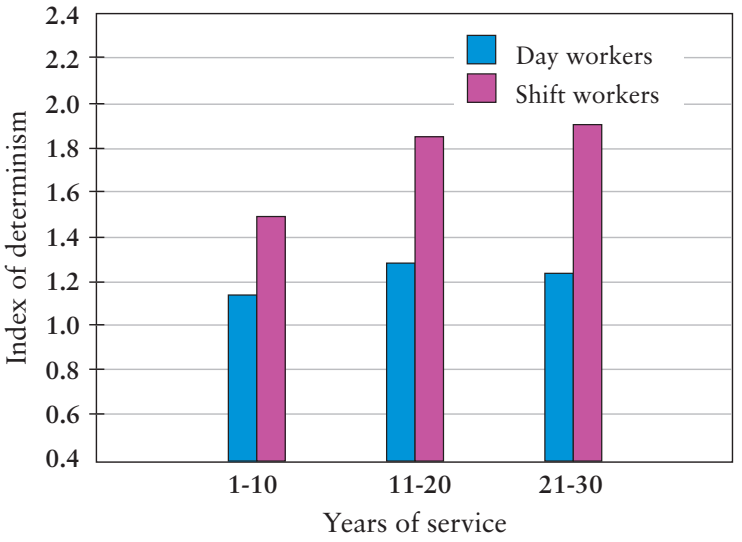

Figure 3 The index of determinism for day and shift workers during a deep sleep

DISCUSSION

The aim of this study was to explore the nonlinear components of cardiac activity dynamics in relation to the duration of shift or day work. The period of cardiac dynamics analysed in this study included the period of deep sleep, because it was assumed that changes in the functioning of the autonomic nervous system that precede the onset of shift work-related disease are most apparent during deep sleep and can be detected in individuals who have not yet developed any clinical manifestations of illness.

The LF/HF ratio was used as a marker to detect deep sleep in this study. The results revealed that shift and day workers differed in target LF/HF during sleep, with day workers displaying higher LF/HF values, particularly in the oldest age group, indicating poorer sleep quality of day workers. These findings are inconsistent with previous research that found higher sympathetic activity during sleep in shift workers, suggesting poorer sleep quality compared to day workers (Chung et al., 2009, 2011; Wehrens et al., 2012). However, age-related changes in autonomic activity may explain these results, with parasympathetic activity decreasing and sympathetic activity increasing with age, particularly in day workers of the third age group. The reason that older shift workers do not experience such changes may be due to the "healthy shift worker" effect (Saksvik et al., 2011), in which shift workers with major health problems switch to day work and those workers who are healthy and tolerate shift work well remain in shift work. It should be noted that the group of day workers in this research did not include former shift workers who switched to day work due to health problems, and previous work experience with shift work was controlled for among current day workers.

The nonlinear parameters generally do not follow changes in the linear LF/HF parameter, except in the youngest group of shift workers. The results showed that shift workers with tenure of up to 10 years had higher corre-

lation dimension scores than the corresponding group of day workers, but shift workers with tenure of more than 10 years had lower correlation dimension scores than comparable groups of day workers. All shift workers, regardless of length of service, had significantly higher indexes of determinism than day workers, with the determinism index increasing slightly with length of service.

In general, nonlinear parameters show less complexity (except for the youngest group of shift workers) and greater determinism of cardiac dynamics in shift workers, although they have deeper sleep (lower LF/HF). Even in the third group of shift workers (work experience of more than 21 years), who fall into the category of so-called healthy shift workers (which is also supported by the changes in linear LF/HF parameter), there is a tendency for relatively permanent changes in the dynamics of cardiac activity, reflected in a lower complexity and greater determinism of cardiac dynamics during the sleep phase.

In other words, although there are no obvious symptoms of the negative effects of shift work, there is a tendency of increased risk of cardiovascular disease even in a "healthy shift worker". The stronger effect of shift work is reflected in the predictability of system dynamics (ID).

Other studies also suggest similar changes in the dynamics of the cardiovascular system as a result of exposure to various stressors. For example, Reić Ercegovac and Gregov (2005) examined the effects of shift work on changes in cardiac activity and emphasized that the cardiovascular system has the characteristics of deterministic chaos, and the effects of stress are reflected in changes in global dynamics, leading to a decrease in the complexity of the system and an increase in its predictability. The results of some laboratory tests (Proroković et al., 2003; Valerjev & Šimić, 2004) also suggest that the dynamics of cardiac activity change in response to increasing psychological stress, i.e., complexity decreases and predictability increases.

Such a pattern of change (decreased complexity and increased predictability) was found in shift workers during the sleep phase (a situation in which there is no external stressor). It can therefore be assumed that the cause is long-term exposure to shift work as a stressor. These changes become significant after 10 years of shift work, which is consistent with the theory of self-organization (Skar, 2004), according to which a stressor (e.g., shift work) causes short-term changes in the dynamics of the cardiovascular system, and when the stressor is removed, the system returns to a steady state. In this case, however, the effects of frequency, intensity, and duration of exposure to the stressor (shift work) accumulate and lead to qualitative and quantitative changes in the dynamics of cardiac activity that become permanent and irreversible features of the cardiovascular system in the long term. Such altered dynamics of the cardiovascular system may still have the characteristics of a "healthy" psychophysiological system, but carry a risk for the development of disease. That is, at a given time, a person may not have manifest symptoms indicating health problems, but the parameters of linear and nonlinear dynamics may indicate certain deviations from the dynamics that characterize a healthy and adaptive system. As a result, changes at the manifest level, i.e., the appearance of symptoms and diseases, can also be expected as a function of time.

This finding could have strong practical implications for disease prevention in shift workers, but it is necessary to mention the main limitations of this study. The generalizability of the results is quite limited because of the small number of participants, so further studies with larger samples are needed. The main advantage of this study is the rigorous

measurement methodology and sample selection, but this is also one of the shortcomings of the study. Due to the rigorous selection of participants (only completely healthy premenopausal nurses), an obvious "healthy shift worker" effect occurs in this study, which also limits our conclusions, as the majority of shift workers who had some problems adjusting to shift work switch to day work.

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Psihofiziološke promjene uzrokovane smjenskim radom

Sažetak: Smjenski rad smatra se čimbenikom rizika po zdravlje zbog kontinuirane denkronizacije i resinkronizacije bioloških cirkadijurnih ritmova uzrokovane radom u različitim razdobljima dana i noći. Ova studija koristila je mjerenje srčane aktivnosti (R-R intervale) kod zdravih smjenskih radnica tijekom spavanja kako bi se utvrdilo utječe li rad u smjenama i njegovo trajanje na nelinearne aspekte kardiovaskularne dinamike koji upućuju na funkcioniranje autonomnog živčanog sustava.

Istraživanje je obuhvatilo 48 zdravih sudionica (medicinskih sestara) u predmenopauzi, podijeljenih u dvije skupine izjednačene po dobi i radnom stažu. Jedna skupina radila je u tri smjene (dnevna, popodnevna i noćna), a druga (kontrolna) samo u dnevnoj smjeni. Srčana aktivnost (R-R intervali) kontinuirano je praćena tijekom spavanja pomoću Data Logging sustava. Srčana aktivnost u spavanju bilježena je i kod dnevnih i kod smjenskih radnica one noći koja je uslijedila nakon druge uzastopne dnevne smjene. Rezultati su pokazali da su smjenske radnice s do 10 godina radnog staža imale veće vrijednosti korelacijske dimenzije od ekvivalentne skupine dnevnih radnica, ali smjenske radnice s više od 10 godina radnog staža imale su niže vrijednosti korelacijske dimenzije od usporedivih skupina dnevnih radnica. Sve smjenske radnice, bez obzira na radni staž, imale su značajno veći indeks determinizma nego dnevne radnice, a on je blago rastao s povećanjem godina staža. Općenito, čini se da smjenski rad od samog početka ima negativan utjecaj na kardiovaskularnu dinamiku, a nelinearni parametri kardiovaskularne dinamike mogu biti potencijalni prediktori zdravstvenih problema u budućnosti.

Ključne riječi: smjenski rad, kardiovaskularna dinamika, nelinearna dinamika, R-R interval, indeks determinizma, korelacijska dimenzija

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