Medical Research Archives

ESMED European Society of Medicine

OPEN ACCESS

Published: April 30, 2022

Citation: Varga J, Kardos K et al., 2022. Study of the Physiological Effects of Shift Work Using the Heart Rate Variability Analysis Method, Medical Research Archives, [online] 10(4). https://doi.org/10.18103/mra.v10i4.2764

DOI: https://doi.org/10.18103/mra.v10i4.2764

ISSN: 2375-1924

RESEARCH ARTICLE

Study of the Physiological Effects of Shift Work Using the Heart Rate Variability Analysis Method

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ABSTRACT

Shift work in industry and services cannot be avoided, but the adverse health effects of shift work are well known. The results of workplace physiological measurements in the Hungarian solid mineral mining oil and gas extraction and processing industry was, carried out under the coordination of the Scientific Committee on Mining Health and Ergonomics of the Hungarian Academy of Sciences, The Committee studiedy the variations of age and life characteristics of the workers, the various working conditions and environment and the heart rate variability (HRV) parameters. Our workplace studies covered 8, 12 and 24-hour shift works alike during morning, afternoon and night shifts with 2, 5 or 7 days per shift. In the evaluation, the significant differences in HRV parameters reflecting different physiological conditions, working conditions and work environment are presented for the morning only (control group) and the shift work groups. Evaluation of the results of the measurements carried out at the workplaces adjusted to the actual work schedule using known methods of mathematical statistics made it possible to investigate the effects of different circumstances and conditions. Based on the reviewed research results regarding the health effects of shift work, IARC/WHO concluded in 2010 that *shift work* was probably carcinogenic to humans (category 2A) - a recommendation that was changed to *night shift work* in 2019, based on the research results revealed in the meantime. Our studies call attention to the potential for using the results of new methods developed through innovation and to the justification for their use in occupational health.

Keywords: work schedule, night shift work, light-dark schedule, circadian disruption, carcinogenicity to humans

List of the abbreviations:

HR	heart rate
HRV	heart rate variability
TP	total power
VLF	very low frequency
LF	low frequency
HF	high frequency
LF/HF ratio	($LF\ m/s^2/HF\ m/s^2$)
SD1, RMSSD	HRV time-domain parameters
SBP/DBP	systolic/diastolic blood pressure
Ti	body mass index, Ti= body mass (kg)/ 0.79 x body height (cm) – 60.7
Ym	years of service
H	hypertension
S	smoking
CHD	coronary heart disease
CAD	coronary artery disease
C18	colon cancer
C19	rectum cancer
C61	prostate cancer
OEP	National Health Insurance Fund Administration

1. Introduction

[1]The developed world is entailed by shift work, which is a feature of modern technology applications 4and cannot be neglected in industrial production and services. According to a survey by the European Foundation for the Improvement of Living and Working Conditions, between 17 and 28% of workers in the EU Member States - 20.7% in Hungary - are employed on shift work .[1] .

According to the literature, after 15 to 20 years of service, the effects of shift work are manifested in sleep disturbance, sleep and consequent fatigue, digestive system problems, stomach pain, hypertension, increase of metabolic factors (blood sugar, cholesterol, triglycerides), and deterioration of mental state[2].

Shift work for more than 20 years may cause alterations in the circulatory (CAD, CHD) and the immune system and can lead to malignant tumours (C18, C19) [3]. These are the number one cause of all colorectal, prostate and gastric cancer in men, and breast and cervical cancer in women.[3 4 5 6 7 8 9 10] This has been connected with a significant decrease of the lev[3]el of melatonin, the hormone, which is produced in the pineal gland only during sleeping in the night hours, and regulates the chronobiology of the human body.[11 12]. .

In 2010 based on the reviewed research results regarding the health effects of shift work, IARC/WHO concluded that *shift work* was probably carcinogenic to humans (category 2A). In 2019 IARC/WHO amended its recommendation to *"night shift-work"* in view of the low interest from member states, mainly due to its economic impact, and taking into account the results of research revealed in the meantime [15].

Based on the information from the results of our workplace physiological measurements, and our collaboration with the OEP, we found that the prevalence rate of cancer among shift-work miners was 3 times higher for items C18 and C19 and more than twice higher for C61, compared to the control data of the counties with the lowest proportion of shift work in the country. The life expectancy at birth of shift miners was less than 68 years in the years prior to the study, which was lower than the average life expentancy for the total population. The aim of our studies was to obtain additional information on the effects of influencing factors (age, years of shift service, life characteristics such as hypertension, smoking, body mass and metabolism) by determining the changes in HRV parameters during different working hours (8, 12, 24 h) and different periods of shift days (1, 2, 3, 5, 7).

The use of information obtained through workplace physiological measurements, in particular through the HRV method, in the field of occupational health is novel and promising, both for regulators and for workers and employers.

The studies that this paper is based on covered male workers working different hours in solid mineral mines and the hydrocarbon extraction and processing sector. The subjects of the studies had valid occupational “fitness for work” qualification, and some of the control group had also previously done shift work. According to the Hungarian legislation, the Occupational Health and Safety Act ordains that workers have the right to safe and healthy working conditions and that the employer is responsible for the implementation of healthy and safe working conditions.

Potential participants in the measurements were provided with written information about the aim of the study and - prior to the first measurement at the workplace - we met in person to discuss the purpose of the measurements, the instruments and the protection of personal data generated during the research. The measurements started with data collection (age, number of years of service, body measurements, smoking habits, regular medication) and blood pressure measurement, carried out with the participation of the occupational health assistant. This was followed by equipping the measuring instruments and performing the measurements at rest in supine position.

The POLAR instrument, which did not interfere with the work, had to be worn during the whole shift and was dismantled at the end of the working time. During the measurements, recording of a traditional working day was carried out based on observation of work processes and working conditions (climatic conditions, noise, lighting data). After dismantling, data from the POLAR devices were downloaded and stored in a laptop.

2. Methods

2.1 Study population

Workers from seven extractive and processing plants participated in our research aimed at understanding complex work strain to the human body between 2002 and 2017 (233 people, 2341 measurements). The workplace physiological measurements were organized by the Department of Occupational Health of the National Public Health Center and its predecessor organizations. Before the measurements, after being informed of the purpose of the study, the workers gave their written consent to participate in the instrumental measurements. The study was conducted with the permission of the Scientific and Research Ethics Committee of the Medical Research Council. We have processed the data in accordance with the rules on personal data protection.

2.2 Execution of workplace measurements

Measurements were performed at the plants using POLAR S810 and RS400 heart rate monitors suitable for recording HR beat-by-beat and recording and storing heart rate variations (HRV parameters). The tests were conducted by measuring blood pressure (OMRON M31) and by interviewing the workers to record individual data (age, years of service, height, body mass, smoking habits, health complaints). This was followed by mounting the sensor of the measuring instrument on the chest and starting the instrument set to beat-to-beat. The 10-minute measurements at rest in supine position were performed in the occupational physicians' office or in other separated, noise-free room of the plant, supplied with clean air, using camp beds. Between 6 and 12 people working simultaneously at the same workstation participated in the measurements. Measurements were taken during all three parts of the day (morning, afternoon, night) and on each working day of the shift (1-7 working days). (It may be perceived that the process of physiological measurements at work is a very time-consuming activity).

A significant number of the workers who participated in the workplace measurements also took part in ergometric tests (Jaeger Oxycon Champion treadmill) at the National Institute of Occupational Health.

2.3 Statistical analysis of the measurement data

The HRV parameters and the life characteristics stored on the computer were sorted in Excel tables. The software running on the POLAR instrument provided absolute and percentage values of the time domain (SD, RMSSD) and the frequency domain (TP, VLF, LF, HF ranges) in addition to the R-R intervals and [3]heart rates (mean, min., max. values) [13].

Mathematical analysis of the substantial data base was performed using SPSS version 13.0, Chicago, IBS SPSS 23.0. The correlation method was used for qualitative analysis of relationships between variables and the analysis was performed using descriptive statistics. The relationships between the continuously varying HRV parameters and the discrete variables (age, life characteristics) were evaluated by regression analysis.

Although more than 25 variables were used to describe the phenomena in the studies, in the detailed analyses fewer variables were used to modelling the individual phenomena, taking the closeness of the correlation relationships into account.

We note that the relationship between functioning of the human organism and the physiological variables is stochastic. However, linear analysis of two or m[4]ore factors with close regression relationships correctly reflects the nature of the changes and there is no significant difference in the extent. [14].

In the model design the following conditions of using linear regression were considered:

- fulfilment of the conditions of linearity
- presence of outliers
- normality of the variables
- verification that the distribution of the residuals does not depend on the predictor variables

Meeting these criteria affects the quality of models. Our basic aim in the tests was to use simple models (with few variables). In the search for complex models, we used the AIC formula or, in the case of IBM, the so-called information criterion. Automatic linear regression models automatically check and handle the conditions for applying regression (e.g., no outliers are included in the regression [12 25 27]

3. *Results*

According to the literature [16 18 20 21 30] HRV analysis is an important method to understand the state of the cardiovascular system in both ill and healthy individuals. At the same time, literature provides information on the relationship between heart rate (HR) and blood pressure (SDP/DBP) and metabolic factors.

When analysing the results of our workplace physiological measurements, with regard to future cardiovascular events, we refer to the recommendations of the European Guidelines on cardiovascular disease prevention in clinical practice (version 2012).

3.1 *Correlation relationships*

Table 1 shows the correlations between the time domain and frequency-domain parameters [13].

Table 1. Correlations between the time domain and frequency-domain parameters

HR	RMSSD: - 0.689	SD1 and SD: - 0.666, -0.622	VLF: - 0.555	TP: - 0.550	HF: - 0.513
TP	VLF: 0.982 LF: 0.973 HF: 0.929	SD: 0.899 SD1, SD2: 0.854 RMSSD: 0.846	HR: - 0.550	HF%: 0.467 VLF%: -0.425	LF/HF: -0.396
VLF	SD: 0.884	HF: 0.864	SD2: 0.832. RMSSD: 0.821	HR: 0.555	HF%: 0.381 LF/HF: 0.358
VLF%	HF%: - 0.747 LF%: - 0.729	HF: - 0.547 LF: - 0.530	SD: - 0.469	RMSSD: - 0.456	LF/HF: 0.482
LF	TP: 0.973 VLF: 0.926 HF: 0.899	SD: 0.884 SD2: 0.858 SD1: 0.819	RMSSD: 0.865	HF%: 0.460 VLF%: 0.330	LH/HF: - 0.340
LF%	VLF%: - 0.729	LF : 0.330			
HF	TP: 0.929 LF: 0.899 VLF: 0.864	SD and RMSSD: 0.839	SD: 0.819 SD2: 0.729	HF%: 0.634 VLF%: - 0.544	LF/HF: - 0.520
HF%	LF/HF: 0.765	VLF%: -0.747	HF: 0.634	RMSSD: 0.554 SD1: 0.500 SD: 0.490	HR: – 0.422
LF/HF	HF%: -0.765	HF: - 0.520	RMSSD: - 0.520	SD1: - 0.502	HR: 0.451

We found that there was generally a strong (> 0.5, sign. = 0.000) correlation between time- and frequency-based parameters. (The correlation between SBP and DBP and HRV parameters was only "medium" strong.)

3.2 HRV parameters as a function of age

The relationships between age and HRV parameters [6 9 13] were examined by evaluating the measurements performed at the start of work at rest in lying position. Taking methodologic[3]al materials into account, regression relationships between age and HRV parameters were assessed using the ANOVA method of the SPSS software system. [12 18 19 22 23] As an example, the plots of and lnHF are presented as a function of age (Figures 1 - 2). The age-dependent variations of all the parameters studied are presented in Table 2.

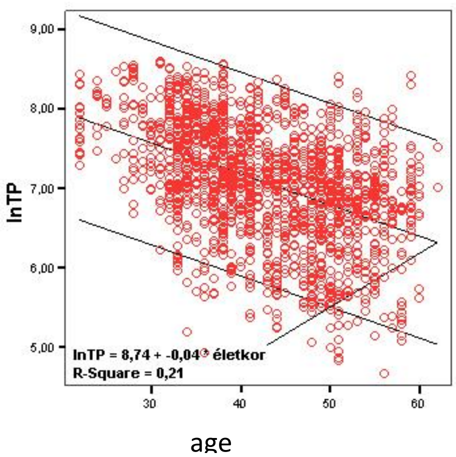

Figure 1.
ln TP as a function of age

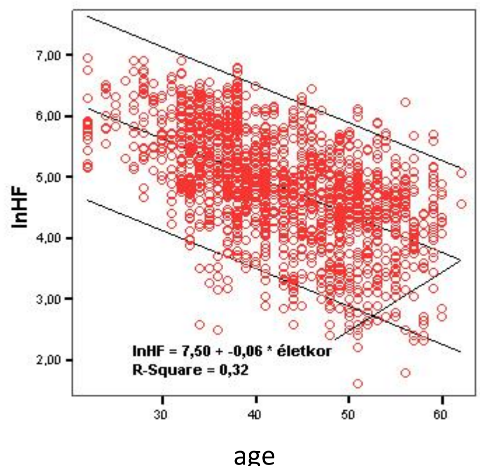

Figure 2.
ln HF as a function of age

(**Note:** the natural logarithmic transformation is justified by the "skewness" of the HRV parameter distribution.)

The closeness of dependence of the HRV parameters on age is demonstrated by the magnitude of R2, which is 0.32 for lnHF (relationship of medium strength).

3.3. Effect of service years in shift work on variations of the HRV parameters

Although there was a positive and strong (0.517, sign. = 0.000) relationship between the length of service in shift work and age, starting the job under study was not necessarily at the age of 17-18 years. Therefore, the changes in the parameters of this group are used only as additional information, alongside the age-dependent data. In the case of the study population, length of service in shift work showed more unfavourable effect than age at the decrease of TP range by 10 years.

Table 2. Parameters depending on service years (s.years) (mean of service years: 16.51)

Parameters	10 years	20 years	30 years	40 years
HR = 0.144 x s.years + 68.931	70.4	71.8	73.3	74.7
R-R = - 1.575 x s.years + 885.962	870	855	839	823
SBP = 0.274 x s.years + 132.308	135	138	141	144
DBP = 0.181 x s.years + 78.193	80	82	84	86
TP = - 36.704 x s.years + 2102.391	1735	1368	1001	634
VLF = - 18.332 x s.years + 1180.209	997	814	630	447
VLF% = 0.224 x s.years + 56.637	58.9	61.1	63.4	65.6
LF = - 11.713 x s.years + 626.966	510	393	276	158
LF% = - 0.073 x s.years + 29.48	28.7	28.0	27.3	26.6
HF = - 6.551 x s.years + 292.315	227	161	96	30
HF% = - 0.151 x s.years + 13.883	12.4	10.9	9.4	7.8
LF/HF = 0.031 x s.years +2.221	2.53	2.84	3.15	3.49

Table 2/1. Changes of parameters by 10 service years

Parameter changes	Between 10 – 20 years	Between 20 – 30 years	Between 30 – 40 years
HR increase in 10 years: unit	1.6	1.6	1.6
SBP increase in 10 years: unit	3	3	3
DBP increase in 10 years: unit	2	2	2
TP decrease in 10 years: %	23	29	42
VLF% increase in 10 years: %	2.3	2.2	2.3
LF% decrease in 10 years: %	0.8	0.7	0.7
HF% decrease in 10 years: %	1.6	1.6	1.6
LF/HF increase in 10 years: unit	0.31	0.31	0.31

Note: for each factor in Table 2, a graph analogous to Figures 1 - 2 can be constructed.

3.4. Effect of shift days on the variations of HRV parameters

Table 3 presents the different values of HRV parameters per working day obtained from the workplace measurements performed on the subjects in the shift and control groups [18 24].

Table 3. Measured values in the shift (S) and the control (C) groups

Measurement day	Group	SBP/DBP	HR	TP	VLF%	LF%	HF%	LF/HF
1	S	136/82	73	1308	58.8	29.6	11.5	2.71
2	S	135/80	71	1289	60.7	28.0	11.2	2.60
3	S	134/81	70.7	1385	60.1	28.8	11.1	2.73
	C	144/82	71.2	1619	59.3	28.4	12.3	2.57
4	S	130/78	73	1285	62.6	27.4	9.9	2.94
	C	139/81	68	1736	61.4	27.1	11.6	2.57
5	S	133/81	72	1293	63.1	27.5	9.4	3.15
	C	13780	66	2062	60.8	27.3	11.8	2.66
6	S	136/81	73	1395	62.2	28.3	9.4	3.22
7	S	126/77	72	1463	62.8	27.3	9.8	3.04

Note: Measurements in the control group were performed on the 3rd, 4th and 5th shift day

The HRV parameters in Table 3 are the results of the measurements at rest in supine position in the "C" and "S" groups. The data show that HF%, which reflects parasympathetic effects, decreases with increasing number of working days, while LF/HF increases. The higher LF/HF value observed in the group „S" is the result of shift work and night work.[16 17].

Figure 3 shows the daytime and night-time variation of the LF/HF value by shift days.

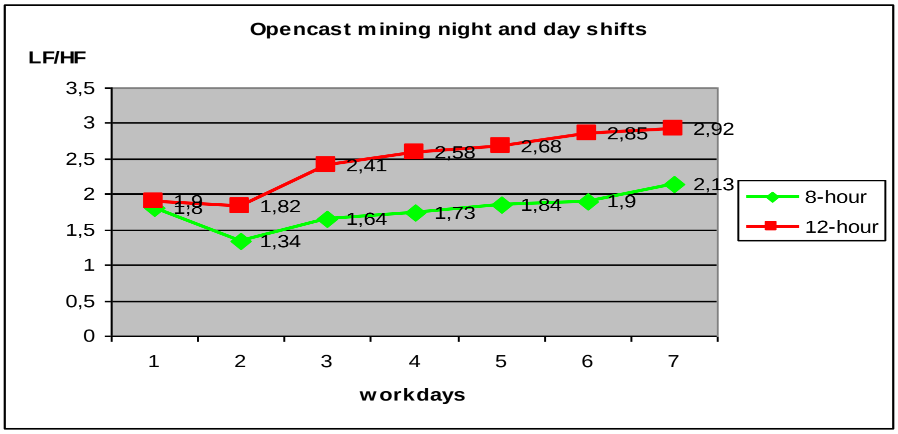

Figure 3. *Changes of the LF/HF parameter during opencast mining night and day shifts*

Figure 4 illustrates the variation of LH/HF parameter in three age groups of the studied opencast mine shift workers on workdays 1 - 7. The data show that the parameter is most unfavourable in the age group ≥ 46 years.

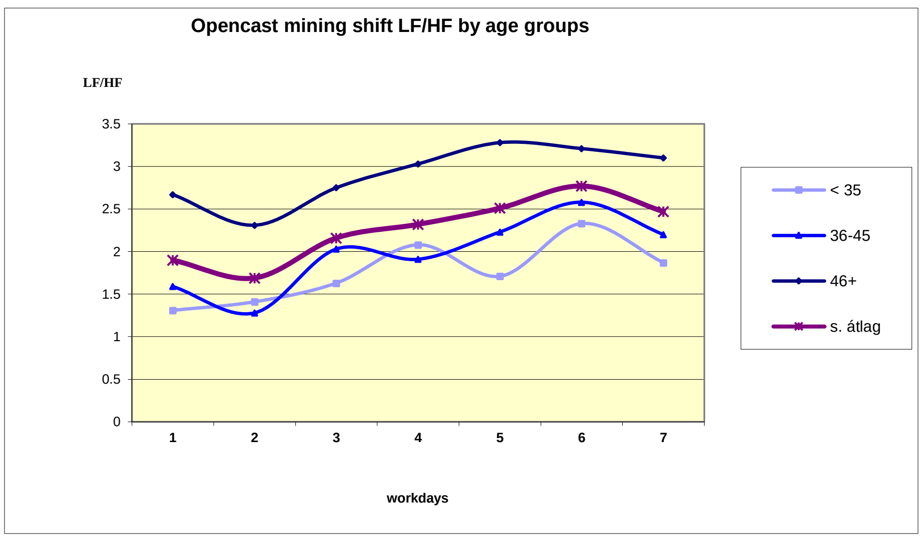

Figure 4. *Changes of the LF/HF parameter during opencast mining shift work by age groups*

Note: Data in Table 4 and Figures 3 - 4 are taken from the database of measurements performed at an opencast mine.

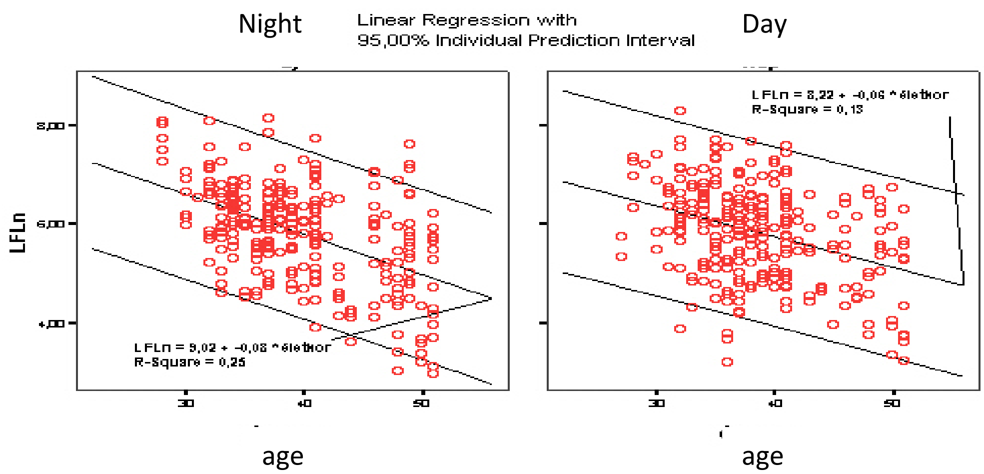

Figure 5. *lnLF during night and day shifts*

3.5. Differences in HRV parameters between the Control and the Shift groups

Table 4. HRV parameters of the Control group in the morning shifts

Workday	SBP	HR	TP	VLF%	LF%	HF%	LF/HF
3	144	71	1620	59.3	28.4	12.3	2.50
4	138	68	1736	61.4	27.0	11.6	2.60
5	137	66	2062	60.8	27.4	11.9	2.74

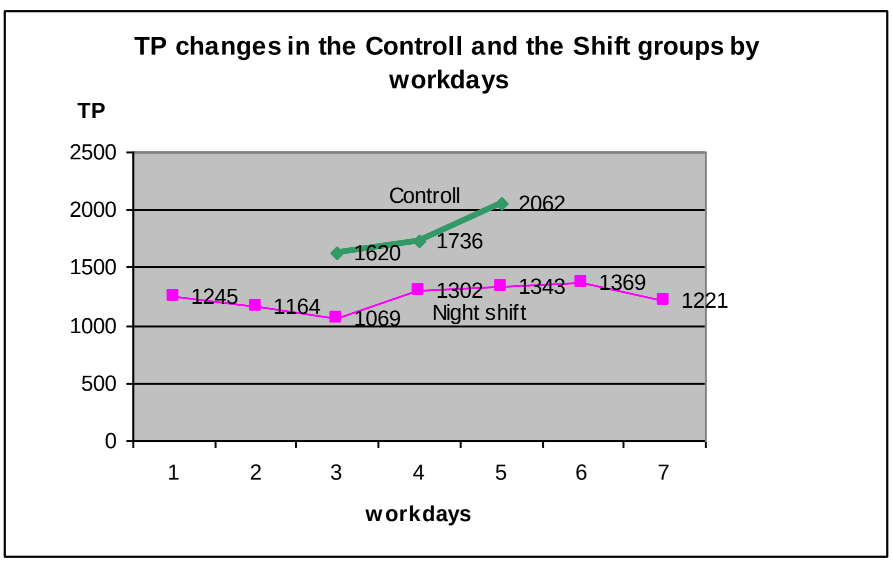

Figure 6. *TP changes in the Control and the Shift groups by workdays*

Figure 6 shows the TP values of the Control group measured on days 3, 4 and 5 (see Table 4) and the nightly TP values of the Shift group measured on days 1-7 (see Table 5). In the case of the Control group, measurement results only for workdays 3 to 5 are shown to remove the effects of the first two days (instrument stress and the supervisor's presence). For the shift-workers, measurement data of the night shift have been included to increase the differences, and as a consequence the real difference between control and shift is more pronounced.

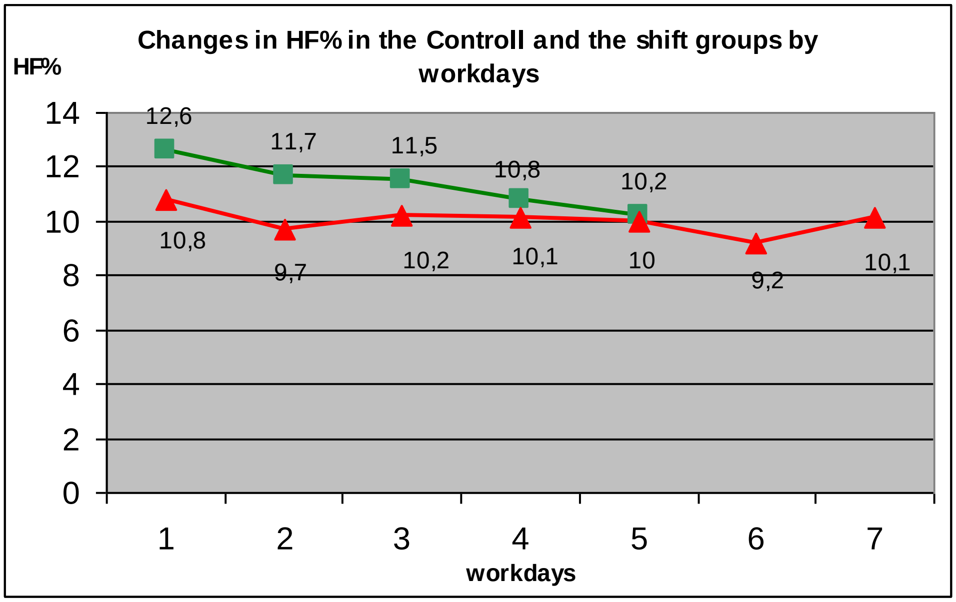

Figure 7. *Changes of HF% in the Control and the Shift groups by workdays*

The HF% values for the Control group are shown in Table 4, and the data for the Shift workers are shown in the "Night Shift" section of Table 6. The rationale for the pairing is the same as described for the TP parameter.

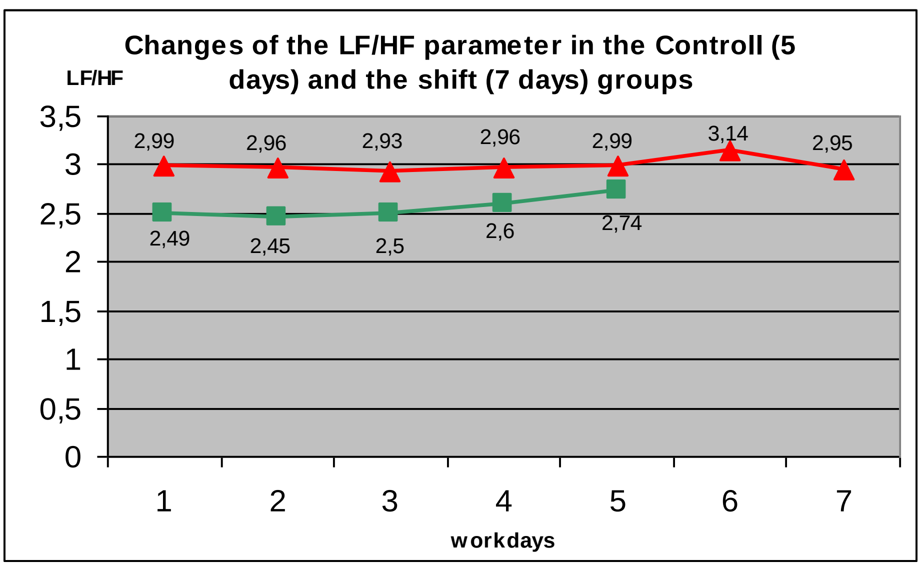

Figure 8. *Changes of the LF/HF parameter in the Control (5 days) and the Shift (7 days) groups*

The LH/HF parameter values of the control group for the days 3 - 5 are included in Table 4 (the values for days 1 - 2 resulted from a low number of measurements). The Shift group data are based on the values measured during 8 hour (Table 5) and 12 hour (Table 6) working time.

Table 5. HRV parameters of shift workers measured during 8-hour shift

	Morning							Night shift						
Workdays	SBP	HR	TP	VLF%	LF%	HF%	LF/HF	SBP	HR	TP	VLF%	LF%	HF%	LF/HF
1	130	74	1370	57.9	30.7	11.4	2.81	128	74	1245	58.0	29.3	12.8	2.38
2	136	72	1059	60.0	28.2	11.5	2.60	127	71	1164	58.5	29.0	12.4	2.38
3	126	66	1493	58.4	29.3	12.3	2.47	127	73	1369	61.9	27.0	11.1	2.57
4	131	71	919	61.4	28.4	10.2	2.89	123	73	1302	62.6	27.0	10.3	2.79
5	132	73	1119	62.2	28.1	9.6	3.07	127	71	1343	63.7	26.6	9.7	3.0
6	136	71	1693	62.0	28.6	9.4	3.24	129	74	1369	63.7	27.6	8.7	3.14
7	131	68	1893	61.0	27.6	11.2	2.61	129	73	1221	66.2	26.1	7.8	2.94

Table 6. HRV parameters of shift workers measured during 12-hour shift

				Day time							Night shift			
Workdays	SBP	HR	TP	VLF%	LF%	HF%	LF/HF	SBP	HR	TP	VLF%	LF%	HF%	LF/HF
1	137	68	1658	59.3	29.7	11.0	2.85	145	74	1154	58.9	30.0	11.1	2.99
2	132	67	1653	60.4	28.2	11.5	2.68	140	71	1293	61.9	27.7	10.4	2.90
3	137	67	1860	61.7	27.9	10.3	2.86	137	72	1069	61.7	28.5	9.8	2.93
4	133	70	1872	63.4	26.9	9.6	2.98	136	74	990	63.6	27.7	8.7	2.96
5	133	68	1627	64.7	26.5	8.8	3.17	140	73	1276	64.9	27.0	8.1	2.99

3.6 Differences in HRV parameters between 8-hour and 12-hour shifts

For the construction of the 8- and 12- hour shifts, the data on HF% (Figure 9) and LF/HF (Figure 10), are presented as night shift data in Tables 5 and 6.

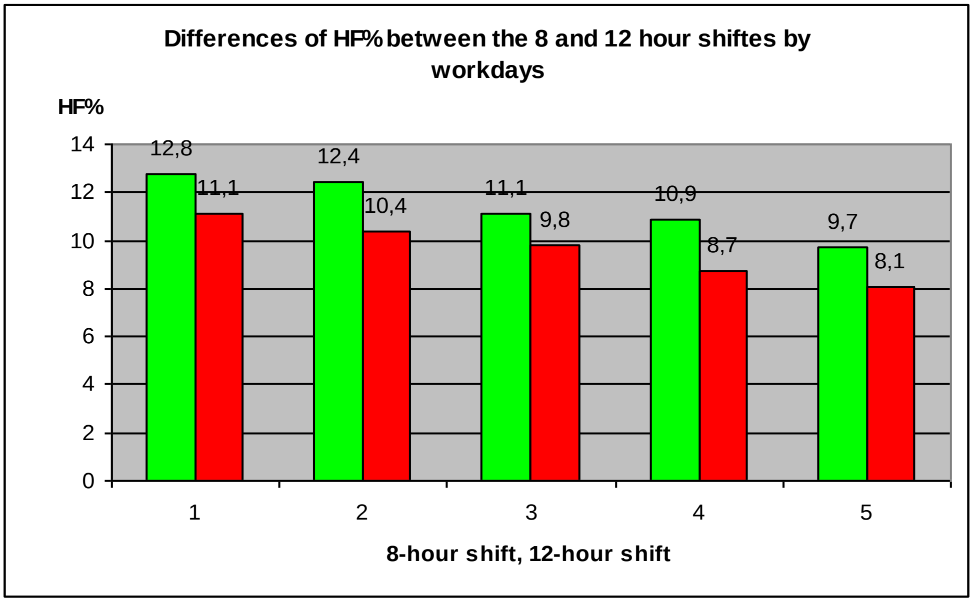

Figure 9. *Differences in HF% between 8-hour and 12-hour shifts by workdays*

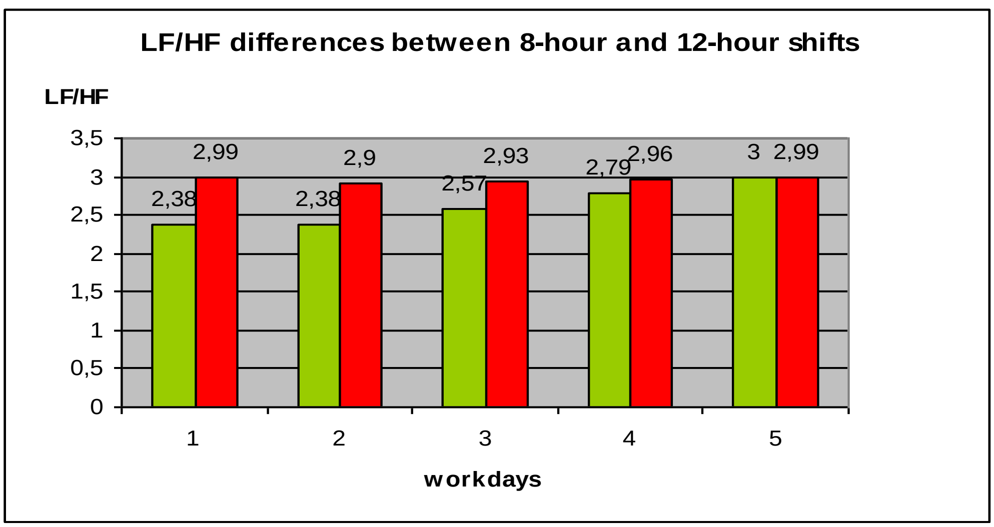

Figure 10. *Differences in the LF/HF parameter between 8-hour and 12-hour shifts, by workdays*

Figures 9 and 10 illustrate the different effects of 8 and 12 hour shifts on the HF% and the LF/HF parameters. Both figures confirm the adverse impact of the 12-hour shift.

4. Discussion

The results presented in this paper are based on 2341 workplace physiological measurements on 233 people doing shift work.

The measurements were organized by the National Public Health Centre and its predecessor institutes.

The workers were informed of the purpose of the measurements and gave their written consent to participate in the instrumental measurements.

The results of the full-time measurements performed with POLAR instruments were analysed using the SPSS software system. Taking into account the closeness of the correlations between the changes in the heart rate variability parameters of the measurements, we presented the changes in various factors (lnTP and lnHF) as a function of age, and the functional relationships with the changes in years of service for each HRV parameter and the variations of heart rate and blood pressure.

In section 3.4, the quantified relationships among the various HRV parameters of the studied workers differing from each other by shift periods (day, night) and shift day (1 to 7 shift days) have been presented, using data of Table 3 and Figures 3 to 5.

In section 3.5, we have presented some HRV parameters for the "control" and shift groups, which differ by shift day (Tables 4, 5, 6 and Figures 6, 7, 8).

In section 3.6, we highlighted the significant differences in some HRV parameters (HF% and LF/HF) between 8 and 12-hour working hours (Tables 5 and 6 and Figures 9 and 10), which illustrate the adverse physiological effects of 12-hour working time.

If we take into account the information in our recent paper [28] [29], which details the decline in HRV parameters as a function of age, we can see that the HRV analysis method, in contrast to previous practice, offers new possibilities for testing the regulation of work planning and occupational health. Given the complexity of the subject, it can be concluded that the methodological developments are interdisciplinary in nature, requiring the collaboration of physicians, psychologists, engineers (designers and work planners), mathematicians and computer scientists. The goal is to preserve the working capacity of the person doing the work.

5. Acknowledgements

The workplace physiological measurements were carried out under the coordination of the Scientific Committee on Mining Health and Ergonomics of the Hungarian Academy of Sciences. The Committee provided a forum for ongoing technical discussions of the partial results.

Thanks are due to those who have held senior positions at the National Public Health Center and its predecessor organizations since 1986, and approved of the research activities being partly linked to the work of the Institute.

Thanks are due to the managers of the enterprises and plants for providing the conditions for the measurements, to the occupational health and technical experts of the plants for their active participation in the implementation, and to the employees who participated in the workplace measurements for their interested and helpful cooperation.

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