RESEARCH ARTICLE

Effect of Age and Life Characteristics on Variations of the Heart Rate Variability Parameters among Active Manual Workers

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Abstract

Objectives: Due to innovation developments new methods can be applied also in the field of occupational health. Results of physiological measurements carried out in the workplace during work support the observation that age and life characteristics of the examined persons, work environment, working system, the working process significantly influence the changes of heart rate variability (HRV) parameters. These sources of information may be useful in developing health-oriented prevention programs.
Methods: The physiological measurements were performed in the workplace in lying (resting) position, during the working process their results (HR, TP, VLF, LH, HF) were processed by correlation and regression analysis and statistically evaluated as a function of age and life characteristics (hypertension, smoking, body mass) and metabolism-syndrome parameters.
Results: Evaluation of the results of nearly 4000 physiological measurements carried out in the workplace of more than 1000 participants showed that age had a close positive correlation with heart rate and close negative correlation with the HRV parameters (TP, VLF, LF, and HF). Considering also life characteristics (hypertension, smoking, body mass index, cholesterol, and triglyceride) beside age, can provide useful information which can be beneficial to develop health-oriented prevention programs.
Conclusions: The results call attention to the possibilities of applying new methods (like HRV analysis) in the field of occupational health and work safety which can be used in the future in education, research, or organization of work, and for interest the health and safety of workers. The developments are multidisciplinary, complex and require the collaboration of physicians, engineers, computer scientists, and mathematicians.

Key words: physiological measurements, HRV parameters, age and life characteristics, prevention programs, innovation in occupational health.

1. Introduction

Due to innovation developments, new methods can be applied also in the field of occupational health. This includes the possibility of using the method of heart rate variability (HRV) analysis. /27/, /29/. The application of heart rate variability analysis in the case of cardiac insufficiency and myocardial infarction has been well-known in the clinic for several decades. However, according to the literature /1, 2, 3, 4/, only few report have been published internationally in the field of occupational health for various reasons.

Variations of HRV parameters are influenced by several factors like age, years of service, life characteristics (hypertension, smoking, body weight), heart rate, and blood pressure, but they are also influenced by work performance, shift work, length of working time, leisure time activity, rest time, travel and accommodation conditions, as well as individual characteristics /28/. The European Society of Cardiology and the North American Society of Pacing and Electrophysiology published a Directive in 1996 /5/ on the uniform interpretation of heart rate variations, determination of measurement methods, and definition of physiological relationships.

In the present paper, we are focusing on examining the effects of age, years of service, life characteristics, and the combination of all these. /30/. Our goal is to understand the logic and extent of variations of the HRV parameters, the unfavorable range of each parameter, and through the knowledge of the parameters to explore the possibilities of health protection and influencing it. We aim to gain a more accurate knowledge of the factors influencing the condition of the human body through the innovation of tools and methods and to contribute to the modernization of health protection regulations by outlining the limits of biomarkers.

Out of the 5,000 workplace measurements carried out with the participation of more than 1,200 people in the Hungarian extractive industry, our publication details the results of 2401 measurements of 720 people (all men) at 7 plants. /23/, /24/, /25/.

Similar to the decrease in HRV parameters detected in heart failure and cardiovascular lesions, our measurements show a significant decrease in HRV, especially in the case of the elderly and those with life characteristics like H (hypertension), S (smoking), and Ti (body mass index) > 1.24, as well as in work with unfavorable work schedules. Based on the logic of the change in parameters, we may have a good reason for the possibility of using HRV analysis methods in the field of occupational health. Determination of combined limit values that can be formed based on biological markers cannot be, in principle, excluded, but it is a research-intensive task.

List of the abbreviations:

H: hypertension

nH: no hypertension

RRs: systolic blood pressure (mmHg)

RRd: diastolic blood pressure

S: smoking

nS: non-smoking

Ti: Body Mass Index = body weight (kg) / 0.79 x body height (cm) – 60.7

TP: total power (0 – 0.40 Hz)

VLF: very low frequency (< 0.04 Hz)

LF: low frequency (0.04 – 0.15 Hz)
HF: high frequency (0.15-0.4 Hz)
LF/HF ratio: LF (ms2) / HF (ms2)
HR: heart rate (pulse)
Ym: years in mine (work years)
SD1, RMSSD: time domain coefficients
TRIG: triglyceride

2. Methods

2.1 Study population

Employees of seven raw material extraction and processing plants took part in our research between 2005 and 2017 aimed at learning about the work strain of the human organism. The workplace investigations reported in the present paper included the activities of a total of 720 people in 2401 shifts. The participants were all men qualified fit for work by the required aptitude tests. The workplace physiological measurements were performed by the National Public Health Centre (NPHC). Before the measurements, the workers agreed in writing to participate in the instrumental measurements after being informed of the purpose of the tests. The study was conducted following the Helsinki Declaration as modified in 1983 and 1989, with the permission of the Scientific and Research Ethics Committee of the Medical Research Council (Budapest). We complied with the regulations on personal data protection when processing the data.

2.2 Execution of the workplace measurements

The measurements were performed at the plants with the POLAR S 810 heart rate monitor, which is suitable for measuring and storing HRV. The tests were started by measuring blood pressure (OMRON M3) and continued by an interview regarding personal data (age, years of service, body height, body weight, smoking habit, health complaints). This was followed by mounting the sensor of the monitor on the chest and starting the instrument. The 10-minute, resting measurements were performed in lying position using camp beds in the occupational physicians' offices or in other noise-free separated rooms supplied with clean air. The POLAR instrument was worn by the workers full-time, shut down, and dismantled at the end of the shift, and the recorded data were stored on a laptop. Working processes during shifts were monitored and recorded in the traditional way by recording points of time. 6-12 people working in the same workplace took part in the measurements at the same time. Measurements were taken at all three parts of the day (morning, afternoon, night) and every working day of the shift (1-7 working days). A significant number of workers involved in workplace measurements were also involved in ergometric (Jaeger Oxycon Champion walking band) tests at NIOH.

The POLAR recording - during the initial lying rest period and then during the entire shift – is illustrated in Figure 1.

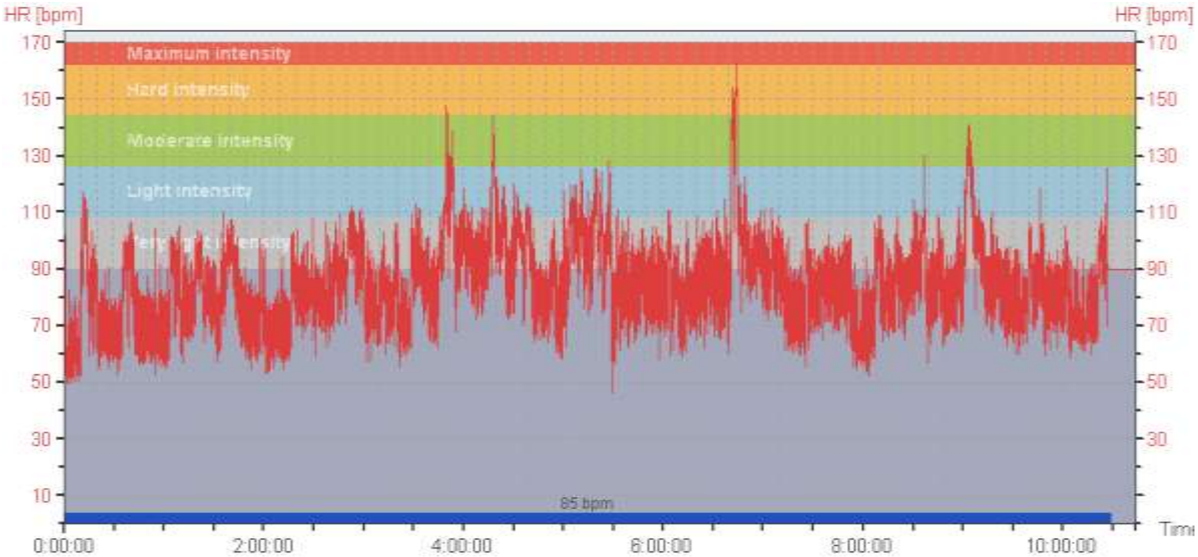

Figure 1. POLAR recording (lying resting and full time)

2.3 Statistical treatment of the measurement data

The data stored on the computer were arranged in Excel spreadsheets according to the directives of the European Society of Cardiology and the North American Society for Pacing and Electrophysiology HRV Standards of Measurement, Physiological Interpretation, and Clinical Use /5/, /29/ as time domain (error rates) and frequency domain (TP ranges: VLF, LF, HF and LF/HF) data.

The statistical analysis included descriptive details (mean, 95% confidence intervals, variance, standard deviation, max/min, skewness) and the dependence of the parameters on life characteristics (H, S, Ti) (standard SPSS Version 13.0 and then SPSS 23; SPSS Inc., Chicago, and IBM). The comparison also included analysis of individuals, groups, shifts, and part of the day, and working processes. SPSS is one of the most common tools in multivariate studies, we used SPSS Linear Models and Linear Regression Procedures. Linear models make it possible to examine the relationships between a continuous dependent variable and one or more so-called predictor variables. Although we used more than 25 variables to describe the phenomena, due to the closeness of the correlation relationships, fewer (5-10) variables were included in the modeling of the individual phenomena.

It is worth mentioning that the functioning of the human body is eurhythmic and the relationship of physiological variables is stochastic /4/, but the linear analysis of the relationships with close regression relations and two or more factors correctly reflects the nature of the changes and there is no significant difference in the extent, either.

The dependence of each HRV parameter on age and years of service was analyzed by Linear Models, mostly by Automatic Linear Models of SPSS. This program performs automatic data preparation, analysis of residuals, determines outliers, and computes model coefficients. We also examined the correlation relationships between each influencing factor and the HRV parameters.

We tested the normality of the variables and the results of each regression relationship were checked by sensitivity analysis. Our paper is based on the use of the lying-rest data values.

3. Results

It is known from the literature that HR, RR, RRs/RRd and HRV parameters are influenced by age, lifestyle (H, S, Ti), /6/, /7/, /29/ work, work environment, work organization (shift work and length of daily working time) /7/ and in addition to other circumstances, even some individual conditions. Our paper presents the effects of age, years of service, and life characteristics (H, S, Ti) and their combinations observed in our investigations.

3.1 Correlation relationships

There was a close correlation (> 0.5, sig.:0.000) between HR and time domain, as well as frequency-domain evaluated error rates and HRV parameters. With this in mind, we examined the relationships between age and years of service, and life characteristics. It was found that there was usually a close (> 0.5, sig. = 0.000) correlation between time- and frequency-domain-based parameters. (The correlation between RRs and Ti and HRV is only of "medium" closeness.)

Table 1. Correlation relationships (where closeness of the relationships among the parameters is > 0.3, and sig. = 0.00)

Age (years)	HF: - 0.737	LH/HF: + 0.732	LF: - 0.688	TP: - 0.662	RMSSD:- 0.465
RRs	TP: - 0.542	LF: - 0.518	HF: - 0.461		
BMI	RRs: + 0.362	HF: - 0.305	LF: - 0.303		
HR	RMSSD: - 0.640	SD1: - 0.627	LF: - 0.419	HF: - 0.419	
TP	HF: + 0.967	VLF: + 0.987	LF: + 0.960	RMSSD:+ 0.688	SD1: + 0.678
LF/HF	Age: + 0.732	TP: - 0.579	RMSSD: - 0.525		

It can be seen from Table 1 that in lying rest position, the correlation relationship was closest between age and HRV parameters, and HF and LF parameters occurred most frequently.

3.2 Effect of age on the changes of HRV parameters

Evaluation of the relationships between age and HRV parameters /8/, /9/ was based on the measurements performed at the start of work in lying rest position. Considering the methodological materials of the literature /9/, /10/, /11/, /12/, we determined the linear regression relationships between age and HRV parameters by Linear Models of the SPSS program. As examples, the age-dependent changes in HR and TP, and also in HF and RRs are shown in Figures 2 and 3, respectively.

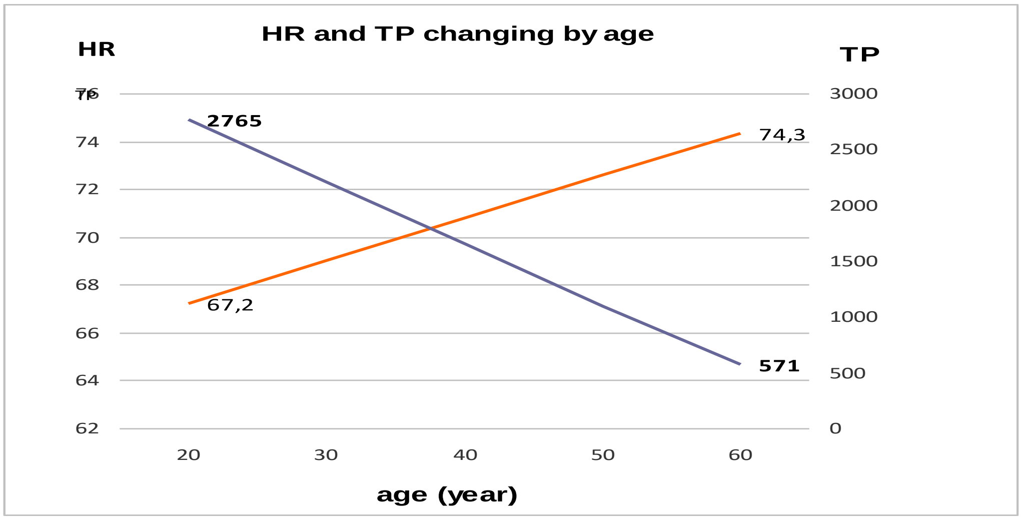

Figure 2. Age-dependent changes of HR and TP

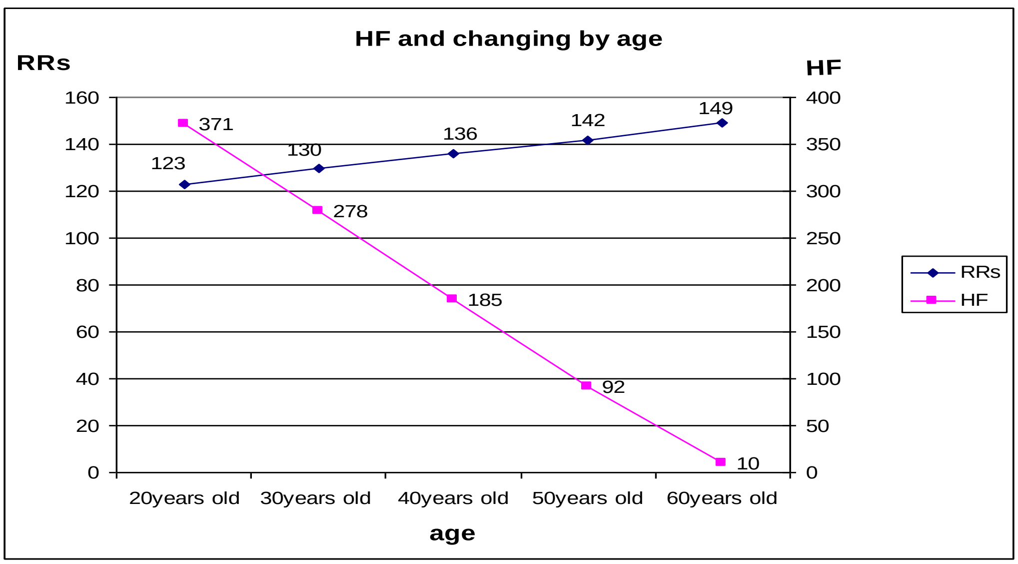

Figure 3. Age-dependent changes of HF and RRs

Figures 2 and 3 show that the heart rate (HR) and blood pressure (RRs mmHg) values in the younger age group were significantly better than those in the older age group. At the same time, the HRV parameters (TP and HF) were significantly reduced.

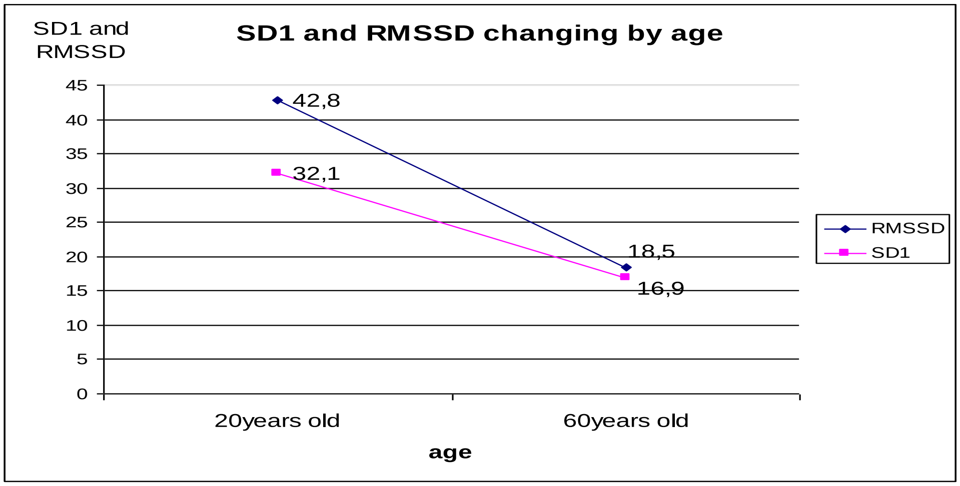

Figure 4. SD1 and RMSSD in relation to age

Figure 4 illustrates that the change in the parameters of the HRV time domain (SD1, RMSSD) and frequency domain (TP / Figure 2 /, and HF / Figure 3 /) is of the same nature as a function of age. The age-dependent changes /11/, /12/ of all examined parameters are shown in Table 2. The information of these relations can be used in the field of occupational health, limit values can be formed, and in case they are reached, it is expedient to take measures to prevent health damage.

Based on the results of the statistical analysis we performed comparative studies, using average values of the data shown in Tables 2 and 3 and taking into account individual life characteristics (age, length of service, body weight, smoking habit, blood pressure, heart rate) and average values of the HRV parameters. Compared to the average values of the whole data set, the influential effect of smoking, hypertension and body weight on variations of the HRV parameters could be perceived.

We found that the measured values (TP, LF. HF) of smokers (43%) decreased by 10% compared to the HRV parameters of the total 2401 samples, while the time domain (SD1 and RMSSD) values decreased by almost 15%. The effect of smoking on HRV parameters - in the case of the studied subjects - is illustrated in Figure 5.

37% of the subjects had hypertension, the effect of hypertension on HRV parameters (TP and HF) exceeded the reduction caused by smoking, as shown in Figure 6. Age-dependent changes /11/, /12/ of all examined parameters are shown in Table 2.
According to Table 2, the HRV parameters, both the time domain and the frequency domain ones, decreased with age, except the heart rate (HR /min), and the LF / HF ratio. /13/, /14/, /15 /.

From the 2401 samples examined, three groups were formed to illustrate the effects of life characteristics on HRV parameters. In addition to the mean values regarding the whole data set, Table 3 shows the values of individuals with “favorable” status (<33 years, nS, nH, BMI < 0.9) and those with increased hypertension (RRs >160 mmHg). The difference between the values of the HRV parameters (TP, LF, HF) of the groups is twice in the case of favorable/average, and the difference exceeds four times in the case of favorable/increased H.

Table 2. Effects of smoking (S) and hypertension (H) on the HRV parameters

Designation	Sample size (n)	Age (years)	Years of employment	Ti	RRs	HR	SD1	RMSSD	TP	LF	HF	LF/HF
Whole data set	2401	42.6	16.3	1.11	138	71.3	16.9	23.2	1324	379	158	2.67
S (43%)	1036	43.1	17.2	1.09	138	74.7	14.4	19.9	1195	341	140	2.74
nS (57%)	1365	42.6	15.7	1.13	137	68.6	18.8	25.7	1421	409	172	2.61
nH (63%)	1510	40.6	14.4	1.07	128	68.6	19.7	27.1	1649	476	204	2.5
H1 (26%)	624	45.7	19.4	1.17	147	74.7	12.8	17.8	819	230	87	2.87
Increased H (11%).	267	48.5	20.0	1.21	168	78.4	10.4	14.6	663	184	64	3.08

Table 3. HRV parameters of favorable, average and increased hypertension groups

Group	Sample size (n)	Age (years)	Ti	HR/min	TP m/s2	LF m/s2	HF m/s2
Favorable	66	26.7	0.88	65	2647	819	410
Average	2401	42.8	1.11	71.2	1324	379	158
Increased H	267	48.5	1.21	78.4	663	184	64

Favorable group: < 33 years, nS, nH, Ti = 0.88
Average group: 42.8 years, H (37%), S (43%), BMI = 1.11
Increased H group: RRs > 160/mmHg

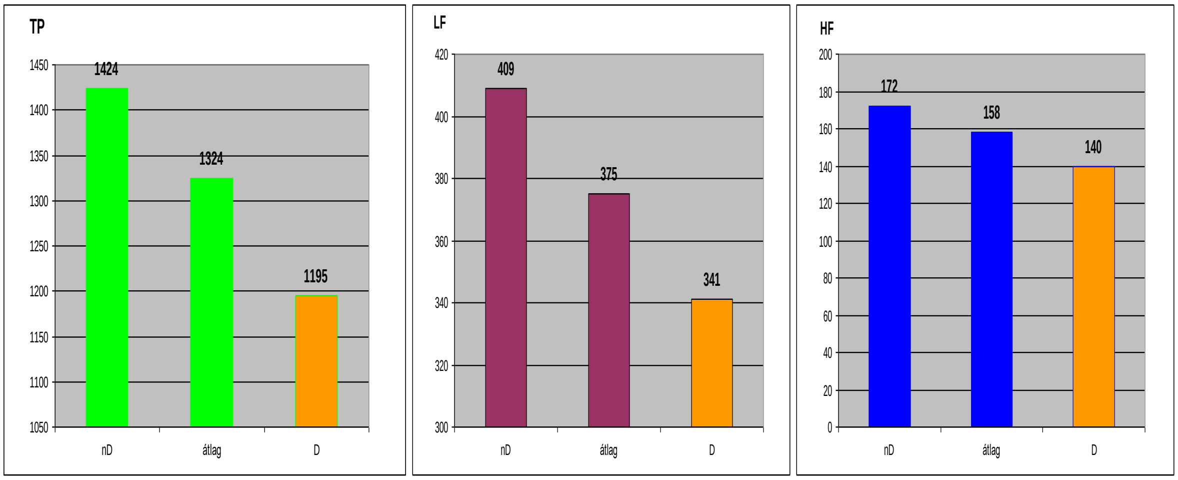

Figure 5. Effects of smoking (S) on the HRV parameters (2401 samples, S: 43%, nS: 57%) TP, LF, HF m/s^2

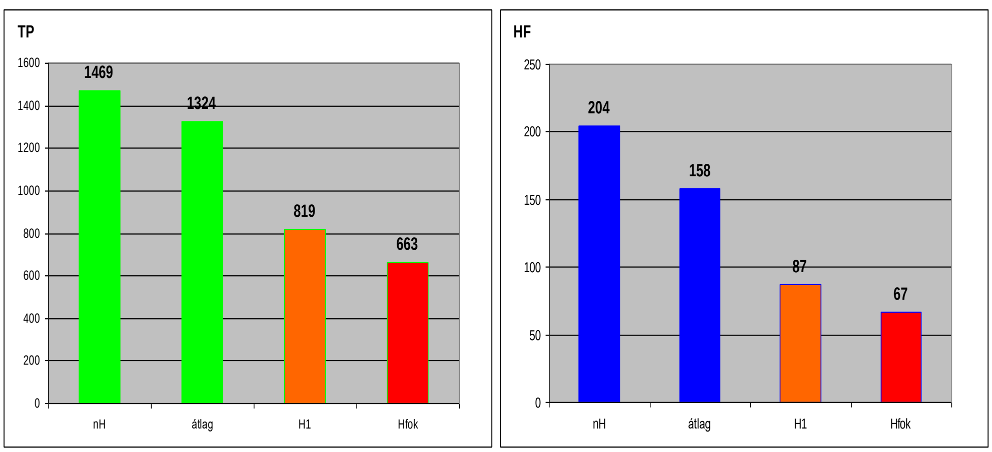

Figure 6. Effects of blood pressure (RRs) on the HRV parameters (TP, HF, m/s^2)

nH (RRs < 139 mmHg), sample size: 1510
H1 (RRs = 140-159 mmHg, sample size: 624
Increased H (RRs > 160 mmHg), sample size: 267

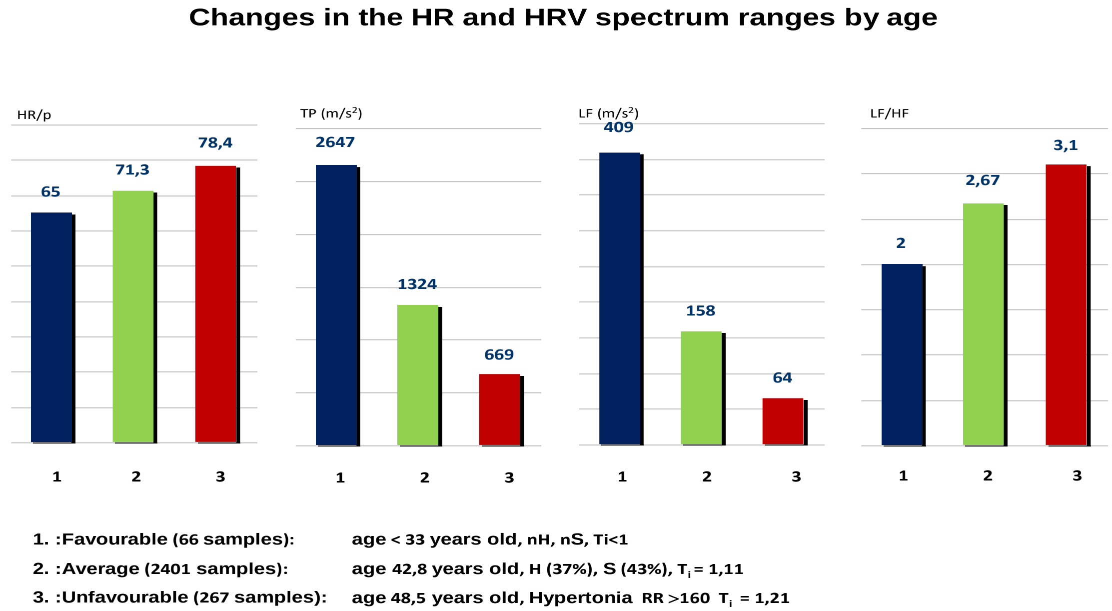

Figure 7. Changes in the HR and HRV spectrum ranges by age and life characteristics

Figure 7 illustrates that in the three groups formed, the HR (heart rate) increases from the favorable group to the unfavorable, the range of TP and LF decreases, and the value of LF / HF also increases. The direction and extent of the change in the parameters draw attention to the possibilities of utilizing the results (the red color means unfavorable).

The results of our studies are in harmony with the extensive literature results regarding the application of the HRV method, according to which age and living conditions - ultimately a person's state of health - can be monitored through changes of cognizable parameters. /29/. Table 3 and the information on the significantly different data in the three groups draw attention to the applicability of the method.

Using the "Automatic Linear Modelling" method, we examined the effects of factors influencing HRV parameters. In Fig. 8 the value of HF is shaped by 5 factors with close correlation relationships (age, hypertension, smoking, years spent in mine, and BMI). Among the factors, age represents 72.4%. The reliability of the test is confirmed by the low value of the information criterion and the sig. = 0.000.

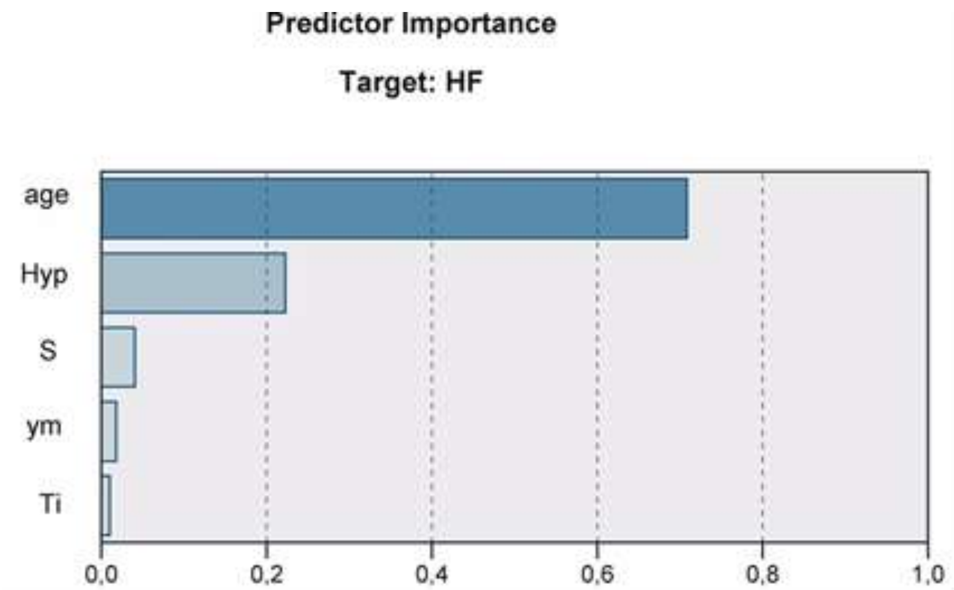

Figure 8. Importance of predictors (Target: HF)

Based on the correlation relationships, age has the greatest effect on changes in HRV parameters. Figure 8 shows the factors influencing the HF parameter. /16/. The numerical relationships, as a result of linear regression analysis, are presented in Table 4.

Table 4. Dependence of parameters on age 2341 samples, mean age: 42.8 years; H=34%; S=43%; Ti=1.11

Parameters	20 years	30 years	40 years	50 years	60 years
HR = 0.161 x (years) + 64.486	67.7	69.3	70.9	72.5	74.1
RRs = 0.576 x (years) + 112.428	124	130	135	141	147
RRd = 0.250 x (years) + 70.560	76	78	81	83	86
SD1 = - 0.580 x (years) + 42.318	30.7	24.9	19.1	13.3	7.5
RMSSD = - 0.807 x (years) + 58.914	42.8	34.7	26.6	18.6	10.5
TP = - 52.748 x (years) + 3662.711	2608	2080	1553	1025	498
VLF = - 25.668 x (years) + 1928.84	1415	1159	902	645	389
VLF% = 0.39 x (years) + 43.889	51.7	55.6	59.5	63.4	67.3
LF = - 17.107 x (years) + 1136.98	795	624	453	282	111
LF% = - 0.143 x (years) + 34.385	31.5	30.1	28.7	27.2	25.8
HF = - 9.77 x (years) + 586.685	391	294	196	98	34
HF% = - 0.246 x (years) + 21.674	16.8	14.3	11.8	9.3	6.8
LF/HF = 0.049 x (years)+ 0.611	1.59	2.08	2.57	3.06	3.55

Table 4/1. Extent of changes in the parameters

Parameter changes	20-29 years	30-39 years	40-49 years	50-59 years
HR increase during 10 years: unit	1.6	1.6	1.6	1.6
RRs increase during 10 years: unit	6	5	6	6
RRd increase during 10 years: unit	2	3	2	3
TP decrease during 10 years: %	20	25	34	51
LF% decrease during 10 years: %	1.4	1.4	1.5	1.4
HF% decrease during 10 years: %	2.5	2.5	2.5	2.5
LF/HF increase during 10 years: unit	0.49	0.49	0.49	0.49

According to Table 4, the HRV parameters - both the time domain and the frequency domain ones - decrease with increasing age /17/, /18/ - except for HR/min (heart rate), and the LF/HF ratio).

4. Discussion

The results are based on the evaluation of 2401 measurements performed in 7 plants with the participation of 720 people following the plant work schedule. The examined individuals worked in shift work schedules (2-7 days shifts). /29/.

The resting measurements in lying position were performed for 10 minutes before the start of work in separate rooms under undisturbed conditions. The measured HRV parameters were evaluated by age, shift work time (years of service), and life characteristics (such as hypertension, smoking, body weight, and combinations of all these) using the SPSS program.

We determined the correlations between the changes of each measured physiological parameter, which were usually close (> 0.5 and sig.:0.000) to each other. It has been found that there is usually a close relationship between the parameters determined by time domain and frequency domain evaluation methods. This phenomenon allows us to perform combined analyses that we also used.

The effects of age change on each HRV parameter can be seen in Figures 2, 3, and 4, and the numerical results determined from the regression relationships in Table 4 show the direction and extent of the changes.

Table 4/1 shows the changes in each HRV parameter by 10 years, from which a dynamic (from 20% to 51%) decrease in the TP range can be observed. This phenomenon is consistent with that one seen in heart failure, which draws attention to the adverse physiological effects of shift work schedule.

The effects of years of service on HRV parameters can be examined by regression methods in a way analogous to age dependence. The symptoms of longer-term changes (decreased HRV parameters) call attention to the possibilities and importance of the prevention of changes.

Of the three groups formed, the most unfavorable physiological effect was found in the case of patients with hypertension that manifested in an increase in heart rate and a decrease in TP ranges. At the same time, the

LF / HF ratio increased in this group (3.08) and at the age > 50 years.

43% of the participants were smokers. The adverse effects of smoking on HRV parameters (Figure 5) succeeded age and hypertension, respectively - presumably, the extent of smoking may change the order. /19/

The unfavorable effect of the increase of body mass index (average value: 1.11) on the change of HRV parameters can be ranked 6th out of the seven factors considered, but depending on the degree of obesity, it can differ significantly and justify an individual examination.

Based on the data of the three groups formed on the basis of life characteristics (Table 3), we can state that in the case of the 267 individuals belonging to the unfavorable group (increased hypertension: RRs > 160 mmHg, age = 48.5 years, Ti = 1.21), all measured values differed significantly from the data of the group (66 individuals) with favorable classification characteristics (age < 39, nH, nS, Ti < 1).

According to Table 2, the group mean value of blood pressure increased from 138/81 to 168/89, and the HR/min value increased from 65 / min to 78 / min. However, the time-domain error rates were reduced by 34% - 55% for each interval evaluated.

The TP range decreased to 25% (one-fourth) (663/2647). It is worth noting that in the case of the HF band the decrease changed to 15.6% (64/410), which means a significant increase of the parasympathetic effects. As a result, the LF / HF ratio increased to 1.15-fold.

The results of our workplace measurements - by accordance with the literature /20/, /21/ - show the applicability of the HRV method in the field of occupational health. The results of HRV measurements make it possible to develop a substantial health protection program. /21/.

5. Limitations

Pre-study surveys did not include a more detailed exploration of smoking habits (e.g., how long they have been smoking and how much they smoked daily). The knowledge of this information could have enriched the results of the evaluation. Neither drinking habits nor leisure activities were included in the data collection, either, because - based on our initial experience - the reliability/reality content of this information was uncontrollable and would have caused confusion in the evaluation of the results.

6. Conclusions

The present paper by the title is limited only to the determination and assessment of parameters collected at rest in lying position out of the full-time period measurements taken at the workplace. The findings revealed that the HRV analysis method can provide essential information to substantiate the changes in occupational health and safety activities and regulations by understanding the influences of age and life characteristics./20/, /21/, /28/.
The results of the measurements made in the supine resting state based on the variation of HRV parameters, age, years of service, and life characteristics, as well as their assessment by groupings, support the possibility of understanding the logic of HRV parameter variation. This requires a large number of measurements to be carried out at the unit under study, taking into account the multitude of influencing factors.

By using the HRV method, in addition to examining the effect of age and life characteristics, it is possible to learn about the effects of working conditions (e.g. shift work and length of working time, nature of work) and to implement a more physiologically favorable working variant in practice.

The results of workplace physiological measurements carried out with the participation of individuals with unfavorable conditions may justify special examinations to be carried out in those concerned, for which the conditions should be created.

Innovation can help to refine research results by developing new measurement tools and evaluation methods. The developments are multidisciplinary, complex, and require the collaboration of doctors, engineers, computer scientists, and mathematicians. /28/, /29/, /30/

7. Acknowledgments

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