Fast and efficient Pre-Trip health examination using pulsogram

Evgeny Dzyuba
Center for Occupational Pathology and Professional Suitability examination
Sergey Shlipakov
NPP System Technologies JSC
Ekaterina Gutor
Central Directorate of Healthcare
Elena Zhidkova
Central Directorate of Healthcare
Marina Gurevich
Central Policlinic RZD-Medicine
Natalia Rudnikova
Academy of Postgraduate Education under the Federal State Budgetary Institution FSCC FMBA
Vera Pankova
All-Russian Research Institute of Railway Hygiene
Mikhail Vilk
All-Russian Research Institute of Railway Hygiene
Konstantin Gurevich (kgurevich@mail.ru)
Moscow State University of Medicine and Dentistry
Victoria Zaborova
Sechenov University
Oksana Drapkina
National Medical Research Center for Therapy and Preventive Medicine

Research Article

Keywords: railway, pre-trip health inspection, heart rate variability, prevention

Posted Date: March 1st, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1349274/v1

Abstract

Relevance: The train drivers are responsible for the safety of transported people and goods. Therefore, medical monitoring of their state of health is an integral part of ensuring the safety of railway traffic.

Purpose: to study the possibilities of using a pulsogram for analyzing the parameters of heart rate variability during pre-trip health examination of members of train crews.

Materials and methods: 183 male train crew members (106 engine train drivers, 77 train drivers' assistants) were examined; the average age was 37.7 ± 9.4 years. ECG and pulsogram were measured simultaneously, and heart rate variability was analyzed.

Results: A high degree of coincidence of mean values and variances of heart rate variability parameters, calculated on the basis of ECG (electrocardiogram) and pulsogram, was found. A high degree of reliable positive correlation was established between these parameters. Significant differences in the parameters of heart rate variability were revealed between the members of train crews who underwent and those who did not undergo the first-time pre-trip medical examination.

Conclusion: Measurements of heart rate variability parameters based on the pulsogram can be used to solve a number of urgent problems of pre-trip medical examination of members of train crews.

Contribution To The Literature

1. The work showed good convergence of heart rate variability parameters determined on the basis of pulsogram and ECG.
2. The determination of heart rate variability parameters based on the pulsogram can be used to solve a number of urgent problems of pre-trip medical examination of members of train crews.
3. The driver's suspension because of the pulse readings could be associated with both tachycardia and bradycardia.

Introduction

Train drivers are responsible for safety of people and freight transported by rail, which is a strong stress factor [1]. Despite the modernization of transport, the role of the human factor remains significant [2]. It is reported that from a psychological point of view, the most stressful experience for members of train crews is moving alongside platforms [3]. Different types of psychological responses to workloads are described in a number of publications [4]. It is shown that the largest number of accidents in railway transport and errors in the train driver's actions in Europe [5], China [6], South Korea [7] and Japan [8] is associated with human factor. Therefore, monitoring the health status of the members of train crews as well as identifying the factors of the potential risk among them is an integral part of the medical aspects of the rail transport safety [9, 10].

In the Russian Federation, the mandatory elements of a pre-trip medical examination (PTME) of members of train crews are medical history collection, thermometry, alcometry, heart rate analysis, blood pressure measurement [11]. There is an urgent need of optimization of the PTME in order not to miss significant changes in the health status of train crew members and / or precursors of the development of these changes. From our point of view, pulse wave analysis can provide additional information without significant cost increases. In the study conducted in the Russian Federation, it was shown that for people of driving professions the analysis of pulsograms provides additional information about their health status and the prognosis of its changes [12].

Recent publications have shown that not only myocardial contractions, but also other factors are involved in the formation of the pulse wave. In this regard, the methods of analyzing heart rate variability (HRV) by pulse have significant limitations in comparison with ECG [13]. The systematic observations show that only photoplethysmography can provide heart rate variability data measured by pulse that will converge with those measured by ECG. The results are strongly influenced by the initial somatic state of the individual. Therefore, the method of pulse variability analysis cannot be fully considered as a substitute for the method for analyzing of heart rate variability [14].

Thus, the purpose of this study was to unravel possibilities of using the pulsogram for analysis of the parameters of heart rate variability of members of train crews during pre-trip medical health examination

Materials And Methods

The study was approved by the Interuniversity Ethics Committee, Protocol No. 05–18, dated May 24, 2018. All methods were performed in accordance with the relevant guidelines and regulations. 183 male train crew members (106 train drivers, 77 train driver assistants) of an average age 37.7 ± 9.4 years were examined. The results of the last medical examination were written out from the medical records and analyzed. The selection of members of train crews was carried out in a randomized manner so that the number of those who underwent and did not undergo the medical exam was in a ratio of 6 : 4 (usually the number of those who did not have health examination does not exceed 10%) (The reasons for the suspension were: pulse more than 90 beats / min or less than 60 beats per minute – 60%, arterial blood pressure more than 140 mmHg. – 53%, blood pressure more than 90 mmHg.- 20% (the total amount is not equal to 100%, since one employee could have several reasons for suspension from work).

The study did not include individuals suspended from duties due to fever and / or alcohol consumption. All included in the study gave their voluntary informed consent. The study was carried out at the pre-trip examination center at the Rostov-Main Station of the North-Caucasian Railway and included only those members of train crews who were permanently assigned to the depot. This made it possible to gain access to the employee's medical records, where the earlier diagnoses were copied from.

A complex of hardware-software measurements as well as analysis of pulse parameters, blood pressure and bioelectric potentials of the heart, pre-working examination of operators of complex technical devices and systems KAPD-02-ST according to Technical Specifications (TS) U 9441-002-45520949-2005, manufacturer: JSC "Scientific and Production Enterprise "System Technologies." were used. Also, the ECG apparatus - electrocardiograph EK 12T-01- "R-D" **in** accordance with TS 9441-005-24149103-2003, manufactured by Scientific and Production Enterprise "Monitor", pulse oximeter - optoelectric sensor DASM.012.554.1 in accordance with TS 9441 -001-30857241-12, manufactured by OJSC "Axioma", blood pressure measuring device for measuring blood pressure LD-60 in accordance with GOST standard R519.1-2002, manufactured by Little Doctor Electronics (Nantong). All devices produced the measurement results in digital form with an interval of 1 ms. The results were recorded on a computer for the further analysis.

The pre - trip medical examination was carried out by a medical assistant who had underwent additional special training in electrocardiography. Blood pressure measurements were taken according to Korotkoff in a seated position. The frequency of heart contractions, systolic and diastolic blood pressure (BPs, BPd), as well as pulse pressure were measured.

The body temperature was taken with a digital thermometer OMRON, manufactured by OMRON HELSKEA Co., Ltd., Japan, while alcometry was carried out with an analyzer of ethanol vapors in exhaled air, Alkotektor Jupiter in accordance with TS 26.60.12-001-82139963-2011, manufactured by Alkotektor LLC. The increase in body temperature up to 37 ° C and above, as well as the presence of alcohol vapors in the exhaled air, served as a contraindication for the inclusion of a train crew member in the study.

The pulsogram and electrocardiogram (second standard lead) were recorded simultaneously in the supine position. 100 RR intervals (approximately 3 minutes of recording) were analyzed. The R 'points were determined as the maximum points for the pulsogram. Based on the measurement of RR intervals for ECG and R'R 'intervals for pulse, the following parameters were calculated:

1. SDNN - standard deviation of NN intervals

$$SDNN = \sqrt{\frac{\sum_{i-1}^{N}(NN_i - NN_{avg})^2}{N}}$$

where NN_i is the value of the i- interval, NN_{avg} is the average over NN_i of the entire record, N is the number of intervals.

2. pNN50 (%) is the percentage of NN50 of the total number of consecutive pairs of intervals

$$pNN50 = \frac{NN50}{N} \times 100$$

where N is the number of intervals.

$$NN50 = \sum_{i=1}^{N-1}[(NN_{i+1} - NN_i) > 50]$$

where NN_i is the value of the i- interval, N is the number of intervals. NN50, the number of pairs of consecutive NN intervals, which differed by more than 50 milliseconds, was obtained over the entire recording period

3. TI - Tension Index

$$TI = \frac{AMo}{2X * MO}$$

where M_o is the mode of RR intervals, AM_o is the amplitude of the mode, the number of cardiointervals corresponding to the value of the mode in% to the sample volume, X is the variation range of the RR or R'R 'interval

4. RMSSD - root-mean-square difference between the duration of adjacent RR intervals, expressed in *ms*. It is calculated as the square root of the sum of the squares of the difference between the values of consecutive pairs of NN intervals (normal RR intervals); an indicator of the activity of the parasympathetic link of autonomic regulation.

$$RMSSD = \sqrt{\frac{\sum_{i=1}^{N-1}(RR_{i+1} - RR_i)^2}{N-1}}$$

For every member of the train crew, a one-time comparison of the variability parameters calculated on the basis of ECG and pulsogram was carried out, regardless of the results of the pre-trip health examination.

Statistics

The results were calculated using Excel. Statistical processing was performed using the Statistica software package. The mean and its standard deviation were calculated. The correspondence of the studied parameters to the normal distribution law was checked on the basis of the Kolmogorov criterion. The correspondence of studied parameters with a normal distribution law was not found. Therefore, the comparison of the mean values was carried out by the U-test. Kendall rank correlation coefficients were calculated. Factorial and discriminant analyzes were also used. In the tables, data are presented as mean ± standard deviation and median [interquartile range].

Research results

According to the conclusions of the medical commission, 54% of the individuals included in the study were healthy (Fig. 1). 14% had hypertension, 10% had atherosclerosis, 8% had cardiac arrhythmias and gastrointestinal diseases. According to the medical documentation, 40% of those surveyed were recommended to take medications on a regular basis, but only 33% of the train crew members indicated that they used self-administered therapy (Fig. 2)

All 100% of those who did not pass the pre-trip medical examination had previously been diagnosed with chronic non-infectious diseases. The average readings of BPd, BP and pulse pressure were significantly lower in the group of individuals allowed to work (Table 1).

Table 1
Heart rate frequency and blood pressure readings among members of train crews

parameter	**those allowed to work**	**those who didn't pass pre-trip medical health examination**	**p**
heart rate	77.1 ± 7.6 80[72;83]	with bradycardia: 62.1 ± 5.5 64 [57;68]	< 0.01
		with tachycardia: 101 ± 10.2 98[92;106]	< 0.01
Arterial blood pressure mm HG	117.2 ± 7.7 116[112;122]	135.2 ± 9.3 125[120;155]	< 0.01
arterial blood pressure mm hg	75.9 ± 5.0 75[73;80]	81.9 ± 5.9 80[75;86]	< 0.05
pulse pressure mm hg	41.4 ± 5.7 38[36;44]	53.3 ± 5.5 39[40;66]	< 0.05
Here and further in Table 1: top line - mean and its standard deviation, bottom line - median and interquartile range			

A high degree of correlation between the parameters of heart rate variability calculated on the basis of ECG and pulsogram was found (Table 2). It should be noted that the greatest deviations from the apromaximum line are observed for large SDNN values (Fig. 3). Thus, if we consider SDNN values which don't exceed 50, then the correlation coefficient of the parameter calculated from ECG and pulse wave becomes 0.98.

Table 2

Comparison of heart rate variability parameters calculated on the basis of ECG and pulsogram

	Correlation coefficient
Tension Index	0.89
PNN50	0.86
SDNN	0.95
RMSDD	0.91

It should be noted that the revealed significant differences in the parameters of heart rate variability both recorded by ECG and by pulsogram (Table 3) between the members of train crews who underwent and did not undergo the pre-trip examination,. The indices of those who did not undergo the PTME are characterized by lower values of the studied parameters, in particular, SDNN ', which corresponds to more stringent characteristics of heart rate variability. The number of individuals with severe heart rate variability parameters was: SDNN ’<40 ms - n = 71 (39%), PN50’ <10 - n = 83 (45%), RMSSD ’<25 - n = 46 (25%)

Table 3

Values of variability calculated on the basis of ECG and pulsogram among members of train crews

Parameter	**those allowed to work**		**those who didn’t pass medical examination**		**P (between who passed/didnot pass medical exam)**
	Pulsogram	**ECG**	**Pulsogram**	**ECG**	
Tension Index	61.7 ± 24.5 44[42;75]	60.2 ± 23.4 43[41;72]	67.0 ± 33.2 61[43;80]	68.1 ± 23.1 62[44;76]	< 0.1
PN50	24.9 ± 12.5 11.1[7.1;34.2]	24.3 ± 10,1 10.9[6.9;32.4]	14.1 ± 12.3 4.0[1.0;34.4]	13.5 ± 9.8 3.9[0.9;26.9]	< 0.01
SDNN	98.5 ± 10.1 85.3[57.7;139.3]	102.3 ± 9.8 89.4[61.1;135.1]	47,7 ± 19,9 37.6[28.1;57.5]	49.1 ± 10.9 36.1[25.2;52.7]	< 0.01
RMSSD	39.5 ± 10.7 35.7[21.5;53.1]	40.7 ± 10.2 36.6[22.4;52.9]	31.2 ± 12.2 29.3[15.5;40.5]	29.3 ± 8,8 27[12;39.3]	< 0.05

Factorial and discriminant analysis (Table 4) shows that the differences between the groups allowed and suspended from work are significant (F (9.174) = 11.471, p < 0,000). Significant variables for classification are: heart rate, tension index ', SDNN'.

Table 4
Results of discriminant analysis (significant ones with $p < 0.05$ are highlighted in color)

Parameter	Wilks lambda	Private lambda	F	p	Tolerance	R^2
Age	0.628843	0.998051	0.33978	0.560710	0.843181	0.156819
Heart rate	0.668361	0.939039	11.29582	0.000955	0.742587	0.257413
САД Systolic BP	0.627651	0.999947	0.00931	0.923230	0.014225	0.985775
ДАД Diastolic BP	0.628747	0.998204	0.31309	0.576512	0.052878	0.947122
Pulse pressure	0.629057	0.997711	0.39925	0.528306	0.026339	0.973661
Tension Index	0.646145	0.971326	5.13665	0.024657	0.574703	0.425297
PNN50	0.633537	0.990656	1.64126	0.201857	0.355515	0.644485
SDNN’	0.658740	0.952754	8.62853	0.003758	0.435531	0.564470
RMSSD	0.627871	0.999597	0.07023	0.791310	0.574949	0.425052

Discussion

Currently, the main reasons for train drivers’ suspension in the CIS countries are the fact that the heart rate and blood pressure indicators go beyond the standard values [15]. Table 1 confirms this conclusion: those suspended from work were characterized by higher values of systolic and diastolic blood pressure. At the same time, the driver’s suspension because of the pulse readings could be associated with both tachycardia and bradycardia, which was also demonstrated in the form of significant differences between the groups. Discriminant analysis (Table 4) proves that heart rate is a significant factor in determining differences between groups.

We should note the correlations of heart rate variability parameters shown in Table 2, calculated on the basis of the pulsogram and ECG. Although in [13] it was shown that the pulsogram is the result of a combination of a number of physiological processes, only one of which is heart contractions determined on the basis of ECG. We have shown a correlation between the parameters of the heart rate variability calculated on the basis of ECG and pulsograms. Thus, the data obtained in the work allow us to assert that for the studied group, the parameters of pulse variability are linearly related to the parameters of ECG variability. This, among other things, is confirmed by the differences identified by us in terms of heart rate rigidity between those individuals who were allowed to work and those who were suspended from work (Table 3). Meanwhile, there was a coincidence of the average parameters of heart rate variability and their variances across groups, with two methods used for determining the variability. Thus, the pulsogram allows you to identify differences between the studied groups.

It should be noted that we are not the only group to attempt to study the parameters of heart rate variability on the basis of pulsograms. A good convergence of the results obtained by two methods (by ECG and by pulse) was shown when analyzing the autonomic response of a healthy individual to the cold [16]. A high convergence of parameters of heart rate variability during sleep, which was assessed using ECG and based on pulse measurements, was described. The correlation coefficient SDNN, calculated on the basis of different measurements, was 0.81. The authors believe that the main error in determining the parameters of pulse variability is caused by the change in the position of human body [17]. We got higher values of the correlation coefficient, because during the measurement, the position of the body did not change.

A special earlobe photoplethysmograph was designed. The authors showed good convergence of heart rate variability parameters measured in healthy volunteers based on heart rate and ECG measurements [18]. In patients with sleep apnea syndrome, pulse recording with a photosensor attached to a finger gave the parameters of heart rate variability indistinguishable from those in ECG recording [19]. The results of the cited studies confirm the data obtained in our work.

The prognostic value of the parameters of heart rate variability, measured by the pulse, was found in individuals who had suffered a stroke. At the same time, a high degree of correlation was shown for the parameters of the heart rate variability determined by the pulse and ECG [20]. A 0.9 correlation was also shown between the parameters of heart rate variability calculated on the basis of heart rate measurements and ECG in hypoglycemia [21]. Heart rate variability parameters calculated on the basis of heart rate, in particular, SDNN, were informative for predicting exercise tolerance in obese elderly people [22]. We have shown the prognostic value of the pulse rate variability parameters during the pre-trip examination of drivers. Probably, these parameters can be used to obtain more information about the health of an individual than a simple measurement of the heart rate. However, the predictive value of the method is to be assessed in the future.

In general, we note that the assessment of heart rate variability is a recognized prognostic method for development of complications of cardiovascular diseases, the assessment of therapy effectiveness [23–24]. The method is widely used in modern clinical settings. Typically, long-duration (one day or more) and short-duration (up to several hours) ECG measurements are used. Despite the information extracted through a long duration ECG measurements, short-interval studies are extremely common due to their lower cost [26–27]. In our study, we used a short-duration measurement, since a long-duration measurement is impossible to carry out in the conditions of a pre-trip examination.

The study of the parameters **of** short-duration heart rate variability increasingly attracts the attention of researchers. It is generally accepted that the "gold standard" of such measurements is ECG recording for 300 seconds (5 minutes). However, it has been proven that a recording duration of 120 seconds is sufficient for a good convergence of heart rate variability parameters, in particular SDNN [27]. It is reported that for the decreed contingent (athletes) ECG recording for 60 seconds [28] or even 30 seconds [29] are enough to calculate the parameters of heart rate variability. Analyzing various methods of short and ultrashort ECG recording for assessing the parameters of heart rate variability, other authors come to the conclusion that a reliable and reproducible result is obtained by recording within 1–2 minutes [30]. Therefore, the selected recording range (100 RR intervals) can be considered adequate for determining the parameters of heart rate variability.

Based on our own data and a number of publications, we can conclude that measuring variability based on the pulsogram has a number of advantages. Undoubtedly, there is a reduction in the cost of pre-trip examination, as there is no need to purchase additional equipment (an ECG apparatus) and carry out its regular metrological verification. The cost of medical personnel training is reduced (Russian law stipulates that a pre-trip medical examination can be performed by a doctor or a nurse. If a nurse works at the PTME point, then in order for him to have the right to take an ECG and interpret it, additional special training is needed). In addition, in depots that serve electrified railways, the issue of electrical insulation of the premises arises separately, since ECG machine standard filters are usually not sufficient to neutralize background noise (The voltage of the power supply network of the railway in the Russian Federation can reach 3000 V for direct current and 25 kV * 2 50 Hz for alternating current).

It should also be taken in consideration that members of train crews are a decreed contingent that complies with the Order of the Ministry of Transport of the Russian Federation dated October 19, 2020 No.428 "On approval of the Procedure for conducting mandatory preliminary (upon admission to work) and periodic (during employment) medical examinations on railway transport "(earlier - Order of the Ministry of Railways of the Russian Federation of March 29, 1999 № 6Ts" On approval of the Regulation on the procedure for conducting mandatory preliminary, upon admission to work, and periodic medical examinations on federal railway transport "). At least once every 2 years, drivers and their assistants undergo a medical expert commission, on the basis of the decisions of which an employee of the train crew is allowed or not allowed to work on the train. According to the indications given by the medical expert commission, Holter monitoring of the ECG, ABPM and other tests are carried out. Despite the good convergence of the heart rate variability parameters measured by the pulse and ECG, the pulsogram cannot reflect hemodynamically insignificant changes in heart contraction, which can be checked by ECG. Most likely, the prognostic value will not be the absolute values of the heart rate variability measured on the basis of the pulse wave, but the dynamics of their change. Most likely, a change in the parameters of pulse variability among members of train crews should serve only as a basis for referral to an in-depth medical study, but not just for a diagnosis. The predictive value of such measurements needs to be explored in the future.

Conclusion

The work showed good convergence of heart rate variability parameters determined on the basis of pulsogram and ECG. Therefore, the determination of heart rate variability parameters based on the pulsogram can be used to solve a number of urgent problems of pre-trip medical examination of members of train crews.

Abbreviations

BP - blood pressure

BPs, BPd - systolic and diastolic BP

ECG - electrocardiography

HRV - heart rate variability

pNN50 - the percentage of NN50 of the total number of consecutive pairs of intervals

PTME - pre-trip medical examination

RMSSD - root-mean-square difference between the duration of adjacent RR intervals

SDNN - standard deviation of NN intervals

TI - Tension Index

Declarations

Declarations section

- *Ethics approval and consent to participate*

The study was approved by the Interuniversity Ethics Committee, Protocol No. 05-18, dated May 24, 2018.

All methods were performed in accordance with the relevant guidelines and regulations
- *Consent for publication*

All authors read the final version of MS and agreed for publication.

- Availability of data and materials

Data is given as Excel files in supplement materials

- Competing interests - Not applicable
- Funding - Not applicable
- *Authors' contributions*

Data collection: Dzyuba E.A., Shlipakov S.V., Gutor E.M., Zhidkova E.A.

Clinical interpretation: Gurevich M.V., Rudnikova N.A., Pankova V.B.

Data analysis: Vilk M.F., Gurevich K.G., Zaborova V.A.

General idea, design: Drapkina O.M.

Statistics: Gurevich K.G.

Writing and translation: Zhidkova E.A., Gurevich K.G., Drapkina O.M.

- Acknowledgements - Not applicable

- Authors' information

Evgeny Anatolievich Dzyuba ORCID 0000-0003-3690-5859

Sergey Valerievich Shlipakov ORCID - 0000-0003-3100-0911

Ekaterina Mikhailovna Gutor ORCID 0000-0001-5725-5918

Elena Anatolyevna Zhidkova ORCID 0000-0002-6831-9486

Marina Valer’evna Gurevich ORCID 0000-0002-3296-2680

Natalia Alexandrovna Rudnikova ORCID- 0000-0002-4827-0662

Vera Borisovna Pankova ORCID 0000-0002-3035-4710

Mikhail Frankovich Vilk ORCID 0000-0001-7103-2905

Konstantin Georgievich Gurevich ORCID 0000-0002-7603-6064

Victoria Alexandrovna Zaborova ORCID: 0000-0001-5044-1152

Oksana Mikhailovna Drapkina ORCID 0000-0002-4453-8430

References

1. Baek JH, Kim J-H, Kim B_N, Park SJ, Fava M, Mischoulon D, Lee D, Jeon HJ. Comparisons of Subthreshold Versus Full Posttraumatic Stress Disorder Distinguished by Subjective Functional Impairment Among Train Drivers: A Population-Based Nationwide Study in South Korea. Psychiatry Investig. 2017 Jan;14(1):1–7. doi: 10.4306/pi.2017.14.1.1. Epub 2016 Dec 29.
2. Wilson JR, Norris BJ. Rail human factors: Past, present and future. Appl Ergon. 2005 Nov;36(6):649–60. doi: 10.1016/j.apergo.2005.07.001.
3. Oliveira LC, Birrell S, Cain R. Journey mapping from a crew's perspective: Understanding rail experiences. Appl Ergon. 2020 May;85:103063. doi: 10.1016/j.apergo.2020.103063. Epub 2020 Feb 1.
4. Oliveira L, Birrell S, Cain R. How technology can impact customer-facing train crew experiences. Ergonomics. 2020 Sep;63(9):1101–1115. doi: 10.1080/00140139.2020.1772377. Epub 2020 Jun 11.
5. Evans AW. Fatal train accidents on Europe's railways: An update to 2019. Accid Anal Prev. 2021 Aug;158:106182. doi: 10.1016/j.aap.2021.106182. Epub 2021 May 27.
6. Gu GZ, Yu SF, Zhou WH, Wu H, Kang L, Chen R. Sleep quality and occupational stress relationship analysis of 1413 train drivers in a railway bureau. Zhonghua Lao Dong Wei Sheng Zhi Ye Bing Za Zhi. 2017 Jul 20;35(7):514–518. doi: 10.3760/cma.j.issn.1001-9391.2017.07.010. [Article in Chinese]
7. Lee DW, Kim SJ, Shin NY, Lee WJ, Lee D, Jang JH, Choi SH, Kang DH. Sleeping, sleeping environments, and human errors in South Korean male train drivers. J Occup Health. 2019 Sep;61(5):358–367. doi: 10.1002/1348-9585.12059. Epub 2019 May 3.

8. Evans AW. Rail safety and rail privatisation in Japan. Accid Anal Prev. 2010 Jul;42(4):1296–301. doi: 10.1016/j.aap.2010.02.007. Epub 2010 Mar 15.
9. Boschman JS, Hulshof CTJ, Frings-Dresen MHW, Sluiter JK. Improving fit to work assessments for rail safety workers by exploring work limitations. Int Arch Occup Environ Health. 2016 Jul;89(5):803–11. doi: 10.1007/s00420-016-1117-7. Epub 2016 Feb 11.
10. Saraei M, Najafi A, Heidarbagi E. Risk factors for obstructive sleep apnea among train drivers. Work. 2020;65(1):121–125. doi: 10.3233/WOR-193064.
11. Burtsev AA, Nenastieva AYu, Shuplyakova AV. Current aspects of training medical personnel and conducting pre-trip examinations in Russia: unresolved problems and development prospects. NARCOLOGY. 2017: 11: 19–27 [Article in Russian]
12. Maksimov I.B., Fesenko M.A., Sinopalnikov V.I., Diashev A.N. Telemetric control in assessing the working capacity of transport industry employees. Russian Journal of Occupational Health and Industrial Ecology. 2021;61(3):191–196. [Article in Russian] https://doi.org/10.31089/1026-9428-2021-61-3-191-196
13. Yuda E, Shibata M, Ogata Y, Ueda N, Yambe T, Yoshizawa M, Hayano J. Pulse rate variability: a new biomarker, not a surrogate for heart rate variability. *J Physiol Anthropol*. 2020 Aug 18;39(1):21. doi: 10.1186/s40101-020-00233-x.
14. Mejía-Mejía E, May JM, Torres R, Kyriacou PA. Pulse rate variability in cardiovascular health: a review on its applications and relationship with heart rate variability. *Physiol Meas.* 2020 Aug 11;41(7):07TR01. doi: 10.1088/1361-6579/ab998c.
15. Vasilevitskaya N.P. The decisive role of medical examinations in ensuring the safety of train traffic and the professional longevity of railway workers. Medicine of transport of Ukraine. 2015. No. 3–4 (55). pp. 60–64.[Article in Russian]
16. Mejía-Mejía E, Budidha K, Abay TE, May JM, Kyriacou PA. Heart Rate Variability (HRV) and Pulse Rate Variability (PRV) for the Assessment of Autonomic Responses. *Front Physiol*. 2020 Jul 23;11:779. doi: 10.3389/fphys.2020.00779. eCollection 2020.
17. Baek HJ, Cho J. Novel heart rate variability index for wrist-worn wearable devices subject to motion artifacts that complicate measurement of the continuous pulse interval. Physiol Meas. 2019 Nov 4;40(10):105010. doi: 10.1088/1361-6579/ab4c28.
18. Vescio B, Salsone M, Gambardella A, Quattrone A. Comparison between Electrocardiographic and Earlobe Pulse Photoplethysmographic Detection for Evaluating Heart Rate Variability in Healthy Subjects in Short- and Long-Term Recordings. *Sensors (Basel)*. 2018 Mar 13;18(3):844. doi: 10.3390/s18030844.
19. Liu S, Teng J, Qi X, Wei S, Liu C. Comparison between heart rate variability and pulse rate variability during different sleep stages for sleep apnea patients. Technol Health Care. 2017;25(3):435–445. doi: 10.3233/THC-161283.
20. Verma AK, Aarotale PN, Dehkordi P, Lou J-S, Tavakolian K. Relationship between Ischemic Stroke and Pulse Rate Variability as a Surrogate of Heart Rate Variability. Brain Sci. 2019 Jul 10;9(7):162. doi: 10.3390/brainsci9070162.

21. Okkesim S, Çelik G, Yıldırım MS, İlhan MM, Karaman Ö, Taşan E, Kara S. Comparison of Pulse Rate Variability and Heart Rate Variability for Hypoglycemia Syndrome. Methods Inf Med. 2016 May 17;55(3):250–7. doi: 10.3414/ME15-01-0088. Epub 2016 Apr 11.
22. Liao C-D, Tsauo J-Y, Hsiao D-J, Liou T-H, Huang S-W, Lin L-F. Association of physical capacity with heart rate variability based on a short-duration measurement of resting pulse rate in older adults with obesity. *PLoS One*. 2017 Dec 21;12(12):e0189150. doi: 10.1371/journal.pone.0189150. eCollection 2017.
23. Johnston BW, Barrett-Jolley R, Krige A, Welters ID. Heart rate variability: Measurement and emerging use in critical care medicine. J Intensive Care Soc. 2020 May;21(2):148–157. doi: 10.1177/1751143719853744. Epub 2019 Jun 11.
24. Routledge FS, Campbell TS, McFetridge-Durdle JA, Bacon SL. Improvements in heart rate variability with exercise therapy. Can J Cardiol. 2010 Jun-Jul;26(6):303–12. doi: 10.1016/s0828-282x(10)70395-0.
25. Cygankiewicz I, Zareba W. Heart rate variability. Handb Clin Neurol. 2013;117:379–93. doi: 10.1016/B978-0-444-53491-0.00031-6.
26. Shaffer F, Meehan ZM, Zerr CL. A Critical Review of Ultra-Short-Term Heart Rate Variability Norms Research. *Front Neurosci*. 2020 Nov 19;14:594880. doi: 10.3389/fnins.2020.594880. eCollection 2020.
27. Munoz ML, van Roon A, Riese H, Thio C, Oostenbroek E, Westrik I, de Geus EJC, Gansevoort R, Lefrandt j 2, Nolte IM, Snieder H. Validity of (Ultra-)Short Recordings for Heart Rate Variability Measurements. *PLoS One*. 2015 Sep 28;10(9):e0138921. doi: 10.1371/journal.pone.0138921. eCollection 2015.
28. Esco MR, Flatt AA. Ultra-short-term heart rate variability indexes at rest and post-exercise in athletes: evaluating the agreement with accepted recommendations. *J Sports Sci Med.* 2014 Sep 1;13(3):535 – 41. eCollection 2014 Sep.
29. Chen Y-S, Clemente FM, Bezerra P, Lu Y-X. Ultra-short-term and Short-term Heart Rate Variability Recording during Training Camps and an International Tournament in U-20 National Futsal Players. Int J Environ Res Public Health. 2020 Jan 26;17(3):775. doi: 10.3390/ijerph17030775.
30. Wu L, Shi P, Yu H, Liu Y. An optimization study of the ultra-short period for HRV analysis at rest and post-exercise. J Electrocardiol. Nov-Dec 2020;63:57–63. doi: 10.1016/j.jelectrocard.2020.10.002. Epub 2020 Oct 11.

Figures

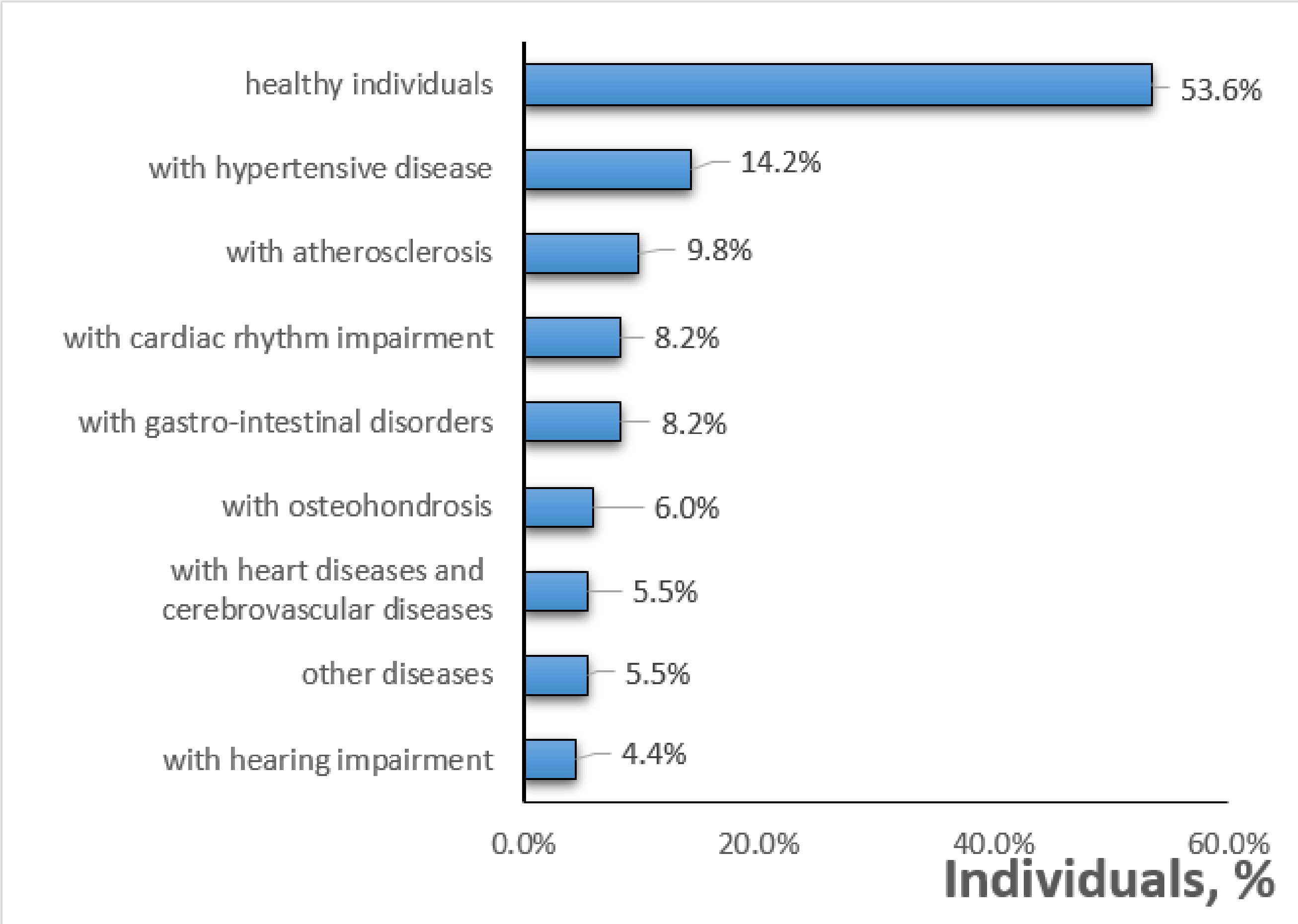

Figure 1

Frequency of various conclusions about health status of members of train crews based on the results of a medical expert commission. The total number exceeds 100%, since one employee could have been diagnosed with several diseases

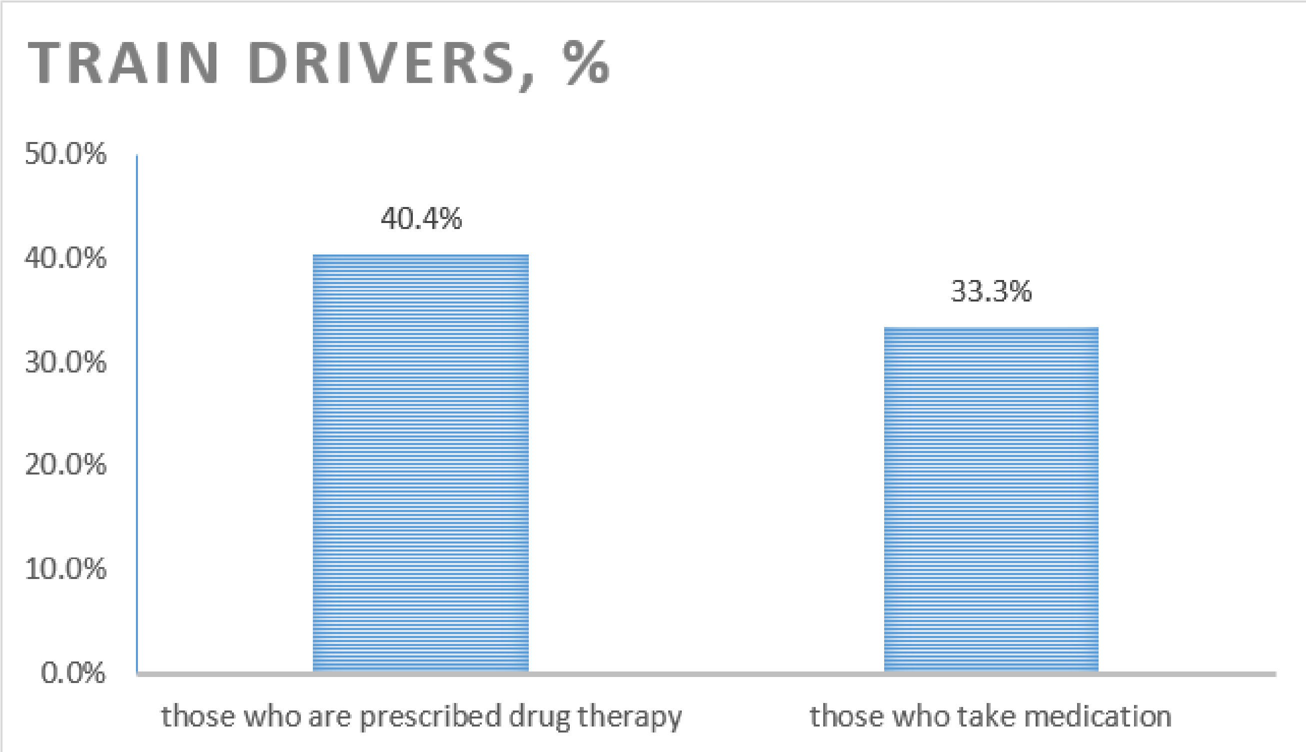

Figure 2

The frequency of prescribed drug therapy and the adherence to medical recommendations by members of train crews

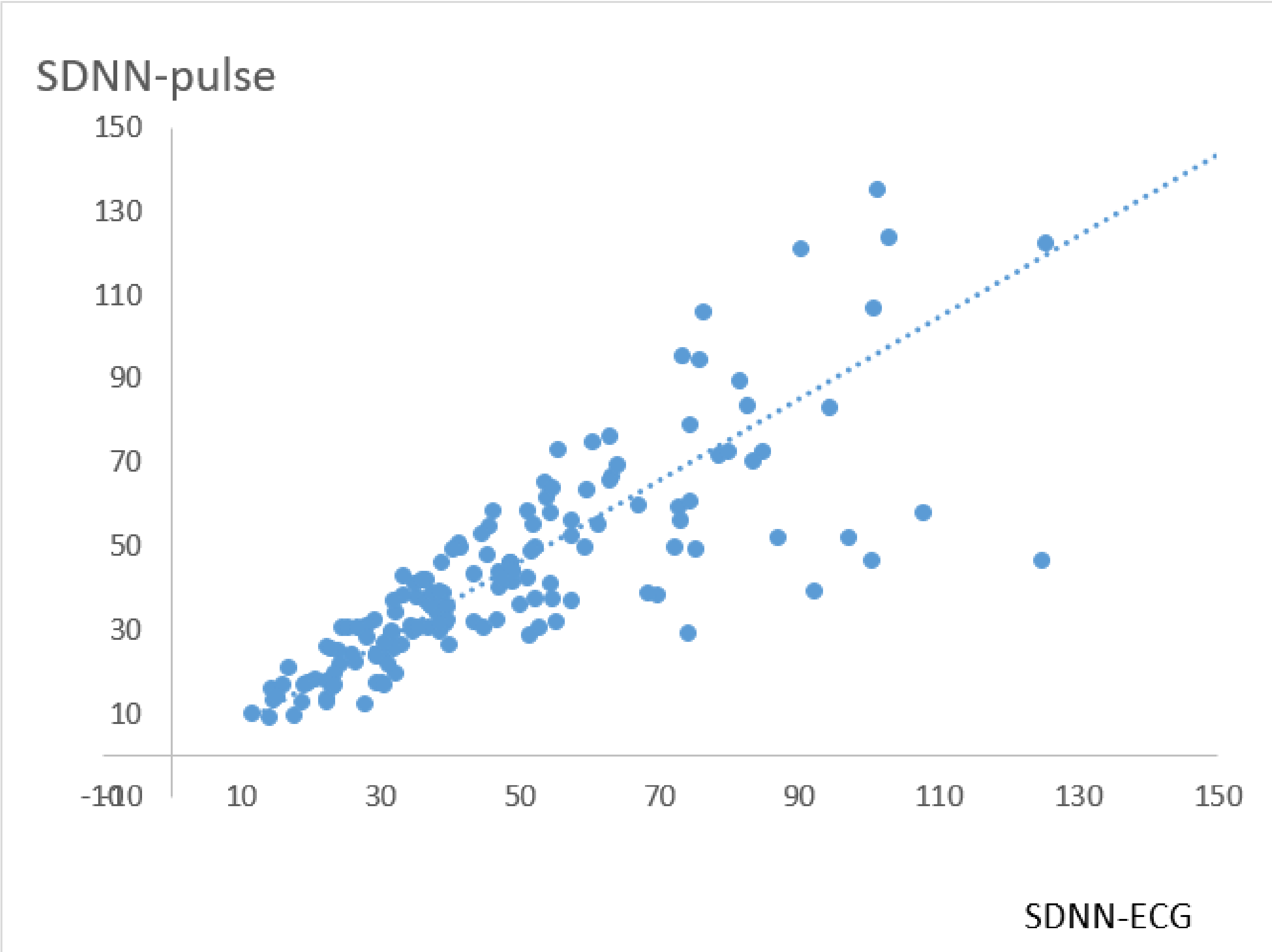

Figure 3

Correlation relationships of heart rate variability parameters calculated from pulse measurements and ECG. The dots represent the results of specific measurements. The approximation line intersects the axes at 0.