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# HEART RATE VARIABILITY AS A STRAIN INDICATOR FOR PSYCHOLOGICAL STRESS IN EMERGENCY MEDICAL SERVICES PERSONNEL DURING WORKING DAYS: A SYSTEMATIC REVIEW

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*Introduction*. Emergency medical services personnel have highly variable workloads. The resulting stress can differ intra- or inter-individually. Consequences for health arise when there is insufficient compensation for prolonged stress. The analysis of heart rate variability (HRV) is a valid noninvasive method for the objective monitoring of workload in the occupational medicine.

*The aim of the research* is to systematically evaluate the literature on HRV as an objective indicator of the mental stress faced by emergency medical services personnel.

*Materials and methods of the research*. A systematic literature review examining the HRV of prehospital emergency medical services personnel in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement for reporting systematic reviews was performed. PubMed, Ovid, Cochrane Library, Scopus, and Web of Science electronic databases were used. Modified STARD for HRV was used to evaluate the methodological quality of HRV measurement. Two authors independently reviewed the papers and performed the evaluations.

*Results*. The literature search identified 5,637 citations. Four studies were included that investigated HRV during working days compared to nonworking days, but no focus on alert operations. Two studies used Holter electrocardiographic, and two used chest belts. Two studies evaluated cardiac autonomic function in the time and frequency domains, and the other two studies used only the time domain. The results showed an adaptation of HRV under working conditions. The studies were not comparable, because the study protocols were different.

*Conclusions*. There is a need for occupational health studies that examine the strains and stress of emergency medical services personnel, especially under alert interventions. The well-established HRV parameters seem to be suitable for objectively measuring stress. HRV measurement is also suitable for active alert and operation around the patient. Future research should further additionally investigate nonlinear parameters or parameters without clear assignment. Guideline standards should be respected.

**Key words: heart rate variability, workload, mental stress, rescue workers, alarm, rescue**

## Introduction

Emergency medical services personnel are constantly exposed to multiple occupational stressors, such as working in dangerous and uncontrollable conditions, having limited use of equipment and resources, witnessing serious accidents with or without deaths, facing threats and violence, performing shift work, having inadequate and interrupted break times, making decisions under pressure regarding the care of patients in critical condition, witnessing other types of death, facing the risk of infection transmission and encountering threats from mentally unstable and intoxicated patients [2, 5, 29]. As a result, these personnel experience a high level of stress and suffer from chronic stress, which could cause stress-related consequences [2] such as fatigue [9, 22], sleep disorders [9, 22], job dissatisfaction [33], anxiety [3], burnout [11], depression [3], suicide [36], career changes [6], and posttraumatic stress disorder [15].

Occupational stressors widely vary in different work conditions, interpersonal relationships, cultures, and social interactions and are affected by intraindividual cognitive variability [2, 24]. These factors likely play a role in both risk and resilience to stress-related consequences [24].

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An objective measurement of subjective stress is highly relevant and important for research, occupational medicine and clinical practice [7]. In addition to the determination of, e. g., stress hormones, skin temperature, and electrodermal or muscular activity, the determination of vegetative functions is possible [7]. These include respiratory rate, blood pressure, heart rate and heart rate variability [7]. Heart rate variability (HRV) is a very sensitive indicator that indicates mental stress in the case of a significant decrease or indicates fatigue in the case of a moderate decrease [7]. HRV is well established as a noninvasive recording method in occupational medicine [16, 26]. It can be determined from 24-h electrocardiographic (ECG) recording so that subjects perform their usual daily/work activity. The 24-h recording is the gold standard of HRV analysis [26, 34]. During HRV analysis, the interaction between the sympathetic and parasympathetic nervous systems is assessed to make conclusions about different subjective stresses: in rest and recovery phases of the body, the activity of the parasympathetic nervous system dominates, whereas in chronic stress situations, the activity of the sympathetic nervous system dominates [26]. Time, frequency and nonlinear domains are available for HRV analysis [26]. An overview of HRV parameters and norms is provided by various publications and guidelines [25, 26, 31, 34]. The HRV parameters that are markers of vagal function are, for example, the root mean square of successive differences (RMSSD), percentage of successive NN intervals that differ by more than 50 ms (pNN50), high-frequency spectrum (HF, HF %, HFnu) and standard deviation of a point plot to the transverse diameter (SD1) [26, 27]. Other parameters are without clear assignment and can be influenced by the sympathetic and parasympathetic nervous systems (e. g., LF, LF/HF) [26]. HRV analysis should be viewed critically. Adequate analysis time should be chosen for each question, e. g., 24-h, short-term (5 min), and ultrashort-term (< 5 min) periods [31]. The numerous factors that impact HRV expression should also be considered [26]. In addition to the objective evaluation of stress, the following additional subjective evaluation of stress is recommended, for example, questionnaires such as mental fatigue, stress levels, levels of monotony, burnout, or mental health [7].

*The aim of the study* of this systematic review is to evaluate the literature on heart rate variability as an objective indicator of mental stress in emergency medical services personnel during their work (during alert operations) in comparison to their leisure time. The work of emergency medical services personnel is restricted to certain time limits for saving lives during alert operations, which can cause additional stress. In addition, the job is characterized by shift work, which can also last 24 h (including night work) and differs from the normal working day. We hypothesized that in periods of work, there is a greater reduction in vagal tone.

## Materials and methods of the research

A systematic literature review was performed to examine heart rate variability in emergency medical services personnel. This was in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement for reporting systematic reviews [20]. The complete study protocol is available at Prospero via the link https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42021241863.

The electronic databases PubMed, Ovid, Cochrane Library, Scopus and Web of Science were used (September 15, 2022). The search terms were defined as follows (here, for example pubmed search): (ambulance service) OR (emergency medical service) OR (ambulance crew) OR (ambulance men) OR (ambulance driver) OR (emergency workers) OR (paramedic) OR (emergency medical technician) OR (paramedic service) OR (rescue service) OR (frontline workers) OR (emergency paramedic) AND (heart rate variability) OR (HRV) OR (cardiac autonomic control) OR (autonomic function) OR (parasympathetic activity) OR (parasympathetic nervous system) OR (cardiac vagal tone) OR (autonomic cardiac modulation) OR (vagus nerve) OR (vagal tone) OR (vagal activity) OR (coefficient of variation). Only articles since January 1, 2005 (used as filter), were included because the method of HRV analysis was undergoing major technical progress at that time. Another filter was «humans». The authors suspected insufficient comparability to previous HRV analyses.

Regarding the inclusion criteria, studies needed to involve workers in emergency medical services (only in prehospital setting, not affiliated with a hospital), measurement of HRV before or after and during working hours with a protocol of activity, classification into different psychological groups, recording of heart rate through a Holter ECG or chest belt, clear state-

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ment of the data treatment for abnormal or ectopic beats, and full text in the English or German language. The exclusion criteria included having diseases relevant to HRV analysis, such as a diagnosis of mental or neurological diseases, endocrinological diseases (diabetes, thyroid gland disease), cardiac diseases, hypertension, or others. In addition, review articles, guidelines, single-case studies, theses, dissertations, scientific conference abstracts and HRV assessment with automatic pulse rate or photoplethysmography were also excluded. The national guidelines on HRV do not suggest the method of pulse rates or photoplethysmography for measurement [26, 34]. Because of the small number of cases, we deviated from the protocol and included one study with a subject number of 9 [19] and one study with an HRV measurement twice in 12 h [37].

A manual search was performed by checking the reference lists of the included studies, but we found no results. An overview of the procedure is shown in Figure.

The articles found via the literature search were transferred to the reference manager Citavi 6 (Swiss Academic Software, Wädenswil, Switzerland). Duplicates were removed, and two authors (B. Thielmann and L. Voß) independently reviewed the titles and abstracts according to the inclusion and exclusion criteria. The full text of each relevant article was acquired. The authors B. Thielmann and L. Voß independently screened the full text of these articles. If no full text was available, the authors were contacted, or the articles were ordered via interlibrary loans from the Faculty of Medicine. Disagreements were resolved through discussion with the third and fourth authors (I. Böckelmann and H. Schumann).

The methodological quality of the included studies was evaluated using the Standard for Reporting Diagnostic Accuracy Studies (STARD) guidelines [8, 10, 18, 23]. The same two authors (B. Thielmann and L.Voß) used a modified STARD for HRV [12]. It included 25 items, so a maximum of 25 points could be achieved. We modified the assessment tools slightly, as done in previous work [14]. However, the maximum score did not change. Disagreement was solved by discussion with the third and fourth authors (I. Böckelmann and H. Schumann).

The HRV parameters of all four studies were assessed. Increases are marked with an upward arrow, decreases with a downward arrow, and no change with an arrow pointing to the left and right. Significant changes were marked with an asterisk. The HRV parameters used in the studies and their assignment to the autonomic nervous system (ANS) are shown in Table 1.

## Results of the research and their discussion

The literature search identified 5,637 citations. There were 13 usable studies after review of the abstract and evaluation inclusion and exclusion criteria considering deviation from the protocol. Finally, 2 studies matched the inclusion criteria with the use of HRV between working days [1, 21]. Two other studies used HRV during working days, but the protocol differed [19, 37]. There was no focus on alert operations. One study differentiated between emergency medical services personnel with few or many health complaints [1]. The total shift was assessed. Only one study reported the number of alert deployments ($4.4 \pm 2.8$) during the shift [21]. An overview of the four included studies is shown in Table 2.

The four studies comprised a total of 70 subjects. Only 9 women (13 %) were included in two studies [1, 37]. The age ranged from 20 years [21] to 52 years [19]. Three studies used a within-subject design that examined emergency medical services personnel during working days and nonworking days [1, 19, 21]. One study assessed them only during working days [37]. One study differentiated between emergency medical services personnel in the field or as dispatchers in the control center and shift work and only working days [37].

Two studies used Holter ECG [1, 19], and two used chest belts [21, 37]. Two studies evaluated cardiac autonomic function in the time and frequency domains [21, 37], and the other two studies used only the time domain [1, 19]. Nonlinear HRV parameters were not presented. Because of the measurement in the field, a breath-controlled measurement and a stabilization phase were not used in all studies. Additionally, short-term measurements of heart rate variability were not used as baseline values.

*Outcome of heart rate variability in the time and frequency domains*

Table 2 compares the results of all HRV measurements. Emergency medical services personnel with many health complaints showed significantly increased LF and significantly decreased HF on working days compared to nonwork days, especially during late

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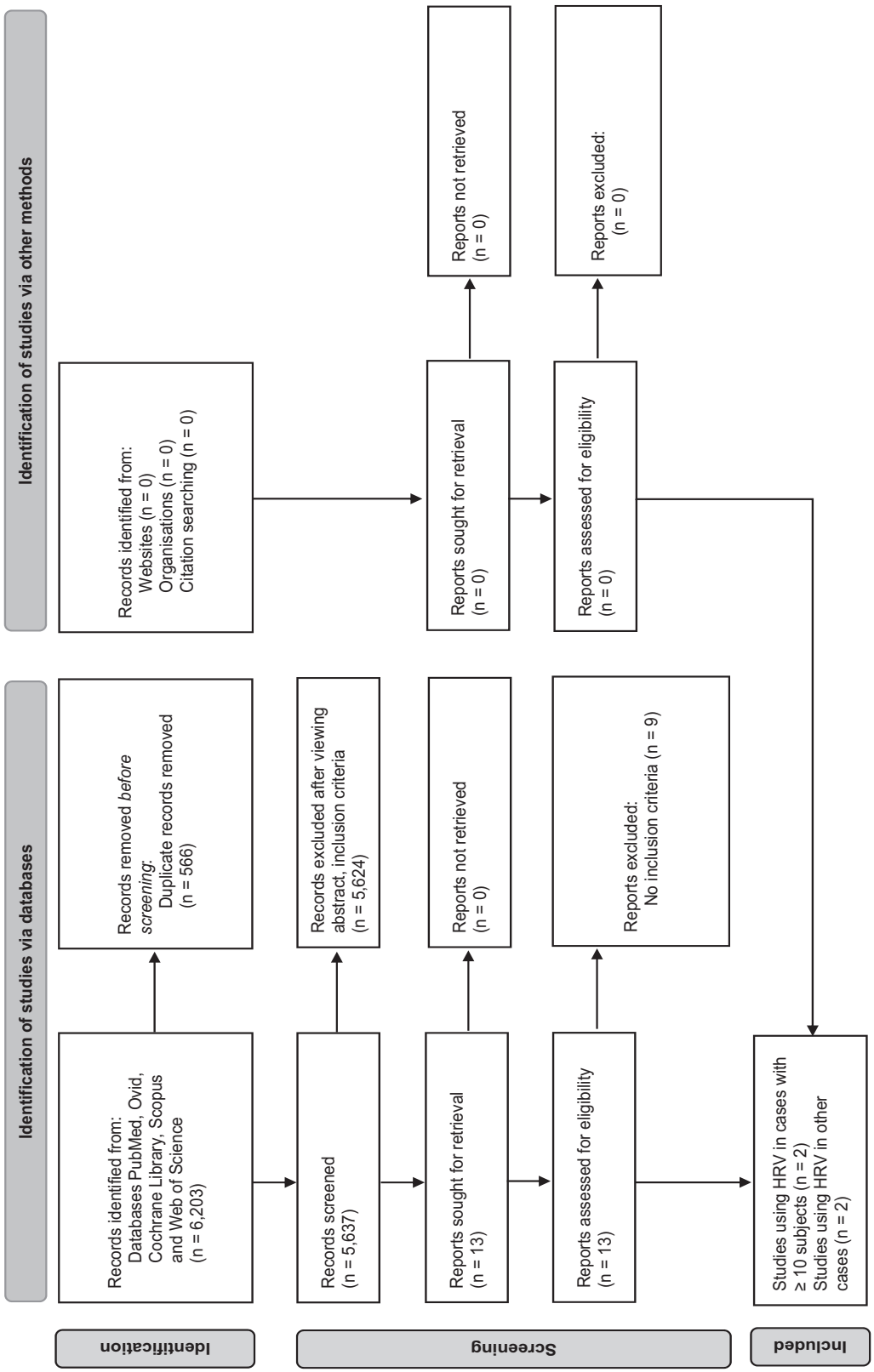


*Figure. Flow chart of data collection*

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Table 1

**HRV parameters and their meaning of the studies under review**

| HRV parameter | Definition and explanation | Part of ANS |
|---|---|---|
| *Time domain* | | |
| SDNN [ms] | Standard deviation of all normal-to-normal R-R (NN) intervals | Sympathetic and parasympathetic nervous system |
| RMSSD [ms] | Root mean square of successive differences of NN intervals | Parasympathetic nervous system |
| pNN50 [%] | Percentage of successive NN intervals that differ by more than 50 ms | Parasympathetic nervous system |
| *Frequency domain* | | |
| HF [$ms^2$] | High frequency power | Parasympathetic nervous system |
| LF [$ms^2$] | Low frequency power | Sympathetic and parasympathetic nervous system |
| LF/HF | LF/HF ratio; Quotient between LF and HF power | Sympathetic and parasympathetic nervous system |
| HF/(HF+LF) | HF/(HF+LF)-ratio | Parasympathetic nervous system |

nights and the early morning hours of the work shift [1]. No significant differences in HRV parameters were found in subjects with few health complaints. It should be noted that subjects with many health complaints were significantly older [1]. The second study found no significant differences between waking and sleeping periods on work days for the HRV parameters LF/HF and HF/(HF + LF), but compared to the values for nonworking days, LF/HF was significantly increased and HF/(HF + LF) was significantly decreased in the awake phase. The third study showed significantly decreased SDNN and HF during working days in comparison to nonworking days [21]. The fourth study found significantly decreased RMSSD in dispatchers compared to emergency medical services personnel in the field [37]. Emergency medical services personnel doing shift work showed reduced HRV parameters compared to those of day workers, but the difference was not significant [37].

*Quality assessment of HRV measurement*

The quality of the HRV methodology was assessed by STARDHRV [12]. The scores were 11.5 [1], 12.5 [19], 15 [37] and 16.5 points [21]. For all studies, full points were given for elevation points 1 (identification as a study of validation), 2 (structured summary of study objective, design, methods, the results, and conclusions), 9 (setup of reference standard and index device described in sufficient detail to allow replication), 14 (description of how estimates or comparison measures were calculated), and 24 (full study protocol). Faults for all studies (zero points) were found in the case of elevation points 6 (intended sample size and how it was determined), 8 (pretesting guidelines reported), 10 (description of environmental conditions), 11 (stabilization period prior to sampling was described), and 13 (acknowledgment of breathing). Points 7 (eligibility criteria including specific restrictions), 12 (raw sampling rate and length of collection), 16 (interbeat artifact identification method), 17 (artifact cleaning methods and percentage of beats corrected), 18 (description of metrics used and software), 19 (specification of frequency bands used and how they were calculated), and other points were listed only in isolated cases.

*Discussion and Conclusions*

The aim of this systematic review was to summarize the existing literature on heart rate variability in emergency medical services personnel during their work.

The HRV parameters used in the studies provide information about the measured workload. The trend in HRV parameters appears to be adaptive to the stress situation of emergency medical services personnel on working days. One study concluded that

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**Table 2**

**Included studies with HRV assessment of emergency medical services personnel during working day**

| Author, year, country | Characteristics of subjects | HRV | Outcome and measurement of HRV | STARD HRV from (max. 25) |
|---|---|---|---|---|
| Aasa, 2006, Sweden | n = 26 (women 8 %, men 92 %), Age from 2 groups: few health complaints: (31 ± 4) years, many health complaints: (43 ± 9) years, no diagnosed healthy problems | 24-h ECG Holter<br><br>between groups within subject design: WD, post-work evening, RD 1 and 2 | *few health complaints:* LF, HF no significant differences<br><br>*many health complaints*: **LF↑***, **HF↓*** on work day compared to nonwork days; especially during late night and early morning hours of the work shift<br><br>*between groups:* **LF***: many health complaints > few health complaints; HF* few health complaints > many health complaints<br><br>*age**: many health complaints > few health complaints | 11.5 |
| Mitani, 2006, Japana | n = 9 (men 100 %) age: 39.7 ± 9.3, healthy | 24-h ECG Holter within subject design: WD, RD for waking and sleeping time between awake, sleep | *work day:* LF/HF, HF/(HF+LF) no significant differences between waking and sleeping time<br><br>*nonwork day:* **LF/HF*, HF/(HF+LF)*** between waking and sleeping time (awake phase: LF/HF higher, HF/(HF+LF) lower) | 12.5 |
| Neufeld, 2017, USA | n = 14 (men 100 %) age: 27 ± 7, healthy | 24-h ECG chest belt within subject design: sleeping time on WD and RD | *work day*: **SDNN↓*, HF↓*** in comparison to nonwork day | 16.5 |
| Wong, 2012, Canada[a] | n = 21 (women 33 %, men 67 %), age from 4 groups: only day (43.1 ± 6.6) years, rotating shift: (40.4 ± 7.9) years, ambulance worker: 43.1 ± 7.7, dispatcher: 37.6 ± 5.6, healthy | 2x12 hours during WD chest belt, between subject design | rotating shift: pNN50↓, RMSSD↓, HF↓ compared to day workers;<br><br>dispatcher: pNN50↑, **RMSSD↓***, HF↓ compared to ambulance worker | 15 |

*Notes. [a]Protocol deviation; significant p-values are marked with asterisks (*for p < 0.05). SLS = stable low strain, RHS = recently high strain, PHS = prolonged high strain. WD = working day, RD resting day. HRV parameter: Time domain: SDNN (standard deviation of all normal-to-normal R-R intervals, RMSSD (root mean square of successive differences of R-R intervals, pNN50 (percentage of successive NN intervals that differ by more than 50 ms). Frequency domain: LF (low frequency power, 0.04–0.15 Hz), HF (high frequency power, 0.15–0.4 Hz), LF/HF-ratio, HF/(HF+LF)-ratio.*

circadian variation in the cardiac autonomic nervous system is disturbed on working days [19], but the number of subjects studied was very small. The study protocols are inconsistent, so that the HRV parameters can be assessed only to a limited extent. Generalization is not possible. Because the studies are voluntary, selection bias is to be expected. Therefore, we recommend that researchers use quality

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criteria for recording cardiac actions and perform HRV analysis according to international and national guidelines. Deficiencies were found in the methodological quality and in the quality of study reports regarding HRV. Monitoring during workdays (regardless of whether alarm operations or normal work) could lead to movement artifacts, which limits assessment. Conducting further research is needed here. The search did not include the keyword «prehospital care», but the keyword «paramedic» explains the prehospital setting.

Similar to emergency physicians [35], there is a need for and high potential for occupational health studies to objectively measure the workloads of emergency medical services personnel during their work but also during alert operations. The first studies show an increasing workload among paramedics, especially under the SARS-CoV-2 pandemic [28, 30]. For example, studies show that paramedics have suffered significantly from emotional exhaustion and depersonalization as symptoms of burnout [17] or suffered from burnout [13, 32]. Burnout can be seen here because of inadequate stress management. The use of an additional objective stress analysis is particularly useful in highly stressful occupations, such as those performed by surgeons in the intraoperative setting [4, 7, 26]. HRV is a suitable method to objectify subjective stress noninvasively. The use of a chest belt increases comfort and seems to be especially useful during alert operations. In addition to the previously established HRV parameters, newer parameters should be evaluated (e. g., nonlinear parameters). This also applies to parameters without a clear assignment thus far. The use of a standardized study protocol (e. g., measurements before, during, and after an alarm intervention and comparison to a normal workday) are recommended.

*Practical conclusion*

They subjective stress should be objectivized, especially for emergency medical services personnel with high subjective stress. HRV is a suitable method for this purpose. It can be performed as an ECG or via a chest belt. More research is needed here among emergency medical services personnel. Emergency physicians are better studied, but also with research gaps.

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## ВАРІАБЕЛЬНІСТЬ СЕРЦЕВОГО РИТМУ ЯК ПОКАЗНИК НАПРУГИ ПСИХОЛОГІЧНОГО СТРЕСУ В ПЕРСОНАЛУ ШВИДКОЇ МЕДИЧНОЇ ДОПОМОГИ ПРОТЯГОМ РОБОЧОГО ДНЯ: СИСТЕМАТИЧНИЙ ОГЛЯД

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*Вступ*. Персонал служби екстреної медичної допомоги має дуже різноманітне робоче навантаження. Результуючий стрес може різнитися всередині чи між індивідуумами. Наслідки для здоров'я виникають за недостатньої компенсації тривалого стресу. Аналіз варіабельності серцевого ритму (ВСР) є дієвим неінвазивним методом об'єктивного моніторингу робочого навантаження у медицині праці.

*Мета дослідження* – систематична оцінка літератури з ВСР як об'єктивного показника психічного стресу, з яким стикається персонал служб невідкладної медичної допомоги.

*Матеріали та методи дослідження*. Проведено систематичний огляд літератури з вивчення ВСР персоналу догоспітальної невідкладної медичної допомоги відповідно до Положення про кращі звітні одиниці для систематичних оглядів та метааналізу (PRISMA) для звітності щодо систематичних оглядів. Використано електронні бази даних PubMed, Ovid, Cochrane Library, Scopus та Web of Science. Модифікований STARD для ВСР використовували для оцінки методологічної якості вимірювання ВСР. Два автори незалежно розглянули документи та виконали оцінки.

*Результати*. Пошук літератури виявив 5637 посилань. Було включено чотири дослідження, в яких вивчалася ВСР у робочі дні порівняно з неробочими днями, але без акценту на невідкладні дії. У двох дослідженнях використовувалася холтерівська електрокардіограма, а у двох – нагрудні ремені. У двох дослідженнях оцінювалася вегетативна функція серця в тимчасовій і частотній областях, а в двох інших дослідженнях використовувалася лише тимчасова область. Результати показали адаптацію ВСР до умов праці. Дослідження були порівняні, оскільки протоколи досліджень були різними.

*Висновки*. Необхідно провести дослідження в галузі гігієни праці для вивчення напруги та стресу персоналу служб невідкладної медичної допомоги, особливо за невідкладних втручань. Параметри ВСР, що добре зарекомендували себе, є придатними для об'єктивного вимірювання стресу. Вимір ВСР також підходить для активного оповіщення та роботи поряд з пацієнтом. Майбутні дослідження повинні додатково досліджувати нелінійні параметри або без чіткого призначення. Керівні стандарти повинні дотримуватись.

**Ключові слова: варіабельність серцевого ритму, робоче навантаження, психічна напруга, рятувальники, тривога, порятунок**

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