# Heart Rate Variability Measurement to Assess Work-Related Stress of Physical Workers in Manufacturing Industries - Protocol for a Systematic Literature Review

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***Abstract*—Although Industry 4.0 automation has replaced the human workforce by machines in industries, physical workers are indispensable in many facilities. One primary source of stress in the manufacturing workplace is inappropriate work content (e.g., unreasonable workload and work pace). With workers facing physical activities or machine operations, work-related stress can affect their performance and cause productivity, quality, and safety problems. Thus, industrial managers constantly seek ways to ease stress among their workforce, as Healthy Operator is proposed as an essential pillar of the Operator 4.0 concept. As the first step of stress reduction is to identify the stress (if possible, its early signs), heart rate variability (HRV) is widely measured, with different methods and technologies adopted to assess the stress levels of workers. Recent technological advancements have developed many non-invasive measurement techniques and systems, offering more convenience and flexibility than traditional clinical methods. Since human centricity is a strategic focus of the forthcoming Industry 5.0 initiative proposed by the European Union, these measurement practices should be disseminated and shared to foster better stress identification and reduction. A systematic literature review is needed to deliver a comprehensive update in the field. Besides synthesizing the relevant development, the review study aims to motivate industrial managers to adopt a similar approach and provide helpful guidance on what to expect with the Heart Rate Variability measurement for the workplace stress assessment. A detailed protocol for the systematic literature review is given.**



***Keywords*—** heart rate variability, stress, manufacturing industry, Operator 4.0, Industry 5.0, systematic literature review



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## I. Introduction

Without a universally recognized definition, stress can be considered in behavioral sciences as emotional tension, anxiety, discomfort with adverse events, and demanding circumstances [1]. According to World Health Organization (WHO), occupational stress-related hazards can be divided into work contents and work context [2]. Work-related stress is the response the workers have been presented with when facing work demands and pressure that out-weight their knowledge and abilities. Poor work organization (i.e., the design of jobs and work systems) and unsatisfactory working conditions can be the stressors, which finally affect work performance [3], [4]. This effect reduces the cognitive coordination of hands during a task execution [5] and exacerbates the exposure to noxious physical-chemical agents in the work environment [6]. Early theoretical studies suggested that when the employee experiences stressful aspects of jobs (stressor), his existence can be affected as a result (strain), [7], [8]. The experienced stress-caused symptoms or outcomes can be categorized as physiological, psychological, or behavioral symptoms [9]. Consequently, the relevant stressors that affect the Occupational Health and Safety (OHS) of the human workers need to be carefully tracked and managed with a proper management system [10].

In manufacturing industries, the work contents can be listed as the primary stressors in the workplace, including workload and work pace, which can be measured in terms of the number of working hours, level of production, or the demand of the work itself. Taking into consideration the case of physical workers, the stress influence of work contents will have a more negligible correlation than the other two job stressors (i.e., organizational constraints and interpersonal conflict) but have a direct relation with physical symptoms [11].

According to many studies on stress in the workplace, a certain level of stress can be helpful to stay focused, thus yielding the best performance [12], [13]. The connection between human arousal and behavioral task performance is described in Yerkes-Dodson Law [14], which states that there is an optimal level of arousal for optimal performance, and over or under-arousal reduces task performance. In manufacturing industries, the performance can be indicated by the operational parameters such as productivity and quality indexes. On the other hand, working in an industrial manufacturing environment with robots, machinery, and parts requires the worker a certain amount of situational awareness [15], which contributes significantly to his safety performance. However, if the work content is overloaded and job stress is accumulated, the situational awareness can be reduced considerably [16], thus causing occupational accidents.

From past relevant literature, the relationship between the performance of human workers and their stress levels is illustrated in Fig. 1. The far left corner of the figure indicates that a relatively minor stress level can create sufficient concentration, yielding a good safety awareness during the work. Nevertheless, the resultant pressure is insufficient to maintain high productivity or output quality performance. The far-right corner shows the opposite scenario: facing a relatively high-stress level reduces situational awareness, yielding more incidence. On the other hand, stress-harmed work motivation can reduce productivity and quality or reduce cognitive ability. The ideal state region is in the middle of the stress levels spectrum, showing the mild stress level, which fosters the best work performance while maintaining a sound awareness of incident cautiousness.

On the other hand, as physical workers usually face harsh work environments, the stress-caused consequences are severe. Repeated exposure to stressful conditions such as body motion and posture, physical effort, active hazards, and environmental stressors at the workplace can have a detrimental effect on both physical and mental health [17]. This effect results in reducing cognitive ability and eventually increasing the accident occurrence [18].

Many attempts have been made to interpret and define work contents stress to detect and prevent it from accumulating. A questionnaire, self-report, or observation is the most conventional technique to measure stress and its effect [19], [20]. The factor analysis in [20] indicated that stress and its reversal (i.e., satisfactory) seriously affect employee productivity. Not only found in office workers, but a similar connection can also be observed in industrial workers [21], with a negative impact of occupational stress on productivity. However, this traditional pen-and-paper stress assessment takes time to implement and cannot yield timely intervention.

Due to that drawback, the stress assessment method based on physiological indicators is widely adopted. One objective, reliable indicator of stress is HRV, with its usability for interpreting stress is scientifically proven by neurobiological evidence [22]. HRV is defined as the fluctuation of the interval between two consecutive heartbeats, which has intrinsic mathematical chaotic characteristics, making it a reliable reflection of many physiological factors [23]. With the attributes of non-invasive, safe, easy to use, and simple diagnostic test, it can replace traditional cardiovascular diagnostic tools [24]. Thanks to its flexibility usage, many HRV metrics in time-domain, frequency-domain, and non-linear measurement are study subjects for optimal performance by clinicians and researchers [25].

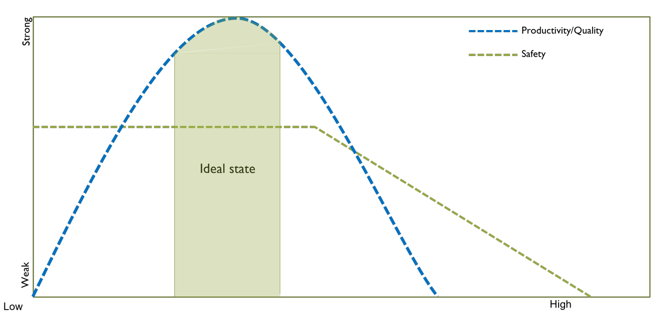


Fig. 1. The ideal working state for industrial workers.

As Industry 4.0 (I4.0) brought game-changing technological advancement, the measurement of HRV to assess the stress levels of workers can be more mobilized. Wearable Electrocardiogram (ECG) device is deployed to measure HRV among nurses in public hospitals [26], considering the environment can cause a high-stress level. The biofeedback of HRV contributes effectively to the stress management initiative [27] or assessing heat strain from environmental stressors [28]. With the I4.0 connectivity, the HRV measurement can serve further purposes, such as upgrading occupational safety, health, and productivity [29]. Along with the digitization and intelligentization of manufacturing processes, a strict integration of human operators in the production system is also interested [30], which aims at an effective utilization and occupational well-being of human resources [31]. Integrating humans with the conventional cyber-physical systems (CPS) established the Human-Cyber-Physical System (H-CPS), in which humans and CPS cooperate to achieve ultimate goals in the shared workspace [32]. These advancements facilitate stress management in a real-time manner and support industrial managers make decisions on time. Thanks to the current growth of technological progress, effective use of labor is expected with higher productivity [33]. For a socially sustainable manufacturing workforce, the ideal symbiosis work system consisting of H-CPS and adaptive automation is proposed in [34]. The Operator 4.0 concept is developed as a new generation of smart operators with new skills and gadgets provided by the I4.0 technologies [35]. With wearable trackers deployed to enhance personal physical and cognitive interaction, the activities of workers can be collected along with their heart rate and other health-related metrics. According to the proper occupational effort and stress levels, the ultimate goal is to adjust the work content, such as their work shifts, rest-break, and physical workload. This concept is elaborated as Healthy Operator 4.0 [36], with the potential from existing technologies [37].

Industry 5.0 (I5.0) is projected by the European Union (EU) as a sustainable, human-centric, and resilient expansion of the existing I4.0 [38], which aims at the further permeation of technologies for developing the shop-floor a better environment, facilitate higher value-added activities from human workers [39]. The production of the future should be built with the human worker at the center of digitization [40], [41], including occupational health, safety, and productivity [42]. For better preparation of the forthcoming I5.0, the best practice of HRV measurement to assess the work content stress of physical workers should be widely shared among manufacturers. Based on the feedback, the work content can be updated and adjusted for a personal fit with the respective worker, thus enhancing his performance.

This research aims to conduct a systematic literature review (SLR) to provide a thorough and comprehensive up-to-date report about the available evidence on HRV measurement using non-invasive methods to assess work content-related stress of physical workers in manufacturing industries. This paper describes the research protocol developed to perform the interested SLR, with the relevant criteria, research questions, and steps to be conducted. In addition, possible applications of the research results are highlighted, and suggest recommendations for future works.

## II. Research Method and Process

By searching in both breadth and depth of the prior existing studies, summarizing, analyzing, and synthesizing the related research [43], an SLR can assess the validity, quality, weaknesses, in-consistences, and contradictions [44], thus providing a solid foundation for further research. Following the Preferred Reported Item for

Systematic review and Meta-Analysis (PRISMA) [45], the intended SLR should investigate different methods of HRV measurement and the way they are deployed within different manufacturing contexts.

There are existing SLRs that can be considered of close interest, as they:

- Discovered the pattern of HRV associated with occupational health [46].
- Study the relationship of HRV with stress [22]
- Synthesize the deployment of smart devices to monitor physiological parameters (including HRV) for stress management purposes [47]

However, these SLRs lack meta-analysis and fail to diagnose the association of HRV measurement with the stress levels caused by work contents. Without any quantitative synthesis of the evidence that HRV can measure work content-related stress, any modification in the workplace can not yield a collective result.

## III. Protocol for a Systematic Literature Review

This section describes the protocol for the intended scoping review, which complies with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (PRISMA) [48]. Though the International Prospective Register of Systematic Reviews (PROSPERO) [49] does not support scoping review, the authors endorse transparency in the research process by publishing this protocol. The main steps to elaborate the SLR are conducted, taking the procedure mentioned in [43] as guidance. The authors are also inspired by how to conduct a review related to digital biomarker-based intervention in [50]. The objectives of the intended SLR are as follow:

- Identify the studies of non-invasive HRV measurement to assess the work content-related stress of physical workers in the manufacturing industries.
- Explore the relevant technical enablers.
- Identify important research gaps and sketch the framework for the future development of physiological monitoring systems for physical workers.

### A. Review questions

The primary review question is: *What are the current methods of non-invasively measuring HRV to assess occupational stress of physical workers in manufacturing industries?*

More specifically, the proposed systematic review will answer the following questions:

1) What are the industries and occupational stress types in the included studies?
2) What are the non-invasive methods and technologies deployed for collecting the HRV, and the methods to assess the stress levels of physical workers based on the collected data?
3) What are the data management and processing methods for the recorded data?
4) What are stress levels in manufacturing industries: individual, group, and corporate scale? What is the suggestion to cope with work content-related stress in the included studies? What are HRV outcomes applied?
5) What is the methodological quality of the studies?

### B. The search terms and search strategy

*1) Search keywords:* The search terms are constructed from three different sets of keywords:

- The first keyword determines the research objectives: *"stress*"* (the asterisk sign allows the search for different forms: stressor, stressed)
- The second keyword set determines the objective of measurement: *"heart rate variability"* OR *"HRV"*
- The third set determines the context of the measurement: *"industr*"* OR *"product*"* OR *"manufactur*"*
- The additional fourth set determines the subject of measurement: *"worker"* OR *"operator"* OR *"employee"*

There is no clear separation of work content stressors between studies. Thus the keyword "stress*" is utilized for a general approach. Consequently, the different work content stressors will be categorized based on the resultant materials, which consider the definitions from the WHO [2]. Therefore, a protocol for SLR is developed as detailed in the next section.

*2) First phase:* The authors perform search in chosen electronic databases: Scopus, IEEEXplore, PubMed, Web of Science.

Applied filters:

- Date: From 01 Jan 2000 to 01 Jun 2022.
- Type of article: Original articles, published or in Press.
- Source type: Journals.
- Language: English.

Search terms:

- **Scopus**
( TITLE-ABS-KEY ( stress* ) AND TITLE-ABS-KEY ( "Heart Rate Variability" OR "HRV" ) AND TITLE-ABS-KEY ( industr* OR product* OR manufactur* ) AND TITLE-ABS-KEY ( worker OR operator OR employee ) ) AND PUBYEAR $>$ 1999 AND PUBYEAR $<$ 2023 AND ( LIMIT-TO ( SRCTYPE , "j" ) )
- **IEEEXplore**
("All Metadata":stress*) AND ("All Metadata":"heart rate variability" OR "All Metadata":HRV) AND ("All Metadata":industr* OR "All Metadata":product* OR "All Metadata":manufactur*) AND ("All Metadata":worker OR "All Metadata": operator OR "All Metadata": employee) Filters Applied: 2000 - 2022 Filters Applied: Journals
- **PubMed**
(("Heart Rate Variability"[Title] OR "HRV"[Title]) AND ("stress, psychological"[MeSH Terms] OR "stress, physiological"[MeSH Terms] OR "Occupational Stress"[MeSH Terms] OR "stress"[Title]) AND ("worker"[Title/Abstract] OR "operator"[Title/Abstract] OR "employee"[Title/Abstract] OR "manufacturing"[Title/Abstract] OR "industry"[Title/Abstract] OR "production"[Title/Abstract])) AND ((clinicaltrial[Filter] OR randomizedcontrolledtrial[Filter]) AND (1999:2022[pdat]))
- **Web of Science**
(TI=(stress*) AND TI=("Heart rate variability" OR "HRV") AND TI=(industr* OR product* OR manufactur*) AND TI=(worker OR operator OR employee) ) OR (AB=(stress*) AND AB=("Heart rate variability" OR "HRV") AND AB=(industr* OR product* OR manufactur*) AND AB=(worker OR operator OR employee) ) OR (AK=(stress*) AND AK=("Heart rate variability" OR "HRV") AND AK=(industr* OR product* OR manufactur*) AND AK=(worker OR operator OR employee) )

*3) Second phase:* While the selected articles are analyzed, new keywords can be identified for a complementary search. References are taken from the most relevant studies. This process will be repeated until no more relevant results are found.

### C. Types of study to be included

The types of selected studies are determined based on the consensus of the authors:

- The intended review will primarily consider original research articles published or in the press, with the English language and full-text available.
- There is no minimum number of participants involved in the experiment. However, the HRV measurement must be conducted during the working condition and working period.
- Systematic literature review papers will be considered a source of complementary information, and references will be tracked for additional articles that fulfill the inclusion criteria.

- Observational studies, Cohort studies, and Experimental studies will be included.

These types of study will be excluded:

- Not published in English, or full-text unavailable.
- As the research goal is to find the updated usage of non-invasive HRV measurement for occupational stress assessment, any theoretical studies such as literature reviews, protocols, and conference papers will be excluded.
- The HRV measurement is conducted by the paper-and-pen method, and outside of working conditions and working period.
- The use of HRV measurement is to diagnose heart disease or other co-morbidities medically.
- Theses, dissertation, and conference abstracts will be included.

### D. Condition or domain being studied

The study will target no specific condition. The use of non-invasive HRV measurement to assess the stress levels of workers within industrial production settings, with exposure to the regular work environment will be studied

### E. Participants/population

The research will focus on investigations or experiments developed within working-age (15-64) participants, who are the physical workers in the manufacturing site and work with machines and/or physical production tasks (assembly, food processing line, packaging line). It will include both female and male populations with no additional restrictions.

### F. Intervention(s), exposure(s)

Intervention: technical non-invasive devices for HRV measurement for stress assessment in various manufacturing environments. Exposure: any work content elements in an actual or simulated industrial manufacturing environment, such as workload, work pace, working hour, and time boundary.

### G. Comparator(s)/control

Studies with any comparator or without comparators will be considered.

### H. Context

Eligible publications include actual or laboratory-simulated physical working tasks in a manufacturing environment.

### I. Main outcome(s)

The HRV variables [51] for physical workers in the manufacturing environment. The work content-related stress levels.

### J. Additional outcome(s)

These results will be collected as secondary outcomes:

1) The connection between HRV and stress levels with different job stressors of industrial workers.
2) The effect of workplace stress on the performance of the workers in different level (individual, group, and corporate level).

### K. Data extraction (selection and coding)

A specifically designed Excel spreadsheet with tables will be used to screen, select papers and compile extracted data. This process will be performed by one reviewer and verified by another. If there is any discrepancy, it will be discussed between the reviewers. After the title and abstract screening phase, full texts will be retrieved to be screened. The included articles are selected to extract the information of interest, including:

1) Study general information: authors, affiliations, publication year, country.
2) Background of the studies: sample size of workforce, mean age, industrial setting.
3) Context of the study: in the field/ laboratory conditions; work environment, work characteristics, work content type.
4) Study primary characteristics: methods and equipment used, measurement characteristics, the measured HRV variables and assessed work content-related stress levels.
5) Major study limitations.
6) Quality assessment: potential risks of bias (assessment of selection, precision, information, investigator bias).

### L. Risk of bias (quality) assessment

To assess the risk of bias during the review process, the "Cochrane Risk of Bias Tool for Randomized Trials" [52] is used for the experimental (randomized) studies and "ROBINS-I" (Risk Of Bias In Non-randomized Studies - of Interventions [53]) for the non-randomized studies. The risk of bias will be assessed individually by the authors in two stages:

1) Firstly, the primary characteristics of each study will be identified and analyzed following the objectives of this review. Considered parameters will include primary purposes, assessed variables, specific outcome assessments, used equipment and software, and assessment procedure.
2) Secondly, considering the Cochrane Collaboration's tools for assessing the risk of bias, methodological issues will be addressed; ethical standards fulfillment, sample justification, clear description of the experimental procedure, and practical difficulties.

Studies presenting explicit answers to the established criteria will be considered suitable for the objectives of this review. The risk of bias will be included when concluding.

### M. Strategy for data synthesis

A meta-analysis will be performed if the retrieved data are comparable and suitable, with the stress levels assessed by validated tools, and the HRV baseline and stimulated status are provided. The meta-analysis result with the r family effect size can reveal the association of HRV with stress levels of workers and how strong and homogeneous it is. The GRADE tool will be used to assess the quality of evidence. Otherwise, a narrative synthesis will be conducted (with information from the selected publications). Bias will also be examined when analyzing the data. The checklist from PRISMA Statement is going to delimitate this process.

### N. Analysis of subgroups or subsets

No pre-specified subgroup analysis has been established. Subgroup analyses will be considered depending on the availability of relevant subgroup-level data in the articles.

## IV. Possible Applications and Future Research

Stress in the manufacturing environment causes negative impacts on physical workers. Industrial managers are finding ways for stress identification and reduction to avoid accumulation during production, which harms productivity, quality, and safety. Physiological parameters are preferred for stress assessment over traditional pen-and-paper questionnaires, reports, and observations. Among relevant parameters, literature has shown that HRV is widely used to measure stress levels thanks to its being non-invasive and relatively easy to perform.

Industrial managers can utilize the HRV-based stress assessment result to monitor the favorable work content that creates the ideal working state for workers. The adjustment can be done via many methods, such as the work position allocation or cycle time control [54], tailored to the specific psychological and physiological condition of their workforce. This data-driven and flexible human resources usage are aligned with the ISO 45000 standard family [55], which promotes a healthier, safer, and more productive work environment by managing work stress via biometrics of the psycho-physiological state of workers. Consequently, the HRV measurement can be incorporated into the OHS management system [10], to bring an integrated solution for the digitized production [30].

Since I4.0 brings more mobility and connectivity, the assessment of work content stress can serve the purpose of integrating human workers into intelligent manufacturing systems. The Healthy Operator pillar in Operator 4.0 concept urges an innovative fusion of technologies and gadgets to adjust the work content according to the physical-physiological condition of workers. As the human factor is one focus of I5.0, the best practice HRV measurement for stress assessment should be disseminated among manufacturers. Solutions based on the assessment result can positively impact production efficiency and improve human resource utilization.

A research protocol for an SLR serving this purpose is proposed and contains the search method and strategy. The extracted data from relevant studies are necessary for the next development step regarding job stress reduction or management. Several issues that emerged from the context of stress data from the industrial workers are also discussed, such as the new role of artificial intelligence and machine learning for automatic data processing [56], personal data privacy protection [57], authentication for IoT and cloud application [58]. This research inspires researchers and practitioners to implement similar approaches with careful precautions, regarding the human worker as an indispensable and focused factor in a modern connected manufacturing facility.

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