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Cardiovascular load assessment in the workplace: A systematic review

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ABSTRACT

Cardiovascular disease (CVD) is the leading cause of death worldwide. Health and safety hazards and risk factors in the workplace are associated with occupational CVD, though inconsistent evidence of causal associations represents a knowledge gap. The assessment of physical load on the cardiovascular system in relation to work different risk factors and occupational groups is necessary, if preventative measures for occupational CVD are to be better tailored to workers' needs.

The pertinent literature reports the use of different objective and subjective metrics to evaluate the cardiovascular load (CVL). We aimed to identify how cardiovascular stress is assessed in the workplace and to bring together related evidence-based recommendations for preventative measures. Hence, we systematically searched the Google Scholar database for corresponding publications to a) gather metrics used to assess CVL, b) summarize the related risk factors investigated, c) report the occupational groups and activities targeted in these studies, and d) compile recommendations resulting from these studies.

The majority of studies reported objective measures, mostly Relative Heart Rate. The identified risk factors included work environment factors, general job features (such as the number of working hours), task-related factors and individual characteristics of the worker. Most studies focused on the industrial sector, namely, the manufacturing industry and construction were the two most frequent occupational groups, due to high exposure to risk factors. Few evidence-based recommendations were identified, though guidelines to promote safety and productivity were proposed. Our results encourage further research on CVL, occupational risk and CVD.

1. Introduction

Heavy physical work, awkward postures, repetitive movements, long working hours and overtime are just some of the many occupational factors associated with an increased risk of cardiovascular disease (CVD) (Id et al., 2018; Kivimäki and Kawachi, 2015; Krause et al., 2007). CVD is a collective term for a group of disorders that affect the blood circulatory system and include coronary heart disease, cerebrovascular disease and other conditions (Benjamin et al., 2018; World Health Organization (WHO), 2021). CVD represent the leading cause of all deaths worldwide, with an estimated 17.9 million CVD-mortalities per year (World Health Organization (WHO), 2021).

Recent data from the European Union shows an average working week of 36.4 h among 20-64 year-olds in their main occupation, though working hours can be considerably longer (Eurostat, 2022a). Long working hours and (the therefore increased duration of) work exposures such as awkward postures and movements, work pace, repetitiveness and noise are significant health and safety hazards and risk factors for occupational CVD (Collins, 2009).

According to the Protocol to the Occupational Safety and Health Convention, an occupational disease is any disease resulting from an exposure to risk factors that arise from work activity (International Labour Organization (ILO), 2009). More specifically, for consideration of a health condition or disorder as an occupational disease, there must be a causal relationship between the specific disease and risk exposure in a specific working environment or work activity and the frequency with which the disease occurs among the exposed workers must exceed that found in the rest of the population (International Labour Organization (ILO), 2009). Critically, the evidence of causal associations between risk factors and occupational CVD is inconsistent (for example, an

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exploratory study performed with the canadian community found inconsistent associations between heart disease and physical exertion at work as well as with occupation type, emphasizing the need for further studies (Nowrouzi-Kia et al., 2018)).

This inconsistency represents an important knowledge gap, especially as occupational disease is an indicator of the quality of working conditions and is associated with the workers' quality of life and disease-adjusted life years (DALYs, i.e., lost years due to premature death and lost healthy years due to disease and disability) (Kivimäki and Kawachi, 2015; Rushton, 2017). In the EU alone, data shows that CVD-related DALYs can amount in a given year to as many as 26 million lost years (World Health Organization (WHO), 2011). This reflects the economic repercussions of occupational disease, as reflected in higher rates of absenteeism, poor staff retention and lower productivity (Burdof, 2007). The latter is estimated to make up a considerable share of the cost of CVD to the EU economy (Wilkins et al., 2017).

The field of ergonomics and occupational health and prevention of work-related disease considers a broad range of factors that impact physical demands on work performance and productivity (e.g. (Nowrouzi-Kia et al., 2018),). These include environmental factors (e.g., noise and temperature), job-related factors (e.g., number of working hours, type of physical work, postures), task-related factors (e.g., postures, movements) and individual worker-related factors (e.g., age, body mass, physical fitness, health condition).

For a better understanding of the relationships between occupational risk exposures and CVD, suitable metrics are needed to assess the effect of physical load on the cardiovascular system and to differentiate the relative impact of different risk factors of CVL on occupational CVD. A range of objective and subjective metrics is available to quantify CVL. Objective metrics are based on the measurement of physiological variables (e.g., heart rate, oxygen consumption, blood pressure). Subjective metrics rely on the use of self-report instruments (or scales) to assess workers' perceived and experienced occupational exposure. While these metrics are many in number, a unified overview of the specific metrics used in observational studies to assess CVL in relation to specific factors, occupational groups and activities investigated in these studies is not available. An overview of the evidence-based recommendations for preventative measures that may have resulted from these studies is also lacking.

The aims of the present paper were therefore to identify how CVL is assessed in the workplace and to bring together related evidence-based recommendations for preventative measures. Specifically, we aimed to

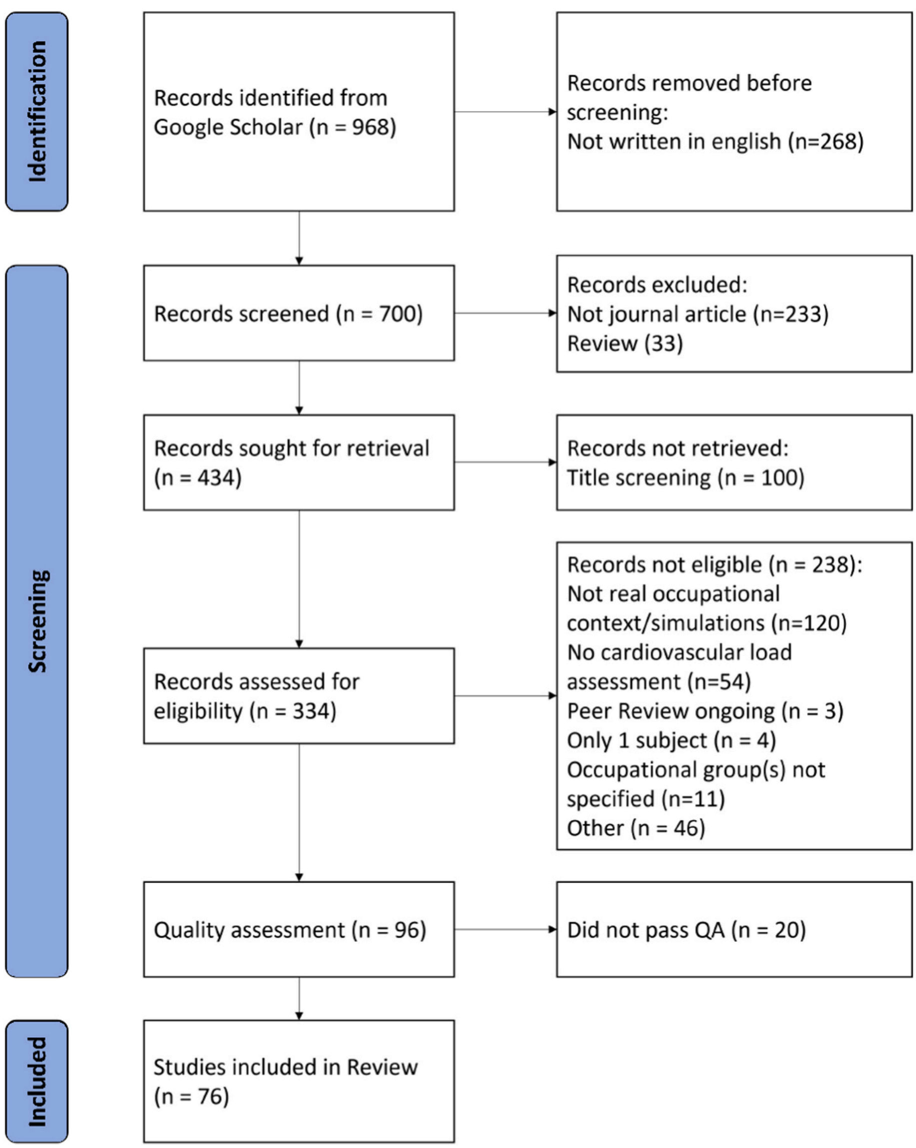

Fig. 1. Flow-chart describing the systematic review process as proposed by PRISMA. "Other" refers to studies that were rejected because the acquisition instruments were not reported or the focus of the article was not the worker's health and safety (papers solely concerned with productivity, for example).

systematically search the Google Scholar database for observational studies in order to a) gather metrics used in these studies to assess CVL, b) summarize the related risk factors that were investigated, c) report the occupational groups and activities that these studies targeted, and d) summarize general recommendations for preventative measures for occupational health that resulted from these studies.

2. Materials and methods

2.1. Search strategy

The search and review process followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) guidelines (for a flow chart of this process, see Fig. 1) (Moher et al., 2009). We performed a comprehensive search of all publications until 22. June 2022, using the Google Scholar database (Google Scholar, 2022). The included literature dates from 1984 to 2022. A recent study of systematic reviews shows that Google Scholar has a recall rate of 96% of primary studies (Yasin et al., 2020), making it unlikely that we missed primary observational studies in the present paper. The search of databases focused on English language publications, irrespective of country of origin. The search terms for the database query were: “cardiovascular load” AND (“occupational” OR “workers”). These terms were as broad as possible to ensure maximal coverage of the literature.

2.2. Eligibility criteria

For inclusion, each publication had to: (i) be published in a scientific journal, (ii) be based on observational study of cardiovascular load assessed during occupational work, (iii) report the studied occupational group, (iv) focus on worker health and safety, (v) focus on real-world occupational tasks, (vi) include the acquisition of objective and/or subjective measures of CVL, and (vii) report the name of the instruments used for the acquisition of measures in the study. Exclusion criteria rejected studies that (i) were based exclusively on the simulation of occupational tasks and work environments and (ii) had a sample of only 1 subject.

2.3. Study selection

Authors M.D. and L.S. searched the electronic database. The same authors screened titles and abstracts of all identified articles. If the screening of the title and abstract was inconclusive, the authors assessed the full-text of articles for inclusion or exclusion according to our eligibility criteria. Disagreements about eligibility were resolved by consensus. For quality assessment, the authors independently reviewed the eligible articles and rated each as qualified or unqualified for inclusion (based on the NIH criteria from ”Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies” (National Heart et al., 2022)); discrepancies were discussed and any disagreement was resolved by consensus. A Kappa Statistic analysis was performed to evaluate the inter-rater agreement, having obtained a Kappa value of 0.868. Fig. 1 represents the different phases of the selection process, as proposed by PRISMA (identification, screening, inclusion). The records were assessed for eligibility based on the inclusion and exclusion criteria described in the previous section. This study selection process resulted in 76 articles, which are presented in Table 1. Table 2 presents which of the results can be found in the renowned databases Scopus (Scopus and Scopus, 2023) and Web of Science (Web of Science, 2023).

2.4. Data extraction

From each of the final 76 articles, the following categories were systematically extracted: study aims, number of subjects, occupational tasks, parameters used to assess cardiovascular load, and main findings. The extracted data is gathered in Table 1.

3. Results

In this section, the results from the review process described in 2.1 are presented. Table 1 summarizes the works included in this review, briefly describing the occupational tasks under study, the parameters chosen to assess CVL and main findings. It is important to note that the results are described regarding their CVL assessment part, *i.e.*, if the included articles have additional aims and findings that are not related to this study’s topic, they are not covered here.

Fig. 2 illustrates the occupational sectors of the results and Fig. 3 represents the CVL variables that were used and the number of articles that used each variable.

4. Discussion

This review aims to provide knowledge on the metrics commonly used in literature to quantify CVL for occupational risk stratification. Seventy-six papers were included in this review. From these papers five dimensions were considered: 1) Cardiovascular load assessment, where the several parameters are described; 2) Occupational risk factors, such as the environment and job, task and worker characteristics; 3) Occupational groups that were found in literature; 4) Impact of physical activity in the workplace; and finally, 5) Science-based recommendations for improving occupational health. In our work, we focused not only on providing a comprehensive description of the cardiovascular parameters, but we delve into a more broad scope by exploring application areas, issues, and limitations that may be associated with each parameter, and providing recommendations that can be useful in the work context.

4.1. Cardiovascular load assessment

In this section, the different parameters used in the literature to assess CVL are described.

4.1.1. Objective assessment methods

4.1.1.1. Heart rate (HR). HR is a measure of the number of heart beats per minute. It can be assessed by various means, such as from detecting the flow through the blood vessels (Lee et al., 2020) or from the calculation of the R–R intervals of an ECG signal (Lunde et al., 2016).

On a clinical perspective, from the HR monitoring, it is possible to extract information regarding certain health conditions. For instance, very low HR values may indicate Sinus Bradycardia, which means the heart is pumping too slow and may be associated with hypothyroidism or hyperkalemia. On the other hand, when HR is very high, it may be a sign of Sinus Tachycardia, which is associated with a series of conditions, such as anxiety, pain, congestive heart failure, etc. Moreover, if the variations between the R–R intervals are too large, this may indicate Sinus Arrhythmia, Sinus Block or Sinus Arrest (Li and Boulanger, 2020).

HR measurement can also be informative in non-pathological situations. During physical exertion, as muscle contraction increases, substrate and oxygen requirements of working muscles increase greatly above resting requirements. Consequently, the blood flow to the muscles is amplified, depending upon an increment in the cardiac output, by both a rise in the HR and in the stroke volume (Burton et al., 2004). HR and stroke volume increase to about 90% of their maximum values during strenuous exercise (Burton et al., 2004).

Several studies have used directly HR as a measure of CVL in the workplace (Schettino et al., 2021; Strauss et al., 2021; Sandmark et al., 1999). For example, Schettino et al. classified different job activities based on the maximum heart rate measured during its performance (Schettino et al., 2021). In *Textbook of Work Physiology*, Astrand and Rodahl classified the severity of physical workload based on HR responses: light work - HR up to 90 beats/min; moderate work - HR from

Table 1
Published studies concerning the assessment of cardiovascular load in the workplace.

Authors (year)	Aims	N	Occupational Tasks	Parameters	Main Findings
Schettino et al. (2021)	Tendency for work-related diseases in harvesting work.	267	Forest harvesting	HR %CVL	High physical workload (%CVL > 40%), favoring occupational diseases.
Souza-Talarico et al. (2021)	Association between awakening cortisol response and CVL.	92	Sugar cane harvesting	HR BP	Negative association between CAR and cardiovascular performance in the harvesting period.
Arman et al. (2021)	Physical workload of tree fellers during clearcut operations.	13	Tree felling	RHR, 50%HRR HR_{work}/50% HRR HR_{work}/HR_{rest}	Tree felling was characterized as heavy work, which may have negative impact on the worker's health.
Sibiya et al. (2021)	Workload from motor-manual pruning against manual operations.	4	Tree pruning	RHR, 50%HRR HR_{work}/50% HRR HR_{work}/HR_{rest}	HR indices showed no significant difference between motor-manual and manual operations.
Thamsuwan et al. (2019)	Platform- versus conventional ladder-based apple harvesting.	20	Apple harvesting	HR RPE and CR-10	Mobile platforms can lower physical risk exposure.
Barbosa et al. (2015)	Physical workload of farm coffee workers.	12	Coffee production (farm)	RHR	HR is positively associated with demanding postural combinations and pace of work.
Pal et al. (2015)	Physiological strain among women potato cultivators.	150	Potato cultivation	VO2 RHR BLA	Moderate work concerning cardiovascular strain.
Melemez et al. (2010)	CVL imposed to chainsaw operators and assistant workers.	138	Felling and delimbing	RHR	Operator's work is heavy and assistant's moderate. Variance in RHR due to worker's stature, terrain, working hours.
Chauhan et al. (2008)	Cardiac load and EE on dairy workers during milking (age and sex adjusted).	70	Milking	HR EE	Age and sex are risk factors in milking jobs.
Ramana (2002)	Effect of postural discomfort in workload and usage of a new tool.	4	Weeding	HR VO2 EE	Using a bent handle tool improved the posture and led to an EE reduction without sacrificing productivity.
Kirk et al. (1996)	Ergonomic evaluation of first lift manual pruning.	6	Manual pruning	RHR, 50%HRR HR_{work}/50% HRR %CVL	First lift pruning is classified as moderate-to-heavy.
Ahonen et al. (1990)	Physical stress and strain in dairy farming.	23	Dairy farming	$\%VO2_{max}$ HR RPE	Women are subject to high physical strain due to heavy work and low $VO2_{max}$ (aerobic capacity).
Harjula et al. (1984)	CVL in logging.	15	Logging	VO2 $\%VO2_{max}$ HR	Motor-manual logging was classified as physically heavy.
Marciniak et al. (2021)	Cardiovascular responses to medical and fire alarms (and BMI influence).	41	Firefighting	$\%HR_{max}$	Alarms increased HR (more in fire than medical calls). Higher BMI relates to greater HR responses in medical calls.
Strauss et al. (2021)	Stress profile during rescue situations in HEMS.	21	HEMS work	BP HR SVES and VES	During the rescue operations, BP, HR_{min}, HR_{max} and HR_{mean} are significantly higher than in standby time.
An et al. (2020)	Factors associated with 24-h variation of BP and HR.	244	Police	BP HR	Temperature and humidity were major factors that influenced the variation of BP and HR.
Bertrandt et al. (2019)	EE of chemical troop soldiers wearing 2 different protective clothes.	29	Troop	HR EE	FOO-1 filter-sorptive PPC lead to lower EE than L2-PPC, while increasing the sense of security.
Apud (2011)	Factors that influence the workload of fire-fighters.	149	Firefighting	%VO2max HR %CVL	Radiant heat, terrain slope, weight of the fuels, fire duration and number of workers in the fireline.
Korshoj et al. (2013)	Feasibility of methods for objective 24-h sampling of PA among cleaners.	20	Cleaning	RHR $VO2_{max}$	Used methods were feasible. 20% of the population was subject to high physical strain (RHR > 30%).
Samani et al. (2012)	Effect of ergonomics guidelines on postural and cardiovascular load.	18	Cleaning	HRV	Following the guidelines reduced CVL and induced a more complex pattern of activity.
Sogaard et al. (2006)	Strategies for enhancing cleaner's occupational health.	6	Cleaning	HR	Switching methods for the same task did not reduce workload. Varying tasks during the day is necessary.
Kumar et al. (2005)	Workload associated with the use of a redesigned cleaning tool.	13	Cleaning	HR VO2 RPE	HR, VO2, RPE significantly lower when using redesigned tool.
Sogaard et al. (1996)	CVL during floor cleaning work (2 methods).	12	Cleaning	RHR $\%VO2_{max}$ RPE	Floor cleaning is associated with high CVL and imposes a large number of improper working postures.
Chen et al. (2022)	New continuous long-term personalized workload indicator.	15	Shield tunnel work	FRHR RHR	PPG-based HR sensor allows to generate a continuous real-time %HRR workload system based on FRHR.
Al-Bouwarthan et al. (2020)	Impact of summer heat exposure on construction workers.	23	Construction	RHR	Heat stress exposure limit is commonly exceeded, which poses health risks.
Brandt et al. (2018)	Participatory ergonomics intervention to reduce excessive workload events.	80	Construction	HR CR-10	No change in the number of events but decreased general fatigue.
Roja et al. (2017)	Work strain indicators for construction workers and measures for prevention.	20	Construction.	HR BP RPE	The strongest work strain predictors were connected with psycho-social risks rather than with physical ones.

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Table 1 (*continued*)

Authors (year)	Aims	N	Occupational Tasks	Parameters	Main Findings
Lunde et al. (2016)	CVL in construction workers during work and leisure.	42	Construction	RHR MAWT $VO2_{max}$	RHR at work, participants' age, and aerobic fitness ($VO2_{max}$) level were correlated.
Gram et al. (2016)	EE, workload, and the effect of a PA-intervention.	67	Construction	HR MET	OPA within the recommended level of $\frac{1}{3}$ of maximum capacity but did not decrease significantly with PA-intervention.
Ismaila et al., (2013a)	Model to predict HR_{work} based on age, body height, body mass and HR_{rest}.	89	Construction	RHR	The neural network predicted HR from the given input, evidencing a non-linear relationship between these variables.
Ismaila et al. (2012)	Physical work strain and work capacity of bricklayers.	89	Construction	$\%VO2_{max}$ RHR EE	There is a need to redesign the bricklayers' work content in order to reduce excessive strain.
Maiti (2008)	Occupational risk factors of construction activities among female workers	11	Construction	HR, RHR VO2 BP	Insufficient rest time and carrying loads weighting more than the Recommended Weight Limit were considered risk factors.
Merati et al. (2021)	Cardiorespiratory fitness and workload of swimming and fitness instructors.	99	Sports instruction	$VO2_{max}$ CR-10 HR, $\%HR_{max}$	Aerobic fitness level was comparable between FI and SI subjects and both groups are exposed to a similar workload.
Wanke et al. (2020)	Cardiovascular stress during dance teaching.	21	Dance teaching	$\%HR_{max}$ RPE	CVL in dance classes is intermittent with individual fluctuations
Sandmark et al. (1999)	Perceived and objective CVL in physical education teachers.	30	Physical education	HR RPE	The ratings of perceived exertion give an indication of an underestimation of the demand.
Shimaoka et al. (1998)	Physical workload between japanese and swedish nursery school teachers.	73	Nursery school teaching	RHR RPE	Slightly higher perceived exertion in japanese teachers comparing to swedish.
Yoopat et al. (2020)	Physiological response to workload and rest (and influence of work experience).	30	Physical therapy	%CVL SWI	A 15-min rest could bring %CVL below 30%. No significant differences found between experience groups.
Yoopat et al. (2018)	Physiological strain and perceived workload in massage therapists.	61	Massage therapy	%CVL SWI	Correlated perceived and objective measurements. %CVL always below 30% (moderate to low physiological strain).
Yoopat et al. (2016)	Physiological strain of Pho Massage therapists and effects of pause time.	30	Massage therapy	$\%HR_{max}$ %CVL	15-min rest after each treatment allows workers to recover from the physiological strain and maintain safe CVL levels.
Jakobsen et al. (2015)	Effect of workplace (supervised) versus home (unsupervised) trainings on RPE	200	Healthcare	RPE	Brief high-intensity strength training sessions in the workplace lead to a reduction of physical exertion during work.
Hui et al. (2001)	Physiological demand in nurses from geriatric wards.	21	Nursing	HR RPE	Tasks involving patient lifting, transfer and turning were the most physically demanding.
Torgén et al. (1995)	Physical workload and capacity among elderly aides in home-care.	20	Eldercare	HR $\%VO2_{max}$	$\%VO2_{max}$ and HR during the work day did not exceed recommendations.
Papoutsakis et al. (2022)	Assess physical strain risk, online during work, using deep learning (DL).	2	Car door assembly	HR	Analysis of worker postures (through computer vision) can help in the prediction of future HR values.
Widana et al. (2020)	Ergonomic workplace design for artists.	10	Crafting	%CVS %CVL	Using an ergonomic workstation leads to a decrease in % CVL and %CVS.
Nurshafa et al. (2020)	Relationship of noise and physical workload to an increase in SBP.	36	Industrial ceramics	BP %CVL	The higher the noise and physical workload, the higher the risk of abnormal SBP.
Batubara et al. (2017)	Redesign the liquid aluminum pouring tools to reduce operator's workload.	14	Aluminum foundry industry	HR %CVL	HR and %CVL significantly lower after ergonomics intervention.
Suarbawa et al. (2016)	Workload before and after an ergonomics intervention.	12	Instrument manufacture	%CVL	Significant differences (decrease) were found in %CVL before and after the working posture intervention.
Santosa et al. (2015)	Effects of an ergonomic intervention on CVL.	34	Dodol Industry	HR %CVL	HR and %CVL significantly lower in the treatment group.
Dehghan et al., (2013a)	Cardiac strain among overweight workers in hot, humid conditions.	71	Petrochemical industry	%CVL RHR	The severity of cardiac strain was higher in overweight workers than in normal weight workers.
Dehghan et al., (2013b)	Cardiac strain among overweight workers in hot, humid conditions.	71	Petrochemical industry	%CVL RHR	The severity of cardiac strain was higher in overweight workers than in normal weight workers.
Dehghan et al. (2012)	Combination of WBGT and HR indices to estimate heat strain.	122	Petrochemical Industry	HR PSI	The combination of WBGT and HR indices can be used as a valid estimator of heat strain.
Palmerud et al. (2012)	Effects on job exposure of a new assembly comparing to the old one.	6	Car manufacturing	RHR	RHR significantly lower in the new system.
Kazmierczak et al. (2005)	Physical workload in car disassembly.	10	Car disassembly	RHR	Disassembly work implies substantial circulatory exposures.
Kim et al. (2003)	Relationship between cold exposure and hypertension in workers.	136	Refrigeration industry	BP	SBP and DBP significantly higher in cold-exposed group.
Bao et al. (1996)	Impact of a rationalization of the assembly on the physical workload.	36	Manufacturing	HR	The new assembly system lead to minor ergonomic improvements.
Lang et al. (2021)	BP in chronic intermittent hypoxia (CIH) and impact of hypertension	37	Mining	HR BP	BP increases at high altitude (more pronounced in hypertensive workers).
Saha et al. (2010)	Cardiac workload in underground coal mines.	8	Mining	RHR	Cardiovascular stress with poor recovery due to an incompatibility between the miner's capabilities and job requirements.
Saha et al. (2008)a	Cardiac strain among drillers of 2 age groups in coal mines.	22	Mining	RHR	High physiological and heat stress hinder the recovery process, particularly for the older workers.
Saha R et al. (2008b)	Physiological strain of 2 age groups of workers (<40 and ≥ 40 years)	39	Coal mining	RHR RVO2	Acceptable levels of physiological strain are surpassed, specially in the older group.
Lee et al. (2020)	Exercise and working hours impact on CVL in high OPA.	36	Mail delivery	$VO2_{max}$ RHR	RHR is positively correlated with working hours. No significant correlation was found with exercise.

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Table 1 (*continued*)

Authors (year)	Aims	N	Occupational Tasks	Parameters	Main Findings
Kim et al. (2018)	Fatigue and accident risk in Korean commercial bus drivers.	16	Bus driving	RHR MAWT	Working hours exceed MAWT, leading to increased risk indices.
Sahu et al. (2013)	Effect of age on CVL of van-rickshaw pullers.	142	Transport driving	RHR	CVL parameters were significantly correlated with age.
Oestergaard et al. (2022)	Physical capacity and work demand of wind technicians (onshore/offshore)	27	Wind technical service	$VO2_{max}$ RHR >60%HRR (time)	RHR tends to be within 30%HRR. Offshore is associated with higher demand than onshore work.
Preisser et al. (2019)	Test the validity of existing european occupational guidelines.	23	Wind technical service	RHR RVO2	Offshore work is heavy physical labor, which justifies the guidelines' physical fitness requirements.
Stieler et al. (2019)	Cardiovascular recovery (CR) of shift and day workers and predictors of CR.	160	Hotel and catering industry (HCI)	HR BP	CR is mainly determined by BP status, smoking, age, PA, sex (and less by shift work). Shift workers had significantly higher BP and HR during work phase than day workers.
Preisser et al. (2016)	Workload of refuse collectors.	65	Refuse collection	RHR RVO2	Refuse collection should be classified as heavy work.
Brabant C et al. (1989)	Relationship between work, thermal exposure and cardiac strain.	11	Laundry	RHR	Cardiac strain surpassed limits in both seasons but more frequently in the summer (due to higher heat exposure).
Merkus et al. (2022)	Does PA paradox extend to CVL and musculoskeletal pain?	72	Construction and healthcare	RHR	The PA paradox may apply to musculoskeletal pain.
Korshoj et al. (2021)	Association between intensity of OPA and HRV	878	Various tasks *	RHR HRV	Higher %HRR during work is associated with lower HRV the following night.
Quinn et al. (2021)	Physiological mechanisms for the paradoxal effects of OPA and LTPA.	19	Healthcare, other services *.	HR HRV BP	High OPA was negatively associated with HRV, which did not happen with MVPA on non-work days.
Youthao et al. (2020)	Problems of sedentarism and how different patterns of PA affect fitness	200	Executives, professors, office workers, janitors	HR BP	The combination of Zumba, Yoga, and Aerobics Cardio leads to greater fitness levels
Rasmussen et al. (2019)	Association between work time spent at a high aerobic workload and leisure time movement behaviour.	803	Various tasks *	RHR	Negative association between work time at >40%HRR and active leisure time in women.
Gupta et al. (2019)	Effects of work and leisure time behaviours on BP.	669	Cleaning, manufacturing and transport.	BP	Various physical behaviors atwork and leisure and time in bed was associated with SBP and DBP.
Jakobsen et al. (2013)	Association between perceived exertion and objectively assessed CVL.	200	Various tasks *	RHR CR-10 $VO2_{max}$	Significant correlation was found between perceived exertion and objectively assessed CVL.
Balogh et al. (2004)	Questionnaire assessed physical activity and direct measurements.	48 41	Cleaning Office work	RHR RPE	Self assessed workload discriminates between high and low exposure groups but not within each group.
Yoopat et al. (2002)	Heat stress and physiological strain in heat exposed and demanding work.	108	Airport, construction and metal jobs	%CVL	High physiological strain due to both heavy dynamic muscular work and high heat stress.

Table 1: * Tasks from Korshoj et al. and Rasmussen et al.: cleaning, manufacturing, transportation, health service, assemblers, construction, garbage collection, mobile plant operations; Quinn et al.: Food service, material moving, maintenance industry; Jakobsen et al.: machine operation, meat cutting, postal service, construction, brewery, mechanics, firefighting.

90 to 110 beats/min; heavy work - HR from 110 to 130 beats/min; very heavy work - HR from 130 to 150 beats/min; extremely heavy work - HR from 150 to 170 beats/min (Åstrand et al., 2003).

One very important characteristic about the measurement of HR that makes it the preferred metric for many researchers in the occupational context is that it is easy to monitor without disturbing the normal performance of the work. There are multiple wearable devices that measure HR (for instance, chest or wrist bands), which are based on one of two methods: photoplesthysmography (PPG), which uses optical sensors to measure the blood volume, or electrocardiography, which measures the electrical activity of the heart (Zhang et al., 2020). Nonetheless, there are less practical means for measuring HR, such as the sphygmomanometer (Ismaila et al., 2013a), which does not allow continuous monitoring and requires stops during work to be used.

The heart rate does not depend exclusively on the physical demand of the tasks that are being performed - it depends on various factors, such as individual traits, namely the stroke volume. For instance, athletes or trained subjects have lower HR as a consequence of a higher stroke volume, resulting from an increase in left ventricular size, myocardial contractility and end-diastolic volume, along with a decreased sensitivity to catecholamines (Jones and Carter, 2000). As such, looking directly at the values of HR to measure CVL can be misleading. However, from HR, a large number of indices can be computed, as will be described in the following sections.

4.1.1.2. Relative Heart Rate (RHR). HR has been measured as a percentage of the individual's maximum Heart Rate (%HR_{max}) (Marciniak et al., 2021; Wanke et al., 2020). One problem with the %HR_{max} approach is the fact that resting HR (HR_{rest}) is never zero, hence the percentage of HR_{max} does not represent load above the resting state (Swain and Leutholtz, 1997). Additionally, HR_{rest} depends on an individual's physical fitness and some exhibit very low HR_{rest}, which makes their Heart Rate Reserve (HRR) (the difference between someone's HR_{max} and HR_{rest}) larger for a given age. The Relative Heart Rate (which can be written as RHR or %HRR) takes HR_{rest} into account by subtracting it from the HR measured during work and from HR_{max} using Karvonnen formula, as shown in equation (1).

$$RHR = \frac{HR_{work} - HR_{rest}}{HR_{max} - HR_{rest}} \times 100\% = \frac{HR_{work} - HR_{rest}}{HRR} \times 100\%, \quad (1)$$

where HR_{work} is the heart rate during work, HR_{rest} is the resting heart rate and HR_{max} is a theoretical value of the maximum heart rate, which depends on age and there are more than one formulas for estimating it (see equations (2) and (3)). HR_{rest} is obtained by measuring the HR of an individual in a resting state, but we found one study that, for simplicity purposes, used estimated values based on age and sex (Lunde et al., 2016).

Tanaka et al. suggested that HR_{max} was calculated from equation (2) (Tanaka et al., 2001) and it has been widely used since (Kim et al., 2018; Merkus et al., 2022).

$$HR_{max} = 208 - 0.7 \times age \quad (2)$$

Table 2
Studies from Table 1 that are found in the Scopus (Scopus and Scopus, 2023) and Web of Science (Web of Science, 2023) databases.

Database	Articles
Scopus	(Schettino et al., 2021), (Souza-Talarico et al., 2021), (Arman et al., 2021), (Sibiya et al., 2021), (Thamsuwan et al., 2019), (Pal et al., 2015), (Ahonen et al., 1990), (Harjula and Rauramaa, 1984), (Marciniak et al., 2021), (Strauss et al., 2021), (An et al., 2020), (Bertrandt et al., 2019), (Apud and Meyer, 2011), (Korshøj et al., 2013), (Samani et al., 2012), (Søgaard et al., 2006), (Kumar et al., 2005), (Sogaard et al., 1996), (Chen and Tserng, 2022), (Al-Bouwarthan et al., 2020), (Brandt et al., 2018), (Roja et al., 2017), (Lunde et al., 2016), (Gram et al., 2016), (Ismaila et al., 2013a), (Maiti, 2008), (Merati et al., 2021), (Wanke et al., 2020), (Sandmark et al., 1999), (Shimaoka et al., 1998), (Yoopat et al., 2020), (Jakobsen et al., 2015), (Hui et al., 2001), (Torgén et al., 1995), (Papoutsakis et al., 2022), (Widana et al., 2020), (Nurshafa and Widajati, 2020), (Batubara and Dharmastiti, 2017), (Dehghan et al., 2013b), (Palmerud et al., 2012), (Kazmierczak et al., 2005), (Kim et al., 2003), (Bao et al., 1996), (Lang et al., 2021), (Saha et al., 2010), (Saha et al., 2008a), (Saha et al., 2008b), (Lee et al., 2020), (Kim et al., 2018), (Sahu et al., 2013), (Oestergaard et al., 2022), (Preisser et al., 2019), (Stieler et al., 2019), (Preisser et al., 2016), (Brabant et al., 1989), (Merkus et al., 2022), (Korshøj et al., 2021), (Quinn et al., 2021), (Gupta et al., 2019), (Jakobsen et al., 2013), (Balogh et al., 2004), (Yoopat et al., 2002).
Web of Science	(Schettino et al., 2021), (Souza-Talarico et al., 2021), (Arman et al., 2021), (Thamsuwan et al., 2019), (Ahonen et al., 1990), (Harjula and Rauramaa, 1984), (Marciniak et al., 2021), (Strauss et al., 2021), (An et al., 2020), (Bertrandt et al., 2019), (Apud and Meyer, 2011), (Korshøj et al., 2013), (Samani et al., 2012), (Søgaard et al., 2006), (Kumar et al., 2005), (Sogaard et al., 1996), (Chen and Tserng, 2022), (Al-Bouwarthan et al., 2020), (Brandt et al., 2018), (Lunde et al., 2016), (Gram et al., 2016), (Maiti, 2008), (Merati et al., 2021), (Wanke et al., 2020), (Sandmark et al., 1999), (Shimaoka et al., 1998), (Yoopat et al., 2020), (Jakobsen et al., 2015), (Hui et al., 2001), (Torgén et al., 1995), (Papoutsakis et al., 2022), (Widana et al., 2020), (Batubara and Dharmastiti, 2017), (Palmerud et al., 2012), (Kazmierczak et al., 2005), (Kim et al., 2003), (Bao et al., 1996), (Lang et al., 2021), (Saha et al., 2008a), (Saha et al., 2008b), (Lee et al., 2020), (Kim et al., 2018), (Sahu et al., 2013), (Oestergaard et al., 2022), (Preisser et al., 2019), (Stieler et al., 2019), (Preisser et al., 2016), (Brabant et al., 1989), (Merkus et al., 2022), (Korshøj et al., 2021), (Quinn et al., 2021), (Gupta et al., 2019), (Jakobsen et al., 2013), (Balogh et al., 2004).

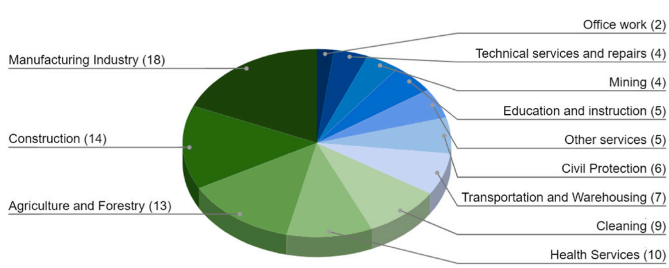

Fig. 2. Occupational sectors of the results presented in Table 1. For each sector, the number of articles that studied that sector is indicated in parenthesis (the total sum exceeds the number of articles included in this review because there are articles studying work from more than 1 occupational group).

Equation (3) (Rodahl, 1989) is also used by some authors (Arman et al., 2021; Pal et al., 2015; Dehghan et al., 2013a), but it underestimates the HR_{max} for adults which results in an increase of RHR, having the effect of overestimating the true level of physical stress imposed (Tanaka et al., 2001).

$$HR_{max} = 220 - age \tag{3}$$

Some studies (Arman et al., 2021; Sibiya et al., 2021; Kirk and Parker, 1996), in addition to RHR, computed the 50% level of Heart Rate Reserve, according to equation (4) (Lammert, 1972) and the ratio of working HR to it, expressed in equation (5). When this ratio is equal to or exceeds 1, the task can be classified as hard continuous work. Moreover, the authors computed the ratio of working HR to HR_{rest}, as in equation (6).

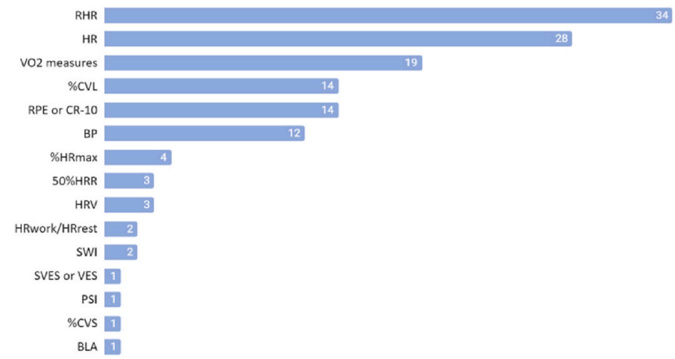

Fig. 3. Parameters used to characterize the CVL in the results presented in Table 1. The number of articles that used each parameter is indicated in the end of each bar (the total sum exceeds the number of articles included in this review because there are articles in which more than one parameters are used). VO2 measures: VO2, $\%VO2_{max}$ or RVO2. RHR: Relative Heart Rate; HR: Heart Rate; VO_2 measures: VO_2 (Oxygen consumption), $\%VO_{2max}$ (percentage of maximum oxygen consumption) or RVO_2 (Relative Oxygen consumption); %CVL: Cardiovascular Load; RPE: Rate of Perceived Exertion; CR-10: Category Ratio; BP: Blood Pressure; $\%HR_{max}$: percentage of maximum heart rate; 50%HRR: 50% level of Heart Rate Reserve; HRV: Heart Rate Variability; SWI: Subjective Workload Index; SVES: Supraventricular Extrasystoles; VES: Ventricular Extrasystoles; PSI: Physiological Strain Index; %CVS: Cardiovascular Strain; BLA: Blood Lactate Accumulation.

$$50\%level = HR_{rest} + \frac{HR_{max} - HR_{rest}}{2} \tag{4}$$

$$Ratio_{50\%level} = \frac{HR_{work}}{50\%level} \tag{5}$$

$$Ratio = \frac{HR_{work}}{HR_{rest}} \tag{6}$$

Oestergaard et al. computed the time spent above 60%HRR in addition to RHR as a CVL measure to characterize wind technicians work (Oestergaard et al., 2022). This way, instead of only reporting mean values of HR indices (which neglect the extremes), the authors could see how much time the workers spent at high cardiac intensity. These latter proposals have been put forward to provide other metrics sensible to CVL intensity. Nevertheless, they all derive from the variables that are included in Karvonnen's formula. The overall concept that is behind of all these proposals is the quantification of relative aerobic workload, which in turn can be defined by the ratio between the physical work demands and the individual capacity.

Chen et al. proposed a workload indicator relying on a new concept - the Field Resting Heart Rate (FRHR) - which expresses the baseline for the individual under non-workload conditions (Chen and Tserng, 2022). The authors suggest that in the work environment, instead of using the HR_{rest} as in the medical field, the lowest heart rate value in the field (FRHR) should be used to compute %HRR, as there are many environmental factors influencing the baseline HR of the worker (such as heat stress, noise, diet), making the available HRR smaller.

4.1.1.3. Percentage of cardiovascular load (%CVL). %CVL is one of the most widely used variables for characterizing cardiovascular stress, as can be concluded from Table 1 and Fig. 3. In this case, it is considered the difference between HR work and rest regarding the maximal HR that is acceptable during a 8 h shift. This parameter is computed from the equation presented in 7 (Kirk and Parker, 1996).

$$\%CVL = 100\% \times [(HR_{work} - HR_{rest}) / HR_{max(8h)}], \quad (7)$$

where $HR_{max(8h)}$ is the maximum acceptable heart rate for a work shift of 8h and is computed as described in equation (8) (Yoopat et al., 2002).

$$HR_{max(8h)} = 1/3 \times (220 - age) + HR_{rest} \quad (8)$$

Some authors consider a HR that leads to 40%CVL to be the Limit Heart Rate (LHR) and when this value is exceeded, there exists the need of reorganizing the work (Schettino et al., 2021; Kirk and Parker, 1996). Nonetheless, these recommended limits are not consensual in the literature.

Yoopat et al. presented the following scale regarding the relationship between %CVL and the actions to implement based on it: < 30%CVL is an acceptable level, no action is required; 30–50%CVL is a moderate level: peak loads should be reduced within a few months; 50–80%CVL is a high level: peak loads should be reduced within a few weeks; >80% CVL is an intolerable level: peak loads should be reduced immediately or work must be stopped (Yoopat et al., 1998).

Other studies (such as (Dehghan et al., 2013a; Yoopat et al., 2002)) used a slightly different scale, according to which < 30% CVL is considered acceptable, from 30 to 60% there is moderate to severe load, 61–100% CVL is considered serious risk and > 100% CVL corresponds to an intolerable high level.

Independently of the proposed scale, there is the need of validation studies that compare cardiovascular load with other intensity measurements for a more reliable categorization.

4.1.1.4. Percentage of cardiovascular strain (%CVS). The last HR-based index for assessing cardiac load is the percentage of Cardiovascular Strain and it is computed as in equation (9) (Ismaila et al., 2013b). It is a ratio between the HR at work minus the HR_{rest} with respect to the HR_{rest}. It is less commonly used (regarding our results, it was only used in (Widana et al., 2020)), probably because its value is not as intuitive as RHR, once RHR is necessarily a value between 0 and 100% and CVS can surpass 100% and it does not take into account the HR_{max}, which depends on age.

$$\%CVS = 100\% \times [(HR_{work} - HR_{rest}) / HR_{rest}] \quad (9)$$

Likewise the cardiac strain measures deformation of cardiac chamber (by the means of its wall length or volume) from a relaxed to a contracted condition. In this case, instead of the deformation of the heart during each cycle, it is expressed the proportion of HR that is used to work in relation to the rest condition.

4.1.1.5. Oxygen uptake (VO_2, $\%VO_{2max}$ and RVO_2). There is a linear relationship between HR and oxygen consumption during the execution of physical work (Karvonen and Vuorimaa, 1988) - the heart pumps faster to respond to the higher demands of oxygen on the working muscles and the respiration rate consequently increases to supply the supplementary O_2. Stress can be objectively described from the measurement of oxygen consumption during work, that is VO2, expressed in litres of oxygen per minute (l/min) or as millilitres per minute per kilogram of body mass (ml/min/kg). However, there is an upper limit to oxygen uptake and, hence, above a certain work rate, the oxygen consumption reaches a plateau, called the maximal oxygen uptake ($VO2_{max}$) (Burton et al., 2004).

Similarly to HR, the oxygen consumption performing a task depends on the individual's cardiopulmonary work capacity: for example, a VO2 of 0.9 L/min means a low aerobic strain for an athlete and a heavy strain for a child (Ilmarinen, 1989).

Maximum oxygen uptake ($VO2_{max}$) indicates the maximal capacity of an individual's cardiovascular and respiratory systems to obtain, transport and deliver O_2 to the muscle cells, as well as the efficiency of this tissue to metabolise oxygen during exercise. As such, $VO2_{max}$ is a measure of physical fitness (Plasqui and Westerterp, 2005; Apud et al., 1989).

The heaviness of a task depends on the relationship between the energy demands of the job and the aerobic capacity of a worker (Apud et al., 1989). Therefore, the percentage of maximum oxygen uptake (% VO_{2max}) has been used as an indicator of physical workload (Sogaard et al., 1996) and a 30–35% of VO_{2max} has been determined as an acceptable workload for an 8 h period (Wu and Wang, 2002).

$$\%VO_{2max} = \frac{VO_{2work}}{VO_{2max}} \quad (10)$$

Nonetheless, it has been shown that the relative oxygen uptake (RVO_2) is a more accurate measure of physical workload (Wu and Wang, 2002), as, similarly to HR_{rest}, VO_{2rest} is not zero. Due to the linearity between VO_2 and HR, we can calculate the RVO_2 in the same way as for HRR, as can be seen in equation (11). A conventional value of 3.5 ml/min/kg can be used as VO_{2rest}.

$$RVO_2 = \frac{VO_{2work} - VO_{2rest}}{VO_{2max} - VO_{2rest}} \quad (11)$$

Usually, to obtain the value of VO_{2max}, physical tests (maximal or submaximal tests) are performed (Lunde et al., 2016; Merati et al., 2021; Lee et al., 2020; Oestergaard et al., 2022; Jakobsen et al., 2013; Yoopat et al., 2002). Maximal tests involve the direct measurement of VO_{2max} by performing a bicycle ergometer, treadmill or step test until an increase in work is not accompanied by an increase in $V0_2$. It is a complex technique that involves risks, specially for older people or individuals who suffer from cardiorespiratory conditions. Submaximal tests have, this way, been developed to estimate VO_{2max}, based on the linear relationship between heart-rate and VO_2 (Apud et al., 1989). Another option is to use a theoretical estimation - based on age, gender, body weight and exercise - developed by Bruce et al. (1973), as Jang et al. did (Jang et al., 2015).

For assessing the oxygen uptake, it is necessary to measure the air flow rates during breathing, and the oxygen and carbon dioxide concentrations in the expired respiratory gas. To enable these measurements, there are portable oxygen measuring systems (such as Medgraphics VO2000, used in (Pal et al., 2015)) - nevertheless, the worker must be wearing a mask and it is very likely to interfere with the normal performance of the job. As such, in Maiti et al. used the following strategy (Maiti, 2008): during a maximal test, both the VO_2 and the HR were being measured simultaneously, and a function relating the two variables was computed for each worker - this way, during work, only the HR was monitored but the approximate corresponding VO_2 value was extrapolated from it.

4.1.1.6. Blood pressure (BP). Blood pressure is the pressure of blood pushing against the walls of the arteries. Systolic blood pressure (SBP) measures the pressure in the arteries when the heart beats, while diastolic blood pressure (DBP) is the pressure in the arteries when the heart rests between beats (diastole) (Centers for Disease Control and Prevention, 2021).

For healthy individuals, there is only a moderate increase in blood pressure secondary to the rise in cardiac output during Physical Activity (PA). This is caused by the stretching of the walls of the arterioles and vasodilatation, which combined reduce peripheral vascular resistance (Burton et al., 2004).

BP is most commonly measured using a sphygmomanometer with the person sat and relaxed, so, in the occupational context, it is necessary that the person stops working momentously. However, ambulatory continuous measurement is also possible using a portable device (holter).

Although BP is not the easiest parameter to monitor in the occupational context, there are some reasons to do it. The presence of hypertension (or high BP), even asymptomatic, is a powerful predisposing risk factor for cardiovascular diseases at all ages and in both sexes (WB, 1993), being not only important to control BP levels, but also to achieve low variability (Munakata, 2018). In (Strauss et al., 2021), blood pressure was used as one of the parameters to characterize the cardiovascular stress profile during rescue operations, as arterial hypertension had been considered to be one risk factor that can be influenced by the CVL in the professional group of emergency services (WB, 1993).

BP is also sensitive to working in high altitude environments and to exposure to chronic intermittent hypoxia (Lang et al., 2021). Compared to sea-level, both SBP and DBP increased at high altitude and this response tended to be more pronounced in hypertensive than in normotensive workers despite them being already treated.

Regarding the relationship between BP and daily tasks, the authors of (Gupta et al., 2019) did a compositional data analysis approach based on 24-h measurements of 669 blue-collar workers (from the cleaning, manufacturing and transport sectors). Dividing the days in 7 motor behaviours: sleep, sedentary work, sedentary leisure, light PA, and moderate-to-vigorous PA (both at work and during leisure), the main significant relationship that was found with BP was that reallocating sedentary time with other behaviours was beneficial, specially (in leisure-time) with time sleeping.

Besides PA, temperature (both heat and cold exposure) has been described as a major influencing factor on BP variation and, to a lesser extent, personal features like body mass index, life habits (smoking, alcohol use, coffee drinking) and stress (An et al., 2020; Kim et al., 2003).

Regarding the BP values that constitute normality (to exclude the hypertension diagnosis), it has been a matter of great discussion, but some consensus has been achieved regarding ambulatory BP monitoring: 24-h average should be lower than 130/80 mmHg, for the awake average 135/85 mmHg and asleep average should not surpass 120/70 mmHg (O'Brien et al., 2013).

4.1.1.7. Heart Rate Variability (HRV). HR is a nonstationary signal and the variation of the period between consecutive heartbeats may contain indicators of current disease or even warnings about imminent cardiac impairments. Heart rate variability (HRV) analysis is a widely used non-invasive tool for assessing the activity of the autonomic nervous system, the nervous control on the HR and the heart's ability to respond. Computer-based HRV analytical tools are very useful in clinical diagnosis and HRV can be analyzed using different approaches, namely through time domain, frequency domain and nonlinear techniques (Acharya et al., 2006).

In general, a high HRV is associated with high oxygen uptake, lower cardiovascular risk, and greater physical fitness and responsiveness to aerobic training while a low HRV is correlated with increased mortality (Tsai, 2017; Tonello et al., 2014). During physical activity, it is normal to have a small reduction in HRV, but if it continues to decrease, the worker is probably experiencing physical fatigue and should take a break (Tsai, 2017). Furthermore, a reduced HRV can also be a good indicator of both physical and mental stress at work (Tonello et al., 2014).

Samani et al. used HRV to characterize CVL (Samani et al., 2012). The authors used both time and frequency domain analysis of the HRV. The time domain analysis consisted on the calculation of the time interval of two consecutive R peaks in ECG (R–R) and its standard deviation. For the frequency domain approach, the authors computed the following parameters: the energy of the HRV power spectrum within specific bands (namely: low frequency (LF) [0.04–0.15Hz] and high frequency (HF) [>0.15Hz]), the ratio of these two quantities, and the normalized LF and HF (NLF and NHF) with respect to total energy power spectrum.

Korshoj et al. found that a higher %HRR during work was associated with lower HRV indices during the following night along with a higher HR, reflecting an imbalanced autonomic cardiac modulation (Korshøj et al., 2021).

4.1.1.8. Cardiac events. From an ECG recording, it is possible to acquire information regarding cardiac events, such as arrhythmia or an anomalous heartbeat (Li and Boulanger, 2020). A normal ECG signal is the result of an electrical impulse that starts from the sinoatrial (SA) node, propagates through the heart muscles, and then to the patient's chest. It is composed of i) a P wave generated by the atrial depolarization, ii) the QRS complex generated by the ventricular depolarization, and iii) a T wave and an U wave generated by ventricular re-polarization (Li and Boulanger, 2020).

It is possible to distinguish three categories of abnormalities in ECG signals (Li and Boulanger, 2020):

- Irregular heart rate, which, as mentioned in section 4.1.1.1, is observed from too large or too small R–R intervals and means the heart is pumping too slow or too fast, respectively, and may be an indicator for the presence of a series of impairments.
- Irregular rhythm, when the signal is abnormal although the heartbeat starts from the SA node, which cause the ST segment and the T wave to have abnormal shapes.
- Ectopic rhythm, which happens when the electrical impulse does not start from the sinoatrial node. Ectopic rythms can be further divided in atrial rhythms (which cause the P wave to be shaped differently), junctional rhythms (in this case the P wave may disappear or become negative) and ventricular rhythms (which cause the QRS complexes to have abnormal shapes and longer lengths).

Strauss et al. (2021) used ECG records to count the number of occurrences of Supraventricular Extrasystole (SVES) and Ventricular Extrasystole (VES) in workers during rescue operations of the Helicopter Emergency Medical Service (HEMS). These cardiac events had previously been associated with adverse cardiovascular outcomes, such as atrial fibrillation and stroke (Meng et al., 2020).

4.1.1.9. Blood Lactate Accumulation (BLA). Blood lactate concentration is a parameter used during clinical exercise testing and performance testing of athletes. Elevated concentration of lactate in the blood may be suggestive of ischemia or hypoxemia, but it can also happen after high physical exertion. During incremental exercise, the lactate concentration starts increasing gradually and as the exercise becomes more intense, it starts increasing exponentially (Goodwin et al., 2007).

Pal et al. evaluated the physiological strain of women cultivators by HR, VO2 and BLA (Pal et al., 2015). The BLA was measured from a blood drop from the finger with a digital blood lactate analyzer. The lactate levels were significantly higher during work than resting levels, having a positive significant correlation with HR and VO2 levels.

4.1.1.10. Physiological strain index (PSI). The physiological strain index (PSI) is a parameter developed to evaluate heat stress, based on rectal temperature (T_{re}) and HR. It materializes on a scale ranging from 0 to 10 and it is computed based on equation (12) (Moran et al., 1998).

$$PSI = \frac{5(T_{ret} - T_{re0})}{39.5 - T_{re0}} + \frac{5(HR_t - HR_0)}{180 - HR_0}, \tag{12}$$

$$PSI_{HR} = \frac{5(HR_t - HR_0)}{180 - HR_0}, \tag{13}$$

From the first equation we can compute just the HR-based part, the PSI_{HR}, shown in equation (13). This parameter has been used in combination with the wet bulb globe temperature (WBGT) to evaluate heat stress in workers from the petrochemical industry (Dehghan et al., 2012). Further information regarding environmental considerations is provided in section 4.2.1.1.

4.1.2. Subjective assessment methods: perceived cardiovascular load

As performing direct measurements can be time-consuming and expensive, approaches based on questionnaires of self-perception of workload - such as Borg's self-perceived exertion scale (Borg, 1990) or the Subjective Workload Index (SWI) (Yoopat et al., 2002) - are often the preferred option. These methods may be more prone to bias, as the results may differ depending on the personal interpretation of the evaluated criteria. Nonetheless, when the instruments are well applied, the subjective metrics can be informative.

The Borg's Rating of Perceived Exertion (RPE) scale is a widely used tool for measuring an individual's perceived exertion and fatigue during physical work. It is based on the physical sensations that the worker experiences, including increased heart rate, increased respiration rate, sweating and/or muscle fatigue (Borg, 1990; Williams, 2017), reflecting a balance between the physical demand and the physical capacity of the individual. The RPE scale is a numerical list (represented in Table 3), designed to grow linearly with exercise intensity and heart rate for work on the bicycle ergometer, ranging from 6 to 20, due to its correlation to the HR: a value of 6 corresponds to 60 beats/minute in a healthy adult, an 8 would correspond to 80 beats/min and so forth.

Self-perceived work exertion has shown to be a valid source of risk identification (Hui et al., 2001), but that does not mean these metrics should replace objective assessment, as the extracted information is not always accordant. In (Sandmark et al., 1999) the authors concluded that the ratings of perceived exertion given by the workers using the RPE scale were indicative of an underestimation of demand. Also, from a study performed with a population of 97 workers (39 males and 58 females) performing diverse occupational jobs (Hjelm et al., 1995), the results showed a significant correlation ($p<0.01$) between the RPE and the average heart rate during work, but only in the male population. When comparing perceived exertion with RHR among cleaners and office workers, the two measures showed low correlation within each group but a high correlation when combining the two group's data (Balogh et al., 2004).

Borg developed a second scale, the Category Ratio (CR-10) scale (see Table 4), raging from 0 to 10, to meet the demand of level estimation, where the values have a quantitative meaning, making it appropriate for purposes of interindividual and intermodal comparisons (Borg, 1990). Thamsuwan et al. used the CR-10 in addition to the RPE scale to measure localized perceived exertion in the shoulders and low back (Thamsuwan et al., 2019).

While RPE was designed to correlate with CVL, CR-10 describes load in localized body regions, giving also an indication of muscular load (Thamsuwan et al., 2019). Logistic and linear multiple regression analysis have demonstrated significant associations between perceived exertion assessed with the CR-10 scale and objectively assessed cardiovascular (RHR and $VO2_{max}$) and muscular load among workers with manual lifting tasks (Jakobsen et al., 2013).

The SWI is composed of ratings given by the operator to express their subjectively perceived discomfort on a 10-point scale (Yoopat et al., 2020). It includes eight factors: 6 negative factors (fatigue, risk, concentration, complexity, work rhythm, and responsibility) and 2 positive factors (interest in the job and degree of autonomy). The index is computed by summing all scores and dividing it by eight. Yoopat et al. measured both the %CVL and the perceived workload in massage therapists using SWI and the results showed that the worker's perception was well correlated with the objective assessments, concluding that this index can also be used as a tool in occupational risk evaluation (Yoopat et al., 2018).

Table 4
Borg's Category Ratio (CR-10) scale (Borg, 1990).

Score	Level of exertion
0	No exertion at all
0.5	Very, very slight (just noticeable)
1	Very slight
2	Slight
3	Moderate
4	Somewhat severe
5	Severe
6	
7	Very severe
8	
9	Very, very severe (almost maximal)
10	Maximal

Table 3
Borg's Rating of Perceived Exertion (RPE) scale (Borg, 1990).

Score	Level of exertion
6	No exertion at all
7	
7.5	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

4.2. Occupational risk factors

There is a wide range of variables that may compose cardiovascular risk factors in the workplace, including 1) work environment factors, such as exposure to high/low temperatures, humidity, uneven terrain, noise, etc., 2) general characteristics of the job, such as the number of working hours or working in shifts, 3) factors concerning the tasks being performed, such as lifting and handling loads above tolerable limits or repetitiveness, and 4) individual worker characteristics, such as Body Mass Index (BMI). Also, there is evidence that psycho-social factors (such as stress) have an impact on cardiovascular demand and can even be the source of cardiovascular illness (Baker, 1985); however, none of the studies that fulfilled the selection criteria explored this risk factor, so it will not be covered in this section.

In the following sections, the contribution of different risk factors for the CVL during work will be discussed.

4.2.1. Work environment

4.2.1.1. Temperature and humidity. Temperature and humidity have been identified as major influencing factors (from the analysis of environmental and individual factors) in the 24-h variations of BP and HR in policemen (An et al., 2020).

While performing physical work, people produce not only mechanical work but also heat, being possible to reach, during heavy muscular, eight to twenty times the resting level. As the optimal body temperature should be kept between 36.5 and 37 °C, there are regulating mechanisms to dissipate the excess heat, through some adjustments of the cardiovascular system: increased blood flow, increased HR and vasodilatation of the blood vessels of the skin (Apud et al., 1989).

We have seen in 4.1.1.1 that physical work and HR have a linear relationship - nonetheless, HR also increases due to environmental heat. Astrand and Rodahl in *Textbook of Work Physiology* (Åstrand et al., 2003), explained the effect of temperature on human response to physical work: a subject exercised for 45 min on a bicycle ergometer 1) in a cool environment and 2) in a hot steel mill, with a temperature of 40–45 °C. Although in both environments the $V0_2$ was the same, the HR in the cool room was 104 beats per minute, while in the hot environment it reached 166 beats per minute, concluding that HR reflects the extra effort to dissipate the excess heat (Apud et al., 1989). It is important to acknowledge that during exercise in hot, humid conditions the heat loss mechanisms might not be able to remove sufficient heat from the body and temperatures may be high enough to cause heat stroke (Burton et al., 2004).

Exposure to high temperatures may also lead to an increase in peripheral blood vessel diameter in order to lose heat by convection, which results in decreased systolic blood pressure (SBP) and diastolic blood pressure (DBP) in young and middle aged people (Zamanian et al., 2017). As BP decreases, to maintain correct blood perfusion necessary for the body functioning, HR has to increase to compensate for this BP decrease (Zamanian et al., 2017).

The wet-bulb globe temperature (WBGT) is an empirical index which combines environmental parameters like temperature, humidity, wind speed, and solar radiation in equation (14) (Minard et al., 1957). The occupational exposure limits (OELs) based on WBGT are widely used and can be computed as in equation (15) (Al-Bouwarthan et al., 2020; Coca et al., 2016). The heat exposure (measured by computing WBGT and subtracting $WBGT_{OEL}$) on construction workers in Saudi Arabia during summer has been shown to have more impact in RHR than the workload itself (Al-Bouwarthan et al., 2020).

$$WBGT = 0.7T_W + 0.2T_G + 0.1T_D, \tag{14}$$

Where T_W is the wet bulb temperature (which indicates humidity), T_G is the globe temperature (which integrates radiation and air movement), and T_D is the ambient air (dry) temperature (Minard et al., 1957).

$$WBGT_{OEL}(^{\circ}C) = 56.7 - 11.5log_{10}M(W), \tag{15}$$

Where M is the work intensity level, in watts.

On the other hand, exposure to cold leads to vasoconstriction and tachycardia, both of which also contribute to an increase in BP and cardiac load (Granberg, 1991). A study conducted in the refrigeration industry corroborates this idea, as from the BP measurements performed in a cold-exposed group and a control group, both SBP and DBP were significantly higher in the first group (Kim et al., 2003).

4.2.1.2. Noise. Exposure to dangerous levels of noise is one of the most common occupational risks worldwide and it is known that susceptibility to noise at or above 85 dBA can cause permanent hearing loss, tinnitus, and other comorbidities like depression, cardiovascular diseases, and cognitive decline (Themann and Masterson, 2019; Basner et al., 2014). Particularly in the Mining, Construction, and Manufacturing sectors the prevalence of noise exposure and hearing loss is very high, mainly due to the extensive use of machines (Themann and Masterson, 2019).

Workers exposed to noise may suffer physiological reactions such as alterations in systolic and diastolic blood pressure, possibly leading to disorders (Chen et al., 2017). Nurshafa et al. studied the relationship of noise and physical workload to an increase in SBP and the results showed a positive correlation between noise levels and risk of abnormal SBP (Nurshafa and Widajati, 2020).

Hearing loss from noise is nearly always preventable, but there is a lack of emphasis on noise control and a normalization of loud noise levels by the society. Noise minimization is imperative and most workers only need 5–10 dB of noise reduction to decrease exposure to an acceptable level: roughly any protector properly and consistently utilized can produce this level of attenuation (Themann and Masterson, 2019).

4.2.2. General job characteristics

4.2.2.1. Working hours. Long working hours affect the occupational health of workers, having a negative impact on the risk of not only cardiovascular diseases and high BP (Kivimäki and Kawachi, 2015), but also sleep disturbances, mental health, and chronic fatigue (Wong et al., 2019). Accordingly, the results from a multiple regression analysis on data collected from Korean mail carriers showed that the number of working hours was positively associated with RHR (Lee et al., 2020).

4.2.2.2. Pause time. In a study assessing the risk factors related to construction building tasks, the working HR was significantly correlated with pause time (Maiti, 2008). Using Murrell's equation (equation (16)) (Murrell, 1965) and the oxygen uptake during work, the authors estimated the recommended rest time for the construction tasks being studied and concluded that the workers were not getting sufficient rest breaks.

$$R = \frac{T \times (E_{work} - E_{rec})}{E_{work} - E_{rest}} \approx \frac{T \times (VO_{2work} - VO_{2rec})}{VO_{2work} - VO_{2rest}}, \tag{16}$$

Where R is the estimated rest time (in minutes), T is the total working time, E_{work} is the energy expenditure at work, E_{rec} the recommended energy expenditure (which is 33% VO_{2max} (Murrell, 1965)) and E_{rest} at rest.

The physiological response to 15-min breaks was studied in physical therapists: after each 20-min treatment the workers did a break. During this pause the CVL levels decreased to values under 30%, allowing for a recovery (Yoopat et al., 2020).

4.2.2.3. Working in shifts. Shift work has been shown to represent an occupational risk factor, as it can be associated with adverse effects on workers' health, such as sleeping disturbances (Lajoie et al., 2015), a negative impact on work–life balance as well as health impairments of the cardiovascular system (Saksvik et al., 2011). Stieler et al. proposed to compare the cardiovascular recovery (CR) of shift and day workers in the hotel and catering industry (HCI) and, contrarily to what could be expected, the results showed that shift work was not a CR predictor (Stieler et al., 2019). Nonetheless, it was shown that shift workers had significantly higher BP (146/87 vs. 140/84 mmHg, $p = 0.034/0.044$) and HR (86 vs. 82 bpm, $p = 0.032$) during their work phase versus day workers.

4.2.3. Task characteristics

4.2.3.1. Heavy physical work. During heavy physical workload, the need for muscular contractions is intense and the human body undergoes several adaptations that affect the individual's organism because the skeletal muscle produces large amounts of lactic acid, which generate increased intra and extracellular acidity and provoke imbalanced biological control systems of the body, consequently favoring the emergence of occupational diseases (Schettino et al., 2021). Consequently, workers with a high occupational physical demand have an increased risk of cardiovascular disease (Krause et al., 2007), especially among those with low cardio-respiratory fitness (Korshøj et al., 2013). Occupations with high levels of physical demand exist in a wide range of areas (such as agroindustry, construction, emergency services) and have been correlated with higher rates of musculoskeletal disorders, disability (Ervasti et al., 2019), decreased physical function, and higher cardiovascular demand (Lunde et al., 2016).

4.2.3.2. Carrying loads. Tasks that involve carrying heavy loads can also establish risks for the operator - as such, Maiti et al. used the revised NIOSH equation (Waters et al., 1993) to compute the Recommended Weight Limit (RWL) associated with the construction tasks being studied and concluded the loads carried by the workers were much above the recommended limit, putting them at risk (Maiti, 2008).

In a study performed to evaluated the physiological demand of 21 female nurses working in geriatric wards, the nurses stated that patient lifting, transfer and turning were the most physically demanding tasks and it was found that these corresponded to the highest recorded HRs (Hui et al., 2001).

4.2.3.3. Repetitiveness. Repetitive tasks are very common in the modern industrial working environment. The muscle fatigue that results from performing these repetitive tasks is perceived by the worker as whole-body fatigue (Ahmad and Kim, 2018) and repetitiveness has been associated with higher prevalence of musculoskeletal disorders (Latko et al., 1999). Additionally, it has been shown that it has negative effects on CVL: in lower body resistance training sessions matching in effort and time under tension but differing on repetition time, cardiovascular stress and perceived exertion are greater for faster times (Mang et al., 2022).

4.2.3.4. Awkward postures. It is known that awkward postures, such as twisting, bending, and reaching, sustain an occupational risk factor for musculoskeletal injuries (Id et al., 2018). Additionally, this type of postural constraints also play a role on the cardiovascular demand of a task.

An illustrative example of this impact is a study that was done in an Indian farm, investigating the performance of the weeding task, an agriculture operation to eradicate weeds from the soil and strengthen the crop, usually done with a handhoe in a bending position (Ramana, 2002). The authors wanted to evaluate how the use of different tools - which require different working postures - affect the Energy Expenditure of the workers and concluded that the weight of the tool, the blade angle with the handle and the bent handle angle had an impact on the CVL. Attending to these factors, the authors propose the use of a new tool, light weighted with a bent handle (30° and 60°), which allowed the operator to improve his/her working posture and, consequently, reduce the Energy Expenditure (EE).

Even in less physically demanding jobs, such as crafting, uncomfortable positions like bending down with folded legs leave the artist exhausted from work. The resulting pain and the increased HR, after spending hours bent at the desk or on the floor have a high impact on the worker's health. Widana et al. proposed the adoption of an ergonomic workstation and, comparing the CVS before and after this introduction, concluded that an individually suitable workstation (which lead to better working postures) improved significantly the cardiovascular strain the worker was subject to (Widana et al., 2020).

Interventions in workstations and work tools for improving the operator's posture during the work day have consistently had a significant positive impact on the operator's CVL as a consequence (Batubara and Dharmastiti, 2017; Suarbawa et al., 2016; Palmerud et al., 2012).

4.2.3.5. Sedentarism. Although high physical demanding work is associated with a variety of risk factors already discussed, low OPA work also comprises a series of risks, such as the sedentary behaviour.

Sedentary behavior and physical inactivity are among the leading modifiable risk factors worldwide for cardiovascular disease and mortality (Lavie et al., 2019). Prolonged sedentary work contributes to this unhealthy lifestyle, as the worker is required to be sitting for long hours every working day, having not only negative consequences for the cardiovascular system but also leading to a premature loss of bone mass (Mahboubi et al., 2019).

Youthao et al. studied the impact of physical activity sessions during work hours to reduce sedentary behaviour in 4 occupational groups with low OPA: executives, professors, office workers, and janitors (Youthao and Kaewchuay, 2020). Different PA patterns (different combinations of zumba, cardio and yoga exercises) were applied to different groups and the results showed that (for all patterns) an 1-h per week session significantly reduced the workers' HR in a 3-min step test, which indicates an improvement in the cardiovascular fitness.

4.2.4. *Worker characteristics*

Individual characteristics also play an important role on the CVL each worker is subject to when performing a certain job. The performance of the same task may provoke different strain levels depending on the worker who is performing it. From an analysis on the effect of 31 factors (including worker's traits, environmental factors and work-related factors) on workload, the stature of the worker was the most impactful one, when explaining workload variance (Melemez and Tunay, 2010) and in another study (Saha et al., 2010), the authors conclude that there is poor recovery from the cardiovascular stress in miners, due to a mismatch between the workers' characteristics and the job requirements. Some individual traits that have been associated with higher occupational risk are discussed in the following sections.

4.2.4.1. Physical fitness and practice of exercise. The worker's level of cardio-respiratory fitness (which can be measured by $VO2_{max}$) is a main predictor of the cardiovascular strain during physically demanding work (Lunde et al., 2016; Preisser et al., 2016). While performing the same task, the worker with a higher aerobic capacity will be subject to lower cardiovascular stress than the worker with lower physical fitness.

As LTPA is a means of maintaining or improving fitness level, not practicing physical exercise during leisure turns into a risk factor for the worker. In (Rasmussen et al., 2019), a negative significant association between active leisure time in women and work time at >40%HRR (n = 356) was found, suggesting that those who practice physical exercise in leisure time are subject to lower levels of cardiovascular strain during blue-collar work.

Nonetheless, the reported effects of the practice of physical exercise on the CVL for high OPA workers have not been consistent. For example, in a study where a "PA-intervention" was performed in construction workers, no significant decrease in CVL during work was found after the intervention (Gram et al., 2016); also, the authors of (Lee et al., 2020) did not find a significant correlation between exercise and RHR during work in mail carriers. It would be necessary to understand if the practice of exercise in these cases had a positive impact on the aerobic capacity of the workers and, if not, possibly the practice was not sufficiently vigorous and/or consistent (through time) for the improvements to be observed.

From a systematic review regarding the effect of LTPA and sedentary behaviour on the health of workers, the evidence suggests that LTPA is beneficial for all workers, but the impact on reducing risk is greater in low OPA than high OPA jobs (Prince et al., 2021).

4.2.4.2. Body mass. Obesity is associated with shorter longevity and increased risk of cardiovascular morbidity and mortality; overweight is correlated with increased risk of developing cardiovascular diseases at an early age (Khan et al., 2018; Katzmarzyk et al., 2012). From the occupational perspective, overweight and obesity, together with inactivity, increase workload, except during young adulthood (Mänttäri et al., 2019).

A study performed on a population of 328743 Swedish construction workers showed that obese men (and to a minor extent overweight men) working in the construction industry were at increased risk of receiving disability benefits mainly through CVD and MSD, with an aggravated risk in the presence of high physical workload combined with obesity (Robroek et al., 2017).

Higher BMI was related to greater HR responses in medical alarm tones in firefighters (Marciniak et al., 2021) and it was shown that the cardiac strain in jobs exposed to hot and humid conditions was higher in obese and overweight workers when compared with normal weight workers (Dehghan et al., 2013a, 2013b).

4.2.4.3. Age and sex. With the increase of the average life expectancy, the proportion of aging workers has raised as well, and it is known that the age of the worker has a significant influence on the worker's physical capacity (Schibye et al., 2001): on the one hand there are age-related alterations that make workers more prone to injuries, but, on the other hand, older workers are often more trained.

During intensive work in road and building construction tasks, performed BP measurements revealed that systolic and diastolic pressure increases in older participants (Roja et al., 2017). RHR was significantly correlated with age in van-rickshaw pullers (indian public transport) (Sahu et al., 2013), but a comparison of cardiac strain among drillers of two different age groups (less versus more than 40 years old) showed no significant differences between groups (neither in RHR during work nor in aerobic capacity) (Saha et al., 2008b).

The effects of both age and sex were shown to be significant on Energy Expenditure (EE) of dairy workers (where female workers and older workers were related to higher EE values) (Chauhan and Dayal, 2008). Another study regarding dairy farming (n = 23) showed that female workers suffered greater levels of exertion due to lower aerobic capacity ($VO2_{max}$) (Ahonen et al., 1990).

During a 16-year follow-up study performed with a multi-occupational sample of 45 workers to study the age-related alterations of musculoskeletal and cardiovascular capacity, both decline and improvement was found among subjects with low workload. On the contrary, for the high workload group, the decline of physical capacity was more prevalent than improved, particularly in aerobic capacity, concluding that high demand seems to have more wearing effects than training effects on ageing workers (Savinainen et al., 2004).

4.2.4.4. Work experience. In the assessment of physiological strain of physical therapists according to work experience (based on the number of years of active employment), the measured CVL did not show any significant difference between different levels of experience (Yoopat et al., 2020). On the other hand, experience in potato cultivators was positively correlated with work pace, which, in turn, was positively correlated with working HR (Pal et al., 2015).

4.3. Occupational groups

Different occupations are associated with different risk factors and some are more prone to the occurrence of hazards during work or to the emergence of certain occupational diseases. The found literature regarding cardiovascular assessment during work is not equally distributed through all existing occupational categories, as we can see in Fig. 2, having very high incidence in the manufacturing industry and agriculture and forestry (sectors that employ a big part of the population (ILOSTAT, 2021; Eurostat, 2022b)), and construction work (where there is a high prevalence of occupational accidents (Chen and Tserng, 2022)). On the other hand, not many studies were found regarding office work and low OPA work in general.

Manufacturing workers are often exposed to awkward postures, repetitive movements, high levels of noise, and excessive loads (Papoutsakis et al., 2022; Suarbawa et al., 2016). In the construction sector, the rates of occupational accidents is elevated, due to the worker's excessive workload and fatigue. Risk factors associated with construction work include carrying loads weighting more than recommended limits (Maiti, 2008), exposure to high heat strain in outdoor environments (Al-Bouwarthan et al., 2020), heavy workload (Ismaila and Oriolowo, 2012), aerobic fitness of the worker (Lunde et al., 2016), and psycho-social factors (Roja et al., 2017). In the agricultural and forestry industry the rate and severity of occupational illness is mainly due to high physical load, awkward postures, great heat strain, and prolonged working hours (Schettino et al., 2021; Arman et al., 2021; Barbosa et al., 2015). Cleaning is an occupation with a high level of physical activity and a high prevalence of cardiovascular diseases (Korshøj et al., 2013; Sogaard et al., 1996). To perform cleaning work, the operators are frequently in awkward postures, which have a negative impact on cardiovascular stress - nonetheless, following ergonomic guidelines can reduce the strain the workers are subject to, inducing a more complex pattern of activity (Samani et al., 2012). The main factors influencing the workload of firefighters during fireline construction are the radiant heat, the slope of the terrain, the weight of the fuels being removed, the duration of the fire and the number of workers in the fireline (Apud and Meyer, 2011). Miners are also subject to various occupational risk factors, which often lead to absenteeism, including critical noise levels, heavy manual work, and hot humid environments (Saha et al., 2008b, 2010). In office work, the main risk factor is sedentary behaviour (Youthao and Kaewchuay, 2020), but in general there is a lack of studies regarding cardiovascular stress in low OPA jobs.

4.4. Impact of physical activity in the workplace

4.4.1. Energy expenditure rate (EER) and metabolic equivalent of task (MET)

The Energy Expenditure (EE) is the energy expended as a result of the performance of physical activity. EE can be directly measured by direct calorimetry, where the heat that is generated by the body is quantified, but the subject needs to be inside a chamber, making it impractical in most situations (Hills et al., 2014). Nonetheless, there are ways of estimating it, namely through indirect calorimetry (which computes the produced heat from the consumed oxygen and produced carbon dioxide) or even solely based on the oxygen consumption or HR (Hiilloskorpi et al., 2003). Pal et al. and Ramana et al. estimated EE from VO2 using equation (17) (Pal et al., 2015; Ramana, 2002). Chauhan et al. studied the CVL of dairy workers from the calculation of EE using equation (18) (Chauhan and Dayal, 2008; Varghese et al., 1994).

$$Energy\ Expenditure\ (kJ\ /\ min) = 20.93 (kJ\ /\ l) \times VO_2 (l\ /\ min) \quad (17)$$

$$Energy\ Expenditure\ (kJ\ /\ min) = 0.159 \times HR_{\text{average}} - 8.72 \quad (18)$$

One Metabolic Equivalent of a Task (MET) is defined as the amount of oxygen consumed while sitting at rest and corresponds to $3.5\ \text{ml} \cdot kg^{-1} \cdot min^{-1}$ (Jette et al., 1990). METs are a simple way of quantifying the energy cost of an activity and the EE in kcal can be calculated by multiplying it by the duration (minutes) and body weight (kg) of the individual (Krause et al., 2007). Gram et al. estimated the EE of construction workers using a combined HR and accelerometry sensor and from then computed the MET for each work task, defining three workload categories: "sedentary" (1–1.5 MET), "light" (1.5–3 MET) and "moderate-vigorous" (>3 MET) (Gram et al., 2016).

4.4.2. Maximum Acceptable Work Time (MAWT) and overwork index

The concept of Maximum Acceptable Work Time (MAWT) was introduced by Wu et al., in order to assess the acceptable time limit to spend working at a given physical workload, in order to guarantee the safety of the operator (Wu and Wang, 2002). MAWT can be estimated based on $\%VO2_{max}$, RHR or RVO2, as in equations 19, 20 and 21, respectively.

$$MAWT = 95.33 \times e^{-7.28 \times \%VO_{2max}} \quad (19)$$

$$MAWT = 26.12 \times e^{-4.81 \times RHR} \quad (20)$$

$$MAWT = 37.80 \times e^{-6.36 \times RVO_2} \quad (21)$$

Overwork index is the ratio between the actual number of working hours and the estimated MAWT: if it is higher than one it means that the worker is exceeding his/her physical ability. From our results, in three studies these parameters were computed based on equation (20) in order to understand if the limits were being surpassed (Lunde et al., 2016; Lee et al., 2020; Kim et al., 2018).

4.4.3. Leisure time physical activity (LTPA) vs occupational physical activity (OPA) paradox

Physical activity during leisure-time is unanimously considered to bring benefits for one's health (Barengo et al., 2017). On the contrary, high levels of occupational physical activity (OPA) are associated with increased long-term sickness absence (Holtermann et al., 2012), cardiovascular disorders (Li et al., 2013) and early mortality (Harari et al., 2015; Cillekens et al., 2022). PA at work is usually performed at lower intensities and for longer durations than LTPA. Consequently, OPA may induce high levels of CVL without reaching sufficient intensity of PA to increase cardiorespiratory fitness, and without the necessary time for the body to recover (Gupta et al., 2019; Holtermann et al., 2012).

With the aim of confirming this paradoxal phenomena, Coenen et al. compared the performance of equivalent physical activities in the two contexts: 1) during work and 2) during leisure time. The results (from a population of 124 blue-collar workers) showed that %HRR was higher when these activities were performed in working hours (Coenen et al., 2018). One factor that the authors point out as a possible cause for this discrepancy is the mental stressors that may additionally increase HR.

Accordingly, higher %HRR values during work have been associated with lower HRV indices in the following night as well as a higher resting HR (Korshøj et al., 2021): these are symptoms of an imbalanced autonomic cardiac modulation, supporting the harmful effect of OPA. Quinn et al. came even further, concluding from the study of 24-h HRV (of a sample of 19 high OPA workers) that moderate to vigorous PA increases HR and decreases HRV on work days while the opposite effect happens on non-work days (Quinn et al., 2021).

4.5. Evidence-based practices towards occupational health

4.5.1. Practical considerations for performing measurements in the workplace

The measurement of physical load on the cardiovascular system in relation to work environment-, job-, task-, and individual worker-related risk factors presents challenges. This is because the instrumentation for performing such measurements can restrict movements (e.g. due to wires) or cause discomfort (e.g. from sweating or skin irritation). This might affect task performance, i) directly, by causing a worker to interrupt or stop work in response and, ii) indirectly, by, for example, distracting a worker's attention or altering their perception of demand and control (i.e. aspects of perceived strain (Karasek, 1979)). Either way, this might induce physiological reactivity (e.g. an increase in HR values associated with the behavioural response induced by instrumentation) (Kamarck et al., 2002). These direct and indirect effects can mask the real effect on CVL of physical work and alter the representation in the data of the normal physiological demand of a regular working day.

The development of small wireless systems has improved the feasibility of performing continuous physiological acquisitions in the workplace (or even 24-h long acquisitions) (Bustos et al., 2021). Nevertheless, in situations where there are no means of performing objective measurements, it is advisable to use subjective self-report instruments. Anchoring procedures should accompany the use of these instruments in order to promote consistency in subjective ratings, ensure appropriate use of the questionnaire and the reliability of the acquired data. To this end, researchers and practitioners should instruct participants on how to use the instrument and familiarize them with the range of sensations that they might experience and on associating these with the different levels (or response options) presented in the instrument (Lagally and Costigan, 2004).

4.5.2. AI-based methods for the prediction of cardiovascular risks

The development of risk detection and prevention systems in the work environment is crucial to guarantee the worker's safety and to promote occupational health. AI-based algorithms are able to combine information from multiple sources, extract patterns and give meaningful outputs. Regarding ECG data, as manual ECG analysis is an arduous task, several automated methods from classical Machine Learning (ML) to Deep Learning (DL) have been developed, namely for the detection of ECG anomalies, heart diseases, etc (Li and Boulanger, 2020). The same approaches can be applied to the study of occupational risks.

Papoutsakis et al. developed a Deep Learning (DL) model based on visual and non-visual inputs which provides feedback regarding the worker's physical fatigue (by predicting near-future HR) and working postures, having achieved in experimental results an F1-score exceeding 70% (Papoutsakis et al., 2022). The visual data was acquired by low cost camera sensors installed in a real manufacturing workplace and the HR data was acquired by smartwatches worn by the workers. In another study, an artificial neural network model was able to predict HR_{work} based on HR_{rest}, age, body mass, body height, meaning that there is a non linear relationship between these indicators and HR_{work} (Ismaila et al., 2013a).

4.5.3. General recommendations and reference values

In Section 4.2, we presented several factors that correlate with higher CVL levels at work. These factors were divided into 4 categories: work environment, general job characteristics, task characteristics, and worker features. By acknowledging that the worker's cardiac strain can be influenced by a wide variety of aspects, it is necessary to take all of these into consideration in order to maintain healthy levels of strain. Although there is not a straightforward list of recommendations to follow, several authors have suggested guidelines to promote the safety and productivity of employees. These will be covered in this section.

The practice of exercise is commonly pointed to as a health promoting habit (Prince et al., 2021). This is particularly important in sedentary jobs. Dedicating at least 1 h per week from working hours to the practice of physical exercise has, in the long term, a good impact on the worker's health and on improving productivity (Youthao and Kaewchuay, 2020). Workers from low and moderate OPA jobs also benefit from this practice (Jakobsen et al., 2015). Some literature also includes high OPA workers as beneficiaries (Preisser et al., 2019), although not consensual as discussed in Section 4.4.3.

A very important element that should always be taken into account is the workstation. An ergonomic workstation is the one that is properly adjusted to best fit the workers' anthropometric measures and protects the worker from an unhealthy environment (regarding temperature, humidity, noise) and awkward postures. The adjustment of the workstation to an ergonomic design leads to significant reductions in CVL and CVS, in addition to preventing injuries (Widana et al., 2020). Furthermore, regarding low OPA work, active office workstations (cycling, treadmill or standing workstations instead of conventional seating workstations) have also showed good results to reduce sedentarism (Yoon et al., 2019; Schellewald et al., 2017).

In the industrial sector, it is important to apply an optimized assembly line balancing (task-to-station assignment) and a job rotation scheduling (worker-to-station assignment) that lower ergonomic risks, such as repetitiveness, awkward postures, carrying heavy loads, exposure to vibration and noise (Otto and Battaïa, 2017), for instance, by changing the assembly layout in a way that allows for better body postures (Suarbawa et al., 2016) or adjusting the length and timing of the rotation periods. Palmerud et al. compared a new machine paced system for engine assembly work with the self-paced system, and the results revealed that in the new system the movements were slower and the workers' RHR was significantly lower (Palmerud et al., 2012). In addition to all the benefits for the worker's health, according to a survey on cost-benefit analysis of ergonomic interventions, the pay-back period of the investments is less than one year, on average, due to fewer work-related disorders, lost workdays, increased productivity as well as decreased absenteeism (Goggins et al., 2008; Otto and Battaïa, 2017).

For jobs that require long-hour outdoor work (such as policemen, firefighters, construction workers) where the laborers are subject to health risks due to temperature and humidity exposure, the design of appropriate uniform and outdoor facilities could help to reduce the influence of these risk factors in the outdoor workplace (An et al., 2020).

The work tools are also relevant to the ergonomic approach, as the postures adapted by the workers are conditioned by them. The ergonomic design of work tools (shape, angles, weight) that allows for better postures and lower musculoskeletal effort has shown to consequently improve the CVL of the worker in a variety of sectors, such as in agriculture and forestry (Sibiya et al., 2021; Thamsuwan et al., 2019;

Table 5
Subjective workload index (SWI) (Yoopat et al., 2020).

SWI	Level of exertion
≤2	very light to light work
2 to ≤3	moderate work (some problems may occur)
3 to ≤ 4	heavy to tough work (problems are likely)
> 4	seriously problematic

Table 6
Severity of Work in terms of Oxygen consumption (VO2), Heart Rate (HR), and Energy Expenditure (EE) (Melemez and Tunay, 2010; Åstrand et al., 2003).

Work Severity	VO2 (L/min)	HR (beats/min)	EE (kcal/min)
Light work	<0.5	<90	<2.5
Moderate work	0.5–1.0	90–110	2.5–5.0
Heavy work	1.0–1.5	110–130	5.0–7.5
Very heavy work	1.5–2.0	130–150	7.5–10.0
Extremely heavy work	>2.0	150–170	> 10.0

Ramana, 2002), industry (Batubara and Dharmastiti, 2017), and cleaning (Kumar et al., 2005).

As a principle, physical work demands should decrease with age because of the natural decline of the physical work capacity (Ilmarinen, 1992). Nonetheless, older individuals can adapt to prolonged endurance training, largely improving their aerobic power (Seals et al., 1984).

The presence of ergonomists to educate the workers to follow ergonomics guidelines when performing their jobs allows not only for the improvement of CVL levels but also to decrease the risk of musculoskeletal disorders (Samani et al., 2012). Job rotation plans (Søgaard et al., 2006), break allowance and enduring leisure time to rest are likewise important to allow for healthy effort-recovery cycles, which support health and performance (Stieler et al., 2019).

Regardless of the existing guidelines, it is often difficult to avoid incurring in occupational risks. Continuous monitoring with the use of wearables is a strategy that can give insights regarding the state of the worker while working (Bustos et al., 2021). For example, Kim et al. developed and tested the use of a monitoring system with a wearable armband that consists of three sensors (photoplesthysmography (PPG), temperature and accelerometer) to monitor the physiological state of construction workers working under high temperatures (Kim et al., 2020). From the acquired data, a risk level is estimated and if the computed risk level surpasses a stipulated value an alert is sent to the manager.

To evaluate the physiological state of the workers, besides acquiring data and computing meaningful metrics, it is helpful to have some reference values in order to evaluate the risk exposure. Although the literature is not unanimous (Preisser et al., 2016; Bustos et al., 2021) and more validations should be done, some authors have proposed limits to the variables described in Section 4.1. Based on the *Textbook of Work Physiology* (Åstrand et al., 2003), Melemez et al. proposed the scale presented in Table 6 (Melemez and Tunay, 2010) (see Table 5).

5. Conclusions

The first aim of the present paper was to identify and gather metrics for the assessment of CVL that have been used in observational studies of occupational work. In Table 7, a brief description and the main limitations of each metric is presented. The majority of these studies reported the use of objective metrics, in particular, HR-based metrics. HR-based metrics include the HR itself, $\%HR_{max}$, RHR, CVL, CVS, and HRV variables. The most frequently used metric was the RHR, possibly due to it being the most intuitive metric and because it considers the person's minimum and maximum HR (which depend on factors such as age and stroke volume). The VO2 is also used as a cardiovascular metric but it is much more difficult to measure, particularly in the workplace. From the ECG signal it is possible to extract meaningful information, such as the HRV (from the distance between consecutive R peaks) and cardiac anomalies (from changes in the different segments of the signal). Although only one study used this approach (to count the occurrences of extrasystoles during work), we believe it is a potential focus of future

Table 7
Description and main limitations of the metrics for CVL assessment and evaluation. HR: Heart Rate; $\%HR_{max}$: percentage of maximum heart rate; RHR: Relative Heart Rate; %CVL: Percentage of Cardiovascular Load; %CVS: Percentage of Cardiovascular Strain; VO_2: Oxygen consumption; RVO_2: Relative Oxygen consumption; BP: Blood Pressure; HRV: Heart Rate Variability; ECG: Electrocardiogram; BLA: Blood Lactate Accumulation; PSI: Physiological Strain Index; RPE: Rate of Perceived Exertion; CR-10: Category Ratio; SWI: Subjective Workload Index.

Metric	Description	Limitations
HR	Number of heart beats per minute. Feasible continuous and direct monitoring during work.	Does not consider inter-individual variability (e.g. stroke volume).
$\%HR_{max}$	Intensity of the worker's HR in relation to the HR_{max}.	Does not consider HR_{rest}, not representing load above the resting state.
RHR	Intensity of effort in relation to HRR. Computed from the direct measure of HR and HR_{rest} and the estimation of HR_{max}.	-
%CVL	Relation between HR_{work} (subtracting HR_{rest}) and $HR_{(8h)}$ (maximum acceptable HR for an 8-h shift). Easy to monitor.	Interpretation is not intuitive. There is lack of validated scales.
%CVS	Relation between HR_{work} (subtracting HR_{rest}) and HR_{rest} itself.	Few studies have used it. Lack of validation. Interpretation is not intuitive.
VO_2	Measurement of oxygen consumption during work. Good measure to objectively describe stress.	Expensive equipment required. Continuous monitoring is often not feasible during work.
RVO_2	Measurement of oxygen consumption during work, considering individual $VO2_{min}$ and $VO2_{max}$.	Expensive equipment required. Continuous monitoring is often not feasible during work. Requires an estimation of $VO2_{max}$.
BP	Pressure of blood in the arteries. High blood pressure is a powerful predisposing risk factor for CVD. Highly studied parameter.	Difficult to monitor in occupational context. Requires the worker to stop momentarily.
HRV	Variation of the period between consecutive heartbeats. May contain relevant indicators of cardiac impairments.	Requires the use of devices that detect the time fluctuations between consecutive heart beats (e.g. ECG) and computer-based analytical tools.
ECG	Record of the electrical activity of the heart. HRV and relevant information can be extracted from the ECG.	Requires analytical tools or a clinician to interpret. The ECG signal obtained during work is easily corruptible with noise.
BLA	Blood Lactate concentration, a parameter commonly used in clinical context, which increases exponentially in intense exercise.	Few studies have used it in occupational context. Continuous monitoring not feasible. Highly intrusive.
PSI	Measure of heat stress, based on rectal temperature and HR.	Does not measure cardiovascular constraints directly. Lack of validation studies on applicability in occupational context.
RPE	Linear correlation with HR. Advisable when objective measures are difficult to apply or to use as supplementary information. Validated scales.	Subjective measure. Requires anchoring procedures (instructing the participant for a correct utilization of the instrument).
CR-10	Advisable when objective measures are difficult to apply or to use as supplementary information. Validated scales.	Subjective measure. Requires anchoring procedures (instructing the participant for a correct utilization of the instrument).
SWI	Level of exertion. Considers both positive and negative factors.	Subjective measure. Lack of validation.

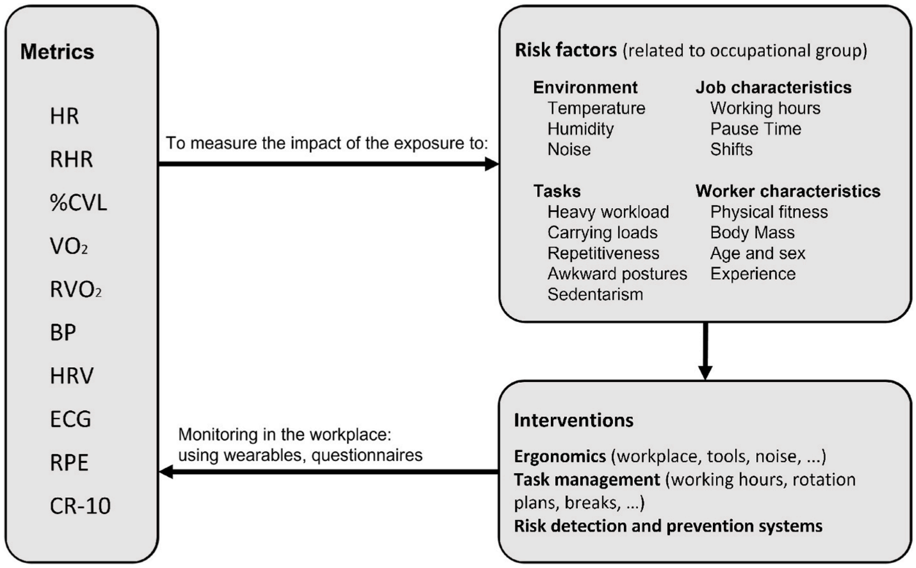

Fig. 4. Schematic illustrating a general guideline for the research on the continuous improvement of occupational health.

research, since it is widely used in the clinical context and has proven to be very informative. Furthermore, the number of automatic algorithms for ECG processing is increasing, thus sparing laborious manual data analysis (Li and Boulanger, 2020). Other metrics include the BLA and the PSI.

The second aim was to summarize the risk factors investigated in the observational studies. A wide range of different aspects were reported to have an influence on cardiovascular stress: environmental factors, general job characteristics, type of tasks performed and individual characteristics. For this multi-factorial phenomenon, the relevance of each factor depends on the occupational context.

The third aim was to report the occupational groups and activities that the observational studies targeted. In fact, most studies focused on occupational health in the manufacturing industry, construction, agriculture and forestry sectors. These occupations employ large parts of the work force and are known to be associated with the emergence of occupational diseases. Nevertheless, less physically demanding and/or sedentary jobs are also known to have negative repercussions for the health of the worker. We found little research has been conducted in this sector of activity.

The fourth aim was to summarize the recommendations for preventative measures for occupational CVD that resulted from these studies. Few evidence-based recommendations were identified, though guidelines to promote safety and productivity were proposed in some studies. As there is still a lack of evidence on the impact of each risk factor on the CVL experienced by the worker, a general recommendation for the continuous improvement of occupational health is illustrated in Fig. 4. The worker's health state and exposure to risks should be supervised (through measurements, either objective or subjective) and the working conditions should be constantly improved towards the minimization of occupational hazards (through ergonomic interventions).

5.1. Future directions

Future directions are considered from a number of different perspectives. From the technological point of view, further improvements in the miniaturization of low-cost and unobtrusive wireless devices would facilitate assessment of physiological signals of workers without disturbing the normal working routine, task or day. Enhancing the robustness of these devices against artefacts (e.g. movement, sweating, and muscle activity) and building software solutions to better handle and process the acquired data would contribute to improved use and understanding of the data.

From a theoretical perspective, more evidence is needed on the predictive power of the present metrics for work performance and occupational health. This challenge needs to address the multi-factorial nature of assessment, given the environment-, job-, task-, and individual worker-related risk factors, the different occupational groups and the association between CVL and occupational CVD. This theoretical effort is needed to build a better understanding of the differential and combined effects of these factors on CVL both within and across different activities as well as within and across different workers (i.e. inter-individual and intra-individual effects).

Finally, from the validation perspective, there is still a lack of validation and impact/risk evaluation studies for the metrics presented in Table 7. It is necessary to a) compare the use of these metrics (are they correlated, do they provide different information?) and b) develop validated risk exposure scales in order to have some reference values and give meaning to the computed metrics. Regarding the subjective parameters, their use can be extremely important, particularly in situations where objective measurements can not be performed or to understand the interactions between the objective measures and worker's perception. Further validation of the scales (particularly, the Subjective Workload Index) is necessary, including validation the association between these scales and objective measurements and risk factors.

The convergence of technical, theoretical and validation perspectives would contribute to generating the knowledge needed to develop evidence-based preventative guidelines for the promotion of safety and occupational health.

5.2. Strengths and limitations of this study

Foremost amongst the strengths of the present study is that we focused on specific questions of particular importance for CVL in the workplace. We supported these questions by ensuring adherence to strict eligibility criteria for inclusion of relevant observational studies from peer-reviewed journals. The results of the study are presented quantitatively and qualitatively. The qualitative analysis and narrative synthesis of the results aimed to support practical application of the knowledge extracted from the identified studies for future work in this field. There is a risk that some observational studies were missed because we focused on English-language publications in peer-reviewed journals and we did not consider studies in the grey literature (e.g. theses and dissertations). The use of one database for search and study identification risked missing all potentially eligible studies, though a recent study suggests that we are likely to have achieved good coverage (Yasin et al., 2020). The search terms were defined as broadly as possible to ensure comprehensive study identification ("cardiovascular load" AND ("occupational" OR "workers")). The quality assessment step, although based on objective criteria and with good agreement between raters, is inevitably partially subjective.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Acronyms

BLA Blood Lactate Accumulation
BP Blood Pressure
CR-10 Borg's Category Ratio
CVD Cardiovascular Disease
CVL Cardiovascular Load
CVS
Cardiovascular Strain
ECG Electrocardiogram
EE Energy Expenditure
HR Heart Rate
HRR Heart Rate Reserve
HRV Heart Rate Variability
LTPA Leisure-Time Physical Activity
MAWT Maximum Acceptable Work Time.
MET Metabolic Equivalent of a Task
OPA Occupational Physical Activity
PA Physical Activity
PSI Physiological Strain Index
RHR Relative Heart Rate
RPE Borg's Rate of Perceived Exertion
RVO_2 Relative Oxygen consumption
SVES Supraventricular Extrasystole
SWI Subjective Workload Index
VES Ventricular Extrasystole
VO_2 Oxygen consumption
WBGT Wet Bulb Globe Temperature

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