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The prevalence of occupational exposure to ergonomic risk factors: A systematic review and meta-analysis from the WHO/ILO Joint Estimates of the Work-related Burden of Disease and Injury

Carel T.J. Hulshof[a,*], Frank Pega[b], Subas Neupane[c], Henk F. van der Molen[a], Claudio Colosio[d,e], Joost G. Daams[a], Alexis Descatha[f,g,h], Prakash Kc[c], Paul P.F.M. Kuijer[a], Stefan Mandic-Rajcevic[d,e], Federica Masci[d,e], Rebecca L. Morgan[i], Clas-Håkan Nygård[c], Jodi Oakman[j], Karin I. Proper[k], Svetlana Solovieva[l], Monique H.W. Frings-Dresen[a]

[a] Amsterdam UMC, University of Amsterdam, Department Public and Occupational Health, Coronel Institute of Occupational Health, Amsterdam Public Health Research Institute, Amsterdam, the Netherlands
[b] Department of Environment, Climate Change and Health, World Health Organization, Geneva, Switzerland
[c] Unit of Health Sciences, Faculty of Social Science, Tampere University, Tampere, Finland
[d] Department of Health Sciences, University of Milan, Milan, Italy
[e] International Centre for Rural Heath, University Hospital San Paolo, Milan, Italy
[f] AP-HP (Paris Hospital), Occupational Health Unit, Poincaré University Hospital, Garches, France
[g] Inserm Versailles St-Quentin Univ – Paris Saclay Univ (UVSQ), Villejuif, France
[h] Univ Angers, CHU Angers, Univ Rennes, Inserm, EHESP, Irset (Institut de recherche en santé, environnement et travail), Angers, France
[i] Department of Health Research Methods, Evidence and Impact, McMaster University, Ontario, Canada
[j] Centre for Ergonomics and Human Factors, School of Psychology and Public Health, LaTrobe University, Melbourne, Australia
[k] Centre for Nutrition, Prevention and Health Services, National Institute for Public Health and the Environment, Bilthoven, the Netherlands
[l] Finnish Institute of Occupational Health, Työterveyslaitos, Finland

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ABSTRACT

Background: The World Health Organization (WHO) and the International Labour Organization (ILO) are developing joint estimates of the work-related burden of disease and injury (WHO/ILO Joint Estimates), with contributions from a large network of experts. Evidence from mechanistic and human data suggests that occupational exposure to ergonomic (or physical) risk factors may cause osteoarthritis and other musculoskeletal diseases (excluding rheumatoid arthritis, gout, and back and neck pain). In this paper, we present a systematic review and meta-analysis of the prevalence of occupational exposure to physical ergonomic risk factors for estimating the number of disability-adjusted life years from these diseases that are attributable to exposure to this risk factor, for the development of the WHO/ILO Joint Estimates.
Objectives: We aimed to systematically review and meta-analyse estimates of the prevalence of occupational exposure to ergonomic risk factors for osteoarthritis and other musculoskeletal diseases.
Data sources: We searched electronic bibliographic databases for potentially relevant records from published and unpublished studies, including Ovid Medline, EMBASE, and CISDOC. We also searched electronic grey literature databases, Internet search engines and organizational websites; hand-searched reference list of previous systematic reviews and included study records; and consulted additional experts.
Study eligibility and criteria: We included working-age (≥15 years) workers in the formal and informal economy in any WHO and/or ILO Member State but excluded children (<15 years) and unpaid domestic workers. The exposure was defined as any occupational exposure to one or more of: force exertion, demanding posture,

* Corresponding author.
E-mail addresses: c.t.hulshof@amsterdamumc.nl (C.T.J. Hulshof), pegaf@who.int (F. Pega), subas.neupane@tuni.fi (S. Neupane), h.f.vandermolen@amsterdamumc.nl (H.F. van der Molen), claudio.colosio@unimi.it (C. Colosio), j.g.daams@amsterdamumc.nl (J.G. Daams), alexis.descatha@inserm.fr (A. Descatha), prakash.kc@tuni.fi (P. Kc), p.p.kuijer@amsterdamumc.nl (P.P.F.M. Kuijer), stefan.mandic-rajcevic@unimi.it (S. Mandic-Rajcevic), federica.masci@unimi.it (F. Masci), morganrl@mcmaster.ca (R.L. Morgan), clas-hakan.nygard@tuni.fi (C.-H. Nygård), j.oakman@latrobe.edu.au (J. Oakman), karin.proper@rivm.nl (K.I. Proper), svetlana.solovieva@ttl.fi (S. Solovieva), m.frings@amsterdamumc.nl (M.H.W. Frings-Dresen).

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repetitive movement, hand-arm vibration, kneeling or squatting, lifting, and/or climbing. We included all study types with an estimate of the prevalence of occupational exposure to ergonomic risk factors.
Study appraisal and synthesis methods: At least two review authors independently screened titles and abstracts against the eligibility criteria at a first stage and full texts of potentially eligible records at a second stage, followed by extraction of data from qualifying studies. We combined prevalence estimates using random-effect meta-analysis. Two or more review authors assessed the risk of bias and the quality of evidence, using the ROB-SPEO tool and QoE-SPEO approach developed specifically for the WHO/ILO Joint Estimates.
Results: Five studies (three cross-sectional studies and two cohort studies) met the inclusion criteria, comprising 150,895 participants (81,613 females) in 36 countries in two WHO regions (Africa, Europe). The exposure was generally assessed with questionnaire data about self-reported exposure. Estimates of the prevalence of occupational exposure to ergonomic risk factors are presented for all five included studies, disaggregated by country, sex, 5-year age group, industrial sector or occupational group where feasible. The pooled prevalence of any occupational exposure to ergonomic risk factors was 0.76 (95% confidence interval 0.69 to 0.84, 3 studies, 148,433 participants, 35 countries in the WHO Europe region, I^2 100%, low quality of evidence). Subgroup analyses found no statistically significant differences in exposure by sex but differences by age group, occupation and country. No evidence was found for publication bias. We assessed this body evidence to be of low quality, based on serious concerns for risk of bias due to exposure assessment only being based on self-report and for indirectness due to evidence from two WHO regions only.
Conclusions: Our systematic review and meta-analysis found that occupational exposure to ergonomic risk factors is highly prevalent. The current body of evidence is, however, limited, especially by risk of bias and indirectness. Producing estimates for the burden of disease attributable to occupational exposure to ergonomic risk factors appears evidence-based, and the pooled effect estimates presented in this systematic review may perhaps be used as input data for the WHO/ILO Joint Estimates.
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1. Background

The World Health Organization (WHO) and the International Labour Organization (ILO) are finalizing their Joint Estimates of the Work-related Burden of Disease and Injury (WHO/ILO Joint Estimates) (Ryder 2017). The organizations are estimating the numbers of deaths and disability-adjusted life years (DALYs) that are attributable to selected occupational risk factors. The WHO/ILO Joint Estimates are based on existing WHO and ILO methodologies for estimating the burden of disease for selected occupational risk factors (Ezzati et al. 2004; International Labour Organization 1999; 2014; Pruss-Ustun et al. 2017). They expand these existing methodologies with estimation of the burden of several prioritized additional pairs of occupational risk factors and health outcomes. For this purpose, population attributable fractions (Murray et al. 2004) are being calculated for each additional risk factor-outcome pair, and these fractions are being applied to the total disease burden envelopes for the health outcome from the WHO *Global Health Estimates* for the years 2000–2016 (World Health Organization 2019). Population attributable fractions are the proportional reduction in burden from the health outcome achieved by a reduction of exposure to the risk factor to zero.

The WHO/ILO Joint Estimates may include estimates of the burden of osteoarthritis and other musculoskeletal diseases (excluding rheumatoid arthritis, gout, and back and neck pain) attributable to occupational exposure to ergonomic (or physical or mechanical) risk factors, if feasible, as two additional risk factor-outcome pairs whose global burden of disease has not previously been estimated. To select parameters with the best and least biased evidence for our estimation models, we conducted a systematic review and meta-analysis of studies on the prevalence of occupational exposure to ergonomic risk factors, as per our protocol (Hulshof et al. 2019). In this review, ergonomic risk factors are limited to physical ergonomic risk factors. We present our findings in the current paper. WHO and ILO, supported by a large network of experts, are in parallel also producing a systematic review an meta-analysis of the effect of occupational exposure to physical ergonomic risk factors on osteoarthritis and other musculoskeletal diseases (Hulshof et al. 2019). The organizations are also in parallel conducting or have completed several other systematic reviews and meta-analyses on other additional risk factor-outcome pairs (Descatha et al., 2018, 2020; Godderis et al., 2018; Hulshof et al., 2019; Li et al., 2018, 2020; Mandrioli et al., 2018; Pachito et al., 2021; Paulo et al., 2019; Pega et al., 2020; Rugulies et al., 2019; Teixeira et al., 2019; Tenkate et al., 2019). To our knowledge, these are the first systematic reviews and meta-analyses (with a pre-published protocol) conducted specifically for an occupational burden of disease study (Mandrioli et al. 2018). The WHO's and ILO's joint estimation methodology and the WHO/ILO Joint Estimates are separate from these systematic reviews, and will be described in more detail and reported elsewhere.

1.1. Rationale

To consider the feasibility of estimating the burden of osteoarthritis and other musculoskeletal diseases attributable to occupational exposure to ergonomic risk factors, and to ensure that potential estimates of burden of disease are reported in adherence with the guidelines for accurate and transparent health estimates reporting (GATHER) (Stevens et al., 2016), WHO and ILO require two systematic reviews. First, a systematic review of evidence on the prevalence of occupational exposure to ergonomic risk factors (the systematic review presented here). Secondly, a systematic review and a meta-analysis of studies with estimates of the relative effect of occupational exposure to ergonomic risk factors on the prevalence or incidence of osteoarthritis and other musculoskeletal diseases respectively, compared with the theoretical minimum risk exposure level (forthcoming). The theoretical minimum risk exposure level is the level which results in the lowest possible population risk, even though it may not be feasible to attain this exposure level (Murray et al., 2004).

We are not aware of any previous systematic reviews of the existing evidence on the exposure to any of the occupational ergonomic risk factors covered in this review independent of a specific disease. The ergonomic risk factors covered in this systematic review are: force exertion, demanding posture, repetitive movement, hand-arm vibration, lifting, kneeling and/or squatting, and climbing. Seven previous systematic reviews have focused on the evidence on the effect of occupational exposure to any of these ergonomic risk factors on one or more musculoskeletal diseases of the shoulder (van Rijn et al., 2010; van der Molen et al., 2017; Lievense et al., 2001); elbow (Descatha et al., 2016); hip (Jensen, 2008; Lievense et al., 2001); and knee (Verbeek et al., 2017), respectively. These systematic reviews identified several occupational ergonomic risk factors as relevant.

For knee osteoarthritis, the Verbeek et al. 2017 systematic review and meta-analysis of 12 case control studies found the following odds ratios (ORs) from exposure (directly measured) to:

- Kneeling or squatting (12 studies): 1.7 (95% confidence interval (CI) 1.35–2.13, I^2 49%).
- Lifting (11 studies): 1.69 (95% CI 1.43–2.00, I^2 51%).
- Climbing (seven studies): 1.6 (95% CI 1.25–1.91, I^2 68%).
- Kneeling and lifting combined (one study): 1.35 (95% CI 1.05–1.73) (Verbeek et al., 2017).

A recent meta-analysis, based on seven studies, found moderate quality evidence for associations between shoulder disorders (ICD-10 codes: M75.1-M75.5) and arm elevation (OR 1.9, 95% CI 1.47 to 2.47, I^2 31%) and shoulder load, a combined biomechanical exposure measure (OR 2.0, 95% CI 1.90 to 2.10, I^2 0%), and low to very low evidence for hand force exertion (OR 1.5, 95% CI 1.25 to 1.87, I^2 66%), and hand-arm vibration (OR 1.3, 95% CI 1.01 to 1.77, I^2 99%) (van der Molen et al., 2017). Van Rijn et al. performed a systematic review on the relationship between work-related factors and specific disorders of the shoulder and based on the 17 included studies that repetitive movements of the shoulder, repetitive motion of the hand/wrist of >2 h/day, hand–arm vibration, and arm elevation showed an association with sub acromial impingement syndrome (ORs between: 1.04, 95% CI 1.00–1.07 and 4.7, 95% CI 2.07–10.68), as did upper-arm flexion of ≥45° for ≥15% of time (OR 2.43, 95% CI 1.04–5.68) and duty cycle of forceful exertions of ≥9% time or any duty cycle of forceful pinch (OR 2.66, 95% CI 1.26–5.59) (van Rijn et al., 2010). Descatha et al. (2016) conducted a meta-analysis of five prospective studies published between 2001 and 2014 and found a positive association between combined biomechanical exposure involving the wrist and/or elbow and incidence of epicondylitis lateralis (OR 2.6, 95% CI 1.9–3.5) (Descatha et al., 2016). A systematic review by van Rijn et al. (2009) found associations between force, posture, repetitiveness, hand-arm vibration and a mixture of these exposures and elbow disorders (van Rijn et al., 2009). Handling tools of >1 kg (ORs of 2.1–3.0), handling loads of >20 kg at least ten times/day (OR 2.6) and repetitive movements for >2 h/day (ORs of 2.8–4.7) were associated with lateral epicondylitis, while handling loads of >5 kg (2 times/min at minimum of 2 h/day), handling loads of >20 kg for at least ten times/day, high hand grip forces for >1 h/day, repetitive movements for >2 h/day (ORs of 2.2–3.6) and working with vibrating tools for >2 h/day (OR 2.2) were all associated with medial epicondylitis. Jensen (2008) evaluated the association between physical work demands and hip osteoarthritis in 22 included studies and concluded that moderate to strong evidence exists for a relationship with heavy lifting (OR ranges between 1.97, 95% CI 1.14–3.4, and 8.5 (95% CI 1.6–45.3) (Jensen, 2008). Furthermore, thirteen studies showed a significantly increased risk between farming activities and hip osteoarthritis, with ORs ranging from 1.9 (95% CI 1.01–3.87) to 12.0 (95% CI 6.7–21.4). Lievense et al. (2001) used a best-evidence synthesis to summarize the results of two retrospective and 14 case-control studies and found moderate evidence for a positive association between previous physical workload and hip osteoarthritis, with ORs ranging from 1.5 (95% CI 0.9–2.5) and 9.3 (95% CI 1.9–44.5) (Lievense et al., 2001). In a subgroup analysis, also ≥10 years farming was positively related to hip osteoarthritis.

Our systematic review covers workers in the formal and informal economy. The informal economy is defined as "all economic activities by workers and economic units that are – in law or in practice – not covered or insufficiently covered by formal arrangements" (104th International Labour Conference 2015). It does not comprise "illicit activities, in particular the provision of services or the production, sale, possession or use of goods forbidden by law, including the illicit production and trafficking of drugs, the illicit manufacturing of and trafficking in firearms, trafficking in persons and money laundering, as defined in the relevant international treaties" (104th International Labour Conference 2015). Work in the informal economy may lead to different exposures and exposure effects than does work in the formal economy. Therefore, we consider in the systematic review the formality of the economy reported in included studies.

1.2. Description of the risk factor

Burden of disease estimation requires accurate and unambiguous definitions of the risk factor, risk factor levels and the theoretical minimum risk exposure level. Table 1 presents these for the risk factor covered in this systematic review: occupational exposure to ergonomic risk factors.

2. Objectives

To systematically review and meta-analyse evidence on the prevalence of any occupational exposure to ergonomic risk factors among working-age workers.

3. Methods

3.1. Developed protocol

The study protocol was registered in PROSPERO (CRD42018102631). This protocol is in accordance with the preferred reporting items for systematic review and meta-analysis protocols statement (PRISMA-P) (Moher et al., 2015; Shamseer et al., 2015). The abstract is in line with the reporting items for systematic reviews in journal and conference abstracts (PRISMA-A) (Beller et al., 2013). Any modification of the methods stated in the present protocol was registered in PROSPERO and is reported in *Section 8*. Our systematic review is reported according to the preferred reporting items for systematic review and meta-analysis statement (PRISMA) (Liberati et al. 2009). Our reporting of the parameters for estimating occupational exposure to ergonomic risk factors in the systematic review adheres to the requirements of the GATHER guidelines (Stevens et al. 2016). This is done because the WHO/ILO burden of disease estimates that may be produced following the systematic review must also adhere to these reporting guidelines.

3.2. Searched literature

3.2.1. Electronic bibliographic databases

We searched the following four electronic bibliographic databases:

1. Ovid MEDLINE with Daily Update (1 January 2005 to 5 December 2018, and updated on 27 August 2019).
2. EMBASE (1 January 2005 to 5 December 2018).

Table 1
Definitions of the risk factor, risk factor levels and the minimum risk exposure level.

	Definition
Risk factor	Occupational exposure to ergonomic risk factors, defined as occupational exposure to one or more of: force exertion, demanding posture, repetitive movement, hand-arm vibration, kneeling or squatting, lifting and climbing.
Risk factor level	No or low occupational exposure to ergonomic risk factors. Any occupational exposure to ergonomic risk factors.[a]
Theoretical minimum risk exposure level	No occupational exposure to ergonomic risk factors

Footnotes: Sourced from (Hulshofet al. 2019). [a] If possible, "any" exposure may be further sub-classified into "moderate" and "high" exposure, preferably based on dose, frequency and/or duration of the exposure.

3. Web of Science with inclusion of three databases: Science Citation Index Expanded (1 January 2005 to 5 December 2018); Social Sciences Citation Index (1 January 2005 to 5 December 2018); and Arts and Humanities Citation Index (1 January 2005 to 5 December 2018).
4. OSH UPDATE with inclusion of three databases: CISDOC (1 January 2005 to 5 December 2018); HSELINE (1 January 2005 to 5 December 2018); and NIOSHTIC-2 (1 January 2005 to 5 December 2018).

The Ovid MEDLINE search strategy was presented in the protocol (Hulshof et al., 2019). Based on this search strategy, the strategies for the other databases were developed by a clinical librarian and information scientist and are presented in Appendix 1 in the Supplementary data. We performed searches in electronic databases operated in the English language using an English-language search strategy. Consequently, study records that did not report essential information (i.e. title and abstract) in English were not captured. Just prior to completion of the systematic review, the search of the Ovid MEDLINE database was updated on 27 August 2019 to capture the most recent publications (e.g., publications ahead of print). Differences between the proposed search strategy and the actual search strategy are documented in *Section 8*.

3.2.2. Electronic grey literature databases.

The following electronic grey literature databases were searched in December 2018:

1. OpenGrey (http://www.opengrey.eu/).
2. Grey Literature Report (http://greylit.org/).

3.2.3. Internet search machines.

In addition, we also searched the Google (www.google.com/) and Google Scholar (www.google.com/scholar/) Internet search engines and screened the first 100 hits for potentially relevant records, a strategy used previously in Cochrane Reviews (Pega et al., 2015; Pega et al., 2017).

3.2.4. Organizational websites.

The websites of the following nine international organizations and national government departments were searched in December 2018:

1. International Labour Organization (www.ilo.org).
2. World Health Organization (www.who.int).
3. Eurofound (https://www.eurofound.europa.eu/en)
4. European Agency for Safety and Health at Work (https://osha.europa.eu/en).
5. Eurostat (www.ec.europa.eu/eurostat/web/main/home).
6. International Ergonomics Association (http://www.iea.cc/).
7. China National Knowledge Infrastructure (http://www.cnki.net/).
8. Finnish Institute of Occupational Health (https://www.ttl.fi/en/).
9. United States National Institute of Occupational Safety and Health (NIOSH), using the NIOSH data and statistics gateway (https://www.cdc.gov/niosh/data/).

3.2.5. Hand-searching and expert consultation.

Hand-searching for potentially eligible studies was undertaken in:

- Reference lists of previous systematic reviews.
- Reference lists of all study records of all included studies.
- Study records published over the past 24 months in the three peer-reviewed academic journals from which we obtained the largest number of included studies (Occup Environ Med, Scand J Work Environ Health, and Int Arch Occup Environ Health).
- Study records that have cited an included study record (identified in Web of Science citation database).
- Collections of the review authors.

Additional experts were contacted with a request to identify potentially eligible studies. This included invitations to the Scientific Committee on Musculoskeletal Disorders of the International Commission on Occupational Health and the International Ergonomics Association to submit potential additional eligible studies.

3.3. Selected studies

Study selection was carried out using Covidence (Babineau, 2014; Covidence Systematic Review Software). All study records identified in the search were downloaded and duplicates were identified and deleted. Afterwards, two review authors independently and in duplicate screened titles and abstracts (step 1) and then full texts (step 2) of potentially relevant records. A third review author resolved any disagreements between the two review authors. If a study record identified in the literature search was authored by a review author assigned to study selection or if an assigned review author was involved the study it was re-assigned to another review author for study selection. The study selection is presented in a flow chart, as per PRISMA guidelines (Liberati et al., 2009).

Considering the complexity of the eligible exposure (i.e., capturing at least five out of seven eligible ergonomic risk factors), we conducted a validation study of our title and abstract screening process, to determine if we had potentially missed eligible studies in this stage. From the 17,924 records that were rejected in the title and abstract screening stage, we randomly drew a sub-sample of 400 records. Two review authors then independently screened the full texts of these records. None of these rescreened studies included exposure to five or more of the assigned risk factors. This supported the accuracy of our abstract and title screening.

3.4. Eligibility criteria

The population and exposure criteria are described below.

3.4.1. Types of populations

We included studies of the working-age population (≥15 years) in the formal and informal economy. Studies of children (aged <15 years) and unpaid domestic workers were excluded. Participants residing in any WHO and/or ILO Member State and workers in any industrial sector or occupation were included. Appendix F of our protocol (Hulshof et al 2019) provides a complete, but brief overview of the eligibility criteria.

3.4.2. Types of exposures

We included studies that defined occupational exposure to ergonomic risk factors in accordance with our standard definition (Table 1). For osteoarthritis, and other musculoskeletal disease (as defined above) respectively, cumulative exposure (e.g. total number of years or total amount of work performed according to one's job history) may be the most biologically relevant exposure metric in theory, but we believe that insufficient cumulative exposure data currently exist to enable burden of disease estimation. Consequently, as has been done in other burden of disease studies, we have in this systematic review prioritized a non-cumulative exposure metric in practice, namely exposure in present work on the day of measurement, rather than taking into account the exposure history. We have included studies on the prevalence of exposure to the respective occupational risk factors, if it is disaggregated by country (defined as a WHO and/or ILO Member State), sex, age (ideally in 5-year age bands, such as 20–24 years) and industrial sector (e.g., International Standard Industrial Classification of All Economic Activities, Revision 4 [ISIC Rev. 4]) (United Nations, 2008) or occupation (as defined, for example, by the International Standard Classification of Occupations 1988 [ISCO-88] (International Labour Organization, 1987) or 2008 [ISCO-08] (International Labour Organization, 2012)). Criteria were sometimes revised to identify optimal data disaggregation to enable potential subsequent estimation of the disease burden.

For the WHO/ILO Joint Estimates of the burdens of osteoarthritis and/or other musculoskeletal diseases attributable to occupational exposure to ergonomic risk factors (if feasible), the ideal exposure measurements would have been exposure to all seven risk factors. However, it is very unlikely that studies on the effect of occupational exposure to ergonomic risk factors on osteoarthritis of knee or hip would capture occupational exposure to hand-arm vibration, and that studies on the effect of occupational exposure to ergonomic risk factors on epicondylitis would include occupational exposure to kneeling, respectively. Therefore, we included studies that had measured occupational exposure to at least five of the seven relevant ergonomic risk factors. To approximate the two risk factor levels (Table 1), we differentiated between no exposure (in the majority of studies proxied by duration of exposure ≤2 h per working day) and any exposure (a proxy of duration of daily exposure >2 h).

We included studies with exposure data for the years 1 January 2005 to 31 July 2018. For optimal modelling of exposure, WHO and ILO require exposure data up to 2018, because recent data points help better estimate time trends, especially where data points may be sparse. The additional rationale for this data collection window is that the WHO and ILO aim to estimate burden of disease in the year 2015, and we believe that the lag time from exposure to outcome will not exceed 10 years (Haibing et al., 2006).

Both objective and subjective measures of exposure were included. Examples of objective measures are real-time observation of posture by video analysis, force measurements or time-weighted acceleration measurements of hand-arm vibration. Subjective measures may be self-reported duration of exposure to the risk factors in a typical working day. If both subjective and objective measures were presented, then we prioritized objective ones, as an estimate based on this is likely more resilient to potential risk of bias in the study. Studies with measures from any data source, including registries, were eligible.

3.4.3. Types of studies

This systematic review included studies of any design reporting quantitative results, including cross-sectional studies. The studies had to be representative of the relevant industrial sector, occupational group or the national population. We excluded qualitative, modelling and case studies, as well as non-original studies without quantitative data (e.g. letters, commentaries and perspectives).

Records published in any language were included. Again, the search was conducted using English language terms, so that records published in any language that presented essential information (i.e. title and abstract) in English were included. If a record was written in a language other than those spoken by the authors of this review or those of other reviews (Descatha et al. 2018; Godderis et al. 2018; Hulshof et al. 2019; Mandrioli et al. 2018; Paulo et al. 2019; Rugulies et al. 2019; Teixeira et al. 2019; Tenkate et al. 2019) in the series (i.e. Arabic, Bulgarian, Chinese, Danish, Dutch, English, French, Finnish, German, Hungarian, Italian, Japanese, Norwegian, Portuguese, Russian, Spanish, Swedish and Thai), then the record was translated into English. Published and unpublished studies were included. Studies conducted using unethical practices were excluded from the review.

3.4.4. Types of prevalence measures

We included studies with a prevalence measure. Prevalence is the presence (and often the level) of an exposure to an occupational risk factor in each individual of the study population or in a representative sample at one particular time point (Porta 2014). The prevalence (as here defined) is usually measured as the number of exposed persons (numerator) divided by the total number of persons (i.e., unexposed persons plus exposed persons) (denominator). It is usually reported in percentage points.

3.5. Extracted data

WHO and ILO developed a standard data extraction sheet and all data extractors piloted this sheet until there was convergence and agreement among them. The majority of the data extractors participated in WHO's online training for the use of the data extraction sheet. At a minimum, two review authors independently extracted the data on occupational exposure to ergonomic risk factors, disaggregated by country, sex, age and industrial sector or occupation. A third review author resolved conflicting extractions. Data were extracted on study characteristics (including study authors, study year, study country, participants and exposure), study design (including study type, exposure measurement and type of prevalence estimate), risk of bias (including missing data, as indicated by response rate and other measures) and study context. The prevalence estimates from included studies were entered and managed with the Review Manager, Version 5.3 (RevMan 5.3).

Data on potential conflict of interest were also extracted from the included studies, such as financial disclosures, funding sources, and authors' affiliated organization. A modification of a previous method was used to identify and assess undisclosed financial interests (Forsyth et al., 2014). If no financial disclosure and conflict of interest statements were provided, other records were searched from this study published in the 36 months prior to the included study record and in other publicly available repositories (Drazen et al., 2010a; Drazen et al., 2010b).

3.6. Requested missing data

Missing data were requested from the principal study author by email or phone, using the contact details provided in the principal study record. If no response was received at two weeks, a follow up email was sent. Of the five included studies (Andersen et al. 2016; Naidoo et al., 2009, Shiri et al., 2009; Fan et al., 2009, Herin et al., 2014) for which we requested missing data (i.e., the number of study participants exposed to one or more of the eligible ergonomic risk factors), we received the requested data for two studies (Andersen et al. 2016, Naidoo et al., 2009) (Appendix 2 in the Supplementary data for details).

3.7. Assessed risk of bias

We used the RoB-SPEO tool for assessing risk of bias in studies estimating the prevalence of exposure to occupational risk factors (Pega et al. 2019). WHO and ILO developed this tool specifically for their systematic review for the development of the WHO/ILO Joint Estimates. For each included study, two or more review authors independently assessed risk of bias with RoB-SPEO, and another review author resolved any conflicts between the individual assessments.

3.8. Synthesised evidence (including conducted meta-analysis)

If we found two or more studies with an eligible prevalence estimate, two or more review authors independently assessed the clinical heterogeneity (Deeks et al. 2011) of the studies in terms of population (WHO region and/or distribution by sex, age, industrial sector and occupation) and exposure (definition, measurement methods and level of exposure) following our protocol (Hulshof et al., 2019). If we judged two or more prevalence estimates to be clinically sufficiently homogenous, we pooled the prevalence estimates of the studies in a quantitative meta-analysis, using the inverse variance method with a random effects model. We assessed statistical heterogeneity using the I^2 statistic, judging a priori that the expected heterogeneity was moderate. The meta-analysis was conducted in RevMan 5.3.

3.9. Conducted additional analyses

We conducted subgroup analyses by:

- WHO region (and/or country).
- Sex.
- Age groups.

- Industrial sector.
- Occupation.

These subgroup analyses were based on disaggregated data from the studies included in the main meta-analysis only (to ensure a sufficiently homogenous dataset).

No sensitivity or other analyses were conducted.

3.10. *Assessed quality of evidence*

We used the QoE-SPEO approach for assessing the quality of evidence in studies estimating the prevalence of exposure to occupational risk factors (Pega, forthcoming). QoE-SPEO was developed by WHO specifically for systematic reviews for the WHO/ILO Joint Estimates.

4. Results

4.1. *Study selection*

A flow diagram of the study selection is presented in Fig. 1. Of the total of 18,129 individual study records identified in our searches, five records reporting results from five studies fulfilled the eligibility criteria and were included in the systematic review (Naidoo et al., 2009; van der Molen et al., 2010; Andersen et al., 2016; Eurofound, 2017; Constances Cohort Study, 2018). For the 30 excluded studies that most closely resembled inclusion criteria, the reasons for their exclusion are presented in Appendix 2 in the Supplementary data. Three included studies were included in the quantitative meta-analysis.

4.2. *Characteristics of included studies*

The characteristics of the included studies are summarized in Table 2.

4.2.1. *Study type*

Three studies were cross-sectional, and two studies were cohort studies (Table 3.).

4.2.2. *Population studied*

The included studies captured 150,895 workers (81,613 females and

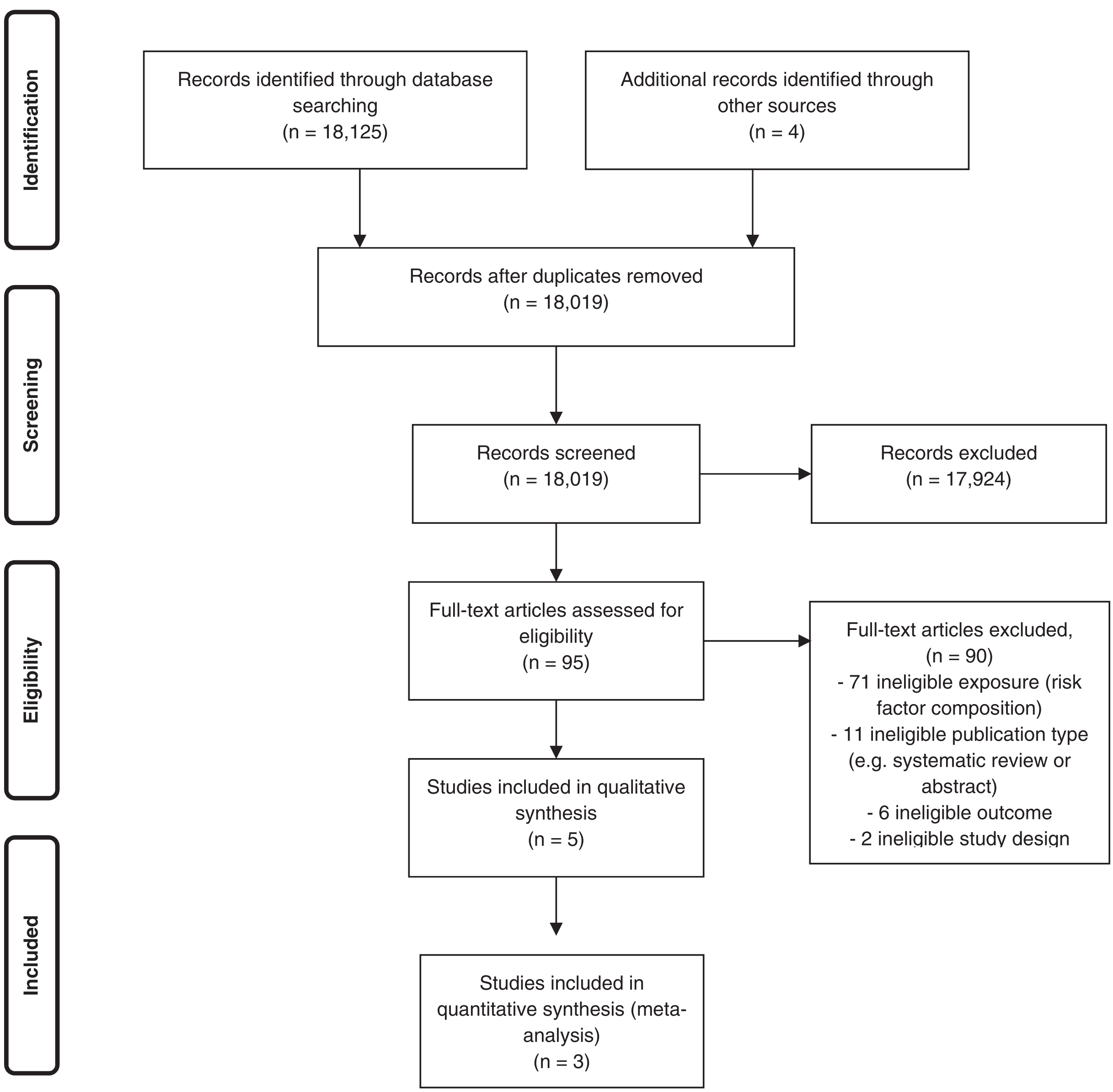

Fig. 1. Flow diagram of study selection.

Table 2
Characteristics of included studies in the systematic review: study population, study type, and study context.

Study	Study population							Study type			Study context
Study ID	Total number of study participants	Number of female study participants	Country of study population	Geographic location	Industrial sector (ISIC-4 code)	Occupation (ISCO-08 code)	Age	Study design	Study period (month of first collection of any data and month of last collection of any data)	Follow-up period (period in months between exposure and outcome)	Latitude and/or seasonality
Andersen et al., 2016	11,908	5,508	Denmark	National	General working population	General working population Blue-collar workers: 5055 White-collar workers: 6853	15–65 Mean: 40.9 ± 11.1	Danish Work Environment Cohort Study (DWECS).	Data from the 2000 and 2005 rounds of the DWECS.	24 months	No
Constances Cohort Study (2018)	92,841	48,770	France	National; 22 selected health screening centres in 20 'départements' in the principal regions of France.	Randomly selected sample of the French adult population, but agriculture sector is excluded	General working population	18–69 Disaggregated by age in file	Cohort study	N.A.		No
Eurofound 2017	43,684	26,424	35 European countries: Albania, Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, FYROM, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, UK	National	General working population	General working population	15–65 Disaggregated by age in file	Cross-sectional; This is not one cross sectional across all of Europe – but 35 separate cross-sectional studies with 35 separate data points.	Feb-Dec 2015	N.A.	No
Naidoo et al., 2009	911	911	South Africa	Rural, Northern KwaZulu-Natal (KZN)	01	1311	≥18 years Mean: Drylands: 42.8 (95%CI 41.7–43.8) Irrigation: 40.6 (39.3–41.9)	Cross-sectional	June - August 2006	N.A.	Unclear
Van der Molen 2010 (unpublished. dataset)	1,551	0	Netherlands	National	41	7111;7112; 7113; 7114;7115; 7119; 7123;7124; 7125	15–64 Disaggregated by age in file	Cross-sectional	October 2010	N.A.	No

Table 3
Characteristics of included studies: exposure assessment, co-exposure, and prevalence estimate.

Study	Exposure assessment							Co-exposure with other occupational risk factors		Prevalence estimate				
Study ID	Exposure definition	Unit for which exposure was assessed	Mode of exposure data collection	Exposure assessment methods	Type of exposure measurement or estimate	Dates covered by exposure assessment (years)	Shortest and longest exposure period	Levels/ intensity of exposure (specify unit)	Potential co-exposure with other occupational risk factors	Prevalence estimate type	Definition of numerator population	Number of study participants in exposed group	Definition of denominator population	Number of study participants in unexposed group
Andersen et al., 2016	Exposure to any of the risk factors: arm elevation; repetition; squatting/kneeling; pushing/pulling; lifting/carrying if ≥25% of day time	Individual level	Telephone interview or postal questionnaire	Self-reports	Prevalence	2000 and 2005 rounds	N.A.	Standing; back bending; twisting/ turning of back		Prevalence in %	All participants reporting exposure	7,321	All study participants which have replied to the physical exposures questionnaire	4,451
Constances Cohort Study (2018)	Exposure to any of the risk factors: demanding posture; vibration; force exertion; repetition; kneeling ≥2 h of typical day time	Individual level	Self-administered questionnaire	Self-reports	Prevalence	2012–2018	N.A.			Prevalence in %	All participants reporting exposure to any of five ergonomic risk factors ≥2 h of day time	36,811	All participants answering the questions on physical risk factors	56,030
Eurofound 2017	Exposure to any of the risk factors: force exertion; demanding posture; repetition; vibration; lifting. Responses 'never or almost never' were classified as 'no or low exposure' and '1/4 of the day time or more' as 'exposure'	Individual level	Face to face computer-assisted personal interview	Self-reports	Prevalence	Feb-Dec 2015	N.A.			Prevalence in %	All participants reporting 'exposure'	33,971	All participants in the study	9,731
Naidoo et al., 2009	Exposure to any of the risk factors: demanding posture; repetition; vibration; kneeling/squatting; lifting. Responses 'seldom or never' and 'now and then' were classified as 'no or low exposure' and 'often' and 'always' as 'high exposure'	Individual level	Questionnaire survey; part of an interview	Self-reports	Prevalence	Unclear, physical exposure on a normal working day in June-August 2006	N.A.	Not reported	Not reported	Prevalence in %	All women reporting high exposure, defined as often and always	792	All women involved in small-scale farming in rural KZN.	119
Van der Molen 2010 (unpub.)	Exposure to any of repetition; lifting/ carrying; pushing/ pulling; arm	Individual level	Questionnaire survey	Self-reports	Prevalence	October 2010	N.A.	Not reported	Not reported	Prevalence in %	All men reporting high exposure	1519	All men reporting 'no or low exposure'	28

(*continued on next page*)

Table 3 (*continued*)

Study	Exposure assessment							Co-exposure with other occupational risk factors		Prevalence estimate				
Study ID	Exposure definition	Unit for which exposure was assessed	Mode of exposure data collection	Exposure assessment methods	Type of exposure measurement or estimate	Dates covered by exposure assessment (years)	Shortest and longest exposure period	Levels/ intensity of exposure (specify unit)	Potential co-exposure with other occupational risk factors	Prevalence estimate type	Definition of numerator population	Number of study participants in exposed group	Definition of denominator population	Number of study participants in unexposed group
	elevation; vibration; kneeling; climbing. Responses 'never' or 'now and then' were classified as 'no or low exposure' and 'occasionally'' 'often'/'always' as 'high exposure'												or 'high exposure'	

69,282 males). One study examined only male workers, one study only female workers, and three studies examined both female and male workers. The most common age groups in the included five studies were workers aged 50–54 years, followed by those aged 45–49 years and 55–59 years, respectively.

Almost all included studies examined populations in the WHO Europe region (four studies in 35 countries). There was one study of workers in one country in Africa (South Africa). For three countries (France, Denmark and Netherlands), data were available from two included studies each. These countries were captured in the Eurofound study (2017), as well as in Andersen et al. (2016), the Constances Cohort Study (2018), and Van der Molen et al. (2010).

Three of the included studies (Andersen et al., 2016; Eurofound 2017; Constances Cohort Study, 2018) analysed samples of the total general population of workers. Two studies (Naidoo et al., 2009; Van der Molen et al., 2010) studied workers in specific industrial sectors, namely agriculture and construction, respectively.

4.2.3. *Exposure studied*

All studies measured the exposure using self-report. Computer-assisted, telephone-based, face-to-face and/or pen-and-paper questionnaire and/or interviewing were used.

Included studies generally categorized the risk factor levels by proxy of the amount of time (generally measured in numbers of hours as units) that workers were occupationally exposed to one or more of the five eligible risk factors per (typical) working day:

- Andersen et al. (2016): "any exposure" defined as ≥25% of the work time occupationally exposed "to different types of physical workloads (i.e., arm elevation; repetition; squatting/kneeling; pushing/pulling; and/or lifting/carrying), and "no exposure" defined as occupational exposure for <25% of working time.
- Constances Cohort Study (2018): "any exposure" defined as two or more hours daily occupationally exposed to any of the ergonomic risk factors (i.e., demanding posture; vibration; force exertion; repetition; and/or kneeling) for were categorized as, and "no exposure" defined as exposed for fewer than two hours per day.
- Eurofound (2017): 'any exposure' defined by the response '1/4 of the day time or more' spent exposed to any of five ergonomic risk factors (force exertion; demanding posture; repetition; vibration; lifting), and "no exposure" defined by any other response responses.
- Naidoo et al. (2009): "no exposure" defined as 'seldom or never' and 'now and then' exposed to any of five ergonomic risk factors (demanding posture; repetition; vibration; kneeling/squatting; lifting), and "any exposure" defined as 'often' and 'always' exposed.
- Van der Molen (2010): "any exposure" defined as occasionally', 'often' or 'always' exposed to any of the eligible seven ergonomic risk factors, and "no exposure" defined as 'never' or 'now and then' occupationally exposed to these risk factors.

4.3. *Risk of bias at the level of the individual study*

The risk of bias ratings for each domain for all included studies is presented in Fig. 2. We prioritized the evidence from the included studies of general populations of workers in our systematic review as the main evidence over studies of selected worker populations only because we are interested in exposures among all workers. In Appendix 4, the justifications for the ratings for each domain of the risk of bias assessments at the individual study level are presented.

4.3.1. *Bias in selection of participants into the study*

For the general working population studies Andersen et al., (2016), Constances Cohort Study (2018), Eurofound (2017) the risk of selection bias was rated as low or probably low. In general, participants were carefully selected based on a well-defined and presented sampling strategy. In the study by van der Molen et al (2010), nine specific occupations in the construction industry were selected. Because of the large sample size and comparability of participant characteristics at baseline and at follow-up (as described in a separate study record (Boschman et al., 2015)), the bias was rated as probably low.

4.3.2. Performance bias

As most data on exposure were based on self-reports by questionnaires or computer-assisted surveys the risk of performance bias was rated as low or probably low. In Eurofound 2017, it was not reported if study personnel could have known the exposure status (or level), and although we judged this to likely not have influenced how the data on exposure were collected or analysed, we selected the rating "no information" for this study.

4.3.3. Bias due to exposure misclassification

Most included studies did not primarily aim to measure occupational exposure to ergonomic risk factors. In no study, exposure was not measured directly; it was always self-reported. Often it was estimated via proxy of the time spent in a specific job activity (or task) or posture; the time frames and cut-off points for these by-proxy exposure estimates used in the general working population studies were generally comparable. According to the criteria of the used RoB-SPEO tool bias due to exposure misclassification was therefore rated Probably High: "there is evidence that the exposure was assessed using indirect measures that have not been validated or empirically shown to be consistent with methods that directly measure exposure (e.g., non-validated questionnaire, job-exposure matrix or self-report without validation)" (Pega et al., 2020)

4.3.4. Bias due to incomplete exposure data

In four included studies (Andersen et al., 2016; Eurofound 2017; Naidoo et al., 2009; and Van der Molen et al., 2010), study participants were carefully selected a priori to be representative of the general working population or a specific occupational group. We judged these studies to have low risk of bias due to incomplete exposure data. In the Constances Cohort Study (2018), the agricultural sector was excluded; as this sector represents a substantial part of the general working population and, moreover, occupational exposure to all relevant ergonomic risk factors in this sector is widespread, we rated the risk of bias for this domain in this study to be "high".

4.3.5. Bias due to selective reporting of exposures

In all included studies, the risk of bias due to selective reporting was rated as "low" or "probably low".

4.3.6. Bias due to conflict of interest

In the included studies, no study author declared any conflict of interest. All authors were affiliated with public (research) agencies or scientific institutions that we judged to be free from commercial interests in the study findings. None of the studies received support from a company or other entity that we judged to have a financial interest in the outcome of the study. Therefore, we rated all studies as having low risk of bias in this domain.

4.3.7. Bias due to differences in numerator and denominator

In the ratios used to estimate prevalence in the included studies, the same (or comparable) definitions and/or counting was used for persons contributing to the numerator and for persons contributing to the denominator. We consequently judged the risk of bias due to differences in numerator and denominator as "plow".

4.3.8. Other bias

We did not identify any other biases and rated all studies as "probably low" risk of other bias.

	Andersen 2016	Constances Cohort Study 2018	Eurofound 2017	Naidoo 2009	Van der Molen 2010
1. Could the exposure status (or level) assessed (or assigned) in the study sample not represent exposure in the target population?	Probably low	Probably low	Low	Probably low	Probably low
2. Could study personnel have known the exposure status (or level) or other characteristics of study participants and could this have influenced the exposure assessment (or assignment)?	Probably low	Low	No information	Low	Probably low
3. Could the methods used for assessing (or assigning) exposure have over- or under-estimated exposure?	Probably high	Probably high	Probably high	Probably high	Probably high
4. Could data on exposure status (or level) be incomplete for eligible participants?	Probably low	High	Probably low	Probably low	Low
5. Could relevant exposures or exposure categories be selectively not reported?	Probably low	Low	Probably low	Low	Probably low
6. Could the study and/or one or more study authors have received support from entities with potential interests in the exposure assessed (or assigned)?	Low	Low	Low	Low	Low
7. Could the definition and/or counting of persons contributing to the numerator differ from those contributing to the denominator in the ratio used to estimate prevalence?	Low	Low	Low	Low	Low
8. Could the study have other problems that could have introduced bias?	Probably low	Probably low	Probably low	Probably low	Probably low

Fig. 2. Summary of risk of bias across studies on prevalence of occupational exposure to ergonomic risk factors.

4.4. Synthesis of results

4.4.1. All prevalence estimates

A data sheet with all prevalence estimates is provided in Appendix 5 in the Supplementary data. If available to us, the prevalence estimates are presented fully disaggregated by country, sex, age group and occupation. The data in the sheet is prepared in a convenient format for ready use as input data for modelling occupational exposure to ergonomic risk factors.

4.4.2. Pooled prevalence estimate

Of the five included studies, three studies (Andersen et al., 2016, Constances Cohort Study, 2018 and Eurofound 2017) with a total of 148,433 participants from 35 countries in one WHO region (Europe) focused on the prevalence of occupational exposure to ergonomic risk factors in the general working population. We considered these three studies to be sufficiently clinically homogenous to be included in the same quantitative meta-analysis. The other two studies (Naidoo et al., 2009 and Van der Molen 2010) included sub-populations of workers only, and could therefore not be included in the quantitative synthesis (see *Section 4.5.3*). The forest plot from the meta-analysis is presented in Fig 3. The pooled prevalence estimate was 0.76 (95% CI 0.69 to 0.84, 3 studies, 148,433 participants, I^2 100%).

4.4.3. Information from the studies not included in the meta-analysis

In the Naidoo 2009 study, the prevalence of occupational exposure to the ergonomic risk factors among 911 female workers in small-scale agricultural work in South Africa was 0.87 (95% CI 0.85–0.89) (Table 4). In re-analyses of unpublished data from Van der Molen 2010, the prevalence of exposure among 1,545 male workers in the construction sector in the Netherlands was 0.98 (95% CI 0.97–0.99). Since both studies were of sub-populations of workers with a likely disproportionately high physical work load, we judged that the relatively higher prevalence estimates reported or found in these two studies support the meta-analysis.

4.5. Additional analyses

4.5.1. Subgroup analyses

We conducted subgroup analyses using the studies included in the main meta-analysis.

4.5.1.1. By WHO region and/or country. When pooling prevalence estimates from specific countries, Figs. 4 and 5 show the forest plots from respectively France and Denmark to come to pooled prevalence estimates from two separate studies for each of these countries.

4.5.1.2. By sex. Subgroup analyses by sex demonstrated no statistical significant difference (test for subgroup differences $p = 0.85$) in the prevalence between women (point estimate 0.77, 95% CI 0.69–0.84) and men (point estimate 0.78, 95% CI 0.69–0.86) (Fig. 6).

4.5.1.3. By age group. In our subgroup analysis by age group, whose forest plot we present in Fig. 7, we found statistically significant differences (test for subgroup differences $p = 0.003$). Relatively higher prevalence of exposure was found among workers of younger age groups, especially so those aged 15–19 years and 20–24 years, respectively.

4.5.1.4. By occupation. Based on our re-analyses of unpublished data from the Eurofound 2017 study, we were able to conduct a subgroup analysis by occupation, using ISCO-08 codes. Appendix 6 shows the forest plots for the different occupational groups as defined in that study. The prevalence estimates range from 0.63 (95% CI 0.60–0.66) for managers to 0.95 (95% CI 0.94–0.96) for craft and related trade. Our subgroup analysis shows that prevalence of occupational exposure to ergonomic risk factors varies substantially by occupation, with a highly statistically significant test for subgroup differences ($p < 0.00001$)

4.6. Quality of evidence

In step 1 of the QoE-SPEO approach for assessing quality of evidence of the entire body of evidence (Pega et al., forthcoming), we judged there to be expected heterogeneity in the prevalence of occupational exposure to occupational ergonomic risk factors, because we expected variability in exposure within and between workers and within and between different countries. However, because of the comparability of the included working populations and of the exposure parameters, we rated the expected heterogeneity to be “medium”.

Overall, we rated the quality of evidence to be “low”. Because we had some serious concern for risk of bias, especially for exposure misclassification, we downgraded the quality of evidence by one level (-1). The main justification for this was the limited accuracy of the exposure assessment due to measurement with self-reports regarding average time of exposure per working day (rather than direct measurement) in the included studies. Secondly, we had serious concern for indirectness due to the fact that the analyses of our systematic review were based almost exclusively on data from countries in Europe and on one occupational group outside of Europe. This indicates indirectness of evidence for the other WHO regions and the global population of workers. Therefore, we further downgraded the quality of evidence by one level (-1). We did not have serious concern for risk of bias or inconsistency. We anticipated the level of expected heterogeneity of the prevalence to be medium, and we did find medium to high heterogeneity across the studies. We neither had serious concerns for imprecision, given the very narrow confidence intervals in the pooled effect estimates, and therefore did not downgrade for this. Also, we did not have any serious concerns for publication bias. In conclusion, we started at “high” quality of evidence and downgraded by two levels (-2) for serious concern for risk of bias and serious concern for indirectness to a final rating of “low”.

5. Discussion

5.1. Summary of evidence

As shown in the table of summary of findings (Table 5), based on the main meta-analysis, the pooled prevalence estimate of any occupational exposure to ergonomic risk factors was 0.76 (95% CI 0.69 to 0.84, 3 studies, 148,433 participants, 35 countries, I^2 100%, low quality of evidence). Subgroup analyses using data included in the main meta-analysis demonstrated no statistically significant differences by sex, but clinically meaningful, statistically significant differences by age, occupation and country.

5.2. Limitations of this review

Our systematic review and meta-analysis have several limitations. First, although our inclusion criteria were broad, the systematic review found only studies from two WHO regions, namely Africa and Europe. Of the five included studies, four were from Europe and one from Africa. The one study from Africa could not be included in the meta-analysis. Consequently, the analyses of our systematic review were based almost exclusively on data from countries in Europe. This already indicated indirectness but, moreover, the indirectness of the evidence for the global population of workers must be prominently noted.

Second, our searches may have missed studies published in languages other than English. However, we searched many electronic bibliometric and grey literature databases using a comprehensive search strategy and consulted additional experts who also did not identify any additional eligible studies. We have some confidence that we identified most if not all studies eligible for inclusion in our systematic review.

Study or Subgroup	Prevalence rate	SE	Total	n	Weight	Prevalence rate IV, Random, 95% CI
1.1.1 Eurofound study						
Albania	0.87	0.0106	1002	871	2.7%	0.87 [0.85, 0.89]
Austria	0.71	0.0142	1024	730	2.7%	0.71 [0.68, 0.74]
Belgium	0.71	0.0089	2587	1845	2.7%	0.71 [0.69, 0.73]
Bulgaria	0.79	0.0125	1064	843	2.7%	0.79 [0.77, 0.81]
Croatia	0.82	0.0121	1007	829	2.7%	0.82 [0.80, 0.84]
Cyprus	0.88	0.0103	1002	882	2.7%	0.88 [0.86, 0.90]
Czech Republic	0.71	0.0144	997	705	2.7%	0.71 [0.68, 0.74]
Denmark	0.73	0.0141	998	724	2.7%	0.73 [0.70, 0.76]
Estonia	0.78	0.0131	1001	779	2.7%	0.78 [0.75, 0.81]
Finland	0.79	0.0129	1000	787	2.7%	0.79 [0.76, 0.82]
France	0.81	0.01	1525	1230	2.7%	0.81 [0.79, 0.83]
FYROM	0.85	0.0112	1010	862	2.7%	0.85 [0.83, 0.87]
Germany	0.74	0.0096	2088	1544	2.7%	0.74 [0.72, 0.76]
Greece	0.88	0.0102	1007	887	2.7%	0.88 [0.86, 0.90]
Hungary	0.72	0.0141	1018	735	2.7%	0.72 [0.69, 0.75]
Ireland	0.7	0.0142	1045	728	2.7%	0.70 [0.67, 0.73]
Italy	0.71	0.0121	1045	992	2.7%	0.71 [0.69, 0.73]
Latvia	0.73	0.014	999	726	2.7%	0.73 [0.70, 0.76]
Lithuania	0.81	0.0124	1004	812	2.7%	0.81 [0.79, 0.83]
Luxembourg	0.8	0.0126	1002	798	2.7%	0.80 [0.78, 0.82]
Malta	0.72	0.0142	1002	722	2.7%	0.72 [0.69, 0.75]
Montenegro	0.78	0.0131	1005	781	2.7%	0.78 [0.75, 0.81]
Netherlands	0.74	0.0137	1028	758	2.7%	0.74 [0.71, 0.77]
Norway	0.73	0.0138	1028	754	2.7%	0.73 [0.70, 0.76]
Poland	0.75	0.0128	1147	855	2.7%	0.75 [0.72, 0.78]
Portugal	0.82	0.0119	1035	844	2.7%	0.82 [0.80, 0.84]
Romania	0.88	0.01	1061	929	2.7%	0.88 [0.86, 0.90]
Serbia	0.74	0.0137	1029	758	2.7%	0.74 [0.71, 0.77]
Slovakia	0.79	0.0129	991	784	2.7%	0.79 [0.76, 0.82]
Slovenia	0.82	0.0096	1601	1305	2.7%	0.82 [0.80, 0.84]
Spain	0.81	0.0068	3359	2734	2.7%	0.81 [0.80, 0.82]
Sweden	0.77	0.0133	1002	772	2.7%	0.77 [0.74, 0.80]
Switzerland	0.79	0.0129	1004	797	2.7%	0.79 [0.76, 0.82]
Turkey	0.83	0.0084	1995	1664	2.7%	0.83 [0.81, 0.85]
UK	0.74	0.0109	1619	1205	2.7%	0.74 [0.72, 0.76]
Subtotal (95% CI)			**43331**	**33971**	**94.6%**	**0.78 [0.76, 0.80]**
Heterogeneity: Tau² = 0.00; Chi² = 800.58, df = 34 (P < 0.00001); I² = 96%						
Test for overall effect: Z = 82.44 (P < 0.00001)						
1.1.2 Andersen et al						
Andersen et al	0.62	0.0045	11772	7321	2.7%	0.62 [0.61, 0.63]
Subtotal (95% CI)			**11772**	**7321**	**2.7%**	**0.62 [0.61, 0.63]**
Heterogeneity: Not applicable						
Test for overall effect: Z = 137.78 (P < 0.00001)						
1.1.3 Constances Cohort						
Constances Cohort	0.4	0.0016	92841	36811	2.7%	0.40 [0.40, 0.40]
Subtotal (95% CI)			**92841**	**36811**	**2.7%**	**0.40 [0.40, 0.40]**
Heterogeneity: Not applicable						
Test for overall effect: Z = 250.00 (P < 0.00001)						
Total (95% CI)			**147944**	**78103**	**100.0%**	**0.76 [0.69, 0.84]**
Heterogeneity: Tau² = 0.05; Chi² = 24876.89, df = 36 (P < 0.00001); I² = 100%						
Test for overall effect: Z = 20.48 (P < 0.00001)						
Test for subgroup differences: Chi² = 3492.96, df = 2 (P < 0.00001), I² = 99.9%						

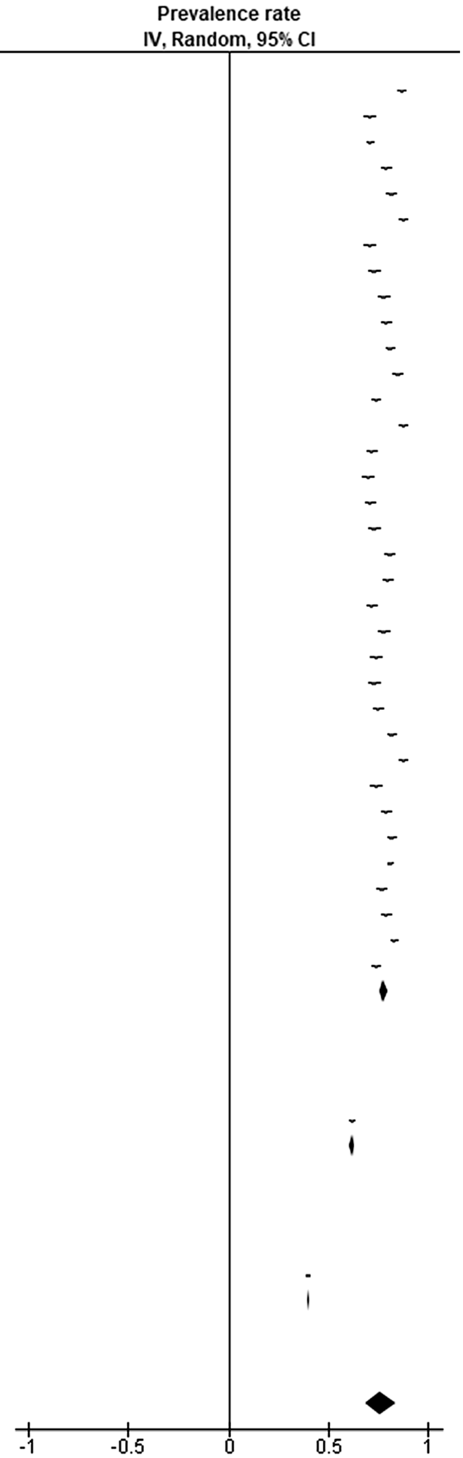

Fig. 3. Main meta-analysis, Outcome: Any occupational exposure to ergonomic risk factors.

Third, assessment and measurement of occupational exposure to the eligible ergonomic risk factors was generally with questionnaire and, consequently subjective data from self-reported exposure. Important aspects of exposure such as frequency and intensity of exposure was often not measured or otherwise included in the exposure assessment (or assignment). Objective measures for occupational ergonomic risk factors collected using observational methods are often also not reliable or validated (Van der Beek and Frings-Dresen, 1998), and this suggests that the evidence from exposure data presented in this systematic review may be acceptable, even if collected subjectively using self-reports from workers. However, because of the serious concern for risk of bias due to exposure misclassification we have further downgraded the quality of evidence by an extra level to ‘low’.

Fourth, the aim of this systematic review was to study the prevalence of occupational exposure to ergonomic risk factors in relation to the prevalence or incidence of ‘musculoskeletal diseases (MSD) other than back or neck pain’. Although we have selected a number of MSD for which there is existing evidence that they can be work-related, this still

Table 4
Studies excluded from the meta-analysis, Outcome: Any occupational exposure to ergonomic risk factors, and reasons for their exclusion from the meta-analysis

Study ID	Prevalence estimate (95% confidence interval (CI))	Reason for exclusion from meta-analysis
Naidoo et al., 2009	0.87 (95% CI 0.85–0.89)	Only specific industrial sector (agriculture) studied; only female workers studied
Van der Molen 2010	0.98 (95% CI 0.97–0.99)	Only specific industrial sector (construction) studied; only male workers studied

includes a rather broad range of health outcomes which means that this entails also a broader range of relevant ergonomic risk factors for these diseases. Therefore, we found only a very limited number of studies that included prevalence data on at least five of our seven selected occupational ergonomic risk factors because in most studies on MSD the relationship between one or more specific exposure risk factors in relation to a more specific health outcome is studied.

Fifth, although in general the prevalence estimates found in this review show a reasonable consistency and comparability, also indicated by relatively narrow confidence intervals, the data from the two French studies (the French part of the Eurofound Study and the Constances Cohort Study) are rather different. One of the reasons for this could be the absence of data from agriculture workers and self-employed workers (Goldberg et al., 2017) but this may probably not explain totally its much lower prevalence. Future studies on the Constances Cohort and on forthcoming waves of the Eurofound Study may shed some light on this.

5.3. Comparison with previous systematic reviews evidence

To our knowledge, there is no prior systematic review or meta-analytic evidence that we could compare our systematic review and meta-analysis against. However, the evidence found in this systematic review and meta-analysis are consistent with the existing evidence on the prevalence of exposures presented in existing systematic reviews and/or meta-analyses on the effect of occupational exposure to some individual ergonomic risk factors on osteoarthritis and/or other musculoskeletal diseases, including Descatha et al 2016, Jensen, 2008, van der Molen et al 2017, and Verbeek et al. 2017, amongst others.

6. Use of evidence for burden of disease estimation

This systematic review and meta-analysis was conducted by WHO and ILO, supported by a large network of experts, for the development of the WHO/ILO Joint Estimates (Ryder 2017). More specifically, it provides the crucial evidence base for both organizations to consider producing estimates of the burdens of osteoarthritis and other musculoskeletal diseases attributable to occupational exposure to ergonomic risk factors. The systematic review found a body of evidence from a small number of studies, but this body of evidence was limited almost exclusively to the WHO European region, raising our concerns for indirectness. Overall, we judged this body of evidence to be of low quality because of serious concern for risk of bias and for indirectness. Producing estimates of the burden of osteoarthritis and other musculoskeletal diseases attributable to occupational exposure to ergonomic risk factors appears evidence-based and perhaps warranted (albeit with major limitations), and the pooled prevalence estimate (and subgroup analyses) appear potentially suitable as input data for WHO/ILO modelling of work-related burden of disease and injury.

7. Conclusions

Our systematic review and meta-analysis found that occupational exposure to ergonomic risk factors is highly prevalent. The current body of evidence is, however, limited, especially by risk of bias and indirectness and was based on a limited number of studies. Producing estimates for the burden of disease attributable to occupational exposure to ergonomic risk factors appears evidence-based, and the pooled effect estimates presented in this systematic review may perhaps be used as input data to contribute to the development of the WHO/ILO Joint Estimates.

8. Differences between protocol and systematic review

- We intended to use a modified version of the Navigation Guide risk of bas tool, but then WHO and ILO developed the RoB-SPEO tool specifically for assessing risk of bias in studies estimating prevalence of exposure to occupational risk factors, and we applied this dedicated tool in our systematic review.

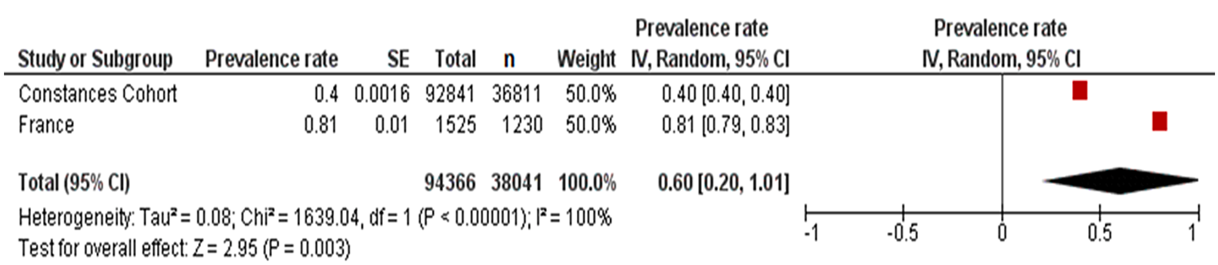

Fig. 4. Supportive meta-analysis, pooled prevalence estimate from prevalence studies in France: the Constances Cohort Study and the French data of the Eurofound study (‘France’).

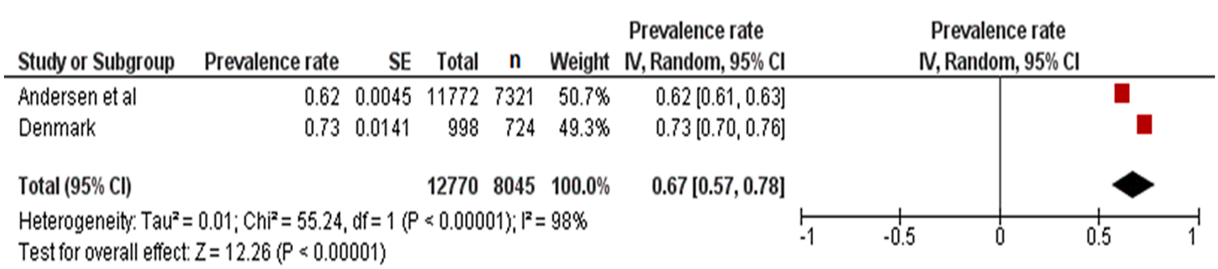

Fig. 5. Supportive meta-analysis, pooled prevalence estimate from two prevalence studies in Denmark: the Andersen study and the Danish data from the Eurofound study (‘Denmark’).

Study or Subgroup	Prevalence rate	SE	Total	Total	Weight	Prevalence rate IV, Random, 95% CI
2.2.1 Sub-group by sex: Female						
Albania	0.85	0.0149	560	478	1.4%	0.85 [0.82, 0.88]
Austria	0.7	0.0191	571	401	1.4%	0.70 [0.66, 0.74]
Belgium	0.72	0.0125	1286	928	1.4%	0.72 [0.70, 0.74]
Bulgaria	0.77	0.0177	572	439	1.4%	0.77 [0.74, 0.80]
Constances Cohort	0.43	0.0022	48770	21044	1.4%	0.43 [0.43, 0.43]
Croatia	0.82	0.017	521	425	1.4%	0.82 [0.79, 0.85]
Cyprus	0.89	0.0143	492	436	1.4%	0.89 [0.86, 0.92]
Czech Republic	0.7	0.02	528	368	1.4%	0.70 [0.66, 0.74]
Denmark	0.74	0.0198	486	361	1.4%	0.74 [0.70, 0.78]
Estonia	0.77	0.0171	607	466	1.4%	0.77 [0.74, 0.80]
Finland	0.81	0.0175	509	410	1.4%	0.81 [0.78, 0.84]
France	0.82	0.0137	800	652	1.4%	0.82 [0.79, 0.85]
FYROM	0.85	0.0171	442	375	1.4%	0.85 [0.82, 0.88]
Germany	0.72	0.014	1025	742	1.4%	0.72 [0.69, 0.75]
Greece	0.88	0.0161	424	371	1.4%	0.88 [0.85, 0.91]
Hungary	0.69	0.0198	546	378	1.4%	0.69 [0.65, 0.73]
Ireland	0.67	0.0212	493	330	1.4%	0.67 [0.63, 0.71]
Italy	0.7	0.0177	677	471	1.4%	0.70 [0.67, 0.73]
Latvia	0.7	0.0191	569	401	1.4%	0.70 [0.66, 0.74]
Lithuania	0.78	0.017	598	465	1.4%	0.78 [0.75, 0.81]
Luxembourg	0.81	0.0177	497	401	1.4%	0.81 [0.78, 0.84]
Malta	0.69	0.0227	414	286	1.4%	0.69 [0.65, 0.73]
Montenegro	0.77	0.0203	431	332	1.4%	0.77 [0.73, 0.81]
Naidoo et al	0.87	0.0111	911	792	1.4%	0.87 [0.85, 0.89]
Netherlands	0.72	0.0197	516	374	1.4%	0.72 [0.68, 0.76]
Norway	0.76	0.0183	551	417	1.4%	0.76 [0.72, 0.80]
Poland	0.71	0.0179	652	460	1.4%	0.71 [0.67, 0.75]
Portugal	0.83	0.0155	592	490	1.4%	0.83 [0.80, 0.86]
Romania	0.89	0.0141	510	452	1.4%	0.89 [0.86, 0.92]
Serbia	0.71	0.0202	506	358	1.4%	0.71 [0.67, 0.75]
Slovakia	0.78	0.0173	566	443	1.4%	0.78 [0.75, 0.81]
Slovenia	0.82	0.0133	839	687	1.4%	0.82 [0.79, 0.85]
Spain	0.82	0.0095	1650	1350	1.4%	0.82 [0.80, 0.84]
Sweden	0.78	0.0185	500	390	1.4%	0.78 [0.74, 0.82]
Switzerland	0.79	0.0186	479	378	1.4%	0.79 [0.75, 0.83]
Turkey	0.83	0.0157	557	465	1.4%	0.83 [0.80, 0.86]
UK	0.72	0.0164	743	536	1.4%	0.72 [0.69, 0.75]
Subtotal (95% CI)			**71390**	**38552**	**50.7%**	**0.77 [0.69, 0.84]**
Heterogeneity: Tau² = 0.05; Chi² = 11202.67, df = 36 (P < 0.00001); I² = 100%						
Test for overall effect: Z = 20.58 (P < 0.00001)						
2.2.2 Sub-group by sex: Male						
Albania	0.89	0.0149	442	393	1.4%	0.89 [0.86, 0.92]
Austria	0.73	0.0209	457	332	1.4%	0.73 [0.69, 0.77]
Belgium	0.71	0.0126	1289	917	1.4%	0.71 [0.69, 0.73]
Bulgaria	0.82	0.0172	491	404	1.4%	0.82 [0.79, 0.85]
Constances Cohort	0.36	0.0023	44071	15767	1.4%	0.36 [0.36, 0.36]
Croatia	0.84	0.0167	483	405	1.4%	0.84 [0.81, 0.87]
Cyprus	0.87	0.0146	511	447	1.4%	0.87 [0.84, 0.90]
Czech Republic	0.72	0.0206	471	340	1.4%	0.72 [0.68, 0.76]
Denmark	0.71	0.02	516	365	1.4%	0.71 [0.67, 0.75]
Estonia	0.81	0.0196	404	326	1.4%	0.81 [0.77, 0.85]
Finland	0.77	0.0191	491	377	1.4%	0.77 [0.73, 0.81]
France	0.8	0.0149	726	579	1.4%	0.80 [0.77, 0.83]
FYROM	0.86	0.0145	567	488	1.4%	0.86 [0.83, 0.89]
Germany	0.76	0.0131	1063	806	1.4%	0.76 [0.73, 0.79]
Greece	0.89	0.0131	581	516	1.4%	0.89 [0.86, 0.92]
Hungary	0.76	0.0195	473	361	1.4%	0.76 [0.72, 0.80]
Ireland	0.72	0.0189	563	407	1.4%	0.72 [0.68, 0.76]
Italy	0.72	0.0167	722	522	1.4%	0.72 [0.69, 0.75]
Latvia	0.78	0.0202	425	330	1.4%	0.78 [0.74, 0.82]
Lithuania	0.85	0.0175	406	347	1.4%	0.85 [0.82, 0.88]
Luxembourg	0.79	0.0182	506	398	1.4%	0.79 [0.75, 0.83]
Malta	0.74	0.018	590	437	1.4%	0.74 [0.70, 0.78]
Montenegro	0.78	0.0172	574	449	1.4%	0.78 [0.75, 0.81]
Netherlands	0.75	0.0191	512	384	1.4%	0.75 [0.71, 0.79]
Norway	0.71	0.0208	477	337	1.4%	0.71 [0.67, 0.75]
Poland	0.79	0.0175	545	430	1.4%	0.79 [0.76, 0.82]
Portugal	0.8	0.019	445	356	1.4%	0.80 [0.76, 0.84]
Romania	0.86	0.0146	553	478	1.4%	0.86 [0.83, 0.89]
Serbia	0.77	0.0185	521	400	1.4%	0.77 [0.73, 0.81]
Slovakia	0.8	0.0191	434	348	1.4%	0.80 [0.76, 0.84]
Slovenia	0.81	0.0141	767	623	1.4%	0.81 [0.78, 0.84]
Spain	0.81	0.0094	1714	1391	1.4%	0.81 [0.79, 0.83]
Sweden	0.76	0.019	501	382	1.4%	0.76 [0.72, 0.80]
Switzerland	0.8	0.0175	527	421	1.4%	0.80 [0.77, 0.83]
Turkey	0.83	0.0098	1442	1203	1.4%	0.83 [0.81, 0.85]
UK	0.76	0.0143	880	672	1.4%	0.76 [0.73, 0.79]
Subtotal (95% CI)			**66140**	**33138**	**49.3%**	**0.78 [0.69, 0.86]**
Heterogeneity: Tau² = 0.07; Chi² = 15655.98, df = 35 (P < 0.00001); I² = 100%						
Test for overall effect: Z = 17.33 (P < 0.00001)						
Total (95% CI)			**137530**	**71690**	**100.0%**	**0.77 [0.72, 0.82]**
Heterogeneity: Tau² = 0.05; Chi² = 26996.77, df = 72 (P < 0.00001); I² = 100%						
Test for overall effect: Z = 29.79 (P < 0.00001)						
Test for subgroup differences: Chi² = 0.03, df = 1 (P = 0.85), I² = 0%						

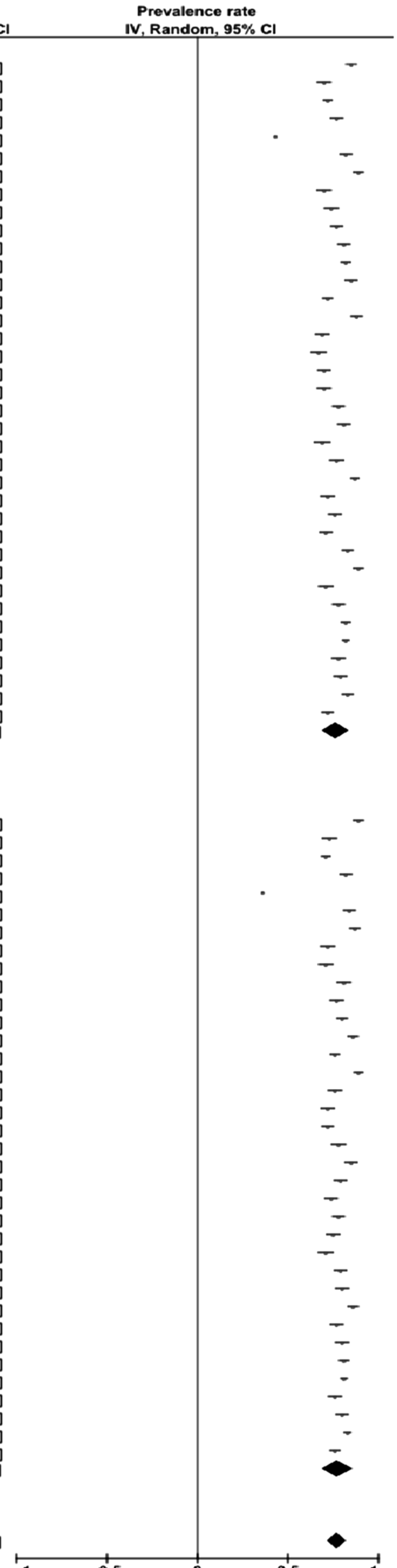

Fig. 6. Subgroup analyses by sex, Outcome: Any occupational exposure to ergonomic risk factors.

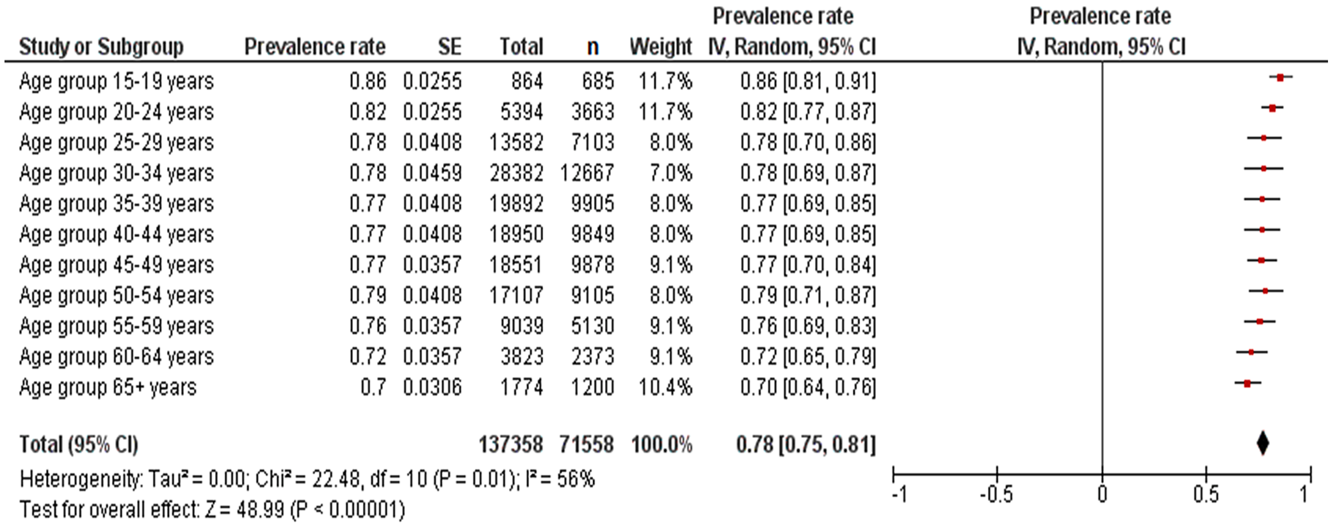

Fig. 7. Subgroup analyses by age group, Outcome: Any occupational exposure to ergonomic risk factors.

Table 5
Table of summary of findings

Prevalence of any occupational exposure with ergonomic risk factors among workers in WHO region Europe
Population: Any workers
Settings: All countries and work settings
Exposure: Occupational exposure to ergonomic risk factors (i.e., one or more of: force exertion, demanding posture, repetitive movement, hand-arm vibration, kneeling or squatting, lifting, and/or climbing)

Outcome	Prevalence estimate (95% CI)	No. of participants (studies)	QoE-SPEO quality of the evidence rating	Comments
Any occupational exposure to ergonomic risk factors	**0.76** (0.69–0.84)	148,433 participants (3 studies)	⊕⊕⊖⊖[a], Low	Evidence from two studies that could not be included in the meta-analysis supported the main estimate.

CI: confidence interval;
QoE-SPEO quality of evidence ratings:**High quality:** Further research is very unlikely to change our confidence in the estimate of prevalence.**Moderate quality:** Further research is likely to have an important impact on our confidence in the estimate of prevalence and may change the estimate.**Low quality:** Further research is very likely to have an important impact on our confidence in the estimate of prevalence and is likely to change the estimate.**Very low quality:** We are very uncertain about the estimate.
Footnotes: [a] Downgraded by two grades, because of serious concerns for risk of bias and indirectness.

- We intended to use a modified version of the Navigation Guide approach for assessing quality of evidence, but WHO developed the QoE-SPEO approach specifically for assessing quality of evidence in studies estimating prevalence of exposure to occupational risk factors, and we therefore shifted to use this dedicated approach.
- We did not intend to quantitatively meta-analyse prevalence estimates but did so in the systematic review because burden of disease estimation will benefit from pooled estimates, rather than having to rely on individual estimates solely.
- We intended to include only studies with occupational exposure to all selected ergonomic risk factors (i.e., force exertion, demanding posture, repetitive movement, hand-arm vibration, kneeling or squatting, lifting, and/or climbing), but in the systematic review included studies with occupational exposure to at least five out of seven ergonomic risk factors, because also after consulting various additional experts at the beginning of the systematic review we realized that such inclusion criterion is not very realistic and not clinically meaningful as you cannot expect that e.g. studies on hip or knee osteoarthritis will deal with exposure to hand-arm vibration.
- We planned to follow up request for missing data for principal study authors twice, at two and four weeks after the initial request; in the systematic review we only followed up once, at two weeks after our initial request.

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Sponsors

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Author contributions

Had the idea for this systematic review: FP, Ivan Ivanov (WHO), Nancy Leppink (ILO).

Selected the lead reviewer and gathered the review teams: FP, Ivan Ivanov, Nancy Leppink.

Coordinated the entire series of systematic reviews: FP, Yuka Ujita (ILO).

Were the lead reviewers of this systematic review: CH, MF.

Led the design of the systematic review including developed the standard methods: FP.

Contributed substantially to the design of the systematic review: All authors.

Conducted the search: JD, HM, CH.

Selected studies: CC, FP, FM, SM, CHN, JO, KP, PrK, SN, CH, HM, MF, PK.

Extracted data: AT, MMF, MR, JS, JL.

Requested missing data: CH, FP, MF, SN, CHN.

Assessed risk of bias: CC, FM, SM, CHN, JO, KP, PrK, SN, CH, HM, MF, PK.

Conducted the meta-analyses: SN, CH.

Assessed quality of evidence: CH, HM, PK, SN

Developed the standards and wrote the template for all systematic reviews in the series: FP.

Wrote the first draft of the manuscript using the template: CH, MF.

Revised the manuscript critically for important intellectual content: All authors.

Ensured tailoring of the systematic review for WHO/ILO estimation purposes: FP.

Ensured harmonization across systematic reviews in the series: FP.

Approved the final version of the systematic review to be published: All authors.

Agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved: All authors.

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.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2020.106157.

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