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Review article

Risk factors for development of lower limb osteoarthritis in physically demanding occupations: A systematic review and meta-analysis

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ABSTRACT

This systematic review and meta-analysis identified and critically reviewed the findings of recent studies (last 15 years) examining relationships between specific physically demanding occupations or occupational tasks and development of lower limb osteoarthritis (OA). Twenty-eight studies with 266,227 cases of lower limb OA were included. Occupational tasks contributing to OA included farming, floor laying, and brick laying. Activities significantly contributing to the risk of knee OA were lifting heavy loads (>10 kg/week) (odds ratio [OR] = 1.52, 95% confidence interval [95%CI] 1.29–1.79), squatting/kneeling (OR = 1.69, 95%CI 1.15–2.49), standing (>2 h/daily) (OR = 1.22 95%CI 1.02–1.46) and walking (OR = 1.40 95%CI 1.14–1.73). Lifting contributed significantly to the risk of hip OA (OR = 1.35, 95%CI 1.16–1.57). The effects of occupational exposures appear to be magnified by previous injury and BMI >25 kg/m^2. Since specific occupational activities increase OA risk, ergonomist should encourage the use of existing tools, or oversee the design of new tools that may decrease exposure to such activities.

1. Introduction

Osteoarthritis (OA) is a common chronic and debilitating musculoskeletal condition estimated to affect over 250 million people worldwide (Hunter and Bierma-Zeinstra, 2019). In 2015, over two million Australians suffered from OA (Australian Bureau of Statistics, 2014–15), with an estimated 3.1 million affected by 2030 (Ackerman et al., 2017). This was estimated to cost the health care system over 2.9 billion Australian dollars (Ackerman et al., 2017). The total financial burden of OA is, however, much greater as these figures do not account for costs other than health care costs, including those arising in occupational contexts from loss of working days, presenteeism, job reallocation, staff repurposing and premature retirement (David et al., 2014). The 2010 United States (US) Medicare Expenditure Panel Survey estimated the annual cost of OA-related absenteeism to be greater than 10 billion US dollars, as workers suffering from OA missed an average of three workdays per year (Kotlarz et al., 2010). In Canada, the lowest estimated cost of presenteeism was $700 per worker per year, $200 more than the cost of absenteeism mentioned above (Zhang et al., 2010a). These substantial impacts on quality of life and projection of further burden of OA worldwide warrant investigation to determine its aetiology and risk factors.

OA has a multifactorial aetiology including genetic (Zeggini et al., 2012), biological and biomechanical elements (Glyn-Jones et al., 2015). Clinically, OA may present with persistent pain, restricted movement, limited morning stiffness, crepitus, bony enlargement and reduced joint function (Zhang et al., 2010b). OA diagnosis can be made using either clinical evidence (indicating presence of three out of the six signs and symptoms listed above) or radiological evidence. Pathological features observed in radiographic imaging include loss of hyaline cartilage (leading to reduced joint space) and alterations to the subchondral bone (e.g. subchondral bone sclerosis, subchondral cysts, osteophyte formation). However, a recent study has shown that, in particular articulations such as the hip, OA may be undetected if the diagnosis relies solely on radiographs (Kim et al., 2015). Therefore the evidence-based recommendation for the diagnosis of knee and hip OA should include both radiographic and clinical features, in accordance with the American College of Rheumatology radiological and clinical criteria for OA of the knee and hip (Altman et al., 1986, 1991; Bijlsma et al., 2011).

Many studies have researched the risk factors associated with

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development of OA. The intrinsic factors include: older age, female sex, overweight and obesity, inflammation, dyslipidaemia and prior injury (Silverwood et al., 2015; Blagojevic et al., 2010; Sturmer et al., 1998; Lohmander et al., 2004; Gelber et al., 2000; Neuman et al., 2008; Saltzman et al., 2005). Obesity induces not only biochemical alterations (i.e. increase in proinflammatory adipokines and cytokines) but also contributes to a mechanical overload, particularly in lower limb joints (Ramage et al., 2009; Widmyer et al., 2013; Harding et al., 2012). Adding to this increased biomechanical demand, extrinsic factors such as participation in trauma-prone sports (Spector et al., 1996) and arduous occupational tasks (e.g. heavy lifting, kneeling/squatting, climbing) have been found to increase the risk of lower limb OA (Coggon et al., 2000).

A recent narrative umbrella review providing an overview of previous literature reviews, examined risk factors for the development of lower limb OA in physically demanding occupations such as the military (Schram et al., 2019). The umbrella review demonstrated a proportional increase in the risk of developing OA in occupations involving heavy physical workloads. Through a dose-response meta-analysis of five case-control studies Verbeek et al. (2017) identified an incremental increase risk for the development of knee OA of OR 1.26 (95% confidence interval 1.17–1.35) per 5000 h of kneeling. Unfortunately, when reporting on lifting and carrying tasks, the studies included in the literature considered in the umbrella review and in Verbeek et al. (2017) have adopted varying definitions of 'heavy' loads, ranging from 10 kg to more than 50 kg (Bergmann et al., 2017; Jensen, 2008a, 2008b), and they have seldom adopted comparable exposure frequencies and durations, if these have been reported at all. To counter these methodological challenges, Seidler et al. (2018) developed a meta-regression which replaced the exposure categories in the available studies with cumulative exposure values. These researchers estimated that 25 to 58 repetitions of lifting and/or carrying weights greater than 20 kg or lifting 0.7–1.6 tons per day in a working life of 40 years would double the risk of hip OA (Seidler et al., 2018). Unfortunately, other occupational tasks such as kneeling, or squatting were not assessed by this group (Seidler et al., 2018).

Given the burden of OA and its complex epidemiology, particular attention to extrinsic factors, such as occupational demands contributing to OA, is warranted. Building on the aforementioned umbrella review (Schram et al., 2019), the primary aim of this systematic review was to identify and critically review the findings of recent studies regarding the relationships between specific physically-demanding occupations or occupational tasks and the development of lower limb OA.

2. Methodology

2.1. Eligibility criteria, data sources and search terms

PubMed, Cumulative Index to Nursing and Health Care Literature (CINAHL) and Elton B Stevens Company (EBSCO) databases were searched systematically using the search terms listed in Table 1. The reference lists of included articles were also manually searched and colleagues with expertise in the subject area were approached to identify additional studies of relevance. The recently published umbrella review from our group identified 16 reviews on OA, reporting on over 500 primary studies with search dates ranging from 1952 to 2014 (Schram et al., 2019). Therefore, aiming to avoid repetition whilst including recent relevant studies, the criteria adopted for study inclusion in this systematic review were: a) the study reported original research conducted in humans; b) the study was published in the English language; c) the study was published within the last 15 years; d) the study investigated risk factors for development of lower limb OA in personnel engaged in physically-demanding occupations; and e) the study included both clinical and radiological diagnostic criteria for OA in their participant inclusion criteria. Original search was completed in 25 November 2018 and an update search was performed on the 19 December 2019. The specific anatomical locations included in the lower body are defined in Table 1. These included the knee, hip, ankle, foot, and the general "lower body" region.

Table 1
Search terms per database.

Database	Search Terms	Filters
PubMed	("arthritis"[Title/Abstract] OR "osteoarthritis"[Title/Abstract]) AND ("ankle"[Title/Abstract] OR "knee"[Title/Abstract] OR "hip"[Title/Abstract] OR "foot"[Title/Abstract] OR "lower limb"[Title/Abstract]) AND ("risk"[Title/Abstract] OR "prevalence"[Title/Abstract] OR "cause*"[Title/Abstract])	Full text, 2003–2018, In English, on Humans
Cinahl	(AB) Arthritis OR osteoarthritis AND (AB) ankle OR knee OR hip OR foot OR lower Limb AND (AB) risk OR prevalence OR cause	Human, peer reviewed, from 2003, in English,
EBSCO	Arthritis OR osteoarthritis AND ankle OR knee OR hip OR foot OR lower Limb AND risk OR prevalence OR cause	Human, peer reviewed, from 2003, in English.

Titles and abstracts of studies identified in the systematic search were screened and both duplicates and studies that were clearly ineligible were removed. Full text copies of all remaining studies were obtained and subjected to the inclusion criteria with ineligible studies excluded and reasons recorded independently by two authors (EFDC & BS). The search, screening and selection processes were documented in a PRISMA flow diagram (Moher et al., 2009).

2.2. Methodological quality assessment

Eligible publications identified through the literature search, screening and selection processes were critically appraised to assess their methodological quality using the Critical Appraisal Skills Programme (CASP) toolkit (Critical Appraisal Skills Programme, 2018a, 2018b) or the AXIS tool for appraising cross-sectional studies (Downes et al., 2016). The CASP toolkit provides checklists to facilitate accurate and fair appraisal of each study, based on method design, but does not include a tool to appraise cross-sectional studies; thus, the CASP toolkit was supplemented by the AXIS tool (Downes et al., 2016) for that purpose. The included studies were all suitable for appraisal using the CASP cohort study checklist, the CASP case-control study checklist, or the AXIS tool. The CASP cohort study checklist (Critical Appraisal Skills Programme, 2018b) contains 12 questions for study quality assessment. The first two questions relate to screening and the following 10 questions guide the reviewer through the assessment of validity, relevance, methodology and result quality. The CASP case-control checklist (Critical Appraisal Skills Programme, 2018a) contains 11 questions, the first three of which are focused on screening and the following eight questions assessing validity, design effectiveness, power, and applicability. The AXIS (Downes et al., 2016) is a 20-question checklist encompassing 11 questions regarding objectives and methodology, seven questions to guide the assessor through the study's findings and discussion and two questions pertaining to ethical considerations such as consent and conflicts of interest.

Questions in each of the three tools were rated on a binary scale, with '1 point' awarded for questions that can be answered 'yes' and '0 points' awarded for those which are answered 'no' or are indeterminable. An exception to this method was question 19 in the AXIS tool, where a 'no' answer was awarded 1 point, since answering "yes" to that question affirms that there are funding sources or conflicts of interest that may affect the authors' interpretation of results. Questions 7–9 on both the CASP cohort study checklist and the CASP case-control checklist were condensed into 1 item, as they are all closely related, and items 7 and 8 cannot be answered numerically. Therefore, cohort studies were scored out of 12 possible points and case-control studies were scored out of nine possible points, while cross-sectional studies were scored out of 20 points, with scores from each tool then converted to a percentage score to derive the final scores considered in the review from all three tools. To ensure validity of score reporting, studies were assessed by two authors (EFDC & BS) independently. Where the scores assigned to a study by the two scoring authors varied by more than 1 point, the paper was re-assessed by a third author (RO). Where differences remained, and consensus could not be reached, the third author (RO) adjudicated to determine the final score. The overall level of agreement between the initial two raters, measured by Cohen's kappa, was $k = 0.700$ and considered a 'substantial agreement' (Viera and Garrett, 2005).

2.3. Data extraction and synthesis

Key data were subsequently extracted from each included study and tabulated. Extracted data included study authors, year of publication, number and characteristics of participants, methods used in the diagnosis of OA and quantification of the exposure to risk factors, and results - the latter with particular emphasis on odds ratios (OR) for risk of developing OA and associated 95% confidence intervals (95% CI), where these could be extracted or derived. Where these were unavailable but relative risks (RR) or hazard ratios (HR) were provided, these were extracted instead. Funding information of included studies were recorded when disclosed but not reported in this article. Following data compilation, key findings from the included studies were initially synthesised using a critical narrative approach. Following the critical narrative synthesis, meta-analyses were conducted where appropriate and these are further described below.

2.4. Statistical and meta analyses

Where possible, odds ratios (OR) and 95% confidence intervals (CI) were calculated (along with standard errors) according to Altman (1991), to indicate estimates of comparative levels of risk associated with specific occupational exposures and other risk factors for lower limb OA. Findings from the included studies were then further analysed through meta-analyses using the Cochrane Collaboration's software package, Review Manager (RevMan, version 5.3). This provided pooled estimates of the contributions of the reported risk factors to the development of lower limb OA using all available studies. When studies presented multiple values for comparative levels of risk associated with particular occupational risk factors (e.g. based on different exposures or weights handled) the comparative risk value included in the meta-analysis was the category with exposure ranges similar to other studies reporting the task. When other risk factors were sub-classified (e.g. sports participation sub-divided into soccer, tennis, and others) and numbers of cases exposed and non-exposed were presented, the sub-classifications were grouped and the calculated OR for the overall factor (e.g. sports participation) was included in the analysis. Heterogeneity was assessed using the standard χ^2 test and I^2 value and was considered statistically significant at $p < 0.10$ (Higgins and Green, 2011). I^2 values between 0% and 30% were considered minimal, 30%–50% moderate, 50%–90% substantial, and >90% considerable heterogeneity (Higgins and Green, 2011). Within subgroup sensitivity assessment was performed with regard to heterogeneity. Values were recorded as OR and 95% CI [lower limit, upper limit], unless stated otherwise. Forest plots were generated from the meta-analyses, where appropriate, to aid in visualisation and interpretation of the results. Publication bias was assessed using funnel plots and the Trim-and-Fill procedure (Sterne and Egger, 2001; Duval and Tweedie, 2000). Funnel plots used here were graphs of standard errors (SE) and ORs. Studies with larger sample sizes tend to cluster near the top of the plot and near the pooled SE while smaller studies are generally near the bottom of the graph. If publication bias is present, the bottom of the plot tends to show a higher concentration on one side since studies with smaller samples are more likely to be published if they had larger SEs (Sterne and Egger, 2001). The Trim-and-Fill procedure adjusts the funnel plot through an iterative process, removing studies concentrated on one side of the plot, reinserting the "trimmed" studies on the other side of the plot, and imputing their counterparts on the original side of the plot (Duval and Tweedie, 2000). A new SE and 95% CI is produced with imputed values.

3. Results

The systematic search resulted in identification of a total of 6407 articles and a further three articles were identified from other sources. Once the screening and selection processes were complete, 28 articles remained for inclusion in the systematic review. The PRISMA diagram outlining the identification, screening, eligibility assessment, and selection of articles is shown in Fig. 1.

Among the included studies, there were two cohort studies (Andersen et al., 2012; Jarvholm et al., 2008), ten case-control studies (Franklin et al., 2010; Holmberg et al., 2004; Klussmann et al., 2010; Mounach et al., 2008; Seidler et al., 2008; Vrezas et al., 2010; Thelin et al., 2004; Yoshimura et al., 2004, 2006; Rubak et al., 2014), and sixteen cross-sectional studies (Allen et al., 2010; Amin et al., 2008; Bernard et al., 2010; D'Souza et al., 2008; Ezzat et al., 2013; Jensen, 2005; Jensen et al., 2012a; Kaila-Kangas et al., 2011; Muraki et al., 2009; Rossignol et al., 2005; Rytter et al., 2009; Showery et al., 2016; Zhang et al., 2004; Kim et al., 2010; Muraki et al., 2011; Jensen et al., 2012b). Eleven studies reported on comparative risks of developing hip or knee OA associated with particular occupations (Andersen et al., 2012; Jarvholm et al., 2008; Franklin et al., 2010; Holmberg et al., 2004; Thelin et al., 2004; Yoshimura et al., 2006; Jensen et al., 2012a, 2012b; Rytter et al., 2009; Showery et al., 2016; Kim et al., 2010), without analysing or specifying occupational tasks as risk factors (Table 2). Two studies reported on both occupations and occupational tasks as risk factors (Seidler et al., 2008; Rossignol et al., 2005) for hip or knee OA (Table 2). A further fifteen studies reported on occupational tasks but not occupations as risk factors for knee or hip OA (Table 2). Only one (Bernard et al., 2010) of the 28 studies included in the review reported on risk factors for OA of a lower limb joint other than the knee or hip (specifically, the first metatarsophalangeal joint).

Key data from the included studies are presented in a structured manner in Table 3 (occupations) and Supplementary Table 1 (occupational tasks), which provide measures of OA risk associated with exposure to specific occupations and specific occupational tasks, respectively. In addition, Supplementary Table 1 identifies other risk factors (for example, high BMI, previous injury, older age and female sex) that appear to affect the relationships between exposure to specific occupational tasks and risk of developing OA.

3.1. Occupations

Occupations considered to be physically demanding, such as construction workers, floor layers, brick layers, fishermen, farmers and service personnel (including but not limited to salespersons, health care workers, police officers) (Andersen et al., 2012; Franklin et al., 2010; Holmberg et al., 2004; Thelin et al., 2004; Allen et al., 2010), were associated with an increased risk of the development of both hip and knee OA. Some occupations showed a dose dependent relationship between OA and years worked (Andersen et al., 2012; Holmberg et al., 2004; Jensen, 2005; Rytter et al., 2009; Jensen et al., 2012b). For example, farmers had an increased risk of hip OA after one to five years of work (hazard ratio [HR], when compared to office workers, 1.63 (95%CI 1.52 to 1.74), which increased substantially (HR 3.00 (95%CI 2.71 to 3.32] in those who had worked longer than 10 years (Andersen et al., 2012). Due to such high comparative risks, Thelin et al. (2004) investigated specific occupational tasks within farming, such as working more than 5 h in an animal barn, which was shown to increase the risk of hip OA substantially (OR exposed/not exposed 13.3 (95%CI 1.2 to

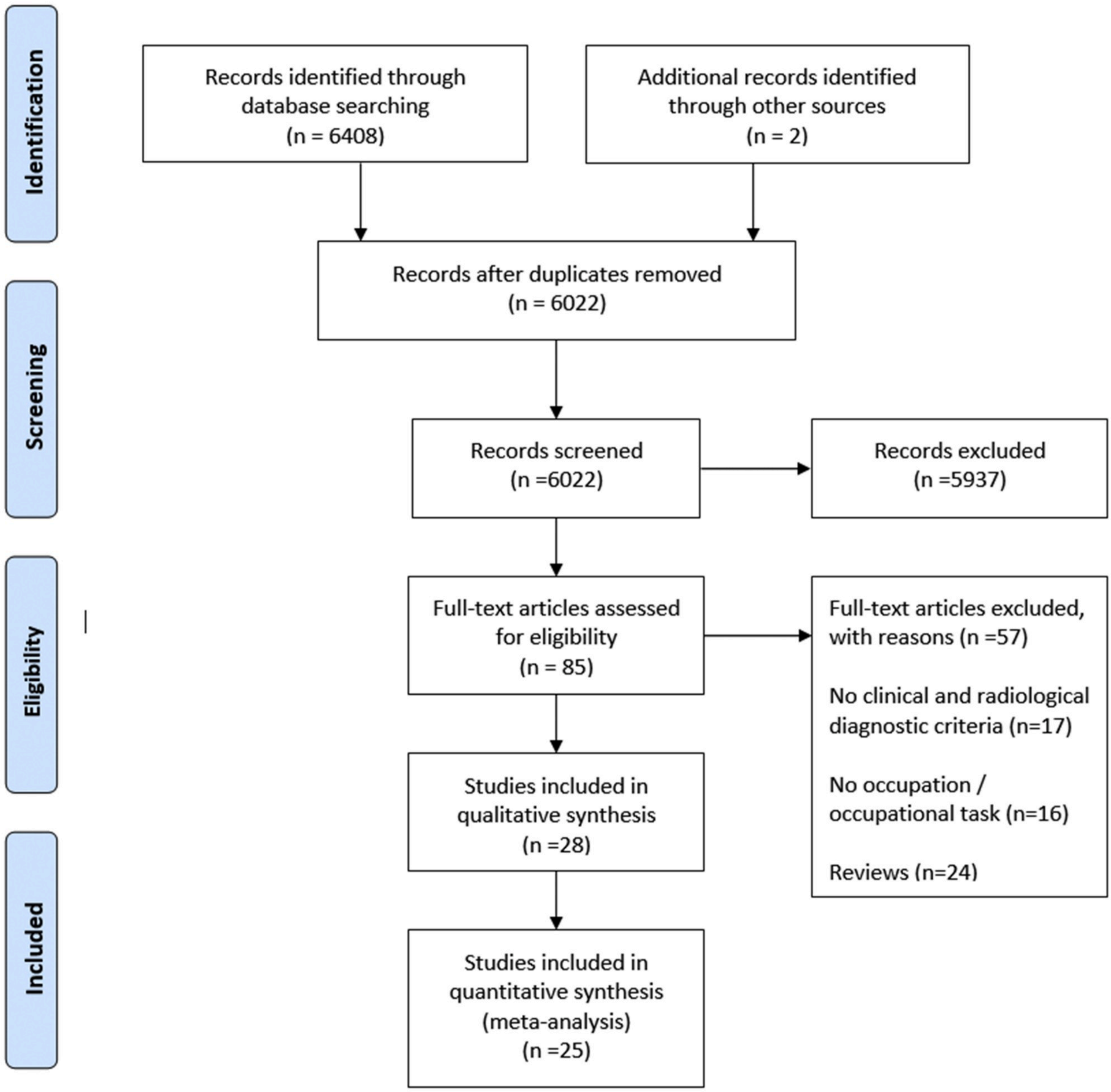

Fig. 1. PRISMA diagram showing results of the search, screening and selection processes for the systematic review and meta-analysis.

145.0)) (Thelin et al., 2004). In another study, construction workers who had worked in the industry for 11–30 years had 3.7 (95%CI 1.2 to 11.3) times the odds of developing knee OA compared to matched controls (Holmberg et al., 2004). However, a dose-response relationship could not be established between exposure and development of OA, as construction workers who had been in the profession for over 30 years had a lower risk (OR 1.6 (95%CI 0.6 to 4.6)) than those exposed for 11–30 years (Holmberg et al., 2004). The authors hypothesised that such findings could be explained by the healthy worker survivor effect, where workers who have developed knee OA may have left the workforce and therefore only those who are healthy remain.

Franklin et al. (2010) found that, compared to controls in managerial occupations, farmers were at a greater risk of having both a total knee replacement (TKR) and total hip replacement (THR) (OR 5.1 (95%CI 2.1 to 12.4) and 3.6 (95%CI 2.1 to 6.2), respectively). This was presumed by the authors to be due to their heavy workload. Likewise, male fishermen were at significantly greater risk of having a TKR for OA when compared to managers and professionals (OR 3.3 (95%CI 1.3 to 8.4)) (Franklin et al., 2010). The increased risk of having surgery due to knee OA in occupations with heavy physical workloads was also found by Jarvholm et al. (2008), who reported that floor layers had 4.7 (95%CI 1.8 to 12.3) times the risk observed in white-collar workers of having surgical treatment for their knee OA. The study concluded that across all construction industry workers, (1) 50% of the cases of severe OA of the knee could be prevented by addressing occupational risk factors (i.e. decreasing exposure to occupational tasks such as squatting/kneeling), and (2) that despite a positive correlation between hip and knee OA ($r = 0.62$, $p = 0.01$), the knee appears to be more affected than the hip (Jarvholm et al., 2008). Floor layers were also the focus of a study by Jensen et al. (2012a) due to the substantial amount of time they spent kneeling. In a separate study with this same cohort of floor layers, Jensen et al. (2012b) highlighted that seniority in the trade was associated with an increased risk of tibiofibular knee OA compared to graphic designers (>30 years of exposure OR 4.82 (95%CI 1.38 to17.0)).

Table 2
Occupational risk factors for knee or hip OA examined in the included studies.

Risk factors	Number of studies	References
Specific Occupations	11	(Andersen et al., 2012; Jarvholm et al., 2008; Franklin et al., 2010; Holmberg et al., 2004; Thelin et al., 2004; Jensen et al., 2012a, 2012b; Rytter et al., 2009; Showery et al., 2016; Kim et al., 2010)
Specific Occupational Tasks	17	
Squatting/knee bending	13	(Klussmann et al., 2010; Mounach et al., 2008; Seidler et al., 2008; Vrezas et al., 2010; Yoshimura et al., 2004; Allen et al., 2010; Amin et al., 2008; Bernard et al., 2010; D'Souza et al., 2008; Jensen, 2005; Muraki et al., 2009; Zhang et al., 2004; Muraki et al., 2011)
Kneeling	7	(Klussmann et al., 2010; Mounach et al., 2008; Yoshimura et al., 2004; D'Souza et al., 2008; Ezzat et al., 2013; Muraki et al., 2009; Muraki et al., 2011)
Lifting/Carrying	13	(Klussmann et al., 2010; Mounach et al., 2008; Seidler et al., 2008; Vrezas et al., 2010; Yoshimura et al., 2004; Rubak et al., 2014; Allen et al., 2010; Amin et al., 2008; D'Souza et al., 2008; Kaila-Kangas et al., 2011; Muraki et al., 2009; Rossignol et al., 2005; Muraki et al., 2011)
Standing	9	(Klussmann et al., 2010; Mounach et al., 2008; Yoshimura et al., 2004; Rubak et al., 2014; Allen et al., 2010; Bernard et al., 2010; D'Souza et al., 2008; Muraki et al., 2009; Muraki et al., 2011)
Walking	7	(Klussmann et al., 2010; Mounach et al., 2008; Yoshimura et al., 2004; Allen et al., 2010; D'Souza et al., 2008; Muraki et al., 2009; Muraki et al., 2011)
Sitting	8	(Klussmann et al., 2010; Mounach et al., 2008; Yoshimura et al., 2006; Yoshimura et al., 2004; Allen et al., 2010; D'Souza et al., 2008; Muraki et al., 2009; Muraki et al., 2011)
Crawling	1	Allen et al. (2010)
Bending, twisting reaching	1	Allen et al. (2010)

The two studies that reported on both occupations and occupational tasks (Seidler et al., 2008; Rossignol et al., 2005) as risk factors for knee or hip OA were added to the occupational task row.

Large cross-sectional surveys have found that OA is prevalent in 40% of physically demanding, heavy labour jobs which require uncomfortable positions, or constant lifting or carrying of heavy objects. These include agriculture, housekeeping, truck drivers and labour workers (Jarvholm et al., 2008; Franklin et al., 2010; Jensen, 2005; Rossignol et al., 2005). These large studies have concluded that OA is in fact linked to occupation and not simply an inevitable disease of ageing. There are subsequently calls for an increased number of occupation-specific studies which develop and evaluate preventative strategies (Showery et al., 2016; Kim et al., 2010).

Likewise, individuals in military occupations were found to be at increasing risk of knee OA as their age or rank increased (Showery et al., 2016). Given the length of service required to reach higher ranks, length of service may also therefore be associated with an increased risk of OA. In addition, service type predicted level of lower limb OA risk (Showery et al., 2016), with service in the Army or Air Force being associated with an increased risk of knee OA ($p < 0.001$) when compared to service in the Marines.

3.2. Occupational tasks

3.2.1. Occupational tasks associated with knee OA

The occupational tasks considered in many studies as risk factors for development of knee OA are depicted in Fig. 2. Five of the seventeen included studies that reported on occupational tasks associated with development of knee OA were excluded from the final meta-analysis for knee OA risk as they either (a) failed to identify the exclusive contribution of a particular task (i.e. utilised exposure indexes [an equation involving multiple task types, self-reported time spent in task and/or years in the occupation]) or (b) did not provide enough information for estimating data. The twelve studies included in the final meta-analysis revealed a significant, though modest, overall contribution of exposure to these physically demanding tasks to the risk of developing knee OA (Fig. 2). Contributions of exposure to individual task categories in increasing knee OA risk (Fig. 2) were generally modest, though in most instances statistically significant. There was moderate overall heterogeneity amongst the task categories analysed, thus a random model was used. Trim-and fill (Duval and Tweedie, 2000) adjustments were performed as visual inspection of a funnel plot revealed likely publication bias (Fig. 3). Trim-and-fill adjustment resulted in the input of 11 values, all to the left of the funnel plot (i.e. lower effect size). The adjusted ORs and 95%CIs were still significant in most task categories except for squatting and climbing (Fig. 2).

3.2.2. Lifting/carrying

Ten studies assessed the association between exposure to lifting/carrying and risk of developing knee OA. Of those, three studies combined the actions of lifting and carrying (Klussmann et al., 2010; Seidler et al., 2008; Vrezas et al., 2010), while the remaining seven studies assessed lifting separately. The reported weight lifted ranged from 4.5 kg to >25 kg, and, when reported, frequency of lifting ranged from once to ten times per week. Meta-analysis results showed a significant association between exposure to lifting/carrying tasks and risk of developing knee OA (Fig. 2).

Lifting 4.5 kg ten times/week (OR 1.42 (95%CI 1.13 to 1.80)) (Allen et al., 2010) and >10 kg/week was reported to increase the risk of OA in both men (OR 2.26 (95%CI 1.52 to 3.40)) and women (OR 1.68 (95%CI 1.24 to 2.26)) (Muraki et al., 2009). Substantial cumulative exposure to lifting and carrying (ranging from 5120 to 37,000 kg*hour) resulted in an increase in the risk of knee OA in men (OR 2.0 (95%CI 1.1, 3.9)) (Seidler et al., 2008) and a 2.6-fold increased risk in men with BMI ≥ 25 kg/m^2 (Vrezas et al., 2010). In women, the cumulative exposure to lifting/carrying more than 1088 tonnes/lifetime (mean reported lifetime 59.6 years (±9.8 years)) was a significant contributing factor to the development of knee OA (OR 2.13 (95% CI 1.14 to 3.98)) (Klussmann et al., 2010).

3.2.3. Squatting/knee bending/kneeling

Twelve studies reported specifically on squatting, kneeling, and knee bending tasks as risk factors for the development of knee OA. Combined, these studies indicated that squatting, kneeling and other knee bending tasks were significantly associated with the development of knee OA, though the comparative risk for those exposed to these tasks was only a little higher than for those not exposed (OR 1.21 (95%CI 1.10 to 1.33), $z = 3.82$, $p < 0.001$). The associations between individual task categories (i.e. squatting, kneeling, and knee bending) and the development of knee OA are provided in Fig. 2.

Of the twelve studies, three case-control studies (Klussmann et al., 2010; Seidler et al., 2008; Vrezas et al., 2010) and one cohort study (Amin et al., 2008) reported on the three tasks without acknowledging the biomechanical differences between them. These three studies, grouped for meta-analysis purposes, demonstrated a significant association between the three task categories combined and the development of knee OA (Fig. 2). Exposure to kneeling/squatting for 3574 to 12,244 h/life was associated with a substantial increase in the occurrence of

Table 3
Occupations as risk factors for OA.

Reference	Joint	Study type	Participants	Methods (OA Diagnosis/Exposure to Risk Factors)	Occupations as Risk Factors: Comparative levels of risk			Methodological Quality[a]
Andersen et al. (Andersen et al., 2012)	Hip and Knee	Cohort	Integrated database for Labour Market research (1996–2006) (n = 2,117,298 workers in wide ranging occupations; cases: ♂hip OA = 8358; ♂ knee OA = 4014; ♀hip OA = 8059; ♀ knee OA = 5957)	Diagnosis of OA according to the Nordic Classification of Surgical Procedures (requirement of the National Patient Register) and had a hip/knee replacement (x-ray required) in the same year.	**Knee**	♂ HR (95%CI)	♀ HR (95% CI)	54%
					Farmers	1.14 (1.04–1.28)	0.95 (0.85–1.06)	
					Construction workers	1.27 (1.17–1.38)	1.37 (1.14–1.64)	
					Floor/Brick layers	1.49 (1.28–1.73)	N/A	
					Healthcare Assistants	1.42 (1.23–1.64)	1.34 (1.27–1.42)	
					Hip	♂	♀	
					Farmers	1.96 (1.84–2.08)	1.22 (1.12–1.33)	
					Construction workers	1.23 (1.15–1.31)	1.21 (1.03–1.43)	
					Floor/Brick layers	1.35 (1.20–1.52)	N/A	
					Healthcare Assistants	1.11 (0.99–1.25)	1.12 (1.07–1.18)	
					Reference: Office workers			
Franklin et al. (Franklin et al., 2010)	Knee and Hip	Case-Control	2490 participants 1408 cases with knee and/or hip OA (832 ♀) 1082 age- and genetically matched (i.e. > 60 years old and relatives of participants) controls (592 ♀)	X-ray (Kellgren & Lawrence grades) Questionnaire	**Knee**	♂ OR [95%CI]	♀ OR [95% CI]	67%
					Farmers	5.1 [2.1, 12.4]	1.4 [0.67, 2.7]	
					Fisherman	3.3 [1.3, 8.4]	N/A	
					Craft Workers	2.5 [1.0, 6.2]	1.2 [0.59, 2.5]	
					Hip	♂	♀	
					Farmers	3.6 [2.1, 6.2]	0.62 [0.36, 1.0]	
					Service and Shop Workers	2.1 [1.0, 4.2]	0.79 [0.48, 1.3]	
					Reference: Managers and professionals (i.e. teachers, doctors and nurses)			
Holmberg et al. (Holmberg et al., 2004)	Knee	Case-Control	1473 participants 778 cases (440 ♀ and 338 ♂) 695 matched (age, sex and county) controls (402 ♀ and 293♂).	X-ray (Kellgren & Lawrence grades) Questionnaire	**Knee**	♂ OR [95%CI]	♀ OR [95% CI]	89%
					Farmers (11–30 years)	0.8 [0.3, 2.1]	2.1 [1.0, 4.5]	
					Building and Construction (11–30 years)	3.7 [1.2, 11.3]	N/A	
					Reference: Matched controls with no OA			
Jarvholm et al. (Jarvholm et al., 2008)	Knee and Hip	Cohort	204,741 males from wide-ranging occupations (including 9136 in control group - white-collar workers)	X-ray (Kellgren & Lawrence grades) Questionnaire	**Knee**	RR (95% CI)		75%
					Asphalt Workers	2.81 (1.11–7.13)		
					Brick Layers	2.14 (1.08–4.25)		
					Drivers	2.01 (0.89–4.54)		
					Floor Layers	4.72 (1.80–12.33)		
					Plumbers	2.29 (1.19–4.43)		
					Rock Workers			

(continued on next page)

Table 3 (*continued*)

Reference	Joint	Study type	Participants	Methods (OA Diagnosis/Exposure to Risk Factors)	Occupations as Risk Factors: Comparative levels of risk		Methodological Quality[a]
					 Sheet Metal Workers Wood workers *Reference: White-collar workers*	2.59 (1.18–5.69) 2.60 (1.06–6.37) 2.02 (1.11–3.69)	
Jensen (Jensen, 2005)	Knee	Cross sectional	Floor layers (n = 133) Carpenters (n = 509) Compositors (n = 327) Video analysis of occupational tasks	X-ray (Kellgren & Lawrence grades) Questionnaire	**Knee complaints (> 30 days in 1 year)** Low-moderate exposure High exposure Very high exposure **Knee complaints + radiographic OA** Low-moderate exposure High exposure Very high exposure *Reference: No exposure to knee-stressing work positions*	OR [95%CI] 2.1 [1.1, 4.4] 3.95 [2.2, 7.3] 6.85 [3.6,13.0] 1.39 [0.3,3.6] 3.07 [0.6,16.8] 4.47 [1.1, 18.9]	65%
Jensen et al. (Jensen et al., 2012a)	Knee	Cross sectional	Floor layers (n = 134) Graphic designers (n = 120) Questionnaire (Knee Injury and Osteoarthritis Outcome Score – KOOS) + MRI	X-ray (Kellgren & Lawrence grades)	**Symptomatic tibiofibular** OA Floor layers *Reference: Graphic designers*	OR [95%CI] 2.6 [0.99,6.9]	70%
Jensen et al. (Jensen et al., 2012b)	Knee	Cross sectional	Floor layers (n = 92) Graphic designers (n = 49) Questionnaire (Knee Injury and Osteoarthritis Outcome Score – KOOS) MRI	X-ray (Kellgren & Lawrence grades)	**Tibiofibular OA** Floor layers Seniority <20 years in trade 21–30 years in trade >30 years in trade **Patellofemoral OA** Floor layers Seniority <20 years in trade >30 years in trade *Reference: Graphic designers*	OR [95%CI] 2.46 [0.8, 7.3] 0.7 [0.1, 7.4] 1.89 [0.3, 12.3] 4.82 [1.4, 17.0] 0.44 [0.1, 1.5] 1.30 [0.3, 6.3] 0.48 [0.1, 1.9]	65%
Kim et al. (Kim et al., 2010)	Knee	Cross sectional	Participants from a range of occupations (n = 504. ♀274, ♂ 230)	X-ray (Kellgren-Lawrence OA (≥2 = all, 3–4 = severe) Interviewer- administered questionnaire (Knee pain/aching/stiffness lasting ≥1 month)	**Symptomatic knee OA** Manual occupations (i.e. farmer, construction worker, labourer) **Radiographic knee OA** Manual occupations (i.e. farmer, construction worker, labourer) *Reference: Non-manual occupations*	OR [95%CI] 2.39 [1.35, 4.22] 2.14 [1.19, 3.84]	82%
Rytter et al. (Rytter et al., 2009)	Knee	Cross sectional	Male floor layers (n = 134) Male graphic designers (n = 120)	OA on modified Ahlback scale -joint space narrowing ≥1 grade (scored for tibiofemoral and patellofemoral	**Radiographic tibiofemoral OA** Floor layers (age) ≤49 years 50–59 years	OR [95%CI] 1.1 [0.1, 13.1] 3.6 [1.1, 12.0]	63%

(*continued on next page*)

Table 3 (*continued*)

Reference	Joint	Study type	Participants	Methods (OA Diagnosis/Exposure to Risk Factors)	Occupations as Risk Factors: Comparative levels of risk		Methodological Quality[a]
				compart ments) + questionnaire	≥60 years	1.9 [0.4, 7.8]	
					Reference: Graphic designers		
					Seniority in trade		
					21–30 years	1.4 [0.1, 21.4]	
					≥31 years	1.6 [0.1, 17.5]	
					Reference: ≤ 20 years		
Showery et al. (Showery et al., 2016)	Knee	Cross sectional	21,318 US military active duty service members with diagnosis of primary or secondary knee OA (Defence Medical Epidemiological Database retrospective 2005–2014)	Dependent and based on patient history, physical examination, and pertinent radiographic imaging	**Primary knee OA**	RR (95%CI)	70%
					Rank		
					Senior Enlisted	1.49 (1.39–1.60)	
					Junior Officer	1.00 (0.94–1.06)	
					Senior Officer	1.59 (1.39–1.60)	
					Reference: Junior enlisted		
					Service		
					Army	1.21 (1.13–.128)	
					Air Force	1.38 (1.30–1.47)	
					Navy	0.85 (0.80–0.91)	
					Reference: Marines		
Thelin et al. (Thelin et al., 2004)	Hip	Case-control	Farmers with OA (n = 369) Controls (n = 369) matched by occupation, age, sex and residential area	X-ray and questionnaire	**OA among farmers**	OR [95%CI]	83%
					Milk > 40 cows/daily	4.5 [1.86, 10.97]	
					Work > 5 h/daily in animal barns from age 30	13.3 [1.22, 144.98]	
					Reference: Not exposed to work with animals/in animal barns		

Kellgren & Lawrence grades: Grade *1*: doubtful narrowing of joint space and possible osteophytic lipping; *Grade 2*: definite osteophytes and possible narrowing of joint space; *Grade 3*: moderate multiple osteophytes, definite narrowing of joint space and some sclerosis and possible deformity of bone ends; *Grade 4*: large osteophytes, marked narrowing of joint space, severe sclerosis and definite deformity of bone ends. OA: osteoarthritis. KOOS: Knee injury and Osteoarthritis Outcome Scores. MRI: magnetic resonance imaging. OR: odds ratio. HR: hazard ratio. RR: relative risk. CI: confidence interval. N/A: not available. NS: not significant. ♂: male. ♀: female.

[a] Methodological quality percentage score is based on the critical appraisal tool specific to each study design, described in the methods section of this review.

Occupational Task / Study	log[Odds Ratio]	SE	Weight	Odds Ratio IV, Random, 95% CI	Adjusted Odds Ratio IV Random 95% CI
1.1.1 Squatting/Kneeling					
Klussmann et al. 2010	0.7701	0.2832	1.5%	2.16 [1.24, 3.76]	
Seidler et al. 2008	0.47	0.3537	1.0%	1.60 [0.80, 3.20]	
Vrezas et al. 2010	0.5878	0.4137	0.8%	1.80 [0.80, 4.05]	
Subtotal (95% CI)			**3.3%**	**1.89 [1.29, 2.77]**	**1.66 [1.17, 2.35]**
Heterogeneity: Tau² = 0.00; Chi² = 0.46, df = 2 (P = 0.80); I² = 0%					
Test for overall effect: Z = 3.27 (P = 0.001)					
1.1.2 Squatting					
Allen et al. 2010	0.0602	0.1135	4.3%	1.06 [0.85, 1.33]	
Bernard et al. 2010	0.4447	0.2863	1.5%	1.56 [0.89, 2.73]	
Muraki et al. 2009	0.207	0.1372	3.7%	1.23 [0.94, 1.61]	
Yoshimura et al. 2004	0.1823	0.305	1.3%	1.20 [0.66, 2.18]	
Zhang et al. 2004	0.0953	0.2306	2.0%	1.10 [0.70, 1.73]	
Subtotal (95% CI)			**12.9%**	**1.15 [0.99, 1.34]**	**1.08 [0.95, 1.23]**
Heterogeneity: Tau² = 0.00; Chi² = 1.92, df = 4 (P = 0.75); I² = 0%					
Test for overall effect: Z = 1.89 (P = 0.06)					
1.1.3 Kneeling					
D'Souza et al. 2008	0.2546	0.0813	5.3%	1.29 [1.10, 1.51]	
Mounach et al. 2008	0.2852	0.3423	1.1%	1.33 [0.68, 2.60]	
Muraki et al. 2009	0.1044	0.1483	3.4%	1.11 [0.83, 1.48]	
Yoshimura et al. 2004	-0.1393	0.3034	1.3%	0.87 [0.48, 1.58]	
Subtotal (95% CI)			**11.1%**	**1.23 [1.07, 1.40]**	
Heterogeneity: Tau² = 0.00; Chi² = 2.17, df = 3 (P = 0.54); I² = 0%					
Test for overall effect: Z = 3.01 (P = 0.003)					
1.1.4 Lifting/Carrying					
Klussmann et al. 2010	0.7561	0.3189	1.2%	2.13 [1.14, 3.98]	
Seidler et al. 2008	0.6931	0.305	1.3%	2.00 [1.10, 3.64]	
Vrezas et al. 2010	0.8755	0.398	0.8%	2.40 [1.10, 5.24]	
Subtotal (95% CI)			**3.4%**	**2.14 [1.46, 3.12]**	
Heterogeneity: Tau² = 0.00; Chi² = 0.13, df = 2 (P = 0.94); I² = 0%					
Test for overall effect: Z = 3.94 (P < 0.0001)					
1.1.5 Lifting					
Allen et al. 2010	0.3507	0.0947	4.9%	1.42 [1.18, 1.71]	
Amin et al. 2008	0.3365	0.3537	1.0%	1.40 [0.70, 2.80]	
D'Souza et al. 2008	0.2231	0.056	6.0%	1.25 [1.12, 1.39]	
Kaila-Kangas et al. 2013	0.5878	0.2069	2.3%	1.80 [1.20, 2.70]	
Mounach et al. 2008	0.4626	0.3428	1.1%	1.59 [0.81, 3.11]	
Muraki et al. 2009	0.6419	0.1206	4.1%	1.90 [1.50, 2.41]	
Yoshimura et al. 2004	0.6471	0.3727	1.0%	1.91 [0.92, 3.97]	
Subtotal (95% CI)			**20.4%**	**1.52 [1.29, 1.79]**	**1.31 [1.10, 1.55]**
Heterogeneity: Tau² = 0.02; Chi² = 12.81, df = 6 (P = 0.05); I² = 53%					
Test for overall effect: Z = 4.92 (P < 0.00001)					
1.1.6 Climbing					
Allen et al. 2010	-0.0408	0.1397	3.6%	0.96 [0.73, 1.26]	
Bernard et al. 2010	0.5016	0.181	2.8%	1.65 [1.16, 2.35]	
Mounach et al. 2008	0.6841	0.2953	1.4%	1.98 [1.11, 3.54]	
Muraki et al. 2009	0.8879	0.2006	2.4%	2.43 [1.64, 3.60]	
Subtotal (95% CI)			**10.3%**	**1.62 [1.03, 2.55]**	**1.20 [0.76, 1.89]**
Heterogeneity: Tau² = 0.17; Chi² = 16.97, df = 3 (P = 0.0007); I² = 82%					
Test for overall effect: Z = 2.10 (P = 0.04)					
1.1.7 Standing					
Allen et al. 2010	0.3221	0.1251	4.0%	1.38 [1.08, 1.76]	
Bernard et al. 2010	0.1546	0.0939	4.9%	1.17 [0.97, 1.40]	
D'Souza et al. 2008	0.2927	0.1007	4.7%	1.34 [1.10, 1.63]	
Klussmann et al. 2010	-0.0424	0.1578	3.2%	0.96 [0.70, 1.31]	
Mounach et al. 2008	0.2175	0.3303	1.2%	1.24 [0.65, 2.37]	
Muraki et al. 2009	0.678	0.1635	3.1%	1.97 [1.43, 2.71]	
Yoshimura et al. 2004	0.4947	0.3858	0.9%	1.64 [0.77, 3.49]	
Subtotal (95% CI)			**22.0%**	**1.32 [1.12, 1.55]**	**1.22 [1.02, 1.46]**
Heterogeneity: Tau² = 0.02; Chi² = 12.21, df = 6 (P = 0.06); I² = 51%					
Test for overall effect: Z = 3.36 (P = 0.0008)					
1.1.8 Walking					
Allen et al. 2010	0.3784	0.1353	3.8%	1.46 [1.12, 1.90]	
D'Souza et al. 2008	0.6043	0.4096	0.8%	1.83 [0.82, 4.08]	
Klussmann et al. 2010	-0.0321	0.1811	2.8%	0.97 [0.68, 1.38]	
Mounach et al. 2008	0.5572	0.2947	1.4%	1.75 [0.98, 3.11]	
Muraki et al. 2009	0.5878	0.121	4.1%	1.80 [1.42, 2.28]	
Yoshimura et al. 2004	0.2546	0.2905	1.4%	1.29 [0.73, 2.28]	
Subtotal (95% CI)			**14.3%**	**1.46 [1.17, 1.81]**	
Heterogeneity: Tau² = 0.03; Chi² = 8.91, df = 5 (P = 0.11); I² = 44%					
Test for overall effect: Z = 3.41 (P = 0.0006)					
1.1.9 Crawling					
Allen et al. 2010	0.4637	0.2117	2.3%	1.59 [1.05, 2.41]	
Subtotal (95% CI)			**2.3%**	**1.59 [1.05, 2.41]**	
Heterogeneity: Not applicable					
Test for overall effect: Z = 2.19 (P = 0.03)					
Total (95% CI)			**100.0%**	**1.41 [1.30, 1.52]**	
Heterogeneity: Tau² = 0.02; Chi² = 74.34, df = 39 (P = 0.0006); I² = 48%					
Test for overall effect: Z = 8.70 (P < 0.00001)					
Test for subgroup differences: Chi² = 18.54, df = 8 (P = 0.02), I² = 56.8%					

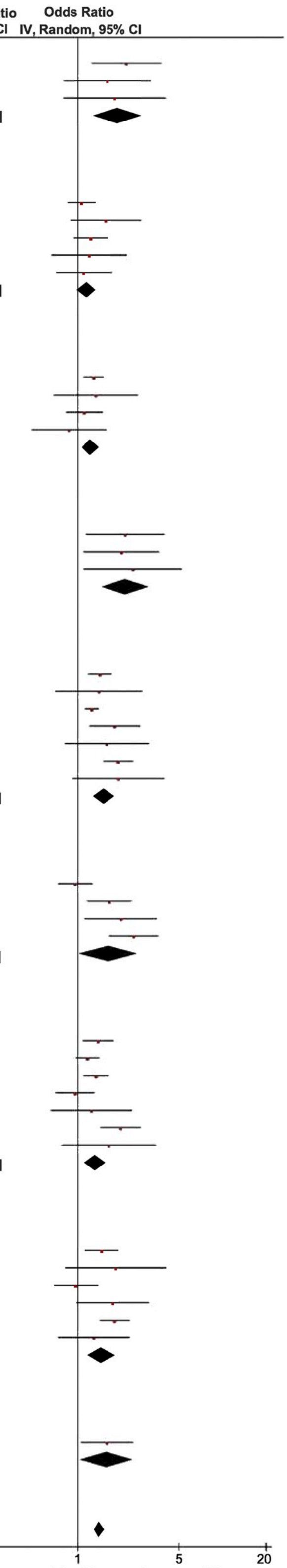

Fig. 2. Occupational tasks examined in included studies and associated comparative risks of developing knee OA following exposure to those tasks* Values obtained after trim-and-fill adjustment.

symptomatic knee OA in male patients when they were compared to apparently healthy controls (OR 2.16 (95%CI 1.24 to 3.77)) (Klussmann et al., 2010). A similar exposure range (4757 to 10,800 h/life) was reported to contribute to the risk of knee OA development in male patients (OR 1.6 (95%CI 0.8 to 3.4)) (Seidler et al., 2008) and to further increase such risk in male patients with a BMI>25 kg/m^2 when they were compared to controls with normal BMI (OR 8.9 (95%CI 4.4 to 17.9)) (Vrezas et al., 2010). Lifetime exposures to these tasks for more than 10,

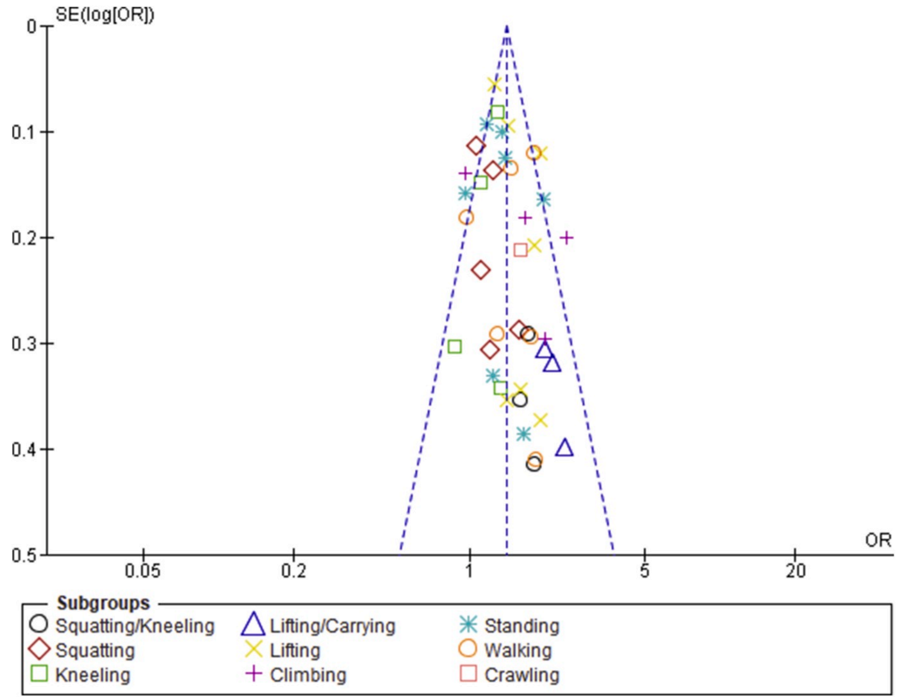

Fig. 3. – Funnel plot for studies of associations between occupational task exposures and lower limb OA.

800 h/life were associated with a significant increase in the risk of knee OA in men – approximately a 2-fold (Klussmann et al., 2010) to 4-fold (Seidler et al., 2008) increase. Similarly, for women, a lifetime exposure of >8934 h/life was associated with more than a two-fold increase in the risk of knee OA (Klussmann et al., 2010). Although most studies by themselves were not statistically significant, the pooled results from the meta-analyses suggested that kneeling, but not squatting, contributed significantly to the development of knee OA (Fig. 2).

3.2.4. Standing

Seven studies reported on standing as a risk factor for the development of knee OA. Results of the meta-analysis showed a significant association between exposure to this task category and development of knee OA (Fig. 2). Two studies (Bernard et al., 2010; D'Souza et al., 2008) indicated that women (but not men) standing for more than 2 h/day were at increased risk of knee OA. Conversely, Monauch et al. (Mounach et al., 2008) described no significant association between standing for more than 5 h per day and development of knee OA when comparing exposed cases to controls. These differences may be due to either study design, sample size or participants' occupations. The two studies in agreement were cross-sectional studies with more than 2000 participants each (Bernard et al., 2010; D'Souza et al., 2008), while the third, a case-control study, included only 95 cases (Mounach et al., 2008). Further, more than half of the cases and controls in the case-control study were housewives, whereas the two cross-sectional studies encompassed a greater variety of trades including farmers, construction workers, labourers, machinery operators and retail workers.

3.2.5. Climbing, walking and crawling

Four studies reported on climbing as a risk factor for the development of knee OA. Whilst three individual studies indicated a statistically significant contribution of climbing for the development of knee OA (Mounach et al., 2008; Bernard et al., 2010; Muraki et al., 2009), trim-and-fill adjusted pooled results, did not (Fig. 2).

The contribution of walking to the development of knee OA was reported in seven studies (Klussmann et al., 2010; Mounach et al., 2008; Yoshimura et al., 2004; Rubak et al., 2014; Allen et al., 2010; D'Souza et al., 2008; Muraki et al., 2009). Of these, only two individual studies identified a statistically significant risk of walking for more than 50% of the time in their occupation (OR 1.46 (95%CI 1.12 to 1.90)) (Allen et al., 2010) or when walking exceeded 3 km per day (OR 1.80 (95%CI 1.48 to 2.28)) (Muraki et al., 2009).

Only one study reported on occupational crawling as a risk factor for the development of knee OA (Allen et al., 2010), with the overall risk for climbing to be related to knee OA found to be 1.39 (95%CI 1.05 to 2.41).

3.2.6. Physical load (without specifying task)

Two studies created a physical load exposure index, by coupling occupational tasks with other variables, such as time and/or years (Ezzat et al., 2013; Jensen, 2005). The first (Ezzat et al., 2013) involved two population based cohorts and a physical load index (i.e. product of the number of years in the job, activity level and knee bending or kneeling score) which was used to categorize cumulative physical load exposures into quartiles (Ezzat et al., 2013). Individuals in the highest physical loading quartile had higher risk of knee OA (OR 8.16 (95%CI 1.89 to 35.27)) when compared to the lowest quartile, as did the second highest quartile when compared to the second lowest quartile (OR 5.73 (95%CI 1.36 to 24.12)). Both MRI-diagnosed and symptomatic OA were found to have dose response relationships with occupational activity level, while radiographically diagnosed knee OA did not. Jensen et al. (Seidler et al., 2008) reported a higher risk of knee OA in participants with high exposure when compared to those with no exposure to such tasks (OR 7.06 (95%CI 3.7 to 13.4)). The same trend was observed for radiographically diagnosed OA, as those with very high exposure to knee-straining tasks were at increased risk of radiographically diagnosed knee OA when compared to those not exposed (OR 4.92 (95%CI 1.1 to 21.9)) (Jensen, 2005).

3.2.7. Occupational tasks associated with hip OA

Only three of the included studies (Rubak et al., 2014; Allen et al., 2010; Kaila-Kangas et al., 2011) provided information on occupational tasks associated with the risk of developing hip OA. Despite the low number of studies, meta-analysis of findings revealed a significant association between exposure to most of these tasks and risk of developing hip OA (Fig. 4). Inspection of the funnel plot (Fig. 5) suggested publication bias for studies of lifting tasks. Trim-and fill (Duval and Tweedie,

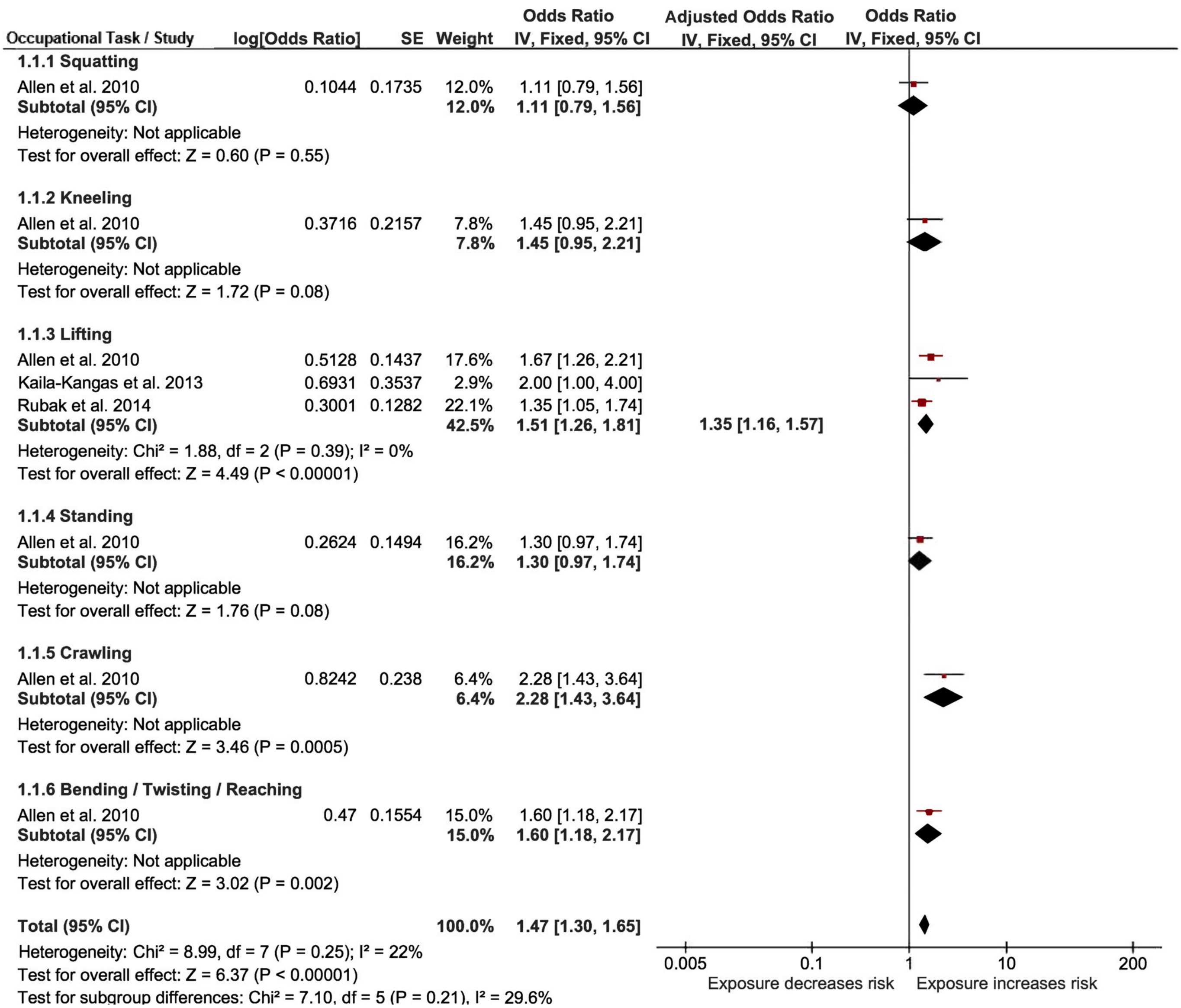

Fig. 4. Occupational tasks examined in included studies and associated comparative risks of developing hip OA following exposure to those tasks* Values obtained after trim-and-fill adjustment.

2000) adjustments resulted in two values being inputted to the left of the funnel plot (i.e. lower effect size). The adjusted OR and 95%CIs still demonstrated significant contribution of lifting to the development of hip OA (Fig. 4).

Three studies reported on the contribution of lifting to the development of hip OA (Rubak et al., 2014; Allen et al., 2010; Kaila-Kangas et al., 2011). Allen et al. (2010) provided strong evidence of increased risk of hip OA development associated with a lifetime exposure to lifting >10 kg (OR 1.71 (95%CI 1.28 to 2.29)), 20 kg (OR 1.63 (95%CI 1.15 to 2.30)) or 50 kg (OR 1.88 (95%CI 1.20 to 2.92)) >10 times per week, in agreement with findings from Kaila-Kangas et al. (2011). There was only one study (Allen et al., 2010) that examined squatting, crawling, bending/twisting/reaching, standing, and kneeling. As shown in Fig. 4, only lifting, crawling and bending/twisting/reaching significantly increased the risk of hip OA.

4. Discussion

Results from this systematic review indicate that individuals in physically demanding occupations or exposed to specific types of physically demanding tasks were at increased risk of lower limb OA. The most frequently reported occupations in which workers were at an increased risk of lower limb OA were farming, floor laying and brick laying. Squatting with kneeling, kneeling alone, lifting/carrying, lifting alone, climbing, standing, walking and crawling constituted specific tasks associated with risk of knee OA (Klussmann et al., 2010; Mounach et al., 2008; Seidler et al., 2008; Vrezas et al., 2010; Yoshimura et al., 2004; Allen et al., 2010; Amin et al., 2008; Bernard et al., 2010; D'Souza et al., 2008; Kaila-Kangas et al., 2011; Muraki et al., 2009; Zhang et al., 2004). The data on hip OA was limited, but at least three studies (Rubak et al., 2014; Allen et al., 2010; Kaila-Kangas et al., 2011) found that hip OA was associated with lifting tasks.

With regard to occupations, Andersen et al. (2012) reported incidence rates of surgically treated hip OA and knee OA in farmers of 157 and 47 per 100,000 person-years, respectively. Other occupations, such as military service, have been identified to have very high incidence rates of OA (Showery et al., 2016; Cameron et al., 2011; Williams et al., 2016; Medical Surveillance Mont, 2010), with 786 cases of OA per 100, 000 person-years recorded across all active duty service members in the US military (Cameron et al., 2011). Only one military study was

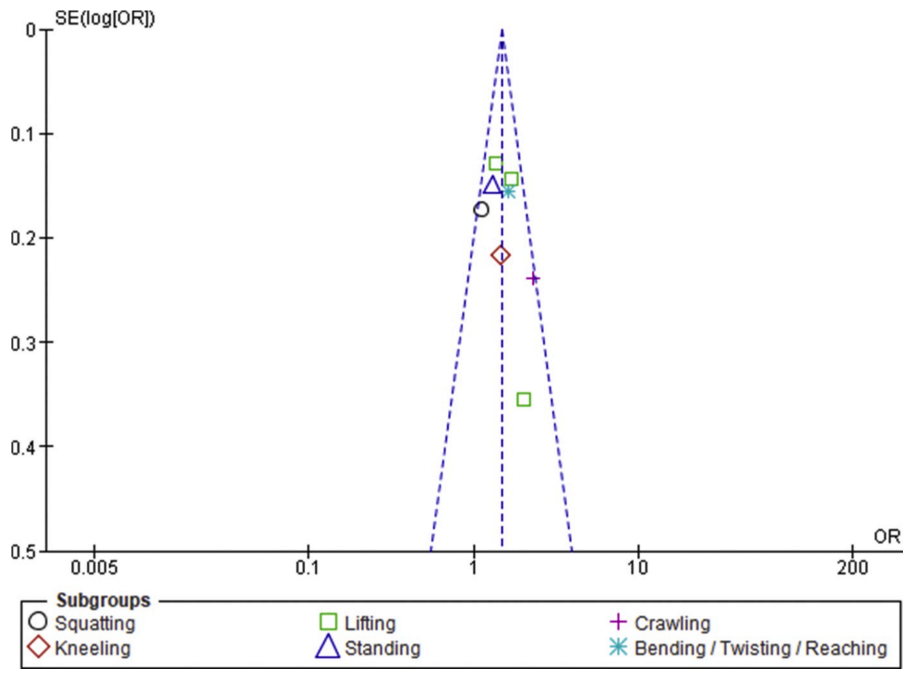

Fig. 5. Funnel plot for studies of associations between occupational task exposure and hip OA.

included in this review (Showery et al., 2016), as others failed to meet the inclusion criteria of image-based OA diagnosis (Cameron et al., 2011; Williams et al., 2016; Medical Surveillance Mont, 2010).

Physically-demanding occupational tasks, such as lifting/carrying heavy weights and kneeling/squatting, routinely performed by farmers and floor layers, have been frequently associated with increased risk of lower limb OA (Klussmann et al., 2010; Mounach et al., 2008; Seidler et al., 2008; Vrezas et al., 2010; Yoshimura et al., 2004; D'Souza et al., 2008; Jensen, 2005; Muraki et al., 2009; Muraki et al., 2011). Exposures to lifting and carrying that have been associated with increased risks vary and have included >1,088tons/life, >10 kgs for 8–20% of workday and >5,120 kg*hour. Exposures to kneeling/squatting (without an external load) that have been associated with increased risk of lower limb OA have ranged from >1 h/day to cumulatively >4757 h. Interestingly, only one of the included studies reported on military personnel (Showery et al., 2016), who, during training and duty are required to kneel, squat and march long distances (>10 km) carrying loads of up to 60% of their body weight (Knapik and Reynolds, 2012; Orr et al., 2015a), with the higher loads in this range exceeding loads reported in other occupations. Simpson et al. (2013) reported on US recruits undertaking their 44-day army basic combat training and noted that, in 7 non-consecutive days, they carried external loads ranging from 23 to 34 kgs for a cumulative average of 5.4 ± 3.8 h. Orr et al. (2015b) reported on the incidence and distribution of load carriage injuries amongst Australian Army soldiers, highlighting that 56% of the injuries affected the lower limb, and 62% of load carriage injuries occurred whilst marching. Marching with external load has been reported to increase ground reaction forces incrementally as load is increased (Birrell et al., 2007), decreasing stability and altering gait patterns (Birrell and Haslam, 2010), and thus exposing all joints in the kinetic chain to risk of injury.

Many tasks that have been consistently identified in literature (Verbeek et al., 2017; Seidler et al., 2018) and confirmed in this review as risk factors for OA, such as squatting/kneeling and standing, share the singularity of being closed kinetic chain movements. They are closed chain kinetic movements because the distal aspect (in this case the foot) is fixed or stationary on the ground while other joints can move. Thus, anomalies in one joint in the chain could influence other joints in the chain and a multi-joint symptomatology is a possibility. For example, Rytter et al. (2009) demonstrated that workers with radiographically confirmed hip alterations had increased likelihood of knee complaints. Recently, Paterson et al. (2017a) identified a significant association between foot and ankle symptoms (i.e. pain, ache, stiffness) and an increase in risk of developing knee OA or experiencing worsening of symptomatic knee OA (Paterson et al., 2017b). Contralateral foot/ankle symptoms have been associated with significantly increased risk of developing radiographically confirmed knee OA (OR 3.08 (95%CI 1.06 to 8.98)) (Paterson et al., 2017a). Interestingly a significant risk of worsening knee pain was also identified in patients with ipsilateral (OR 1.5 (95%CI 1.07 to 2.10), $p = 0.017$), contralateral (OR 1.44 (95%CI 1.02 to 2.06), $p = 0.038$) or bilateral (OR 1.61 (95%CI 1.22 to 2.13), $p < 0.001$) ankle pain (Paterson et al., 2017b). None of the studies included in this review alluded to pain in any other joint besides the knee and hip. However, data from military personnel have identified the incidence of ankle injuries (e.g. sprains) is 45.14 per 1000 person-years (Bulathsinhala et al., 2015). Given the biomechanical adaptations to load carriage and the related high incidence of injuries in the kinetic chain, it might then be postulated that military personnel are at a higher risk of developing or further aggravating conditions affecting the lower limb, and particularly knee and hip OA.

This review is not without its limitations. The methodological quality of the studies included in this review was rated on different scales, dependent on study design. Most of the studies included in this review were of a cross-sectional design, which may create a selection bias and disallows definitive identification of a causal relationship (Mann, 2003). Further, most studies reviewed have adopted questionnaires to obtain information on exposure to occupational tasks, which can be affected by recall bias. This methodological approach (i.e. self-reported questionnaires), has been found to provide, at times, an overestimation of workload of up to 45% (Klussmann et al., 2010). Such issues are also common in case-control studies (Teschke et al., 2002), which make up 36% ($n = 10$) of the studies reviewed. Additionally, the disparity in reporting of cumulative loads poses a challenge when attempting to suggest exposure thresholds. Studies have reported exposure utilising different measures (e.g. kg/week; tonnes; kg*hour; tonnes/lifetime), and often fail to provide the duration of exposure (i.e. years worked, lifetime in years). Without such information one is left to speculate if the risk of OA is linked to the weight of the load, frequency of the task, duration of the task, or the combination of all four.

Future studies assessing risk of OA development based on occupational task exposures should aim to disclose all information on the data captured and aim to standardise exposure assessment, thus allowing direct comparisons between exposures. Therefore, findings of this review must be interpreted with caution as they are based heavily on self-reported assessments and poorly defined cumulative loads.

5. Conclusion

Findings of this review indicate a consensus that highly physical occupational demands contribute to the development of knee and hip OA. This review provides evidence that exposure to knee-straining occupations and occupational tasks, particularly kneeling, lifting and lifting/carrying are indeed risk factors for the development of OA, in corroboration with the two latest dose-response exposure analysis by Seidler et al. (2018) and Verbeek et al. (2017). Further, combinations of arduous occupational tasks (i.e. kneeling/squatting and heavy lifting/-carrying), seem to impose a greater risk for the development of lower limb OA, when compared to single tasks. Therefore, ergonomist should encourage the use of existing tools, or oversee the design of new tools that may decrease exposure to such tasks.

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.apergo.2020.103097.

References

Ackerman, I.N., Bohensky, M.A., de Steiger, R., Brand, C.A., Eskelinen, A., Fenstad, A.M., et al., 2017. Lifetime risk of primary total hip replacement surgery for osteoarthritis from 2003 to 2013: a multinational analysis using national registry data. Arthritis Care Res. 69 (11), 1659–1667.
Allen, K.D., Chen, J., Callahan, L.F., Golightly, Y.M., Helmick, C.G., Renner, J.B., et al., 2010. Associations of occupational tasks with knee and hip osteoarthritis: the Johnston County Osteoarthritis Project. J. Rheumatol. 37 (4), 842–850.
Altman, D.G., 1991. Practical Statistics for Medical Research. Chapman and Hall, London.
Altman, R., Asch, E., Bloch, D., Bole, G., Borenstein, D., Brandt, K., et al., 1986. Development of criteria for the classification and reporting of osteoarthritis. Classification of osteoarthritis of the knee. Diagnostic and Therapeutic Criteria Committee of the American Rheumatism Association. Arthritis Rheum. 29 (8), 1039–1049.
Altman, R., Alarcon, G., Appelrouth, D., Bloch, D., Borenstein, D., Brandt, K., et al., 1991. The American College of Rheumatology criteria for the classification and reporting of osteoarthritis of the hip. Arthritis Rheum. 34 (5), 505–514.
Amin, S., Goggins, J., Niu, J., Guermazi, A., Grigoryan, M., Hunter, D.J., et al., 2008. Occupation-related squatting, kneeling, and heavy lifting and the knee joint: a magnetic resonance imaging-based study in men. J. Rheumatol. 35 (8), 1645–1649.
Andersen, S., Thygesen, L.C., Davidsen, M., Helweg-Larsen, K., 2012. Cumulative years in occupation and the risk of hip or knee osteoarthritis in men and women: a register-based follow-up study. Occup. Environ. Med. 69 (5), 325–330.
Australian Bureau of Statistics, 2014-15. National Health Survey: First Results.
Bergmann, A., Bolm-Audorff, U., Krone, D., Seidler, A., Liebers, F., Haerting, J., et al., 2017. Occupational strain as a risk for hip osteoarthritis. Dtsch Arzteblatt Int. 114 (35–36), 581–588.
Bernard, T.E., Wilder, F.V., Aluoch, M., Leaverton, P.E., 2010. Job-related osteoarthritis of the knee, foot, hand, and cervical spine. J. Occup. Environ. Med. 52 (1), 33–38.
Bijlsma, J.W., Berenbaum, F., Lafeber, F.P., 2011. Osteoarthritis: an update with relevance for clinical practice. Lancet 377 (9783), 2115–2126.
Birrell, S.A., Haslam, R.A., 2010. The effect of load distribution within military load carriage systems on the kinetics of human gait. Appl. Ergon. 41 (4), 585–590.
Birrell, S.A., Hooper, R.H., Haslam, R.A., 2007. The effect of military load carriage on ground reaction forces. Gait Posture 26 (4), 611–614.
Blagojevic, M., Jinks, C., Jeffery, A., Jordan, K.P., 2010. Risk factors for onset of osteoarthritis of the knee in older adults: a systematic review and meta-analysis. Osteoarthritis Cartilage 18 (1), 24–33.
Bulathsinhala, L., Hill, O.T., Scofield, D.E., Haley, T.F., Kardouni, J.R., 2015. Epidemiology of ankle sprains and the risk of separation from service in U.S. Army soldiers. J. Orthop. Sports Phys. Ther. 45 (6), 477–484.
Cameron, K.L., Hsiao, M.S., Owens, B.D., Burks, R., Svoboda, S.J., 2011. Incidence of physician-diagnosed osteoarthritis among active duty United States military service members. Arthritis Rheum. 63 (10), 2974–2982.
Coggon, D., Croft, P., Kellingray, S., Barrett, D., McLaren, M., Cooper, C., 2000. Occupational physical activities and osteoarthritis of the knee. Arthritis Rheum. 43 (7), 1443–1449.
Critical Appraisal Skills Programme, 2018a. CASP case-control checklist [Available from: https://casp-uk.net/wp-content/uploads/2018/01/CASP-Case-Control-Study-Checklist-2018.pdf.
Critical Appraisal Skills Programme, 2018b. CASP cohort study checklist [Available from: https://casp-uk.net/wp-content/uploads/2018/01/CASP-Cohort-Study-Checklist_2018.pdf.
D'Souza, J.C., Werner, R.A., Keyserling, W.M., Gillespie, B., Rabourn, R., Ulin, S., et al., 2008. Analysis of the third national health and nutrition examination survey (NHANES III) using expert ratings of job categories. Am. J. Ind. Med. 51 (1), 37–46.
David, J.H., Deborah, S., Emily, C., 2014. The individual and socioeconomic impact of osteoarthritis. Nat. Rev. Rheumatol. 10 (7).
Downes, M.J., Brennan, M.L., Williams, H.C., Dean, R.S., 2016. Development of a critical appraisal tool to assess the quality of cross-sectional studies (AXIS). BMJ Open 6 (12), e011458.
Duval, S., Tweedie, R., 2000. Trim and fill: a simple funnel-plot–based method of testing and adjusting for publication bias in meta-analysis. Biometrics 56 (2), 455–463.
Ezzat, A.M., Cibere, J., Koehoorn, M., Li, L.C., 2013. Association between cumulative joint loading from occupational activities and knee osteoarthritis. Arthritis Care Res. 65 (10), 1634–1642.
Franklin, J., Ingvarsson, T., Englund, M., Lohmander, S., 2010. Association between occupation and knee and hip replacement due to osteoarthritis: a case-control study. Arthritis Res. Ther. 12 (3), R102.
Gelber, A.C., Hochberg, M.C., Mead, L.A., Wang, N.Y., Wigley, F.M., Klag, M.J., 2000. Joint injury in young adults and risk for subsequent knee and hip osteoarthritis. Ann. Intern. Med. 133 (5), 321.
Glyn-Jones, S., Palmer, A.J.R., Agricola, R., Price, A.J., Vincent, T.L., Weinans, H., et al., 2015. Osteoarthritis. Lancet 386 (9991), 376–387.
Harding, G.T., Hubley-Kozey, C.L., Dunbar, M.J., Stanish, W.D., Astephen Wilson, J.L., 2012. Body mass index affects knee joint mechanics during gait differently with and without moderate knee osteoarthritis. Osteoarthritis Cartilage 20 (11), 1234–1242.
Version 5.1.0 [updated March 2011]. In: Higgins, J.P.T., Green, S. (Eds.), 2011. Cochrane Handbook for Systematic Reviews of Interventions. The Cochrane Collaboration [Available from: Available from: http://handbook.cochrane.org/. Acessed 28-11-2018.
Holmberg, S., Thelin, A., Thelin, N., 2004. Is there an increased risk of knee osteoarthritis among farmers? A population-based case-control study. Int. Arch. Occup. Environ. Health 77 (5), 345–350.
Hunter, D.J., Bierma-Zeinstra, S., 2019. Osteoarthritis. Lancet 393 (10182), 1745–1759.
Jarvholm, B., From, C., Lewold, S., Malchau, H., Vingard, E., 2008. Incidence of surgically treated osteoarthritis in the hip and knee in male construction workers. Occup. Environ. Med. 65 (4), 275–278.
Jensen, L.K., 2005. Knee-straining work activities, self-reported knee disorders and radiographically determined knee osteoarthritis. Scand. J. Work. Environ. Health 31 (Suppl. 2), 68–74.
Jensen, L.K., 2008a. Knee osteoarthritis: influence of work involving heavy lifting, kneeling, climbing stairs or ladders, or kneeling/squatting combined with heavy lifting. Occup. Environ. Med. 65 (2), 72–89.
Jensen, L.K., 2008b. Hip osteoarthritis: influence of work with heavy lifting, climbing stairs or ladders, or combining kneeling/squatting with heavy lifting. Occup. Environ. Med. 65 (1), 6–19.
Jensen, L.K., Rytter, S., Bonde, J.P., 2012a. Symptomatic knee disorders in floor layers and graphic designers. A cross-sectional study. BMC Muscoskel. Disord. 13, 188.
Jensen, L.K., Rytter, S., Marott, J.L., Bonde, J.P., 2012b. Relationship between years in the trade and the development of radiographic knee osteoarthritis and MRI-detected meniscal tears and bursitis in floor layers. A cross-sectional study of a historical cohort. BMJ Open 2 (3), e001109.
Kaila-Kangas, L., Arokoski, J., Impivaara, O., Viikari-Juntura, E., Leino-Arjas, P., Luukkonen, R., et al., 2011. Associations of hip osteoarthritis with history of recurrent exposure to manual handling of loads over 20 kg and work participation: a population-based study of men and women. Occup. Environ. Med. 68 (10), 734–738.
Kim, I., Kim, H.A., Seo, Y.I., Song, Y.W., Jeong, J.Y., Kim, D.H., 2010. The prevalence of knee osteoarthritis in elderly community residents in Korea. J. Kor. Med. Sci. 25 (2), 293–298.
Kim, C., Nevitt, M.C., Niu, J., Clancy, M.M., Lane, N.E., Link, T.M., et al., 2015. Association of hip pain with radiographic evidence of hip osteoarthritis: diagnostic test study. BMJ 351.
Klussmann, A., Gebhardt, H., Nubling, M., Liebers, F., Quiros Perea, E., Cordier, W., et al., 2010. Individual and occupational risk factors for knee osteoarthritis: results of a case-control study in Germany. Arthritis Res. Ther. 12 (3), R88.

Knapik, J., Reynolds, K., 2012. Chapter 11: Load Carriage in Military Operations: a Review of Historical, Physiological, Biomechanical and Medical Aspects. Military Quantitative Physiology: Problems and Concepts in Military Operational Medicine. Borden Institute, Maryland, USA, pp. 303–337.
Kotlarz, H., Gunnarsson, C.L., Fang, H., Rizzo, J.A., 2010. Osteoarthritis and absenteeism costs: evidence from US national survey data. J. Occup. Environ. Med. 52 (3), 263–268.
Lohmander, L.S., Ostenberg, A., Englund, M., Roos, H., 2004. High prevalence of knee osteoarthritis, pain, and functional limitations in female soccer players twelve years after anterior cruciate ligament injury. Arthritis Rheum. 50 (10), 3145–3152.
Mann, C.J., 2003. Observational research methods. Research design II: cohort, cross sectional, and case-control studies. Emerg. Med. J. 20 (1), 54.
Medical Surveillance Monthly Report (MSMR), 17 N, December 2010.
Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Ann. Intern. Med. 151 (4), 264–269 w64.
Mounach, A., Nouijai, A., Ghozlani, I., Ghazi, M., Achemlal, L., Bezza, A., et al., 2008. Risk factors for knee osteoarthritis in Morocco. A case control study. Clin. Rheumatol. 27 (3), 323–326.
Muraki, S., Akune, T., Oka, H., Mabuchi, A., En-Yo, Y., Yoshida, M., et al., 2009. Association of occupational activity with radiographic knee osteoarthritis and lumbar spondylosis in elderly patients of population-based cohorts: a large-scale population-based study. Arthritis Rheum. 61 (6), 779–786.
Muraki, S., Oka, H., Akune, T., En-Yo, Y., Yoshida, M., Nakamura, K., et al., 2011. Association of occupational activity with joint space narrowing and osteophytosis in the medial compartment of the knee: the ROAD study (OAC5914R2). Osteoarthritis Cartilage 19 (7), 840–846.
Neuman, P., Englund, M., Kostogiannis, I., Friden, T., Roos, H., Dahlberg, L.E., 2008. Prevalence of tibiofemoral osteoarthritis 15 years after nonoperative treatment of anterior cruciate ligament injury: a prospective cohort study. Am. J. Sports Med. 36 (9), 1717–1725.
Orr, R.M., Pope, R., Coyle, J., Johnston, V., 2015a. Occupational loads carried by Australian soldiers on military operations. J. Health Saf. Environ. 31 (1), 451–467.
Orr, R.M., Johnston, V., Coyle, J., Pope, R., 2015b. Reported load carriage injuries of the Australian Army soldier. J. Occup. Rehabil. 25 (2), 316–322.
Paterson, K.L., Kasza, J., Hunter, D.J., Hinman, R.S., Menz, H.B., Peat, G., et al., 2017a. The relationship between foot and ankle symptoms and risk of developing knee osteoarthritis: data from the osteoarthritis initiative. Osteoarthritis Cartilage 25 (5), 639–646.
Paterson, K.L., Kasza, J., Hunter, D.J., Hinman, R.S., Menz, H.B., Peat, G., et al., 2017b. Longitudinal association between foot and ankle symptoms and worsening of symptomatic radiographic knee osteoarthritis: data from the osteoarthritis initiative. Osteoarthritis Cartilage 25 (9), 1407–1413.
Ramage, L., Nuki, G., Salter, D.M., 2009. Signalling cascades in mechanotransduction: cell-matrix interactions and mechanical loading. Scand. J. Med. Sci. Sports 19 (4), 457–469.
Rossignol, M., Leclerc, A., Allaert, F.A., Rozenberg, S., Valat, J.P., Avouac, B., et al., 2005. Primary osteoarthritis of hip, knee, and hand in relation to occupational exposure. Occup. Environ. Med. 62 (11), 772–777.
Rubak, T.S., Svendsen, S.W., Soballe, K., Frost, P., 2014. Total hip replacement due to primary osteoarthritis in relation to cumulative occupational exposures and lifestyle factors: a nationwide nested case-control study. Arthritis Care Res. 66 (10), 1496–1505.
Rytter, S., Egund, N., Jensen, L.K., Bonde, J.P., 2009. Occupational kneeling and radiographic tibiofemoral and patellofemoral osteoarthritis. J. Occup. Med. Toxicol. 4, 19.
Saltzman, C.L., Salamon, M.L., Blanchard, G.M., Huff, T., Hayes, A., Buckwalter, J.A., et al., 2005. Epidemiology of ankle arthritis: report of a consecutive series of 639 patients from a tertiary orthopaedic center. Iowa Orthop. J. 25, 44–46.
Schram, B., Canetti, E.F.D., Orr, R.M., Pope, R.P., Knapik, J., 2019. Risk factors for development of lower limb osteoarthritis in physically-demanding occupations like the military: a narrative umbrella review. J. Occup. Health 1–13, 00.
Seidler, A., Bolm-Audorff, U., Abolmaali, N., Elsner, G., Gül, A., Ridder, S., et al., 2008. The role of cumulative physical work load in symptomatic knee osteoarthritis - a case-control study in Germany. J. Occup. Med. Toxicol. 3 (1).
Seidler, A., Lüben, L., Hegewald, J., Bolm-Audorff, U., Bergmann, A., Liebers, F., et al., 2018. Dose-response relationship between cumulative physical workload and osteoarthritis of the hip - a meta-analysis applying an external reference population for exposure assignment. BMC Muscoskel. Disord. 19 (1) (N.PAG-N.PAG).
Showery, J.E., Kusnezov, N.A., Dunn, J.C., Bader, J.O., Belmont, P.J., Waterman, B.R., 2016. The rising incidence of degenerative and posttraumatic osteoarthritis of the knee in the United States military. J. Arthroplasty 31 (10), 2108–2114.
Silverwood, V., Blagojevic-Bucknall, M., Jinks, C., Jordan, J.L., Protheroe, J., Jordan, K. P., 2015. Current evidence on risk factors for knee osteoarthritis in older adults: a systematic review and meta-analysis. Osteoarthritis Cartilage 23 (4), 507–515.
Simpson, K., Redmond, J.E., Cohen, B.S., Hendrickson, N.R., Spiering, B.A., Steelman, R., et al., 2013. Quantification of physical activity performed during US army basic combat training. US Army Med. Dep. J. 55–65.
Spector, T.D., Harris, P.A., Hart, D.J., Cicuttini, F.M., Nandra, D., Etherington, J., et al., 1996. Risk of osteoarthritis associated with long-term weight-bearing sports: a radiologic survey of the hips and knees in female ex-athletes and population controls. Arthritis Rheum. 39 (6), 988–995.
Sterne, J.A., Egger, M., 2001. Funnel plots for detecting bias in meta-analysis: guidelines on choice of axis. J. Clin. Epidemiol. 54 (10), 1046–1055.
Sturmer, T., Sun, Y., Sauerland, S., Zeissig, I., Gunther, K.P., Puhl, W., et al., 1998. Serum cholesterol and osteoarthritis. The baseline examination of the Ulm Osteoarthritis Study. J. Rheumatol. 25 (9), 1827–1832.
Teschke, K., Olshan, A.F., Daniels, J.L., De Roos, A.J., Parks, C.G., Schulz, M., et al., 2002. Occupational exposure assessment in case–control studies: opportunities for improvement. Occup. Environ. Med. 59 (9), 575.
Thelin, A., Vingard, E., Holmberg, S., 2004. Osteoarthritis of the hip joint and farm work. Am. J. Ind. Med. 45 (2), 202–209.
Verbeek, J., Mischke, C., Robinson, R., Ijaz, S., Kuijer, P., Kievit, A., et al., 2017. Occupational exposure to knee loading and the risk of osteoarthritis of the knee: a systematic review and a dose-response meta-analysis. Saf. Health Work 8 (2), 130–142.
Viera, A.J., Garrett, J.M., 2005. Understanding interobserver agreement: the kappa statistic. Fam. Med. 37 (5), 360–363.
Vrezas, I., Elsner, G., Bolm-Audorff, U., Abolmaali, N., Seidler, A., 2010. Case-control study of knee osteoarthritis and lifestyle factors considering their interaction with physical workload. Int. Arch. Occup. Environ. Health 83 (3), 291–300.
Widmyer, M.R., Utturkar, G.M., Leddy, H.A., Coleman, J.L., Spritzer, C.E., Moorman 3rd, C.T., et al., 2013. High body mass index is associated with increased diurnal strains in the articular cartilage of the knee. Arthritis Rheum. 65 (10), 2615–2622.
Williams, V.F., Clark, L.L., Oh, G.T., 2016. Update: osteoarthritis and spondylosis, active component, U.S. Armed Forces, 23 (9), 14–22, 2010-2015. MSMR.
Yoshimura, N., Nishioka, S., Kinoshita, H., Hori, N., Nishioka, T., Ryujin, M., et al., 2004. Risk factors for knee osteoarthritis in Japanese women: heavy weight, previous joint injuries, and occupational activities. J. Rheumatol. 31 (1), 157–162.
Yoshimura, N., Kinoshita, H., Hori, N., Nishioka, T., Ryujin, M., Mantani, Y., et al., 2006. Risk factors for knee osteoarthritis in Japanese men: a case-control study. Mod. Rheumatol. 16 (1), 24–29.
Zeggini, E., Panoutsopoulou, K., Southam, L., Rayner, N.W., Day-Williams, A.G., Lopes, M.C., et al., 2012. Identification of new susceptibility loci for osteoarthritis (arcOGEN): a genome-wide association study. Lancet 380 (9844), 815–823.
Zhang, Y., Hunter, D.J., Nevitt, M.C., Xu, L., Niu, J., Lui, L.Y., et al., 2004. Association of squatting with increased prevalence of radiographic tibiofemoral knee osteoarthritis: the Beijing Osteoarthritis Study. Arthritis Rheum. 50 (4), 1187–1192.
Zhang, W.E.I., Gignac, M.A.M., Beaton, D., Tang, K., Anis, A.H., 2010a. Productivity loss due to presenteeism among patients with arthritis: estimates from 4 instruments. J. Rheumatol. 37 (9), 1805.
Zhang, W., Doherty, M., Peat, G., Bierma-Zeinstra, M.A., Arden, N.K., Bresnihan, B., et al., 2010b. EULAR evidence-based recommendations for the diagnosis of knee osteoarthritis. Ann. Rheum. Dis. 69 (3), 483–489.