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Men and Women's Occupational Activities and the Risk of Developing Osteoarthritis of the Knee, Hip, or Hands: A Systematic Review and Recommendations for Future Research

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Objective. To systematically review the evidence for an increased risk of osteoarthritis in the hip, knee, hand, wrist, finger, ankle, foot, shoulder, neck, and spine related to diverse occupational activities of men and women and to examine dose-response information related to the frequency, intensity, and duration of work exposures and the risk of osteoarthritis (OA).

Methods. Established guidelines for systematic reviews in occupational health and safety studies were followed. MEDLINE, Embase, CINAHL, and Cochrane Library were searched from inception to December 2017. Studies were reviewed for relevance, quality was appraised, and data were extracted and synthesized.

Results. Sixty-nine studies from 23 countries yielded strong and moderate evidence for lifting, cumulative physical loads, full-body vibration, and kneeling/squatting/bending as increasing the risks of developing OA in men and women. Strong and moderate evidence existed for no increased risk of OA related to sitting, standing, and walking (hip and knee OA), lifting and carrying (knee OA), climbing ladders (knee OA), driving (knee OA), and highly repetitive tasks (hand OA). Variability in dose-response data resulted in an inability to synthesize these data.

Conclusion. Evidence points to the potential for OA occupational recommendations and practice considerations to be developed for women and men. However, research attention is needed to overcome deficits in the measurement and recall of specific work activities so that recommendations and practice considerations can provide the specificity needed to be adopted in workplaces.

INTRODUCTION

Osteoarthritis (OA) ranks among the top 10 causes of disability world-wide and is associated with significant pain, stiffness, fatigue, and activity limitations (1–5). Although medical treatment often occurs in later stages of the disease, early intervention is increasingly recognized as a critical unmet need. One domain of importance for education and intervention is the workplace. To date, numerous studies have examined the relationship of physically demanding occupations like farming, mining, and floor laying, as well as work activities like kneeling, squatting, and heavy lifting to the onset of OA (6–16).

Also creating impetus for greater attention to the workplace is the aging of workforces and policy changes in many countries that push for longer employment trajectories (17–19). A longer work life increases the duration of exposure to work activities that may create risks for OA development. Older workers also may be at greater risk for workplace musculoskeletal injuries than younger workers (20), which can increase the likelihood of developing OA (21). As a result, workplace regulators and insurers are increasingly

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SIGNIFICANCE & INNOVATIONS

- A synthesis of 69 studies from 23 countries yielded strong and moderate evidence for lifting, cumulative physical loads, full-body vibration, and kneeling/squatting/bending as increasing the risks of developing osteoarthritis (OA) in men and women.
- Strong and moderate evidence existed for no increased risk of OA related to sitting, standing and walking (hip and knee OA), lifting and carrying (knee OA), climbing ladders (knee OA), driving (knee OA), and highly repetitive tasks (hand OA).
- Greater attention is needed to improve measures assessing employment activities and recall periods.
- A lack of consistency in dose-response information makes synthesizing data problematic and hinders practical recommendations.

seeking guidance, not only about specific types of work activities that may be problematic, but also about dose-response thresholds that can illuminate the frequency, intensity, and duration of job activities and their association with the development of OA. To date, few jurisdictions provide work disability compensation for job activities that may have resulted in OA disability (22). A focus on specific activity types (e.g., squatting), as opposed to broad occupational categories (e.g., farming) and dose-response information is needed by regulators to make informed decisions.

By going beyond occupational categories and identifying job activities and dose-response thresholds that may increase the risk for OA, we can inform occupational health and safety practices focused on earlier recognition of problematic work activities and the development of new strategies and interventions to prevent occupationally related OA. We can also identify subgroups of workers who may be particularly vulnerable to occupationally related OA. For example, some studies report sex (i.e., biologic) differences related to the development of OA in some joints (e.g., knees, hands), while others report gender effects (i.e., differences in social roles) related to the occupations of women and men that may signal differences in the likelihood of developing OA (23–26). However, assessing sex/gender differences in OA development has been hampered by less available data from women (27).

Several excellent reviews of the literature have examined occupational factors and OA (6–12,14–16,27). Most have focused on knees or hips, with less attention to other joints, differences between men and women, and dose-response data. The synthesized evidence has often been limited or moderate. To update and better target the available information, this systematic review focused on specific occupational activities and their relationship to OA of the hip, knee, hand, wrist, finger, ankle, foot, shoulder, neck, and spine. We synthesized study findings for men and women separately where possible and examined dose-response information to identify potential thresholds related to the frequency, intensity, and duration of work exposures and the associated risk of developing OA.

MATERIALS AND METHODS

Search strategy and relevance. We followed established guidelines for systematic reviews in occupational health and safety studies (28,29). Search terms were developed iteratively in consultation with a librarian, content area experts, and stakeholders. We searched MEDLINE, Embase, CINAHL, and Cochrane Library from inception to December 31, 2017. All English, peer-reviewed literature was included. The complete list of terms is shown in Supplementary Table 1, available on the *Arthritis Care & Research* web site at http://onlinelibrary.wiley.com/doi/10.1002/acr.23855/abstract. References were managed using DistillerSR software (30), which enables screening, quality appraisal, and data extraction of study material.

Articles were included if the research was about OA and if OA was distinguishable from other conditions and diagnosed by a clinician (including self-report of a clinician diagnosis), if the research focused on paid employment activities and their potential impact on the development of OA, and if it was an original quantitative research study. In keeping with previous reviews on this topic, we included longitudinal, observational, cohort, cross-sectional case–control, and intervention studies. Where possible, we extracted data separately for men and women.

All authors participated in the review. Titles and abstracts were screened by a single reviewer after all reviewers came to a consensus on a set of titles and abstracts. Subsequently, the remaining full-text articles were screened using inclusion/exclusion criteria, with 2 authors independently reviewing each article and coming to a consensus. If a consensus could not be reached, a third author was consulted.

Quality appraisal. Relevant articles were appraised for their reported methodologic quality using 17 criteria, assessing the study design and objectives, sample/recruitment, study characteristics, outcomes, and analyses (see Supplementary Table 2, available on the *Arthritis Care & Research* web site at http://onlinelibrary.wiley.com/doi/10.1002/acr.23855/abstract). Scores were calculated based on previous research that developed weighted criteria for each question (1 = somewhat important, 2 = important, and 3 = very important) (31). Studies scoring ≥85% in quality were ranked as high quality. Studies scoring between 50% and 84% were classified as medium quality and scores of <50% were deemed lower quality (31). Only medium- and high-quality studies were synthesized.

Data extraction and evidence synthesis. Standardized forms were used for data extraction. We documented sample sizes, the direction and significance of the relationship between work exposures and an OA diagnosis, and information about potential covariates. Data were sorted by the anatomical joint affected by OA. Evidence synthesis considered the quality, quantity, and consistency of findings (Table 1). A strong level of evidence

Table 1. Evidence synthesis algorithm*

Level of evidence	Minimum quality†	Minimum quantity	Consistency	Strength of message
Strong	H	3	3H agree; if ≥3 studies, ≥3/4 of the M + H agree	Recommendations
Moderate	M	2H or 2M + 1H	2H agree or 2M + 1H agree; if ≥3, ≥2/3 of the M + H agree	Practice considerations
Limited	M	1H or 2M or 1M + 1H	2 (M and/or H) agree; if ≥2, >1/2 of the M + H agree	Not enough evidence to make recommendations or practice considerations
Mixed	M	2	Findings are contradictory	Not enough evidence to make recommendations or practice considerations
Insufficient‡	–	–	–	Not enough evidence to make recommendations or practice considerations

* H = high; M = medium.
† High = score >85% in quality assessment; medium = score ranges from 50% to 84% in quality assessment.
‡ Medium quality studies that do not meet the above criteria.

reflects the potential for making recommendations and consists of a minimum of 3 high-quality studies that agree in their findings. A moderate level of evidence (a minimum of 2 high-quality studies or 2 medium-quality studies plus 1 high-quality study) points to possible practice considerations. For evidence scored lower than moderate, we lack evidence to guide policies or practices. This consideration does not mean that work exposures were not significantly associated with OA, only that evidence was insufficient to draw conclusions.

Due to the heterogeneity of outcome measures, study designs, and reported data, we did not calculate pooled effect estimates. If a study stratified the analyses by men and women separately and combined them, we only synthesized the stratified analyses. If a study did not stratify analyses by sex, the combined data were synthesized. There are no standardized criteria in the OA and work literature to evaluate dose-response levels. Hence, we extracted all dosage levels and reviewed the data for minimum thresholds where findings were associated with increased risks of OA versus no effect.

RESULTS

A total of 4,134 references were identified after removing duplicates (Figure 1). Relevance screening excluded 3,701 articles after title and abstract review and a further 321 articles upon full article review. Excluded studies often focused on OA's impact on work (e.g., absenteeism, productivity loss), the work of health care professionals managing OA, and the development of OA in working animals (e.g., dogs, horses). Quality appraisal was conducted on the resultant 112 articles, and data were synthesized from 69 unique studies appraised as medium quality (n = 30) or high quality (n = 39) in their reported methods.

Study characteristics are shown in Table 2. Research originated in 23 countries, with two-thirds of studies (65.2%) comprising samples of >500 respondents. Studies examined OA in knees (n = 41), hips (n = 28), wrists/hands/fingers (n = 14), spine (n = 6), shoulder (n = 5), ankles/feet/toes (n = 4), necks (n = 3), and elbows (n = 3). Study designs included retrospective cohorts (n = 10), prospective cohorts (n = 14), case–control studies (n = 22), and cross-sectional studies (n = 23). Samples were drawn from census, tax, or disability records (n = 38), surgical wait lists/hospital charts (n = 15), community advertising (n = 4), and occupational groups (e.g., dock workers) (n = 12).

Measurement of OA. Assessment of OA was rated as valid and reliable in 97% of the studies, with many studies using multiple methods to determine OA (e.g., radiographic evidence and clinical examination). OA was measured using radiographic

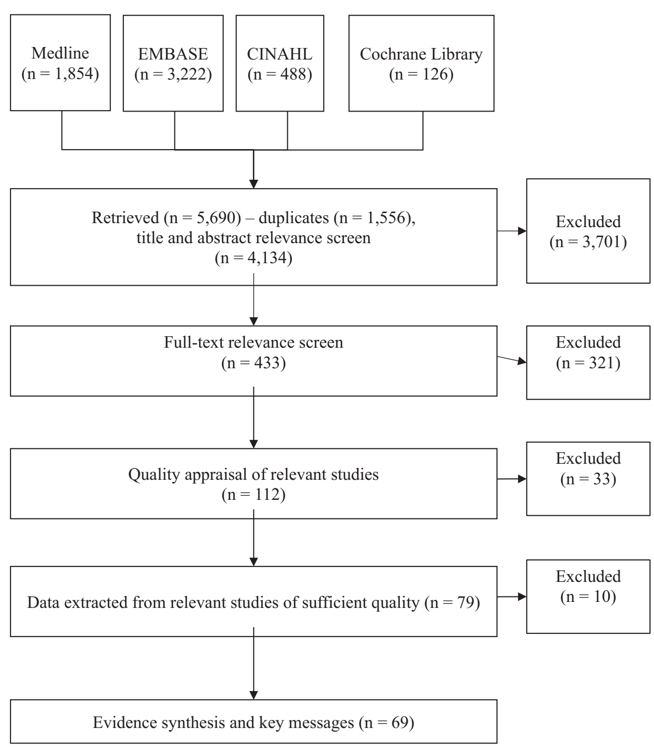

Figure 1. Summary of literature search.

Table 2. Summary of study characteristics*

First author, year (ref.)	Country	Study design (quality)	Sample type	Joints with OA	OA diagnosis	Industry	Work activities	Work history	Sample (no., % male, mean ± SD age [when given] years)
Allen, 2010 (32)	US	Cross-sectional (M)	Comm.	Hip, knee	Radiograph, other	Multiple	Walking, lifting, carrying, moving objects, sitting, standing, bending, twisting, reaching, kneeling, squatting, climbing, crawling, crouching, heavy work while standing	Work lifetime	Total: n = 2,729, 34.2%, 63.3
Amin, 2008 (33)	US	Retrospective cohort (M)	Clin.	Knee	ACR diagnostic criteria	Multiple	Squatting, kneeling, heavy lifting	Work lifetime	Occ. 1 (heavy lifting): n = 40, 100%, 69 ± 9; occ. 2 (squatting/kneeling, heavy lifting): n = 47, 100%, 64 ± 9; occ. 3 (neither 1 or 2): n = 98, 100%, 70 ± 9
Andersen, 2012 (23)	Denmark	Retrospective cohort (M)	Pop.	Hip, knee	ICD codes	Multiple	Occ. type	Work lifetime	Total: n = 2,117,298, 48.0%, 38
Anderson, 1988 (34)	US	Cross-sectional (M)	Pop.	Knee	Radiograph	Multiple	Bending	Not described	Total: n = 315, 30%, age not reported
Apold, 2014 (35)	Norway	Prospective cohort (H)	Pop.	Knee	Other	Multiple	Sedentary, moderate, intermediate, or heavy work	>10 years	Total: n = 315,495, 48.7%, 58.8 ± 7.1
Armenis, 2011 (36)	Greece	Case–control (M)	Occ.	Ankle/foot/toes	Radiograph, clinical exam	Sport	Soccer activities	>5–10 years	OA group: n = 170, sex not reported, 49.8 ± 7.4; non-OA group: n = 132, sex not provided, 50.7 ± 9.9
Badve, 2010 (37)	India	Cross-sectional (M)	Occ.	Neck	Clinical exam, other	Sales/service/hospitality	Carrying loads on the head	>2–5 years	OA group: n = 107, 100%, 32.6; non-OA group: n = 107, 100%, 34.6
Bernard, 2010 (26)	US	Cross-sectional (H)	Comm.	Knee, wrists, hands, fingers, ankle, foot/toes, neck	Radiograph	Unknown	Stair climbing, standing, walking, squatting, kneeling, jolting, lifting, carrying, jumping	Work lifetime	Total: n = 3,548, 30.9%, 63.4 ± 10.9
Bovenzi, 1980 (38)	Italy	Cross-sectional (H)	Occ.	Multiple	Radiograph, clinical exam	Construction	Vibration activities	Work lifetime	Occ. 1 (exposed to vibration): n = 169, 100%, 40.7; occ. 2 (not exposed to vibration): n = 60, 100%, 34.8

(Continued)

Table 2. (*Cont'd*)

First author, year (ref.)	Country	Study design (quality)	Sample type	Joints with OA	OA diagnosis	Industry	Work activities	Work history	Sample (no., % male, mean ± SD age [when given] years)
Bovenzi, 1987 (39)	Italy	Retrospective cohort (M)	Occ.	Multiple	Radiograph, clinical exam	Manufacturing	Occupational groups	Not described	OA group: n = 67, sex not reported, 39.6 ± 7.3; non-OA group: n = 46, sex not reported, 39.6 ± 7.2
Cleveland, 2013 (40)	US	Cross-sectional (M)	Comm.	Hip	Radiograph, clinical exam	Multiple	Kneeling, squatting, lifting, walking, sitting, standing, driving, climbing	Not described	Total: n = 3,087, 43.2%, 62.7 ± 9.9
Coggon, 2000 (41)	UK	Case–control (H)	Clin.	Knee	Radiograph	Multiple	Kneeling, squatting, lifting, walking, sitting, standing, driving, climbing	Work lifetime	OA group: n = 518, 40%, age not reported; non-OA group: n = 518, 40%, age not reported
Cooper, 1994 (42)	UK	Case–control (H)	Pop.	Knee	Radiograph, self-reported diagnosis	Multiple	Squatting, kneeling, climbing, lifting, walking, standing, sitting, driving	Work lifetime	OA group: n = 102, 29%, 72.7; non-OA group: n = 218, sex and age not reported
Cvijetic, 1999 (43)	Croatia	Cross-sectional (M)	Comm.	Hip	Radiograph	Multiple	Physical strain related to sitting, standing, walking, lifting	>10 years	Total: n = 590, 49.5%, 62.4 ± 10.3
Dahaghin, 2009 (44)	Iran	Case–control (H)	Pop.	Knee	ACR diagnostic criteria	Multiple	Standing, walking on flat ground, walking up/downhill, sitting on floor, sitting on chair, squatting, knee bending, cycling, climbing stairs, carrying loads	Work lifetime	OA group: n = 480, 30.2%, 57 ± 12; non-OA group: n = 490, 35.9%, 46.8 ± 15
D'Souza, 2008 (45)	US	Cross-sectional (M)	Pop.	Knee	Radiograph	Multiple	Sitting, standing, walking, running, carrying, lifting, kneeling, squatting, stooping, crawling, working in cramped spaces	>5–10 years	OA group: n = 314, 39.1%, 72.4; non-OA group: n = 966, 51.1%, 69.6
Ezzat, 2013 (13)	Canada	Cross-sectional (H)	Pop.	Knee	Radiograph, other	Multiple	Physical loads, knee bending, kneeling	Work lifetime	OA group: n = 109, 43.1%, 63.6 ± 9.6; non-OA group: n = 218, 53.8%, 55.9 ± 10.7
Felson, 1991 (46)	US	Prospective cohort (H)	Pop.	Knee	Radiograph	Multiple	Knee bending, physical demands	Not described	Total: n = 1,376, 41%, 73

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Table 2. *(Cont'd)*

First author, year (ref.)	Country	Study design (quality)	Sample type	Joints with OA	OA diagnosis	Industry	Work activities	Work history	Sample (no., % male, mean ± SD age [when given] years)
Franklin, 2010 (47)	Iceland	Case–control (H)	Clin.	Hip, knee	Other	Multiple	Occupational groups	Work lifetime	OA group: n = 1,408, 40.9%, 74.25; non-OA group: n = 1,082, 45.3%, 70.5
Goekoop, 2011 (48)	Netherlands	Prospective cohort (M)	Pop.	Multiple	Radiograph	Unknown	Standing, walking, lifting, operating heavy machinery, bending, kneeling	Not described	OA group: n = 82, 32.9%, 90.4; non-OA group: n = 175, 23.4%, 90.6
Haara, 2003 (49)	Finland	Retrospective cohort (H)	Pop.	Wrists/hands/fingers	Radiograph	Multiple	Lifting, carrying, awkward work postures (stooping, twisted), vibration equipment, repetitive movement, paced work	Work lifetime	Total: n = 3,595, 43%, age not reported
Haara, 2004 (50)	Finland	Prospective cohort (M)	Pop.	Wrists/hands/fingers	Radiograph, clinical exam	Multiple	Lifting, carrying, vibration equipment, awkward work postures	Not described	Total: n = 7,217, sex and age not reported
Holte, 2000 (51)	Norway	Prospective cohort (H)	Pop.	Multiple	ICD codes	Unknown	Manual labor	>10 years	Total: n = 276,385, 39%, age not reported
Jacobsen, 2004 (52)	Denmark	Cross-sectional (H)	Pop.	Hip	Radiograph	Multiple	Sitting, standing, walking, daily lifting levels	Work lifetime	Total: n = 3,686, 38%, 61.5
Jacobsen, 2005 (53)	Denmark	Cross-sectional (M)	Pop.	Hip	Radiograph	Multiple	Lifting	Work lifetime	Total: n = 3,568, 62.5%, 61
Jacobsson, 1987 (54)	Sweden	Cross-sectional (M)	Clin.	Hip	Clinical exam, other	Multiple	Heavy labor, lifting, walking, standing, tractor driving, occupational groups	Work lifetime	OA group: n = 236, 100%, 78.8; non-OA group: n = 106, 100%, 77.8
Jarvholm, 2004 (55)	Sweden	Prospective cohort (M)	Pop.	Hip	ICD codes	Construction	Whole body vibration from heavy vehicles	>10 years	OA group: n = 5,643, 100%, age not reported; non-OA group: n = 64,225, 100%, age not reported
Jarvholm, 2008 (56)	Sweden	Prospective cohort (M)	Occ.	Multiple	ICD codes, other	Construction	Diverse construction occupations	Work lifetime	OA group: n = 204,731, 100%, age not reported; non-OA group: n = 9,136, sex and age not reported

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Table 2. (*Cont'd*)

First author, year (ref.)	Country	Study design (quality)	Sample type	Joints with OA	OA diagnosis	Industry	Work activities	Work history	Sample (no., % male, mean ± SD age [when given] years)
Jensen, 2005 (57)	Denmark	Cross-sectional (H)	Occ.	Knee	Radiograph	Construction	Kneeling, squatting	>10 years	Occ. 1 (floor layers): n = 798, 100%, age not reported; occ. 2 (carpenters): n = 798, 100%, age not reported; occ. 3 (compositors): n = 500, 100%, age not reported
Jensen, 2012 (58)	Denmark	Cross-sectional (M)	Pop.	Knee	Radiograph, MRI	Multiple	Kneeling	Not described	Occ. 1 (floor layers): n = 92, 100%, 54.5 ± 7.2; occ. 2 (graphic designers): n = 49, 100%, 57.7 ± 5.6
Jones, 2002 (59)	Australia	Cross-sectional (H)	Admin.	Wrists/hands/ fingers	Radiograph, other	Multiple	High impact hand activities	>10 years	Total: n = 522, 33%, 53–57
Kaerlev, 2008 (60)	Denmark	Prospective cohort (M)	Pop.	Hip, knee	ICD codes	Fishing and seafaring	Fishing and seafaring activities	Work lifetime	Occ. 1 (fishermen): n = 4,410, 100%, 37.2 ± 9.8; occ. 2 (seamen non-officers): n = 4,845, 100%, 35.0 ± 11.1; occ. 3 (seamen officers): n = 4,774, 100%, 40.2 ± 10.0
Kaila-Kangas, 2011 (24)	Finland	Cross-sectional (H)	Pop.	Hip	Radiograph, clinical exam	Multiple	Lifting, carrying, pushing heavy loads	Work lifetime	OA group: n = 129, sex and age not reported; non-OA group: n = 6,427, sex and age not reported
Karkkainen, 2013 (61)	Finland	Prospective cohort (H)	Pop.	Multiple	ICD codes, other	Multiple	Sitting, standing, walking, lifting, carrying, heavy labor	>10 years	Total: n = 176, 50.8%, 41.8 ± 8.9
Klussman, 2010 (62)	Germany	Case–control (H)	Pop.	Knee	Radiograph, other	Multiple	Kneeling, squatting, sitting, standing, walking, climbing stairs, jumping, lifting, carrying	Work lifetime	OA group: n = 739, 41%, 58.5 ± 10.5; non-OA group: n = 571, 47%, 52.8 ± 12.3

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Table 2. (*Cont'd*)

First author, year (ref.)	Country	Study design (quality)	Sample type	Joints with OA	OA diagnosis	Industry	Work activities	Work history	Sample (no., % male, mean ± SD age [when given] years)
Kujala, 1995 (63)	Finland	Retrospective cohort (H)	Pop.	Knee	Radiograph, clinical exam	Sport	Previous kneeling, squatting, heavy work	Work lifetime	Occ. 1 (Olympic long distance runners): n = 28, 100%, 59.7 ± 4.7; occ. 2 (Olympic soccer players): n = 31, 100%, 56.5 ± 5.1; occ. 3 (Olympic weight lifters): n = 29, 100%, 59.3 ± 5.3
Lindberg, 1984 (64)	Sweden	Retrospective cohort (M)	Pop.	Hip	Radiograph	Multiple	Heavy labor	Work lifetime	OA group: n = 332, 100%, 66 ± 5; non-OA group: n = 790, 100%, 64.4 ± 4
Manninen, 2002 (65)	Finland	Case–control (H)	Pop.	Knee	Other	Multiple	Walking, lifting, driving, standing, climbing, kneeling, squatting	Work lifetime	OA group: n = 281, 20%, 68.4 ± 5.5; non-OA group: n = 524, 27%, 67.1 ± 5.6
Martin, 2013 (66)	UK	Prospective cohort (H)	Pop.	Knee	ACR diagnostic criteria	Multiple	Kneeling, squatting, lifting, walking, climbing ladders or stairs, sitting	>10 years	Total: n = 302, 36.1%, 53
Mounach, 2008 (67)	Morocco	Case–control (M)	Clin.	Knee	Radiograph	Multiple	Standing, sitting, climbing stairs, kneeling, squatting, walking, heavy lifting	≥12 months to 2 years	OA group: n = 95, 27.4%, 59.7 ± 8.5; non-OA group: n = 95, 27.4%, 60.0 ± 8.5
Muraki, 2009 (68)	Japan	Prospective cohort (H)	Pop.	Knee, spine	Radiograph	Multiple	Sitting on a chair, kneeling, squatting, standing, walking, climbing, heavy lifting	Work lifetime	Total: n = 1,471, 36%, 68.4 ± 9.2
Muraki, 2011 (25)	Japan	Prospective cohort (H)	Pop.	Knee	Radiograph	Multiple	Sitting on a chair, kneeling, squatting, standing, walking, climbing, heavy lifting	Work lifetime	Total: n = 1,402, 36.5%, 68.2 ± 9.2
Nakamura, 1993 (69)	Japan	Cross-sectional (M)	Occ.	Wrists/hands/fingers	Radiograph	Multiple	Cooking activities (e.g., food washing, chopping)	>10 years	Occ. 1 (elementary school cook): n = 260, sex not reported, 49.3; occ. 2 (preschool cook): n = 222, sex not reported, 47.2; occ. 3 (municipal employee): n = 298, sex not reported, 48.7

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Table 2. *(Cont'd)*

First author, year (ref.)	Country	Study design (quality)	Sample type	Joints with OA	OA diagnosis	Industry	Work activities	Work history	Sample (no., % male, mean ± SD age [when given] years)
Olsen, 1994 (70)	Sweden	Case–control (H)	Pop.	Hip	Other	Multiple	Physical workload	Work lifetime	OA group: n = 233, 100%, age not reported; non-OA group: n = 322, 100%, age not reported
Ozturk, 2008 (71)	Turkey	Case–control (M)	Occ.	Spine	Radiograph	Multiple	Soccer activities	>10 years	Occ. (soccer players): n = 70, 100%, 45.6 ± 8.4; control group: n = 59, 100%, 46.0 ± 9.4
Ratzlaff, 2011 (72)	Canada	Prospective cohort (M)	Pop.	Hip	ACR diagnostic criteria, clinical exam, self-reported diagnosis	Multiple	Cumulative peak force index (lifetime physical load)	Work lifetime	Total: n = 2,918, sex and age not reported
Ratzlaff, 2012 (73)	Canada	Cross-sectional (M)	Pop.	Knee	ACR diagnostic criteria, clinical exam, self-reported diagnosis	Multiple	Cumulative peak force index (lifetime physical load)	Work lifetime	Total: n = 4,269, 37%, 60.0 ± 11.1
Roach, 1994 (74)	US	Case–control (H)	Clin.	Hip	Radiograph	Multiple	Light work standing, sitting, heavy work standing, kneeling, crouching, walking	Work lifetime	OA group: n = 99, 100%, 69.3; non-OA group: n = 233, 100%, 63.4
Rossignol, 2003 (75)	France	Cross-sectional (M)	Clin.	Multiple	Clinical exam	Multiple	Occupational groups	Not described	Total: n = 10,412, 33.8%, 66.2 ± 10.2
Rossignol, 2005 (76)	France	Cross-sectional (M)	Clin.	Multiple	Clinical exam	Multiple	Occupational groups	Work lifetime	Total: n = 2,834, 58%, 61.8 ± 9.3
Rubak, 2013 (77)	Denmark	Retrospective cohort (H)	Pop.	Hip	ICD codes	Multiple	Cumulative physical workload (lifting, vibration, standing, walking)	Work lifetime	Total: n = 1,910,493, 52.9%, 49.1 ± 10.5
Rubak, 2014 (78)	Denmark	Case–control (H)	Pop.	Hip	Other	Multiple	Lifting, standing, walking, sitting, kneeling, squatting, whole body vibration	Work lifetime	Total: n = 3,552, 51.5%, 64.9

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Table 2. *(Cont'd)*

First author, year (ref.)	Country	Study design (quality)	Sample type	Joints with OA	OA diagnosis	Industry	Work activities	Work history	Sample (no., % male, mean ± SD age [when given] years)
Sahlstrom, 1997 (79)	Sweden	Case–control (M)	Clin.	Knee	Radiograph	Multiple	Light work (sitting, walking, carrying), medium (lifting and carrying, climbing stairs or ladders), heavy (light and medium plus jumping with and without carrying)	Work lifetime	OA group: n = 266, sex and age not reported; non-OA group: n = 463, sex and age not reported
Sairanen, 1981 (80)	Finland	Case–control (H)	Occ.	Multiple	Radiograph, clinical exam	Forestry	Tree felling activities	Work lifetime	OA group: n = 226, 100%, 42; non-OA group: n = 98, 100%, 42
Sandmark, 2000 (81)	Sweden	Case–control (H)	Pop.	Knee	Other	Multiple	Lifting, jumping, vibration, squatting, knee bending, kneeling, standing, sitting, climbing	Work lifetime	OA group: n = 625, 52%, age not provided; non-OA group: n = 548, 48.2%, age unknown
Seidler, 2001 (82)	Germany	Case–control (H)	Clin.	Spine	Radiograph	Multiple	Low, medium, high lifting and carrying, forward bending, whole body vibration	Work lifetime	OA group: n = 94, 100%, 48.4 ± 10.1; non-OA group (1): n = 107, 100%, 43.1 ± 10.3; non-OA group (2): n = 90, 100%, 39.7 ± 10.6
Seidler, 2012 (83)	Germany	Case–control (H)	Clin.	Knee	Radiograph	Multiple	Kneeling, squatting, lifting, carrying	Work lifetime	OA group: n = 295, 100%, age not reported; non-OA group: n = 327, 100%, age not reported
Seok, 2017 (84)	Korea	Cross-sectional (H)	Pop.	Knees/hips	Radiograph	Multiple	Occupational groups	Work lifetime	Total: n = 9,905, 45%, all participants age ≥50 years

(Continued)

Table 2. *(Cont'd)*

First author, year (ref.)	Country	Study design (quality)	Sample type	Joints with OA	OA diagnosis	Industry	Work activities	Work history	Sample (no., % male, mean ± SD age [when given] years)
Solovieva, 2006 (85)	Finland	Cross-sectional (M)	Occ.	Wrists/hands/fingers	Radiograph	Health	Dentistry-related manual hand tasks	Work lifetime	Occ. 1 (dentists with variable tasks): n = 96, sex not reported, 52 ± 5.0; occ. 2 (dentists who perform restorative treatment 50% of time; perform prosthodontics 50% of time): n = 64, sex not reported, 54 ± 6.0; occ. 3 (dentists who perform restorative treatments): n = 64, sex not reported, 54 ± 6.0
Stenlund, 1992 (86)	Sweden	Cross-sectional (H)	Occ.	Shoulder	Radiograph	Construction	Vibration, lifting	Work lifetime	Occ. 1 (rock blasters): n = 55, sex not reported, 51.8 ± 11.6; occ. 2 (bricklayers): n = 54, sex not reported, 50.2 ± 11.4; occ. 3 (foremen): n = 98, sex not reported, 45.8 ± 10.2
Thelin, 1997 (87)	Sweden	Case–control (H)	Clin.	Hip	Radiograph	Multiple	Heavy physical work, machine work, occupational groups	Work lifetime	OA group: n = 216, 100%, age not reported; non-OA group: n = 479, 100%, age not reported
Toivanen, 2010 (21)	Finland	Prospective cohort (H)	Pop.	Knee	Radiograph, clinical exam	Multiple	Categories of light, sedentary work through to heavy manual work	Not described	Total: n = 823, 45%, 41.6 ± 8.3
Verrijdt, 2017 (88)	Belgium	Retrospective cohort (M)	Occ.	Thumb	Radiograph, clinical exam	Banknote processing	Hand activities related to banknote counting	Job role and production rate	Total: n = 195, 34%, 52.9
Vingard, 1991 (89)	Sweden	Retrospective cohort (H)	Pop.	Multiple	ICD codes	Multiple	High physical workload occupational groups	>10 years	OA group: n = 135,015, 54%, age not reported; non-OA group: n = 115,202, 46%, age not reported

(Continued)

Table 2. *(Cont'd)*

First author, year (ref.)	Country	Study design (quality)	Sample type	Joints with OA	OA diagnosis	Industry	Work activities	Work history	Sample (no., % male, mean ± SD age [when given] years)
Vingard, 1997 (90)	Sweden	Case–control (H)	Pop.	Hip	Other	Multiple	Sitting, standing, heavy lifting, jumping, twisting positions, stair climbing	Work lifetime	Total: n = 503, sex not reported, 63
Vrezas, 2010 (91)	Germany	Case–control (H)	Clin.	Knee	Radiograph	Multiple	Kneeling, squatting, lifting, carrying, vibration, posture	Work lifetime	OA group: n = 295, 100%, age not reported; non-OA group: n = 327, 100%, age not reported
Yoshimura, 2004 (92)	Japan	Case–control (H)	Admin. records	Knee	Radiograph, clinical exam	Multiple	Standing, sitting, climbing stairs, kneeling, squatting, driving, walking, heavy lifting	Work lifetime	OA group: n = 101, sex not reported, 73.3 ± 9.8; non-OA group: n = 101, sex not reported, 73.3 ± 9.8
Yoshimura, 2006 (93)	Japan	Case–control (H)	Pop.	Knee	Radiograph, clinical exam	Multiple	Standing, sitting, climbing stairs, kneeling, squatting, driving, walking, heavy lifting	Work lifetime	OA group: n = 37, 100%, 70.0 ± 6.6; non-OA group: n = 37, 100%, 70.1 ± 7.0
Zhang, 2013 (94)	China	Cross-sectional (M)	Pop.	Knee	Radiograph, ACR diagnostic criteria	Multiple	Underground work history	Not described	OA group: n = 983, 45.3%, age not reported; non-OA group: n = 6,143, 51.5%, age not reported

* (M) = medium quality; (H) = high quality; Admin. = administrative records; Comm. = community; Clin. = clinical; Occ. = occupational categories; Pop. = population; ACR = American College of Rheumatology; ICD = International Classification of Diseases; OA = osteoarthritis.

evidence in 65% of studies (n = 45; Kellgren/Lawrence grade 2 or greater), and in 24.6% of studies clinical examinations were used (n = 17) (95). Other methods of assessing OA were World Health Organization categories from the International Classification of Diseases, Eighth/Ninth/Tenth revisions (n = 8), American College of Rheumatology diagnostic criteria (n = 6), self-report of a clinician diagnosis (n = 4), and magnetic resonance imaging (n = 2).

Measurement of work. Three-quarters of studies included workers from multiple industries (n = 51), and the majority (85.5%; n = 59) asked about the duration of work activities. Overall, 70% of studies provided a reasonable description of work activities (n = 48). However, many studies classified duration as work "lifetime" (62%; n = 43), which lacked specificity (e.g., ≥10 years at a job activity). Moreover, a wide range of work activities were combined with other activities (e.g., kneeling/squatting/bending). As a result, only 55% of work history measures were appraised as reliable and valid.

Potential covariates. Nearly all studies included ≥1 covariate, commonly age, sex, body mass index (BMI), or smoking, and many studies included multiple covariates. Hip and knee studies often controlled for previous injury and other sport or physical leisure activities. Covariates were typically controlled for in statistical analyses, but no data were available for extraction.

Data extraction and synthesis. Data were synthesized for hips, knees, wrists/hands/fingers, and spines, and for studies that combined multiple joints. There were too few studies to synthesize findings for necks, ankles/feet/toes, shoulders, and elbows. Table 3 shows a summary of work activities associated with strong and moderate evidence for OA development in the knees and hips among men and women. Evidence was sometimes contradictory, depending on how an activity was measured. For example, when studies labeled their exposure as kneeling, squatting, and bending, there was strong evidence for a risk of developing knee OA in both men and women. Yet studies that examined kneeling separately found strong evidence for no increased risk of knee OA in both men and women. Squatting examined separately resulted in strong evidence for no increased risk of knee OA in men and a moderate level of evidence for no increased risk of knee OA in women. Overall, this finding meant that when we combined all studies that variously measured kneeling, squatting, or bending in some form, there was a moderate level of evidence for the development of knee OA among men only.

Lifting was associated with strong evidence of developing hip OA in both men and women, and vibration activities and cumulative physical workloads were associated with a moderate level of evidence for hip OA among men. Findings differed for knee OA, with lifting and carrying being associated with a moderate level of evidence for no increased risk of knee OA in women.

Table 3. Summary of strong and moderate evidence for work activities and risk of developing osteoarthritis (OA)*

Evidence level: work activities (references)	Men	Women
Strong evidence: increased risk of OA		
Lifting (24,32,40,43,48,52–54,61,77,78,90)	Hip	Hip
Kneeling, squatting, bending (13,25,32,33 41,42,44,45,48,57,62,63,65–68,81,83, 91–93)	Knee	Knee
Heavy physical demands (13,21,35,46,61,63,79,89)	–	Knee
Moderate evidence: increased risk of OA		
Vibration (38,55,77,78)	Hip	–
Cumulative physical load (70,72,77)	Hip	–
Kneeling, squatting, and/or knee bending (all studies combined) (13, 25, 32–34, 41, 42, 44, 45, 48, 57, 62, 63, 65–68, 81, 83, 91–93)	Knee	–
Strong evidence: no increased risk of OA		
Sitting, standing, walking (32,40,43,48,52,54,61,74,78,90,92)	Hip	–
Kneeling (13,25,32–34,41,42,44,45,48,57,62,63,65–68,81,83,91–93)	Knee	Knee
Squatting (13,25,32–34,41,42,44,45,48,57,62,63,65–68,81,83,91–93)	Knee	–
Climbing stairs/ladders (25,26,32,41,42,44,62,65,66,68,81,92)	–	Knee
Moderate evidence: no increased risk of OA		
Sitting, standing, walking (25,26,32,41,42,44,45,48,61,62, 65–68,81,92,93)	Knee	Knee
Squatting (25,32,33,41,42,44,45,57,62,63, 67,68,83)	–	Knee
Lifting, carrying (25,32,41,44,45,48,61,62,65–68,81,83,91–93)	–	Knee
Driving (65,92,93)	Knee	Knee

* References identify literature relevant to a category (e.g., lifting). The level of evidence is based on the totality of findings across relevant studies in that category and does not reflect the findings of an individual study.

Strong and moderate levels of evidence for no increased risk of knee or hip OA also were found for some work activities. There was strong evidence for no increased risk of hip OA in men related to sitting, standing, or walking activities, and moderate evidence for no increased risk of knee OA in men and women for these activities. There was also strong evidence for no increased risk of knee OA in women related to climbing stairs or ladders, and a moderate level of evidence for no increased risk of knee OA related to driving as an occupational activity in men or women.

For all other work activities, evidence was limited, mixed, or insufficient. Among men, this lack included insufficient evidence for jumping being associated with either hip or knee OA, lifting having a limited association with knee OA, and heavy physical demands yielding mixed evidence for knee OA. Among women there was insufficient evidence linking jumping and vibration activities to hip OA and mixed evidence for cumulative physical loads and sitting, standing, and walking being associated with hip OA. There was also insufficient evidence linking jumping and cumulative physical load to knee OA.

Studies examining OA of the hand or spine, and studies that combined joints, mostly did not analyze data for men and women separately. In these studies men and women were combined and the evidence for highly repetitive hand tasks was moderate for no effect of these tasks on the development of wrist/hand/finger OA. Evidence was insufficient for work activities described as “jolting” of the hands. For men and women combined, evidence was mixed for lifting activities related to developing OA in the spine. Evidence was also mixed for physically demanding work related to developing OA in multiple joints. Evidence was insufficient in studies examining OA in multiple joints and work tasks related to sitting, standing, and lifting/carrying.

Dose-response data. To further illuminate the findings, particularly variable and contradictory evidence, we extracted dose-response information from the studies and examined them for thresholds that might link to an increased risk of OA (Table 4). Currently, there are no standardized dose-response criteria available to evaluate the relationship of work exposures to OA. This absence was reflected in the highly diverse and often unique criteria used across studies. Examples include dose levels related to frequency (e.g., daily), intensity (e.g., lifting >25 kg; number of stairs climbed), duration (e.g., >2 hours per day, 10 years or more), and total amount (e.g., lifetime kneeling >3,500 hours). In some cases, dose levels were combined (e.g., >80% of time in nonsitting positions AND frequent walking and lifting). In general, the data were too diverse and too few studies used similar dose-response exposure measures for any synthesis. However, measures of frequency were most common. Studies that used a measure of ≥1 hour/day spent at an activity across multiple years, or a minimum of 3,542 hours spent at an activity, were often linked to an increased risk of developing OA in the knee or hip, particularly related to kneeling, squatting, and bending. Studies that provided qualitative descriptors to assess dose levels (e.g., heavy lifting or a great deal of the time) often reported no significant effects. Table 4 summarizes examples of the doses used in studies for knees and hips related to different job activities.

DISCUSSION

This is the first systematic review to include a wide range of joints affected by OA. By also examining sex and extracting information on work exposures, we more comprehensively addressed the impact of specific occupational activities on the risk of developing OA and illuminated key gaps in research and measurement. Data synthesis yielded several work activities with strong or moderate evidence for the development of OA in hips and knees. However, the absence of clear dose-response information and contradictory findings limits the ability to provide workplaces and legislators with the specificity they need to implement recommendations and considerations. Moreover, there remains mixed or insufficient evidence related to work and OA of the hands, spine, and multiple joints, and too few studies exist to synthesize information on other joints affected by OA. Continued evidence is needed for these joints to refine measures and generate data.

Across men and women, strong or moderate evidence emerged for knee OA when combining kneeling, squatting, and bending activities. Yet there was no effect when squatting and kneeling were examined individually. This diversity in findings has been noted previously (7,14,27), and it highlights the need for attention to measurement, including whether compartmentalizing or differentiating among knee bending tasks accurately reflects real-world work conditions in the frequency and duration of knee bending, and whether knee bending occurs in conjunction with lifting heavy loads (7,16,27). Some jurisdictions are trying to address these issues and have identified minimum thresholds for frequency and duration of kneeling related to work compensation claims (22), but in the absence of detailed evidence, thresholds are set high.

In men, strong evidence emerged for hip OA risk related to lifting, and moderate evidence exists for cumulative physical loads and full-body vibration. This level of evidence is novel and warrants attention for worker awareness and prevention efforts. Previous research has speculated about loads and prolonged vibration in occupations like farming. By focusing on specific activities (e.g., driving a tractor), this review provides greater specificity of evidence and directions for moving forward. However, a lack of clarity related to dose-response levels linking full-body vibration to an increased risk for hip OA limits current practice recommendations. Many studies used vague descriptors (e.g., never versus ever; much tractor driving). Greater precision and specificity of measures is needed in future research.

Among women, fewer occupational activities reached levels for strong or moderate evidence, likely due to fewer available studies (9,11,27) and traditional differences in the types of occupations and levels of physical demands in the work undertaken by women compared to men. However, similar to men, there was strong evidence for an increased risk of hip OA in women related to lifting. This is the first systematic review to have examined lifting activities separately for women, and it underscores the need for greater attention to this aspect of work and its impact among women.

Of interest was strong and moderate evidence for a lack of association among several activities and increased risks of hip, knee, or hand OA. These included sitting, standing, and walking (hip and knee OA), lifting and carrying (knee OA), climbing ladders (knee OA), driving (knee OA), and highly repetitive tasks (hand OA). There are many reasons why studies yield null effects, suggesting caution in drawing conclusions. Moreover, although not a high priority in developing OA, activities like prolonged

Table 4. Summary of dose-response categories by joints and work activities

- Hips
  - Lifting
    - >20 kg at least 10 times/day: from 1–12 years, 13–24 years, >25 years
    - Heavy lifting (comparison not specified in 2 studies; 1 study compared high and medium versus low)
    - Tons lifted: high and medium versus low
    - No. of lifts >40 kg: high and medium number of lifts versus low
    - Ton years: 0 versus >0–9, 10–19, 20–115/86 (men: upper value of 115; women: upper value of 86)
    - Daily lifting equivalent: a) 50 lifts × 20 kg OR 20 lifts × 50 kg; b) 50–100 lifts × 20 kg OR 20–50 lifts × 50 kg; c) 200–500 lifts × 20 kg OR 100–250 lifts × 50 kg
  - Standing/sitting/walking
    - >80% of time sitting
    - >80% of time standing
    - Frequent walking, but low strain and light lifting up to 5 kg
    - Sitting: high versus low
    - Stairs climbed: high versus medium versus low
    - Standing years: 0, >0–9, 10–19, 20–29
  - Jumping
    - Number of jumps; low, medium, high
  - Vibration
    - Machine operator versus tractor in agriculture, forestry machine, dumper, etc.
    - Much tractor driving
    - Heavy equipment operation
    - Whole-body vibration (ever versus never)
  - Cumulative physical workload
    - Heavy work before age 16 years
    - >80% of work nonsitting, frequent walking, lifting heavy objects (with some analyses including years worked)
    - Cumulative physical workload (based on an industry exposure matrix with scores of 0–4, 5–14, 15–24, 25–34, 35–86)
    - Cumulative peak force index
- Knees
  - Sitting/standing/walking
    - Percent of day (e.g., 22–32%, 32–54%, >54%)
    - Time per day: ≥2 hours per day
    - Time per day: ≥3 hours per day
    - Time per day: floor and chair separately 1–2 hours/day, 2–3 hours/day, >3 hours/day
    - Unspecified intensity: medium and high
    - Lifetime hours: <16,032 hours, 16,032–33,119 hours, >33,119 hours
    - Likelihood of sitting: unlikely and highly likely versus somewhat likely
    - Distance: ≥3 km/day
    - Distance: ≥2 km/day
    - Distance: >2 miles/day for 1–9 years, 10–19 years, ≥20 years
    - Time: flat ground 1–2 hours, 2–3 hours, >3 hours plus up or downhill >30 minutes/day
  - Kneeling/squatting/bending
    - Percentage of day: 4–7%, 8–13%, >14% of workday
    - Time: ≥1 hour/day
    - Time: >30 minutes
    - Likelihood: unlikely and highly likely versus somewhat likely
    - Unspecified intensity: high exposure
    - Qualitative intensity: medium plus heavy bending
    - Qualitative intensity: sedentary or light, medium, heavy, very heavy
    - Amount: none, some, much
    - Qualitative intensity plus load: kneeling/squatting with heavy lifting

(Continued)

Table 4. (*Cont'd*)

- Knees (cont'd)
  - Kneeling/squatting/bending (cont'd)
    - Lifetime/cumulative hours: <3,542, 3,542–8,934, 8,934–12,244, >12,244
    - Lifetime/cumulative hours: <4,757, >4,757, >4,757 with body mass index >24.92
    - Lifetime/cumulative hours: 0 to <870 hours, 870 to <4,757, 4,757 to <10,800, ≥10,800
    - Time per day: <2 hours/day, >2 hours/day, time/day plus duration: >1 hour/day plus: 1–9.9 years, 10–19.9 years, >20 years
  - Getting up from kneeling/squatting
    - Frequency: >30 times/day
    - Frequency plus duration: >30 times/day: 1–9.9 years; 10–19.9 years; >20 years
  - Lifting/carrying
    - Qualitative intensity: heavy lifting
    - Qualitative intensity: high exposure
    - Qualitative intensity: medium, high
    - Frequency: unlikely, somewhat likely, highly likely
    - Amount: weights >25 kg on an average day
    - Amount: 2–4 kg/day, >4 kg/day
    - Amount plus frequency: ≥10 kg at least once/week
    - Amount plus frequency (plus duration): ≥10 kg >10 times/week, ≥25 kg >10 times/week, ≥50 kg >10 times/week; all categories repeated with: 1–9.9 years, 10–19.9 years, ≥20 years
    - Percentage of day: 4–7% of day, 8–19% of day, >20% of day
    - Cumulative lifting by hours: 0 to <630 kg × hours, 630 to <5,120 kg × hours, 5,120 to <37,000 kg × hours, ≥37,000 kg × hours
    - Cumulative hours: <5,120, >5,120, >5,120 with body mass index ≥24.92
    - Cumulative weights: <1,088 tons/life, ≥1,088 tons/life
  - Climbing
    - Time/day: ≥1 hour/day
    - Episodes plus episodes with duration: >30 times/day, >30 times/day for 1–9.9 years, 10–19.9 years, ≥20 years
    - Qualitative intensity: medium; high
    - Qualitative intensity: high exposure
    - Amount, no. of flights: 3–5 stories, 5–10 stories, >10 stories
    - Amount, no. of flights: >10 flights/day
    - Amount, no. of stairs: ≥50 steps/day
  - Driving
    - Time/day: >4 hours/day
    - Qualitative intensity: medium, high level
  - Physically demanding
    - Qualitative intensity: sedentary, light, medium, heavy, very heavy
  - Jumping
    - No. of jumps
  - Cumulative physical loads
    - Cumulative occupational physical load: data in quintiles
    - Occupational cumulative peak force index: data in quintiles
- Hands
  - Total hours exposed
  - Banknotes/bank sheets counted manually or electromechanical (e.g., 15,000–25,000), stacking banknotes, preparation of packages

sedentary behavior are linked to morbidity and mortality for other health conditions (96).

Our quality appraisal identified several constraints and limitations to study designs and measurement. Most research used case–control or cross-sectional designs, with few longitudinal studies and no interventions. This methodology is likely, because of the prolonged time at a job that is needed before joint strain or damage would develop and lead to OA or become symptomatic. We can expect more longitudinal research in the future, given that many countries have established large, longitudinal OA cohorts. However, most cohorts have clinical treatment foci. In the current literature, we found that generally, the assessment of OA used valid and reliable methods, including standardized clinical and radiographic assessments. Many studies also controlled for a range of covariates (e.g., BMI, injuries, sports activities). Measures to assess employment activities and recall periods were problematic. Only approximately half of work exposures were rated as both valid and reliable, with exposures examining lower-extremity OA being of better quality than those for upper-extremity OA. For example, nearly two-thirds of studies asked participants to recollect their occupation or activity levels over their entire work history. There is a potential for recall bias across all methods of collecting work history, which is a limitation of most of the studies reviewed. Currently, we have little evidence for the validity of long-term recall assessments, which may be more appropriate for measuring occupation type (e.g., are you a farmer?) but less reliable for specific activities (e.g., do you engage in lifting activities?). Additional efforts are needed in research to help improve recall and work measurement, potentially through guided recall techniques, sensor technology, video assessment of work tasks, and longitudinal designs with repeated work activity measures that assess activities and the duration, frequency, and intensity of those activities.

A different bias that needs addressing in future research is a potential healthy worker effect. Specifically, some workers who develop joint problems (e.g., pain, stiffness) may give up their jobs prematurely. This phenomenon may result in a healthier or genetically different sample of workers who remain working in jobs that are thought to cause risks for OA than those who leave these occupations. This result can mask the impact of some work activities on OA in the population at large, leading to the conclusion either that some activities are not related to the development of OA or that damage occurs slowly and over a significantly longer period (97). This possibility highlights the complexity surrounding work and OA and the need for additional information about job tenure and work changes, as well as longitudinal data to assess work history and joint symptoms.

As noted, our extraction of data included dose-response information. These data highlighted a lack of consistency that made synthesizing data impossible. For example, lifting was measured in terms of differing levels of frequency, duration, intensity, lifetime composite levels, and combinations of doses. A similar difficulty arose for kneeling, squatting, and bending activities. Studies not only had differing dose-response data, but variously combined activities (e.g., kneeling alone; kneeling and squatting). Moreover, concerns about knee damage have started to change the nature of work in some occupations. Kneeling devices exist to help offset knee damage and a variety of practices have been put into place with recommendations and strategies to change knee activity patterns. To date, few studies ask about assistive devices or gadgets to ameliorate the impact of activities on OA. Additional research is needed with greater precision of dose-response information aimed at frequency, intensity, and duration of activities, as well as in gathering other relevant information like the use of assistive devices, work cessation, and job turnover related to specific job activities.

In conclusion, a synthesis of 69 studies from 23 countries yielded several work activities with strong and moderate evidence for increasing the risks of developing OA in men and women. These include lifting, cumulative physical loads, full-body vibration, and kneeling/squatting/bending combined. The levels of evidence point to the potential for recommendations and practice considerations to be developed and that those can be tailored for women and men. However, in going forward, additional attention is needed to overcome study deficits, particularly in the measurement and recall of work activities, so that recommendations and practice considerations can provide the specificity needed to be adopted in workplaces.

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