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## Review Article

# Vibration and Ergonomic Exposures Associated With Musculoskeletal Disorders of the Shoulder and Neck



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## ABSTRACT

**Background:** According to the US Bureau of Labor Statistics, musculoskeletal disorders (MSDs) accounted for 32% of all nonfatal injury and illness cases in 2014 among full-time workers. Our objective was to review and summarize the evidence linking occupational exposures to vibration and awkward posture with MSDs of the shoulder and neck.

**Methods:** A literature search was conducted using the terms musculoskeletal disorders, vibration, and awkward posture. All types of observational epidemiologic studies, with the exception of case reports, published during 1998–2015 were included. Databases searched were MEDLINE (Ovid), Embase (Ovid), Scopus, Ergonomic Abstracts, NIOSHTIC-2, and Health and Safety Science Abstracts.

**Results:** Occupational exposures to whole-body or hand–arm vibration were significantly associated with or resulted in MSDs of the shoulder and neck. Awkward postures while working were also associated with MSDs in these locations. These findings were consistent across study designs, populations, and countries.

**Conclusion:** Occupational exposure to vibration and awkward posture are associated with shoulder and neck MSDs. Longitudinal studies are required to elucidate the mechanisms responsible for these associations, and intervention studies are warranted.

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## Introduction

According to the Bureau of Labor Statistics, musculoskeletal disorders (MSDs) accounted for 32% of all injury and illness cases in 2014 among full-time workers [1]. These statistics indicate that MSDs represent one of the largest work-related problems in the United States. The incidence rate for MSDs in 2014 was higher among male workers (37.5 per 10,000 full-time workers) compared with female workers (29.7 per 10,000 full-time workers) [1]. MSDs are especially prevalent in certain occupational sectors and industries such as transportation and warehousing, manufacturing and goods producing, health care and social assistance, agriculture/forestry/fishing/hunting, construction, services, and art/entertainment/recreation providing [1–3].

MSDs place a huge economic burden on employers and the public health-care system. According to Davis et al (2014), the

annual total cost of MSDs to the Ohio Workers' Compensation system between 1999 and 2004 was nearly \$3 billion [2]. Similar data on MSDs for other American states were not identified in the literature. The costs for shoulder MSDs showed a persistent increase among persons of all ages in the manufacturing, service, and wholesale and retail trade sectors. In the construction industry, the costs increased for workers aged 18–45 years and then leveled off for those older than 65 years. From 1999 to 2004, the industries with the largest number of claims were manufacturing (25.1%) and service (32.8%) industries in the state of Ohio [3]. Service and manufacturing industries accounted for the highest total costs at \$909 and \$673 million, respectively. The industries with the highest average indemnity and medical costs per claim were transportation, warehouse, and utilities and construction industries.

The development of interventions to reduce the prevalence of risk factors that contribute to MSDs is necessary. However, the first

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step in this process is the identification and understanding of their major influencing factors. Because MSDs are found in almost every industrial sector and may occur in several areas of the human musculoskeletal system, it is very difficult to investigate every MSD in a single study. The present study focused primarily on the review of epidemiologic studies of the shoulder and neck published since 1998 as studies published before 1998 have already been reviewed [4]. Our objective was to summarize and present results found in the epidemiologic literature, published during 1998–2015, on selected occupational risk factors, primarily vibration, and awkward posture, which are associated with or contribute to the development of MSDs of the shoulder and neck.

## Material and methods

For this review, a literature search was conducted using the terms musculoskeletal disorders, vibration, and awkward posture. Only articles published in English during the years 1998–2015 were selected. All types of observational epidemiologic studies, with the exception of case reports, were included. We considered all studies that included our search terms, chosen language, and years of publication without regard to sample size, study design, or assessment methods used for the risk factors. The databases searched were MEDLINE (Ovid), Embase (Ovid), Scopus, Ergonomic Abstracts, NIOSHTIC-2, and Health and Safety Science Abstracts. The following sections summarize the literature on the influence of occupational exposure to vibration, awkward posture, and a few other physical and psychosocial factors on MSDs of the shoulder and neck. Most of the studies were conducted in the United States and Europe (Sweden, United Kingdom, Finland, Portugal, Denmark, France, and Norway); some of the studies were conducted in Asia (Japan, Malaysia, India, and Thailand) and the Middle East (Turkey and Iran). Most studies comprised populations of individuals in blue-collar or manual labor occupational sectors or industries such as construction, forestry, poultry processing, fish processing, petroleum gas, and automobile manufacturing. In addition, most studies comprised only men or a preponderance of men.

## Results

### *Vibration and MSDs of the shoulder and neck*

In Table 1, we present studies that investigated associations between exposure to work-related vibration and MSDs. Five cross-sectional studies were identified that investigated associations between work-related vibration and MSDs of the shoulder and neck. Several studies on construction workers found that exposure to whole-body vibration or local vibration was significantly associated with stiff shoulders or neck and upper extremity disorders [5–7]. Researchers investigating the association between exposure to occupational whole-body vibration and MSDs among 9,798 Swedish workers found that exposure to whole-body vibration for at least half the working time was significantly associated with MSDs in the neck and shoulder/arm in addition to other locations [8]. For the neck and shoulder/arm MSDs, there was a visible increase in the prevalence ratio (as high as 5 times) when combined exposures of whole-body vibration, lifting, frequent bending, twisted posture, and noise were included in the analysis. Merlino et al (2003) found that MSD symptoms were widespread among construction workers, gradually increased as the number of years worked in the trade increased, and these symptoms were highly prevalent among female apprentices [6]. In another cross-sectional study, 355 construction workers, who were exposed to whole-body vibration and local vibration, reported symptoms of stiff shoulders [7]. Two cross-sectional studies by Palmer et al reported results that

contradicted each other. In one of these studies, the authors found a significant association between hand-transmitted vibration and recent pain in the upper limbs among men who were mostly in manual labor occupations [9]. Findings from the second study reported no significant association between exposure to vibration and neck pain among white-collar and blue-collar men and women [10]. Among female workers in France, upper extremity MSDs were associated with the use of vibrating hand tools [11]. Men had different factors that were associated with upper extremity MSDs, and this information is presented in the following section on awkward posture.

Two prospective cohort studies were identified, and both found significant associations between work-related vibration and shoulder pain/injury. Sutinen et al (2006) investigated (1) the prevalence of and changes in hand–arm vibration syndrome and (2) the association of hand–arm vibration syndrome with MSDs of the upper extremity and neck among 52 forestry workers using antivibration chain saws in Finland [12]. Their results showed that 38% of the workers were diagnosed with regional neck pain and that hand–arm vibration was associated with right rotator cuff syndrome. Grooten et al (2007) studied 803 workers in Sweden who reported neck/shoulder pain at baseline to determine the proportion that was symptom free 5–6 years later [13]. After adjustment for sex and age, only 36% of the workers were symptom free 5–6 years later. The relative risk of being symptom free at the end of the study was significantly lower [0.61 (95% confidence interval = 0.40–0.94)] for workers with at least two of these simultaneous biomechanical exposures at work: manual handling for  $\geq 60$  min/day, working with vibrating tools  $\geq 60$  min/day, and working with the hands above the shoulder level  $\geq 30$  min/day.

Two case–control studies were identified that investigated associations between work-related vibration and MSDs of the shoulder and neck. Researchers in Turkey investigated the stages in the development of vibration syndrome in 50 rock drill workers and 64 heavy-vehicle operators (as cases), and 54 office workers (as controls) [14]. Hand-held power tools have been known to cause peripheral circulatory disturbances in peripheral nerves, muscles, bones, and joints. Complaints of finger numbness and pain at night, wrist to elbow pain, and shoulder pain when holding arms up were among the symptoms that were more pronounced in rock drillers than in heavy-vehicle operators and office workers. In the other case–control study, 1,195 railroad engineers (cases) and 323 civil engineers (controls) were studied to obtain information about MSDs, especially those affecting the upper and lower spine, associated with exposure to whole-body vibration at work [15]. Results showed that rates of neck and shoulder problems were higher among railroad engineers who have higher levels of exposure to shock and vibration.

### *Ergonomic exposures and MSDs of the shoulder and neck*

In Table 2, we present studies that investigated associations between occupational exposure to awkward posture, repetitive movements, and so forth and MSDs of the shoulder and neck. Several cross-sectional studies were identified that investigated associations between awkward posture and MSDs of the shoulder and neck. Although not the main focus, psychosocial factors were often observed as cofactors with awkward posture and other physical factors in these associations [16–20]. Most of these studies showed that working in awkward positions, working with the hands above the shoulders, or using repetitive movements were associated with shoulder and neck pain, rotator cuff syndrome, and epicondylitis [16,21–27]. Among Latino women who worked in manual labor occupations in North Carolina, USA, awkward posture was one of the ergonomic factors that were

**Table 1**  
Epidemiologic studies of vibration and musculoskeletal disorders of the neck and shoulder

Author	Study design	Industry or occupation	Sample	Exposure(s)	Outcome(s)	Results and comments
Engholm and Holmstrom, 2005	Cross-sectional	Sweden: construction workers	85,191 men	Vibration exposure	Neck and shoulder disorders	Neck and shoulder disorders were significantly associated with vibration exposure.
Grooten et al, 2007	Longitudinal	Sweden: workers in various occupations	803 men and women (77% response rate)	Working with vibrating tools; sitting $\geq 75\%$ of working time	Incidence of self-reported neck and shoulder pain at the end of follow-up	Simultaneous exposure to $\geq 2$ of the following: (1) manual handling, (2) working with hands above shoulder level, and (3) working with vibrating tools is associated with a lower chance of being symptom free at the end of the study.
Hagberg et al, 2006	Cross-sectional	Sweden: workers in various occupations (e.g., agriculture, forestry, fishery, plant & machinery)	9,798 men and women (70% response rate)	WBV	MSDs in neck, shoulder/arm, and hand	Exposure to WBV ( $\geq 50\%$ working time) was associated with increased prevalence of MSDs in neck, shoulder/arm, and hand.
Issever et al, 2003	Case-control	Turkey: rock drill workers, heavy-vehicle operators, and office workers	114 workers (50 rock drill workers and 64 heavy-vehicle operators) and 54 controls (office workers)	HTV and WBV	Variety of health complaints including shoulder pain	Compared with controls, rock-drilling operators (HAV exposure) had significantly more shoulder pain when holding arms up.
Johanning et al, 2004	Case-control	USA: railroad engineers (men and women)	1,195 engineers (47% response rate) and 323 controls (41% response rate)	WBV	Neck and shoulder pain	Compared with the control group, a significantly greater proportion of railroad engineers who are exposed to WBV reported severe neck and shoulder pain in the past year (OR = 1.86, 95% CI = 1.06–3.28).
Merlino et al, 2003	Cross-sectional	USA: apprentice construction workers	996 men and women (84.8% response rate)	Occupational exposures associated with construction (e.g., repetitive tasks, working in cramped positions, awkward posture, grasp small objects, bending or twisting)	MSDs of neck, shoulder, upper and lower limbs	Most apprentice construction workers reported MSD symptoms in at least one of nine anatomical sites during the previous year. Women reported significantly more MSD symptoms in the neck, shoulder, and a few other regions than men.
Miyashita et al, 1992	Cross-sectional	Japan: construction machinery operators (power shovel operators, bulldozer operators, forklift operators) and office workers	184 power shovel operators, 127 bulldozer operators, 44 forklift operators, and 44 controls	WBV and local vibration	Stiff shoulder, and low back pain	WBV was associated with stiff shoulder (43.5–56.8%) in operators. No significant differences were found in the upper limbs between operators and controls.
Palmer et al, 2001a	Cross-sectional	England: manual occupations (e.g., carpenters, fitters, construction workers, motor mechanics, electricians, welders, gardeners) and armed forces	1,856 men	HTV	MSDs of upper limbs, neck, shoulder	Prevalence of pain in the past week: Neck: PR = 1.8 (1.4–2.3) Shoulder: PR = 1.9 (1.4–2.4). There was a significant association between dose of HTV and recent pain in upper limbs and neck.
Palmer et al, 2001b	Cross-sectional	UK: workers in several industries (blue-collar and white-collar workers, and the armed forces)	12,907 men and women (61% response rate)	HAV and WBV	MSDs of upper and lower limbs, neck, shoulder	4,348 workers (34%) reported neck pain in the past year. Neck pain was most prevalent among male construction workers (38%). No associations were found with exposure to vibration

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Table 1 (continued)

Author	Study design	Industry or occupation	Sample	Exposure(s)	Outcome(s)	Results and comments
Roquelaure et al. 2009	Cross-sectional	France: salaried workers in various industries	3,710 men and women	Working with arms at or above shoulders, vibrating hand tools, extreme wrist bending, psychosocial factors	MSDs of upper extremities	13% had $\geq 1$ upper extremity MSD. Men: MSDs associated with repetitiveness, arms at or above shoulders, full elbow flexion, and psychological demands. Women: MSDs associated with extreme wrist bending, and vibrating hand tools.
Sutinen et al. 2006	Prospective cohort	Finland: forestry workers	52 men	HAV	MSDs of upper extremity, neck, and shoulder, HAVS, rotator cuff syndrome, epicondylitis	38% of workers had neck pain. HAV was associated with right rotator cuff syndrome. There was a dose-response relationship between vibration and HAVS, rotator cuff syndrome, and epicondylitis.

CI, confidence interval; HAV, hand–arm vibration; HAVS, hand–arm vibration syndrome; HTV, hand–arm vibration syndrome; MSD, musculoskeletal disorders; OR, odds ratio; PR, prevalence ratio; WBV, whole-body vibration.

associated with rotator cuff syndrome and epicondylitis [16]. Another study reported that a group of painters in the automobile industry with work-related MSDs had a longer exposure time when compared with the workers without MSD symptoms [28]. Therefore, adopting awkward posture for long and continuous periods of work time was an exacerbating factor.

In a cross-sectional study of construction workers, in addition to vibration, other factors that were significantly associated with MSDs of the neck and shoulder were stooping, having a twisted posture, and working with hands above shoulders [5]. Chandrasakaran et al (2003) reported that bending and sitting were both significantly associated with neck and shoulder pain. Other investigators found that frequent lifting, prolonged sitting without back support, carrying out repetitive tasks with hands and fingers, and standing with awkward posture were associated with a high prevalence of neck and shoulder pain [23]. Among 3,710 workers in France who participated in a surveillance program of MSDs, the most frequent MSD (among several upper extremity MSDs) was rotator cuff syndrome [11]. Occupational exposures for MSDs differed by gender. Among men, MSDs of the upper extremity were associated with high repetitiveness of the task and awkward posture with arms at or above shoulder level in addition to other factors. Among women, upper extremity MSDs were associated with extreme wrist bending among other factors.

Seven longitudinal studies that investigated occupational risk factors for MSDs of the shoulder and neck were identified. Most of the studies reported that both physical and psychosocial factors such as job demands, low levels of social support, low job control, and monotonous work were risk factors [18,19,29]. Among workers in Denmark, physical factors (e.g., twisting and bending) together with psychosocial factors at work were associated with the incidence of chronic neck and shoulder pain [18]. In a longitudinal study conducted among 12,714 French participants, results showed that awkward posture, forceful effort, job demands, and decision control were risk factors for chronic shoulder pain at work [19]. However, the most significant predictor was awkward posture. After following up 12,550 Norwegians for 3 years, results showed that mechanical risk factors for neck and shoulder pain included lifting in awkward posture, neck flexion, hand/arm repetition, and working with hands above the shoulder [29].

A longitudinal study conducted in seven regions of France found that awkward working conditions and repetitive work under time constraints were among several factors that resulted in the development of chronic neck and shoulder pain [17]. Working in awkward posture with high levels of speed and repetitive movements were associated with MSDs of the back, shoulder, and neck among liquid petroleum gas workers in Mumbai, India [30]. Two longitudinal studies conducted in Finland reported several occupational risk factors for shoulder MSDs [31,32]. These work-related exposures included working with trunk flexed forward, with hands above shoulders, physical work with a heavy load, and repetitive movements.

Although many of the studies in this section were conducted in Southeast Asian, Middle Eastern, and developing countries, a few were conducted in the United States, United Kingdom, Europe, and other industrialized countries [11,16,28,33]. Exposures to awkward posture and repetitive movements are common in various manufacturing industries, construction, petroleum, automotive, and several manual occupations [20,24,25,34–38].

## Discussion

In this narrative review, we found that occupational exposures to vibration, awkward working postures, and several other physical factors were associated with or resulted in MSDs of the shoulder

**Table 2**  
Epidemiologic studies of awkward posture and musculoskeletal disorders of the neck and shoulder

Author	Study design	Industry or occupation	Sample	Exposure(s)	Outcome(s)	Results and comments
Abd Rahman et al, 2010	Cross-sectional	Malaysia: workers in a car tire service center	12 (possibly all men)	Poor body posture, prolonged standing, squatting and kneeling, bending the back and neck, highly repetitive motions, lifting heavy objects, use of hand tools, and poor workstation design	Pain/discomfort in hand/wrists, shoulder, back, elbow/forearm, and other locations	The main sources of injury/discomfort were poor body posture, bending the back, highly repetitive motions, lifting heavy objects, long-term standing, long-term squatting, bending the neck, and high hand force.
Alipour et al, 2008	Cross-sectional	Iran: workers in an automobile-manufacturing industry	14,384 men and women (79.8% response rate)	Awkward working position, repetitive work, sitting for long hours, monotonous work, and psychosocial factors	Neck/shoulder pain	<i>Men:</i> awkward working positions & repetitive work were physical risk factors. <i>Women:</i> repetitive work & sitting were physical risk factors.
Arcury et al, 2014	Cross-sectional	USA: women in poultry processing and other manual work	234 women	Awkward posture, heavy load, and psychological factors	Epicondylitis, rotator cuff syndrome, etc.	Awkward posture, decision latitude, and work organization characteristics were associated with epicondylitis, and rotator cuff syndrome among women.
Boschman et al, 2015	Longitudinal	Netherlands: construction workers (bricklayers and supervisors)	750 bricklayers and 750 supervisors (gender not stated)	Working above height, repetitive arm–hand movements, and vibrating tools	MSDs of the shoulder, and upper extremities	Working above height, repetitive arm–hand movements associated with MSDs of the shoulder and upper extremities.
Carnide et al, 2006	Cross-sectional	Portugal: paint area production workers in an automobile plant	29 (mostly men)	Awkward posture and physical workload	MSDs of the neck and upper limbs	Physical workload and awkward posture associated with MSDs of the shoulder, neck & upper limbs.
Cassou et al, 2002	Prospective cohort	France: workers in various occupations (from executive to blue-collar workers)	21,378 men and women (response rate 88.2%)	Awkward posture, carrying heavy loads, vibrations, repetitive work, and psychosocial factors	Neck and shoulder pain.	In addition to several ergonomic factors, the aging of the workforce appeared to have contributed to the MSD symptoms. Psychosocial factors also played a role.
Chandrasakaran et al, 2003	Cross-sectional	Malaysia: female workers in the wafer fabrication & semiconductor industry	529 women	Prolonged bending and sitting	Neck and shoulder MSDs	Pain in the shoulder and neck was among the most common MSDs. Neck/shoulder pain significantly associated with sitting and bent forward positions.
Chee et al, 2004	Cross-sectional	Malaysia: female workers in semiconductor industries	906 women	Awkward posture, sitting without back support, lifting weights, prolonged standing, and repetition	Neck/shoulder MSDs and upper and lower extremity pain	Frequent lifting, awkward posture & prolonged sitting significantly associated with neck/shoulder pain.
Chowdhury et al, 2012	Cross-sectional	India: male workers in liquid petroleum gas industries	100 men	Awkward posture and repetitive motions	Severe injury to back, neck, shoulder, knees, and toes	Awkward posture associated with MSD injuries.
Engholm and Holmstrom, 2005	Cross-sectional	Sweden: construction workers	85,191 men	Awkward posture, working with hands above shoulders, heavy lifting, kneeling, and psychosocial factors	Neck and shoulder disorders	Neck and shoulder disorders were significantly associated with vibration exposure, heavy lifting, and working with hands above the shoulder.
Feveile et al, 2002	Longitudinal	Denmark: workers in various industries	Baseline: 5,001 men and women, follow-up: 3,990	Physical hard work, heavy lifting, twisting/bending, working with hands at/above shoulders, and psychological factors	MSDs of the neck/shoulder and wrist/hand	Among men and women, twisting or bending and psychosocial issues predicted neck/shoulder MSD symptoms.

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Table 2 (continued)

Author	Study design	Industry or occupation	Sample	Exposure(s)	Outcome(s)	Results and comments
Gangopadhyay et al, 2010	Cross-sectional	India: male workers in carbon dioxide and chemical sand core-making operations	50 men	Awkward posture	MSDs of the shoulder, neck, and other regions	Awkward posture was significantly associated with MSDs of the shoulder, neck, and other regions.
Ghasemkhani et al, 2008	Cross-sectional	Iran: workers manufacturing hygienic products	75 workers	Repetitive movements and awkward posture	MSDs of the neck and shoulders	Repetitive movements with awkward posture were significantly associated with MSDs.
Ghosh et al, 2010	Cross-sectional	India: male goldsmiths	120 men	Awkward posture and repetitiveness	MSDs of the neck, shoulder, lower back, and wrists.	Awkward posture associated with MSDs especially those of the neck and low back.
Grzywacz et al, 2012	Cross-sectional	US: Latino immigrant workers in the poultry industry	138 men and 138 women each in poultry and nonpoultry work groups	Awkward posture and repeated movements, heavy load, psychological demands, and abusive supervision	Epicondylitis, rotator cuff syndrome, and back pain	Awkward posture and repeated movements were associated with epicondylitis, rotator cuff syndrome, and back pain.
Hanklang et al, 2014	Cross-sectional	Thailand: female workers using hand-operated rebar benders	272 women	Awkward posture, repetitive movements, prolonged working hours, bending of neck or trunk, stooping, and psychosocial factors	MSDs of the neck and shoulders	Workers with prolonged working hours and awkward posture were more likely (43.8 times) to develop MSDs.
Herin et al, 2012	Longitudinal	France: workers in various industries	1990: 21,378 and 1995: 18,695, men and women	Physical factors: forceful effort, effort with tools, heavy loads, movements, posture, and vibration and psychological factors	Shoulder pain	Forceful effort and awkward posture were predictive of chronic shoulder pain at 5 years; the most robust predictor was awkward posture. Decision control was also a predictor.
Kaminskas and Antanaitis, 2010	Cross-sectional	Lithuania: construction workers	276 (62.7% response rate)	Awkward work posture, and high use of physical force	Pain and discomfort in the neck, shoulders, and other regions.	Awkward work posture and high use of physical force were significantly associated with pain and discomfort in the neck, shoulder, and other regions.
Lemasters et al, 1998	Cross-sectional	USA: carpenters (e.g., drywall, ceiling, framing, building concrete forms, etc.)	522 (97.8% men) (83% response rate)	Repetitiveness, awkward posture, exhaustion, and psychosocial issues	MSDs of shoulders, and upper and lower extremities.	Psychosocial issues associated with MSDs of the shoulder, etc. MSDs of upper extremities are most prevalent among all carpenters, particularly drywall and ceiling installers.
Miranda et al, 2001	Longitudinal	Finland: workers in the forestry industry	2094 women and men	Working with trunk forward flexed, with hand above shoulders, and physical work with a heavy load	Shoulder pain	Working with trunk forward flexed, with hand above shoulders, physical work with a heavy load increased the risk of incident shoulder pain.
Miranda et al, 2008	Longitudinal	Finland: workers in various industries	883 women and men	Repetitive movements, vibration, awkward posture, lifting heavy loads, and psychosocial factors	Shoulder MSDs	63 incident cases of shoulder MSDs. <i>Men:</i> vibration and repetitive movements. <i>Women:</i> lifting heavy loads and awkward posture significantly associated with MSDs.
Nag et al, 2012	Cross-sectional	India: workers in fish-processing industry	450 women	High levels of physical activity, cold environment, poor task clarity, and manual material handling	Pain and discomfort in neck and shoulders.	High levels of physical activity, cold environment, poor task clarity, and manual material handling were associated with pain and discomfort in the neck and shoulder.

Roquelaure et al, 2009	Cross-sectional	France: salaried workers in various industries	3,710 men and women	Working with arms at or above shoulders, vibrating hand tools, extreme wrist bending, and psychosocial factors	MSDs of upper extremities	13% had $\geq 1$ upper extremity MSD. Men: MSDs associated with repetitiveness, arms at or above shoulders, full elbow flexion, and psychological demands. Women: MSDs associated with extreme wrist bending, and vibrating hand tools.
Sim et al, 2006	Cross-sectional	UK: workers in various manual occupations (e.g., pottery)	10,000 men and women (53.5% response rate)	Lifting heavy objects, prolonged bending of neck, working with arms above shoulder, and psychosocial factors	Neck and upper limb pain.	Significant association between neck & upper limb pain and several physical & psychosocial factors.
Sterud et al, 2014	Longitudinal	Norway: workers in various industries	12,550 men and women (67% response rate)	Lifting in awkward posture, neck flexion, repetitive motions, and psychosocial factors	Neck and shoulder pain	Highly demanding jobs, neck flexion, awkward lifting, hand/arm repetition, and working with hands above the shoulder were important predictors of neck/shoulder pain.

and neck. These findings were consistent across countries, populations, and study designs. They were also consistent with the findings of studies reported before 1998 [4,39–41].

Based on these findings, we hypothesize that the MSDs of the workers who used powered hand tools or were exposed to whole-body vibration result, at least partially, from the combined physical stresses induced from applied hand or body forces, vibration, and awkward working posture. It is understood that one of the major MSD mechanisms is sprains or strains resulting from overexertion [1,42]. Each tissue of every person's musculoskeletal system has its own load tolerance. When the physical loads in the tissue exceed the load tolerance, the tissue may be injured or damaged [43]. Awkward posture may increase the physical load of the tissue and/or reduce its load tolerance by changing the physiological conditions of the tissue. For example, when the hand and arm are in an awkward posture in an overhead position such as when installing a light fixture to the ceiling, the load in the shoulder is substantially increased and the blood flow in the hand–arm system is reduced. This position quickly results in fatigue of the shoulder–arm–hand system even when the operation may only last a few minutes. More importantly, this position also substantially increases the injury potential because of the increased physical load and reduced tolerance due to the decreased blood circulation. Vibration from powered tools can add another series of physical loads to the system through the following mechanisms: (1) the handgrip force required for controlling the tool under vibration may be increased; (2) the vibration transmitted to the muscles may cause tonic reflex (involuntary reflex action) of the muscles and/or may influence their motor unit synchronization which may affect the muscle internal loads and their fatigue and injury tolerances [42]; (3) the vibration-induced numbness of the fingers or hands may make it difficult to apply only enough force to control the tools; and (4) the dynamic force induced from the vibration transmitted to the system can increase the load in the joints and bones [44]. More studies are needed to further elucidate these mechanisms because the exact relationship between physical loads and MSDs has not yet been established. More epidemiological studies are required to help further test these hypotheses and to identify the quantitative dose–effect relationship between repetition and shoulder MSDs.

While we found a number of cross-sectional studies, relatively few longitudinally designed studies on this topic were identified in the literature. This is a limitation of this study. In the future, it would be useful to conduct more longitudinal studies that assess the influence of exposures to vibration and awkward posture on neck and shoulder MSDs and to conduct studies identifying differences in exposures by gender and occupational category. More importantly, intervention studies to mitigate such exposures to workers, thereby decreasing the incidence of MSDs, are warranted.

A strength of this narrative review is the contribution it makes to the literature on risk factors for shoulder and neck MSDs. It is also a continuation of a review that was conducted on this topic before 1998 and published by NIOSH in 1997.

#### Practical applications

There is abundant evidence showing that workers are at increased risk of MSDs of the shoulder and neck from exposure to vibration, awkward postures, and other physical factors at work. The information presented here underscores the need for employers to adopt strategies to reduce MSDs that are associated with exposure to these factors. It is also important for occupational physicians to ask their patients about occupational exposures when they present with various MSD problems.

## Conflicts of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

## Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

## Author contributions

Dr Charles and Ms Ma conceived of the research question, conducted literature search and review, and revised it for important intellectual content. Dr Charles drafted the manuscript. Dr Burchfiel and Dr Dong contributed to the text and revised the manuscript for important intellectual content. All authors approved of the final version and agreed to be accountable for all aspects of the work.

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