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This meta-analysis showed moderately strong evidence for improvement by occupational health and safety (OHS) legislation and inspections with respect to injuries and fatalities, while limited evidence is available for effects of training, campaigns and introduction of technical devices. Studies of intervention targeted at reducing psychological and musculoskeletal disorders are few and inconclusive. Further studies of the effect of OHS interventions are strongly warranted.

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Systematic literature review on the effects of occupational safety and health (OSH) interventions at the workplace

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Objectives The aim of this review was to assess the evidence that occupational safety and health (OSH) legislative and regulatory policy could improve the working environment in terms of reduced levels of industrial injuries and fatalities, musculoskeletal disorders, worker complaints, sick leave, and adverse occupational exposures.

Methods A systematic literature review covering the years 1966–2017 (February) was undertaken to capture both published and gray literature studies of OSH work environment interventions with quantitative measures of intervention effects. Studies that met specified in- and exclusion criteria went through an assessment of methodological quality. Included studies were grouped into five thematic domains: (i) introduction of OHS legislation, (ii) inspection/enforcement activity, (iii) training, such as improving knowledge, (iv), campaigns, and (v) introduction of technical device, such as mechanical lifting aids. The evidence synthesis was based on meta-analysis and a modified Grading of Recommendations, Assessment, Development and Evaluation (GRADE) approach.

Results The search for peer-reviewed literature identified 14 743 journal articles of which 45 fulfilled the inclusion criteria and were eligible for meta-analysis. We identified 5181 articles and reports in the gray literature, of which 16 were evaluated qualitatively. There was moderately strong evidence for improvement by OHS legislation and inspections with respect to injuries and compliance.

Conclusions This review indicates that legislative and regulatory policy may reduce injuries and fatalities and improve compliance with OHS regulation. A major research gap was identified with respect to the effects of OSH regulation targeting psychological and musculoskeletal disorders.

Key terms campaign; GRADE; introduction of technical devices; labor inspection; labor law; labor regulation; labor policy; meta-analysis; OHS intervention; regulation; regulatory policy; training; workplace intervention.

Occupational injuries and diseases still contribute sizably to mortality and morbidity on a world-wide scale (1). More than 350 000 workers lose their lives each year due to occupational injuries (1, 2). Work-related ergonomic and psychosocial stressors are not life-threatening but can cause considerable morbidity and are major drivers of work absence. Musculoskeletal diseases and mental disorders are significant contributors to the amount of years lived with disability (3).

The Work Environment Authority (WEA) in Denmark main function is to identify workplace hazards, promulgating rules to regulate those hazards and ensur-

ing compliance through enforcement, such as inspections, guidance, recommendations, and perhaps penalties for violations. In this context, work environment interventions are defined as actions or activities performed by or relevant to WEA with the objective of improving the work environment and employees' health, and/or to reduce sickness absence and early retirement due to working environment exposures.

In an earlier review, Tompa et al (4) made one of the first attempts to review the effectiveness of incentives for prevention through insurance and regulations. The authors addressed challenges in defining specific inclusion and

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quality criteria and using best evidence synthesis. They found that the introduction of occupational safety and health (OHS) regulations did not have a clear impact on the level of occupational injuries but that penalties for violating regulations did. Tompa et al recently updated the knowledge base by reviewing the effectiveness of occupational health and safety regulatory enforcement (5). They concluded that there was strong evidence from actual inspections with penalties and moderate-to-limited evidence of no effect from inspections without penalties. There was moderate evidence that the introduction of OHS legislation had an effect on injuries and fatalities. Introduction of smoke-free workplace legislation improved proximal outcomes such as smoke exposure and cigarette consumption (strong evidence) and distal outcomes in terms of respiratory and sensory symptoms (moderate evidence). Awareness campaigns mostly showed limited evidence. In a Cochrane collaboration review on occupational safety and health enforcement tools for preventing occupational diseases and injuries from 2013 (6), the authors concluded there is evidence that inspections decrease injuries in the long- but not short term and with uncertain magnitude of effect. Moreover, focused inspections could have larger effects than inspections in general and effect of fines and penalties are uncertain. The quality of the evidence was considered low to very low and therefore conclusions are tentative and could be easily changed by future studies. A Cochrane collaboration review on interventions to reduce injuries among construction workers (7) concluded regulation alone is not effective in reducing non-fatal and fatal injuries. Continuing company-oriented interventions among management and construction workers, such as a targeted safety campaign or a drug-free workplace program, seem to have an effect in reducing injuries in the longer term. The review also concluded that there is very low-quality evidence for regulations and safety campaigns, and training for reducing fatal and non-fatal injuries in construction companies (7). In November 2015, WEA invited tenders to carry out a systematic literature review on the effects of working environment interventions on (i) harmful working environment exposures, (ii) employee health, (iii) sickness absence, and (iv) job retention. The purpose of the call was to provide an overview of the existing evidence based upon the international research literature, enabling the WEA to prioritize between different interventions based on the level of evidence. The WEA specifically called for a broader approach than the one used by the two Cochrane reviews (6, 7).

The aim of this current review was to assess the evidence that legislative and regulatory policy could improve the working environment in terms of reduced levels of industrial injuries and fatalities, musculoskeletal disorders, worker complaints, sick leave, and adverse occupational exposures.

Methods

Literature search

We reviewed the literature according to the MOOSE guidelines for systematic reviews of observational studies. We identified eligible papers for this review through two separate literature searches, one addressing peer reviewed original journal articles and one addressing the gray literature (non-journal articles and reports). Peer-reviewed papers were searched in PubMed, Web of science, HSELINE and NIOSHTIC-2 from OSH UPDATE. Gray literature was retrieved from searches in HSELINE, NIOSHTIC-2 and from OSH UPDATE. The search methodology followed a PICO (population or patient, intervention, comparison, and outcome) format. The search strategy combined sets of keywords, using AND/OR terms in Boolean logic. Keywords for the search strategy are provided in the appendix (table S2, www.sjweh.fi/show_abstract.php?abstract_id=3775). Details of the search strategy are also shown in the appendix. Six earlier reviews (4–9) were scanned to include additional studies.

In order to be included in this review the following criteria had to be fulfilled: (i) The study should be in English or Scandinavian language and published between 1966 and February 2017 in a peer-reviewed journal, report or on a website (gray literature). Abstracts only were excluded. (ii) The study should have investigated working environment issues. (iii) The study should report on a well-defined intervention relevant for an occupational safety and health authority such as regulatory actions that the WEA could make on OHS legislation or other regulations that could be enforced by the WEA, such as inspections, training, campaigns or the introduction of technical device. Studies of workplace interventions that do not explicitly involve OSH authorities as an active or potential player were not included. Thus, intervention studies of physical and mental health training of workers at the workplace and/or treatment studies were not eligible. (iv) The study should include a relevant outcome eg, injuries, fatalities, occupational exposure, sick leave, work-related symptoms and disease and compliance. (v) The study should at best include a control group or a reference such as before-after comparisons or other types of controlled designs. Simple before-after comparisons without a control group were included to meet the call for a broader review. (vi) The study should provide quantitative measures of intervention effects with confidence intervals (CI) or provide data enabling calculation of risk estimates and associated uncertainties.

At the title and abstract screening stage, the facilities from www.covidence.org were used. One author screened all studies identified by the search according to the eligibility criteria, and three other authors

provided second screenings. Disagreements (7% of papers) between readers were resolved by consensus. Two authors screen all the gray literature from OSH and NIOSH in Covidence using the same inclusion criteria as that of journal papers except that risk estimates were not requested because most of the gray literature did not provide sufficient information to calculate risk estimates.

In an initial step, one author read the full-text of papers selected by sifting titles and abstracts; an additional author then re-reviewed the full-text of papers fulfilling the inclusion criteria. Included studies in both searches were grouped into five thematic domains: (i) introduction of OHS legislation, which considered different legislations on reduction of injuries and miscellaneous outcomes; (ii) workplace inspection with or without citations and /or penalties on injuries, compliance and compensation claims; (iii) training, such as improving knowledge of worker protection, safety and health training programs, and use of checklists and algorithms; (iv) campaigns, such as dissemination of guidelines and educational materials; and (v) introduction of technical device, such as mechanical lifting aids. See supplemental tables S3 and S4 for details of the included studies (www.sjweh.fi/show_abstract.php?abstract_id=3775).

Quality assessments

Three authors performed quality assessment and data extraction and independently scored each included study. We used a quality appraisal protocol developed by Tompa et al (4, 5) specifically for this type of review. It consists of ten items in two parts (study quality and policy lever relevance, see appendix, www.sjweh.fi/show_abstract.php?abstract_id=3775). Each item was ranked on a 5-point Likert scale. The lower of the two scores from the two raters was chosen to reach the final quality score, which was grouped into high ($\geq 70\%$), medium (50–70%) and low ($\leq 50\%$) as also used in the noted study (5).

We used a modified GRADE approach developed by the Swedish Council on Health Technology Assessment (SBU) for observational studies (10, 11) to categorize the level of evidence. Thus, in accordance with SBU, we classified the strength of evidence as strong (+++), moderately strong (+++0), limited (++00) and insufficient (+000). The implication of using the modified GRADE classification is relabeling "limited evidence" (GRADE) to "moderately strong evidence" (modified GRADE) in cases where consistent evidence was revealed though several observational studies of medium or high quality.

Statistical analysis

Even though the studies were heterogeneous with respect to study design, setting, interventions and outcomes,

we performed a meta-analysis to summarize the result from the studies within each domain. For the domain legislation, the analysis was divided into legislation to reduce injuries and legislation to reduce miscellaneous exposures and/or outcomes. The latter was excluded in the meta-analysis because it was too heterogeneous for pooling in the analysis. For inspections, we divided the analysis into injuries, compliance and compensation claims. It was not possible to extract enough meaningful estimates from the gray literature studies. These studies were used to provide supporting or conflicting evidence for the five thematic domains noted above.

We extracted risk estimates from the studies to obtain relative risks (RR), odds ratios (OR) or effect sizes (risk difference, Cohen's *d*) with 95% CI. If the relevant risk estimates were not reported but data were available, the authors of this paper computed risk estimates and CI (12,13).

Meta-analysis of the included risk estimates (with Cohen's *d* estimates transformed to OR) was performed by applying a random effect model to each of the five domains separately. Estimates from random effects models are presented regardless of tests for heterogeneity since all studies are conceptually heterogeneous. We constructed funnel plots to assess evidence for publication bias and forest plots to illustrate the summary odds-ratios from the random effect models. The summary OR is the average OR across studies weighted by the inverse variance giving more weight to large studies. All analyses were performed using R v.3.2.3 (2015-12-10) and a significance level of 0.05. We also used R to create funnel and forest plots.

Results

The literature search from electronic databases identified 14 743 unique titles and abstracts after removal of duplicates. Of the 14 743 titles and abstracts, 437 passed to full-text review and, in combination with hand search, 61 studies were retrieved for the quality assessment and data extraction. See supplemental table S3 for details of the studies, of which 18 (29.5%) were included from snowballing, which is not unusual in reviews (14). The flow diagram of peer-reviewed studies retained at each stage is presented in supplementary figure S1 (www.sjweh.fi/show_abstract.php?abstract_id=3775).

Figure S2 reveals a separate flow chart for the gray literature (www.sjweh.fi/show_abstract.php?abstract_id=3775). From the gray literature, 16 studies were retrieved for full assessment, 8 on legislation (15–22) and 8 on inspection (23–30). The included studies are shown in supplementary table S4.

Figure 1. Forest plot and risk estimates of included studies on the effects of legislation on injuries.

Study quality

Of the 50 peer-reviewed studies, 22 were graded as being of high quality according to the chosen quality assessment scheme, 28 of medium quality and 0 of low quality. The main reasons that studies fell below the high-quality rank were lack of adjustments and shortcomings in internal and external validity. The corresponding numbers for the gray literature reports were 2 of high quality, 7 of medium and 7 of low quality. Low quality was due to lack of confounder control, missing information of study population and lack of proper statistical methods.

Introduction of legislation

There were 16 studies retained in this domain: 11 were undertaken in the US (31–41), 2 in the UK (42, 43), and 1 each in Spain (44), Canada (45) and Germany (46). Of the total, 11 studies concerned injuries and fatalities. There was moderately strong evidence that the introduction of OHS legislation has an effect on reducing injuries and fatalities based on these ten medium quality studies (table 1). Studies considered the introduction of different legislations such as broad OHS regulations (31, 44, 46), self-regulation (45), machine regulation (32), mine safety regulation (34), needle stick regulation (38) vertical fall arrest standard (47), and standards introduced in manufacturing (35, 36). Violence-assault rates among hospital workers were assessed on a study where the Hospital Safety and Security Act in California in 1995 reduced assault rates by around 50% in the follow-up period (33). The majority of studies showed an interven-

tion effect with a pooled estimate for all legislation to reduce injuries (OR 0.73, 95% CI 0.62–0.86). Studies with miscellaneous outcomes included ergonomic regulations on physical exposures (37), exposure to ethylene oxide (39) and the effect of workplace exposure limits for short latency respiratory disease (43), incidence of CTS following a program for ergonomics (40), regulation to reduce latex and rubber glove allergens on skin diseases (42), and finally the effect of cameras in taxis on homicide among taxicab drivers (41). The studies of miscellaneous outcomes all favored the intervention, but they were too heterogeneous for pooling them into the meta-analysis. The gray literature showed that reduction of the threshold limit value (TLV) for laughing gas reduced the exposure afterwards (15, 17). The overall findings in the gray literature were consistent with the peer-review literature. The funnel plot for the effect of legislation on injuries indicated a lack of smaller negative studies as shown by the open circles to the right in the funnel plot (supplementary figure S3, www.sjweh.fi/show_abstract.php?abstract_id=3775).

Workplace inspections

There were 23 studies retained in this domain, 14 high and 9 medium quality studies. Of these, 17 were from the USA (48–63), and 2 from Italy (64, 65), Sweden (66, 67) and Canada (68, 69), respectively. Injuries, were examined in 14 studies, workers compensation claims in 2 studies, compliances with OSH regulation and violations in 5 studies, noise awareness and compliance in 1 study, and reducing workload and employment status as secondary prevention in 1 study. The studies considered

Table 1. Summary of findings and quality of evidence assessment according to a modified GRADE assessment (11). [MSD=musculoskeletal disorders]

Intervention domain	Outcome	GRADE assessment	
Legislation Inspection	Injuries/ Fatalities	+++0	Moderately strong
	Injuries	+++0	Moderately strong
	Compliance	+++0	Moderately strong
	Claims	++00	Limited
Training	Knowledge/practice	++00	Limited
Campaign	Injuries	++00	Limited
Device	Injuries	++00	Limited
	MSD	++00	Limited

inspection sequence (57, 63, 70), general inspection deterrence and specific deterrence with/without penalties (61), consultative activities (48, 51, 69), and supportive inspection (68). Several studies found that specific deterrence from inspections with penalties reduced final outcomes, most clearly for injuries and the intermediate outcome compliance (51, 53–56, 58, 60). Figure 2 shows the forest plot of studies on inspections for injuries (OR 0.83, 95% CI 0.73–0.93), compliance (OR 0.65, 95% CI 0.50–0.83) and compensation claims (OR 0.96, 95% CI 0.94–0.98), favoring the effect of inspections on injuries and compliance. The funnel plot for injuries did not reveal major risk of publication bias (supplementary figure S4, www.sjweh.fi/show_abstract.php?abstract_id=3775), whereas the funnel plot for compliance points to large heterogeneity of included studies (supplementary figure S5, www.sjweh.fi/show_abstract.php?abstract_id=3775). The funnel plot for compensation claims is based on very few studies, but shows no major risk of publication bias (supplementary figure S6, www.sjweh.fi/show_abstract.php?abstract_id=3775). The gray literature was consistent with the overall assessment. One high quality study from the gray literature found that inspection after an accident reduces the prevalence of accidents the following years with 9% and with 13% for serious accidents with personal injury. Inspections in enterprises with no preceding accident had no effect on the prevalence of accidents the following years (28).

The overall evaluation of inspection/enforcement activity in GRADE showed that there is moderately strong evidence for the effect of inspections on injuries and compliance with OHS legislation, and low evidence for compensation claims and other outcomes (table 1).

Training

Different forms of training were evaluated in 6 studies: 2 high quality and 4 medium quality, of which 5 came from the US (71–76) and 1 from India (77). Worker protection knowledge among vineyard workers was examined in 1 study (71) and the effect of safety and health training among construction workers in another

(73). The study from India examined education and knowledge among pesticide handlers (77), and another study examined the effect of OSHA's outreach training program for carpenters (75). Safety practices to improve machine-related safety were addressed in 1 study (74). A managerial training program to enhance awareness and compliance was studied in California (76). All the training studies favored interventions (see figure 3) with a pooled risk estimate of OR 0.29, 95% CI 0.15–0.56, because there were few studies and different types of interventions the evidence according to GRADE was limited. The funnel plot was based on few studies, but indicated a very large heterogeneity (supplementary figure S7, www.sjweh.fi/show_abstract.php?abstract_id=3775). A study not included in the pooled analysis, because no risk estimate could be extracted, showed that exposure judgment skills among hygienists could be enhanced after training and use of checklists and algorithms in a before-and-after comparison (72).

Campaigns

Campaigns were evaluated in 2 high- and 1 medium-quality study. An Italian study investigated the effect of written material and broadcasting in television and radio and on eye-injuries during a follow-up period with several unannounced inspections (78), and a US study evaluated injuries to children after active dissemination of the North American Guidelines for Children's Agricultural Tasks (79). Both studies showed an effect of the interventions, see figure 3. The funnel plot is based on very few studies and publication bias could be present (supplementary figure S8, www.sjweh.fi/show_abstract.php?abstract_id=3775).

Devices

The use of mechanical lifts at hospitals and nursing homes was considered in 3 US studies (80–82), 2 of which were high quality. The studies found that the interventions reduced injuries in general and musculoskeletal injuries, see figure 3. Publication bias cannot be ruled out (supplementary figure S9, www.sjweh.fi/show_abstract.php?abstract_id=3775).

Summary of findings

Table 1 summarizes findings and quality of evidence according to the modified GRADE statement. Most evidence was limited, mainly because of few studies. The assessment of moderately strong evidence for the effect of introduction of legislation on injuries/fatalities and inspection/enforcement activity on injuries/fatalities and compliance was due to several studies pointing in the same direction.

Figure 2. Forest plot with risk estimates and funnel plot for the effect of inspections on injuries, compliance and compensation claims.

Discussion

This review indicates that OSH activities such as the introduction and enforcement of legislation and workplace inspections are effective in reducing injuries and improving compliance. For training, campaigns and the introduction of specific technical devices there are too few studies to provide stronger evidence. Even though the evidence was evaluated as limited or moderately strong in the modified GRADE system, the picture seems rather uniform, especially regarding the introduction of legislation and workplace inspections. The GRADE system weighs randomized controlled studies as the highest evidence, but very few RCT have been performed in the OSH area. This is not surprising because it is difficult and sometimes even unethical to perform RCT at the workplace level, and the complexity of many workplace interventions and contexts render RCT unfeasible in the real world. Other alternative designs for the evaluation of occupational health interventions have recently been proposed (83).

Tompa et al (5) also reviewed the literature and used a “best evidence” synthesis to assess the strength of evidence. They concluded that there is strong evidence for several OHS policy levers in terms of reducing injuries and/or increasing compliance with legislation. A Cochrane review from 2013 (6) used the GRADE approach and assessed the quality of the evidence as low to very low.

This discrepancy between the two reviews is caused by different methodology in both quality assessment of individual studies and evidence synthesis and the use of different studies. We adopted Tompa et al's assessment of individual studies and we also used the GRADE approach, but in a modified version, where the agreement of several studies could upgrade GRADE from limited to moderately strong (11). Our use of meta-regression with pooled estimates was performed in very broad categories. The heterogeneity of studies in each of the five domains legislation, inspection, training, campaigns and device was large, with I^2 values up to 100%. Part of the strong heterogeneity is due to large differences in magnitude of effect but differences in settings, content of interventions and definition of outcomes also contribute. The pooled estimates must be interpreted with caution, but they nevertheless provide an indication of direction and magnitude of the association (84). There were 17 studies of legislation from US, UK, Spain, Canada and Germany and the results may be applicable to developed countries around the world. Legislation covered more broad regulation and some specific regulations such as self-regulation and safety standards; 11 studies investigated injuries and fatalities.

For inspections we included 23 studies from US, Italy, Sweden and Canada. In these countries, the OSH administration functions by identifying workplace hazards, promulgating rules to regulate those hazards and ensuring compliance through enforcements, such as

Figure 3. Forest plots and risk estimates for the effect of Training, campaigns and devices.

inspections, citations, and perhaps penalties for noncompliance. Initial inspections, follow-up inspections, and complaint and accident-prompted inspections resulted in higher compliance rates compared to the average effect of any other type of inspections. Inspections with citations or with more penalties resulted in fewer injuries and more compliance.

The training domain included 7 studies: 6 from the US and 1 from India. All the studies showed an effect of different forms of training. The introduction of technical devices in the form of mechanical lifts was investigated in 3 US studies, which showed a positive intervention effect. The scarcity of studies and the risk of publication bias rules out any substantive evidence statements.

In our search, we found a single study on psychosocial risk factors that was relevant according to our criteria (33). The lack of studies of interventions to prevent/reduce psychosocial risk factors and their effects on psychological health should probably be seen in the light of difficulties in both exposure assessment and valid outcomes.

A lot of effort has been put into studies about cognitive behavioral interventions, mindfulness and other individual approaches to intervene on psychological health at the workplace, but those approaches are not a part of the working environment authorities' jurisdiction and not part of this review. We found 5 studies on MSD outcomes and intervention studies to reduce MSD. One study reported that from 1998–2003 there was a reduc-

tion in reported ergonomic exposures among workplaces in the highest hazard industries after the Washington State ergonomics rule was enacted. Following the rule's repeal in 2003, however, hazardous exposures increased. While more workplaces reported taking steps to reduce exposures between 1998–2001, this gain was reversed in 2003 and 2005. Employers who took steps reported positive results in injury and absenteeism reduction (37). In another study from the same group, there was no evidence of MSD injury reduction following a state OSH program activity in the workplace in the year following the activity year. However, they found mixed evidence for a reduction of MSD injuries beginning in the second year following the program activity year and suggested that cases of MSD injuries respond more slowly to the intervention and need a longer and more delayed period of follow-up (51). In 2 studies introducing mechanical lifts in different care settings, a decreased rate of musculoskeletal injuries and reduction in lost workdays was shown (80, 81). An earlier Cochrane review on the effectiveness of manual material handling advice and training and the provision of assistive devices in preventing and treating back pain found no evidence for assistive devices (85). This discrepancy was due to inclusion of different studies and the few studies about MSD preclude any conclusions of strength of evidence, and further studies are warranted. Most intervention studies about MSD have included exercise therapy, behavioral change techniques, workplace adaptations

and provision of additional services (86), which are outside the scope of this review. Difficulties arise in this literature in defining relevant OSH regulation and defining relevant outcomes to measure. In countries with good registers, such as the Nordic countries, there are probably opportunities to investigate a variety of outcomes (eg, inspections, MSD claims and register-based disease occurrence) in a meaningful way to gain more insight.

In Denmark as well as other Western countries, a myth that OSH activities are ineffective has been around for at least a decade or more, and opponents have proposed that voluntary efforts or consultative activities would be more effective. The results from this review indicate that general and specific legislation and workplace inspections with or without penalties are indeed effective means to improve the working environment. The recommendations for OSH would be to strengthen and improve those known instruments rather than eliminate enforcement activities.

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