Interventions for preventing injuries in the construction industry (Review)

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ABSTRACT

Background
Construction workers are frequently exposed to various types of injury-inducing hazards. A number of injury prevention interventions have been proposed, yet the effectiveness of these is uncertain.

Objectives
To assess the effects of interventions for preventing injuries among workers at construction sites.

Search strategy
We searched the Cochrane Injuries Group's specialised register, CENTRAL, MEDLINE, EMBASE, PsycINFO, OSH-ROM (including NIOSHTIC and HSELINE), EI Compendex. The reference lists of relevant papers, reviews and websites were also searched. The searches were not restricted by language or publication status. All databases were searched up to June 2006.

Selection criteria
Randomized controlled trials, controlled before-after studies and interrupted time series of all types of interventions for preventing fatal and non-fatal injuries among workers at construction sites.

Data collection and analysis
Two authors independently extracted data and assessed study quality. For interrupted time series, we reanalysed the studies and used an initial effect, measured as the change in injury-rate in the year after the intervention, as well as a sustained effect, measured as the change in time trend before and after the intervention.

Main results
Five interrupted time series studies met the inclusion criteria. Three studies evaluated the effect of regulations, one evaluated a safety campaign, and one a drug-free workplace program on fatal or non-fatal injuries compared to no drug-free workplace program. The overall methodological quality was low. The regulatory interventions did not show either an initial or sustained effect on fatal or non-fatal injuries, with effect sizes of 0.69 (95% confidence interval (CI) -1.70 to 3.09) and 0.28 (95% CI 0.05 to 0.51). The safety campaign did have an initial and sustained effect, reducing non-fatal injuries with effect sizes of -1.82 (95% CI -2.90 to -0.75) and -1.30 (95% CI -1.79 to -0.80) respectively. The drug-free workplace program did have an initial and sustained effect, reducing non-fatal injuries compared to no intervention, with effect sizes of -6.74 (95% CI -10.02 to -3.54) and -1.76 (95% CI -3.11 to -0.41) respectively.

Authors' conclusions
The vast majority of technical, human factors and organisational interventions which are recommended by standard texts of safety, consultants and safety courses, have not been adequately evaluated. There is no evidence that regulations for reducing fatal and non-

fatal injuries are effective. There is limited evidence that a multifaceted safety campaign and a multifaceted drug program can reduce non-fatal injuries in the construction industry.

PLAIN LANGUAGE SUMMARY

Occupational injury rates among construction workers are the highest among the major industries. While several injury control strategies have been proposed by various organizations, their effectiveness for reducing the rate of injuries in the construction industry remains uncertain.

A systematic search of the literature was conducted on preventing occupational injuries among construction workers. The quality of the studies was assessed and the effectiveness of interventions was evaluated. Five studies were identified.

There is moderate evidence that regulation alone is not effective in preventing non-fatal and fatal injuries in the construction industry. There is limited evidence that a safety campaign and a drug-free workplace program are effective in reducing non-fatal injuries in the construction industry.

Introducing regulation alone is not effective in reducing fatal and non-fatal injuries in the construction industry. Additional strategies are needed to increase the compliance of employers and workers to the safety measures as prescribed by regulation. Continuing 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 vast majority of technical, human factors and organisational interventions which are recommended by standard texts of safety, consultants and safety courses, have not been adequately evaluated; there is an urgent need to address this gap in the evidence base.

BACKGROUND

The construction industry is a vital component of the economies of all countries around the world, employing a considerable workforce. The quality of life for construction workers and the business of excellence in construction are compromised by occupational injuries. During a ten-year follow-up, 16% of German construction workers were granted a disability pension (Arndt 2004). Injuries were one of the major causal factors for the high proportion of occupational disability, with a standardized injury ratio of 2.52 compared with the general workforce (Arndt 2004). Poor construction safety and associated fatal and non-fatal occupational injuries have been reported in many studies from around the world, including the USA (Bondy 2005; Hoonakker 2005), the UK (Haslam 2005), Taiwan (Chi 2005), Australia (Larsson 2002) and the Netherlands (Lourens 2005). Fatal injury incidence rates of four (UK) to 11.7 (USA) per 100,000 construction workers were reported in 2003 (Dong 2004b; Haslam 2005). In addition, recent reports show a non-fatal major injury (for example, fractures or eye penetration) rate of 375 per 100,000 construction workers in the UK in 2002 to 2003 (Haslam 2005), and an annual injury incidence rate for any injury of 10% in the Netherlands in 2004 (Lourens 2005). The majority of construction fatalities result from falls from heights and being struck by moving vehicles, whilst the majority of non-fatal injuries result from falls from heights and on the level, from slips and trips, and from being struck by a moving or falling object (Bentley 2006; Haslam 2005).

Construction injuries have significant financial implications. During a large construction project in the USA, direct workers' compensation costs due to slips, trips, and falls ranged from $0.04 in insulation work to $20.56 in roofing, with an average of $4.3 per $100 payroll costs (Lipscomb 2006). Medical, productivity, supervisory and liability costs further increase the financial losses (Leamon 1995; Loushine 2005). The cost of construction-related traumatic injuries further emphasises the importance of the implementation of effective health and safety interventions. Effective interventions for preventing occupational injuries should be the basis of an effective health and safety policy in the construction industry to protect the health of its workers.

Although the construction work environment and workforce will vary between projects and over time, interventions for reducing injuries are likely to work in similar ways for most construction projects. Haslam 2005 described the following five areas for interventions according to the elements of a typical construction project.

1. Worker and work team (the causal factors include worker actions and behaviour, capabilities, communication, health, and available supervision);
2. Workplace (the causal factors include site conditions and layout, work environment, work scheduling, and housekeeping);
3. Materials (the causal factors include material suitability, usability, and condition);

4. Equipment (the causal factors include equipment suitability, usability, and condition);
5. Organisation (the causal factors include construction job design, project management, construction processes, safety culture, risk management, and productivity control).

Various interventions to prevent occupational injuries have been proposed and studied (Becker 2001; Darragh 2004; Suruda 2002; Winn 2004). The effectiveness of these interventions for preventing injuries, however, remains unclear (Lipscomb 2003). Attempts have been made to summarize the effectiveness of safety interventions in other previous reviews, however, these are not up-to-date and focus on the prevention of one event, for example, falling (Hsiao 2001; Rivara 2000), or focus on one injury type (Lipscomb 2000). This review systematically summarizes the most current scientific evidence on the effectiveness of interventions to prevent injuries associated with construction work.

OBJECTIVES

To assess the effects of interventions aimed at preventing occupational injuries among workers at construction sites.

CRITERIA FOR CONSIDERING STUDIES FOR THIS REVIEW

Types of studies

Randomized controlled trials (RCTs), cluster randomized controlled trials (cRCTs), controlled before-after studies (CBAs) and interrupted time series studies (ITSs) were eligible for inclusion in this review.

Random allocation is not considered feasible for all interventions in this setting, thus we decided to include non-randomized study designs.

A study was considered to be an Interrupted time series when i) there were at least three time points before and after the intervention, irrespective of the statistical analysis used, and ii) the intervention occurred at a clearly defined point in time (EPOC 2006; Ramsay 2003).

In addition, we searched for before-after studies without a control group as well as case-reference and retrospective cohort studies. We described them and compared the results with the included studies in the discussion section.

Types of participants

The population was limited to construction workers (company workers or self-employed worker). For the purposes of this review, construction workers were defined as persons working at a construction site for building/housing/residential or road/highway/civil engineering or offices/commercial or industrial installation (for example, ventilation, pipelines and siding) work.

Construction work is generally managed at a fixed place of business (office), but construction activities are performed at (multiple) project sites. Construction work carried out by the workers includes new work, additions, alterations, or maintenance and repairs. These definitions are based on the North American Industry Classification System (NAICS 2002). Other significant areas of construction are refurbishment and demolition of building and engineering projects as well as plumbing, heating, ventilation and air conditioning work.

Types of intervention

All interventions aimed at preventing occupational injuries were included. Five categories of interventions were distinguished:

- worker and work team,
- workplace,
- materials,
- equipment,
- organization.

Types of outcome measures

For a study to be included, work-related injury must have been an outcome.

Primary outcome measures

The primary outcome measures were fatal and non-fatal occupational injuries. We used the following modified definition of injury, which was used in The Injury Chartbook by the World Health Organization (Baker 1984; Peden 2002);

"Non-fatal occupational injury is a body lesion at the organic level, resulting from acute exposure to energy (mechanical, thermal, electrical, chemical or radiant) in a work environment in amounts that exceed the threshold of physiological tolerance. In some cases (for example, drowning, strangulation, freezing), the injury results from an insufficiency of a vital element."

Injuries resulting from traffic crashes were included, if they occurred during the workers' commute to or from their construction work.

All sources of injuries data, including self-report, were considered.

Secondary outcome measure

If injuries were reported in an included study as a primary outcome measure, the following secondary outcomes were then considered if also reported:

- the number of lost working days, and
- behaviour changes, such as working habits (Van der Molen 2005).

SEARCH METHODS FOR IDENTIFICATION OF STUDIES

See: Cochrane Injuries Group methods used in reviews.

Electronic searches
We searched the following electronic databases;

- Cochrane Injuries Group's specialised register,
- Cochrane Central Register of Controlled Trials (CENTRAL),
- MEDLINE (from 1966),
- EMBASE (from 1988),
- PsycINFO (from 1983),
- OSH-ROM (including NIOSHTIC and HSELINE),
- EI Compendex (from 1990).

All databases were searched up to June 2006.

We used search terms that covered the concepts of 'construction workers' (participants), 'injury' (primary outcome measure), 'safety' (interventions) and 'study design' to identify studies in the electronic databases. Further details of how the search strategy for the electronic databases was developed are presented in Table 01.

We used the following search strategy adapted as appropriate to the specifications of each database:
#1 construction*[tiab] OR building*[tw] OR builder*[tiab]OR laborer* [tw] OR labourer* [tw] OR contractor* [tw] OR supervisor*[tw] OR "machine driver"[tw] OR "machine drivers"[tw] OR "machine operator"[tw] OR "brick mason"[tw] OR "pile driver"[tw] OR "pile drivers"[tw] OR "concrete worker"[tw] OR "concrete workers"[tw] OR "metal worker"[tw] OR "metal workers"[tw] OR "road builder"[tw] OR "road builders"[tw] OR "pipe driver"[tw] OR "pipe drivers"[tw] OR "tower crane"[tw] OR fitter*[tw] OR carpenter* [tw] OR rammer* [tw] OR scaffolder* [tw] OR bricklayer* [tw] OR pointer* [tw] OR plasterer* [tw] OR plasterpainter* [tw] OR roofer* [tw] OR plumber* [tw] OR glazier* [tw] OR screeder* [tw] OR electrician* [tw] OR tiler* [tw] OR painter* [tw] OR paviour* [tw] OR pavier*[tw] OR ironwork*[tw] OR metalwork*[tw] OR asphalt*[tw] OR roofing[tw] OR painting[tw] OR "construction materials"[MeSH] OR "facility design and construction"[MeSH]
#2 injur*[tw] OR accident*[tw] OR "accidents, occupational"[MeSH] OR "wounds and injuries"[MeSH] OR harm*[tw] OR wound*[tw] OR fall[tw] OR falling*[tw] OR burn*[tw] OR slipper*[tw] OR poison*[tw] OR fatal*[tw] OR "injuries"[MeSH Subheading]
#3 Safety[MeSH] OR "Safety Management"[MeSH] OR "prevention and control"[MeSH Subheading] OR safet*[tw] OR prevent*[tw] OR control*[tw] OR risk[tiab] OR "risk"[MeSH Term] OR "risk management"[MeSH Terms] OR "accident prevention"[MeSH Terms]
#4 = #1 AND #2 AND #3
#5 (randomized controlled trial[pt] OR controlled clinical trial[pt] OR randomized controlled trials[mh] OR random allocation[mh] OR double-blind method[mh] OR single-blind method[mh] OR clinical trial[pt] OR clinical trials[mh] OR "clinical trial"[tw] OR ((singl*[tw] OR doubl*[tw] OR trebl*[tw] OR tripl*[tw]) AND (mask*[tw] OR blind*[tw])) OR "latin square"[tw] OR placebos[mh] OR placebo*[tw] OR random*[tw] OR research design[mh:noexp] OR comparative study[mh] OR evaluation studies[mh] OR follow-up studies[mh] OR prospective studies[mh] OR cross-over studies[mh] OR control*[tw] OR prospectiv*[tw] OR volunteer*[tw]) NOT (animal[mh] NOT human[mh])
#6 = #4 AND #5
#7 (effect* [tw] OR control* [tw] OR evaluation* [tw] OR program* [tw]) NOT (animal[mh] NOT human[mh])
#8 = #4 AND #7
#9 = #6 OR #8

Other sources

We also checked the reference lists of relevant papers and searched the following websites:

- http://www.cdc.gov/elcosh/index.html;
- http://www.pubs.asce.org/journals/jrns.html;
- http://www.hse.gov.uk/research/rrhtm/index.htm;
- http://www.inrs.fr;
- http://www.arbetslivsinstitutet.se/biblioteket/default.asp;
- http://www.hvbg.de/d/bia/pub/ueb/index.html.

The searches were not restricted by language or publication status.

METHODS OF THE REVIEW

Study identification and selection
Title and abstracts were independently screened by two authors (ML and HM) to identify potentially relevant studies. The full text of these articles were assessed for eligibility against the inclusion criteria.

Disagreement was resolved by discussion. In any case that a disagreement persisted, a third author (JL) made the final decision. Articles in languages other than English were translated by a native speaker.

Data extraction and management
Data were extracted independently by two authors (ML and HM). A form was developed to extract data from each article. We extracted data on the following;

- study design ((cluster) randomized controlled trial, controlled before-after study, or interrupted time series),

- participants (number, trade, age, gender, and exposure),
- intervention (target (worker and work team, workplace, materials, equipment, or organisation), form (information, compulsion, education, facilitation, or persuasion) and content intervention),
- outcome (primary and secondary outcome, methods used to assess outcome measures, and duration of follow-up),
- setting (size of the company, culture, country, industry sub-sector, and trade and job).

Assessment of methodological quality of included studies

The quality of the included studies was independently assessed by two authors (ML and HM). For interrupted time series (ITS) studies the quality criteria developed by the EPOC Review Group (EPOC 2006) were used. The checklist questions were answered as 'done', 'not clear' or 'not done' as presented in the table 'Characteristics of included studies'.

For randomized and non-randomized studies, we intended to use the internal validity scale of Downs and Black (Downs 1998) to assess quality, however, no such study designs were found.

Disagreement was resolved by discussion between the two authors.

Measures of intervention effect

To obtain comparable and reliable effect sizes from included ITS studies, data from original papers were extracted and reanalyzed according to recommended methods for analysis of ITS designs for inclusion in systematic reviews (Ramsay 2003). These methods utilize a segmented time series regression analysis to estimate the effect of an intervention while taking into account secular time trends and any autocorrelation between individual observations. If the ITS used a control group, we used the difference in rates between the intervention and the control group as the outcome. For each study, a first order autoregressive time series model was applied to the data using a modification of the parameterization of (Ramsay 2003). Details of the mode specification are as follows:

Y= ß0+ ß1time+ ß2 (time-p) I(time > p) +ß3 I(time > p)+ E, E~ N(0, s2)

For time =1,...,T, where p is the time of the start of the intervention, I(time > =p) is a function which takes the value 1 if time is p or later and zero otherwise, and where the errors E are assumed to follow a first order autoregressive process (AR1). The parameters ß have the following interpretation:
ß1 is the pre-intervention slope.
ß2 is the difference between post and pre-intervention slopes.
ß3 is the change in level at the beginning of the intervention period, meaning that it is the difference between the observed level at the first intervention time point and that predicted by the pre-intervention time trend.

The statistical analysis was performed in Stata 9.2 for Windows (StataCorp LP, College Station, Tx USA).

Data on observations over time were derived from tables of results (Spangenberg 2002) or graphs (Derr 2001; Wickizer 2004) from the original studies, or directly from the study authors (Lipscomb 2003; Suruda 2002). All studies with fatal injuries (Derr 2001 (monthly data); Suruda 2002 (yearly data)) as an outcome were standardized into fatal injuries per 1,000,000 workers per year. The studies with non-fatal injuries (Lipscomb 2003 (quarterly data); Spangenberg 2002 (yearly data); Wickizer 2004 (quarterly data)) as outcome were standardized into injuries per 100 person-years per year. For the study from the USA (Lipscomb 2003) the denominator was converted from working hours into person-years by assuming that one person-year equals 2000 working hours. For the Danish study (Spangenberg 2002) the denominator was converted from working hours into person-years by using the calculation provided in the study, that is one person-year equals 1600 working hours.

Reanalysis with autoregressive modelling made it possible to estimate regression coefficients corresponding to two standardized effect sizes for each study: i) change in level and ii) change in slope of the regression lines before and after the intervention (Ramsay 2003). The ß parameters in the above regression model were estimated using the Prais-Winstein first order autocorrelation version of generalized least squares (GLS) regression, as implemented in the Stata software package (version 9.2). A change in level was defined as the difference between the observed level at the first intervention time point and that predicted by the pre-intervention time trend. A change in slope was defined as the difference between post- and pre-intervention slopes. The change in level stands for an immediate intervention effect and a change in slope for a sustained effect of the intervention. A negative change in level or slope represents an intervention effect in terms of a reduction in injuries.

In the controlled interrupted time series we used the difference between intervention and control group as the intervention effect in a similar way. Therefore, a negative change in level or slope represents a larger decrease in injuries in the intervention group compared to the control group.

Data were standardized by dividing the outcome and standard error by the pre-intervention standard deviation as recommended by Ramsay 2001 and entered into RevMan as effect-sizes.

Unit of analysis issues

There were no units of analysis issues in this review.

Dealing with missing data

Missing data were sought from study authors.

Assessment of heterogeneity

Methodological heterogeneity was assessed in respect to research setting, applied interventions, study design and population. Statistically, heterogeneity was examined with the I^2 statistic (notable heterogeneity when I^2 > 60%). If there was statistical

heterogeneity between studies a random effects model was used in the meta-analysis, otherwise a fixed effect model was used.

Data synthesis (meta-analysis)
Results were pooled for studies which evaluated similar interventions, participants and outcomes. Where sufficient quantitative data were available meta-analyses were performed. For ITS the standardised change in level and change in slope were used as effect measures. Meta-analysis was performed using the generic inverse variance method. The standardized outcomes were put into RevMan as effect sizes and their standard errors. Since we did not find any randomised controlled trials, there was no data synthesis conducted for these types of studies.

A rating system, based on the Levels of Evidence, was used to summarize the strength of scientific evidence for the effects of the intervention. The rating system was based on both the quality and the outcome of the studies (Van Tulder 2003):

- I. Strong evidence - consistent evidence in multiple high quality randomized controlled trials or controlled trials;
- II. Moderate evidence - consistent findings in multiple low quality randomized controlled trials, controlled trials, interrupted time series and/or one high quality randomized controlled trial;
- III. Limited evidence - one low quality randomized controlled trial or controlled trial or interrupted time series;
- IV. Conflicting evidence - inconsistent findings in multiple trials;
- V. No evidence.

The outcome of the studies was considered 'consistent' if at least 75% of the trials report statistically significant results in the same direction.

Subgroup analyses
We planned to perform subgroup analyses according to participants, interventions or settings as listed in the 'Data extraction and management' section, because safety policy and culture can vary between work places according to worker and setting characteristics. However, we did not have sufficient data to perform any subgroup analyses.

DESCRIPTION OF STUDIES

Results of the searches
Overall, 7522 references were retrieved: n = 7484 from electronic databases, n = 35 from websites and n = 3 from checking the reference list of relevant papers. The full texts of 55 potentially eligible articles were examined, of which 15 described studies of interventions for preventing fatal and/or non-fatal occupational injuries among workers at construction sites. Five studies met the inclusion criteria and are included in the review (Derr 2001; Lipscomb 2003; Spangenberg 2002; Suruda 2002; Wickizer 2004).

Included studies
Of the five included studies, four are from the USA (Derr 2001; Lipscomb 2003; Suruda 2002; Wickizer 2004) and one from Denmark (Spangenberg 2002) and were carried out in 1995, 1991, 1990 and 1996 (two studies) respectively.

Three studies evaluated the effectiveness of regulation (Derr 2001; Lipscomb 2003; Suruda 2002), one assessed a multifaceted safety campaign (Spangenberg 2002) and one appraised a multifaceted drug-free workplace program (Wickizer 2004). No studies were found that used information, education, facilitation or persuasion as the main implementation strategy.

Regulation
The regulatory interventions were implemented by means of a compulsory implementation strategy and could be characterized as an intervention requiring construction companies to execute safety measures. They targeted (where reported) workers/work team, materials, equipment, workplace and organization.

Derr 2001 is an ITS which evaluated the effect of a vertical fall arrest standard on the risk of fatal falls in construction workers. The intervention was implemented in 1995 throughout most states of the USA. The vertical fall arrest standard requires the use of personal protective equipment and establishment of a fall protection plan that covers actions to reduce the risk of falling, such as appropriate cover for openings and leading edge warnings. Outcome data were obtained from state and national administrative databases.

Lipscomb 2003 is an ITS which evaluated the effect of a vertical fall arrest standard on the risk of non-fatal injuries in carpenters. The intervention was implemented in Washington State, USA, in 1991. As for Derr 2001 the vertical fall arrest standard required the use of personal protective equipment and establishment of a fall protection plan that covers actions to reduce the risk of falling, such as appropriate cover for openings and leading edge warnings. Outcome data were obtained from state and national administrative databases.

Suruda 2002 is an ITS which evaluated the implementation of a trench and excavation standard (a regulatory intervention with a targeted inspection program) on the risk of fatal injuries in trench and excavation workers. Outcome data were obtained from national administrative databases.

Safety campaign
Spangenberg 2002 is an ITS which evaluated a safety campaign which used informative, facilitative (feedback about injury rates) and enforcing (safety inspections) implementation strategies on the risk of non-fatal injuries in construction workers. The campaign focused on workers, work teams and organization. The intervention consisted of attitudinal and behavioural aspects with

the following components: campaign mascots at the entrance of all construction sites, leaflets to new workers with the information on purpose of campaign and good practices; quarterly published newsletter with safety activities, accident cases causing injuries and preventive measures; results of the campaign on noticeboards; safety inspections of working environment, planning, training and housekeeping; financial incentive awarded to workers at the safest sites; themes on injury risks (for example, crane accidents) during working hours. Outcome data were obtained from the company's records.

Drug-free program

Wickizer 2004 is a controlled ITS which evaluated a drug-free workplace program targeted at workers, work teams and organization, on the risk of non-fatal injuries in construction workers. The intervention consisted of the following components: a formal written substance abuse policy, payment for drug testing, a worker assistance program for referral to treatment, no termination of worker employment when they agreed to receive treatment, an annual educational program on substance abuse and a minimum of two hours training for supervisors and managers. The program used informational, educational, facilitative (for example, financial incentive) and compulsory (drug testing) implementation strategies. Outcome data were obtained from state administrative databases.

See table 'Characteristics of included studies' for further details.

Excluded studies

Among the eight excluded studies, one was not about preventive measures (Spangenberg 2005); two (Dong 2004a, Kinn 2000) did not measure injury rates before and after the intervention, four were before-after studies (Altayeb 1992; Darragh 2004; Gerber 2002; Johnson 2002) and one was a retrospective cohort study (Nelson 1997). See the tables 'Characteristics of excluded studies' and Table 03 for further information.

Studies awaiting assessment

Two studies (Halperin 2001; Yassin 2004) are awaiting assessment, pending further information from the study authors.

METHODOLOGICAL QUALITY

Comments on the important methodological features of each study are presented in the table of 'Characteristics of included studies'.

Overall, the methodological quality of the three regulation studies was below the 75% limit of the total quality score for ITS studies (EPOC 2006). The quality scores were 50% with three out of the six quality criteria being met for two studies (Derr 2001; Suruda 2002) and 67% with four out of the six quality criteria being met for one study (Lipscomb 2003). The studies did not sufficiently assess time trends in the statistical analyses according to EPOC 2006 or make it clear that the intervention was independent from other changes.

The ITS study which evaluated the multifaceted safety campaign (Spangenberg 2002) had a methodological quality score of 33% with only two of the six quality criteria being met (EPOC 2006). In addition, the risk of injuries probably changed over time, because the population changed over time as the building process changed. This aspect, however, was not covered by the quality checklist.

One controlled ITS study that evaluated a drug-free workplace program (Wickizer 2004) used a non-equivalent concurrent comparison group. Therefore it was possible to classify this study also as a controlled before-after study. According to both the internal validity scale of Downs and Black's quality checklist of controlled cohort studies (Downs 1998) as well as the ITS quality checklist (EPOC 2006) the methodological quality score was low (43% and 67% respectively).

RESULTS

Effectiveness of regulation on fatal and non-fatal injuries

While all three studies (Derr 2001; Lipscomb 2003; Suruda 2002) which evaluated regulation had a downward trend of injuries over time as indicated by the significant negative pre-intervention slopes (Table 02), none showed a significant initial or sustained intervention effect in terms of a significant downward change in level or slope. On the contrary, one study showed a significant increase in level and one showed a significant increase in slope after the intervention.

The three studies were sufficiently homogeneous to be combined in a meta-analysis because the mechanism of the intervention (regulation) was assumed to have a similar effect for both fatal and non-fatal injuries. The changes in level were statistically heterogeneous (I^2 = 87.8%) and therefore pooled using a random-effects model. The changes in slope were homogeneous and were pooled using a fixed-effects model. In the meta-analysis, the confidence interval (CI) for the effect sizes of changes in level overlapped largely with zero (effect size 0.69; 95% CI -1.70 to 3.09), indicating that there was no significant effect. The considerable heterogeneity in the results can possibly be explained by the much higher initial pre-intervention level of injuries in the Derr 2001 study. The meta-analysis of the change in slope showed a small but significant effect, indicating an increase in injuries after the intervention (effect size 0.28; 95% CI 0.05 to 0.51).

In conclusion, data from the three low quality studies indicated that there is no evidence that regulation had an initial or sustained reducing effect on fatal and non-fatal injuries.

Effectiveness of a safety campaign on non-fatal injuries

One study (Spangenberg 2002) evaluated the effect of a multifaceted safety campaign aimed at promoting positive attitudes towards safety and at behavioural safety aspects at work; the study

had an upward trend of injuries over time. The study showed an initial intervention effect of a 3.75 reduction in non-fatal injuries per 100 person-years (Table 02). A sustained effect of the intervention was observed with a 2.67 reduction in non-fatal injuries per 100 person-years per year. This yielded effect sizes of -1.82 (95% CI -2.90 to -0.75) and -1.30 (95% CI -1.79 to -0.80) for initial effect and sustained effect respectively.

In conclusion, limited evidence exists for the effectiveness of a multifaceted safety campaign to prevent non-fatal injuries based on one low-quality study.

Effectiveness of a drug-free workplace program on non-fatal injuries

One study (Wickizer 2004) showed a significant initial intervention effect of a drug-free workplace program with non-fatal-injury rate difference of -7.55 per 100 person years between the intervention and control group; the study had an downward trend of injuries over time (Table 02). A sustained effect of the intervention was observed with an injury rate difference of -1.97 per 100 person-years per year between the intervention and control group. This yielded effect sizes of -6.78 (95% CI -10.02 to -3.54) and -1.76 (95% CI -3.11 to -0.41) for initial effect and sustained effect respectively.

For the intervention group alone, an initial effect of a drug-free workplace program was found with a reduction in non-fatal injuries of -4.62 per 100 person-years; no sustained intervention effect was found.

In conclusion, limited evidence exists for the effectiveness of a drug-free workplace programme to prevent non-fatal injuries based on one low-quality study.

DISCUSSION

Principal findings

We found no evidence that regulation is effective in preventing non-fatal and fatal injuries in the construction industry. Limited evidence exists showing that a multifaceted safety campaign and a multifaceted drug-free workplace program can reduce non-fatal injuries in the construction industry.

The searching in multiple databases and websites of major health and safety institutions makes it very likely that most of the published studies have been located. Publication bias due to missing of non-published negative studies is still conceivable. The inspection of the excluded lower quality studies, however, revealed that there were also relatively small studies with a reported statistically negative outcome. Therefore, it has been assumed that the risk of publication bias is low.

Implementation level and strategy

Due to the scarce description of most of the interventions, it was not possible to characterize all interventions precisely. Another concern is the lack of information about the implementation of the proposed intervention, since inadequately implemented interventions make it impossible to draw firm conclusions about the potential effectiveness.

No information was available on how and to what extent the regulatory interventions were implemented at work sites. No information was given as to the way in which employers and workers were motivated to comply with the regulation. Two regulatory studies did not report any target, and the target of the other regulatory intervention was, although not clearly defined, probably directed at the workplace, material, equipment, workers and the organization. One could argue that obligatory regulatory interventions are just organisational interventions to commit or compel employers and workers to reduce the risks for injuries. Lipscomb 2003 for example stated in the discussion section that informational and educational programs could accompany regulation. Also in a health and work ability studies, it is argued that legislation or regulation alone is not powerful enough to change attitudes and behaviour in the desired direction in today's society (Ilmarinen 2006).

The studies of the multifaceted safety campaign (Spangenberg 2002) and the drug-free workplace program (Wickizer 2004), described the content of their interventions and the corresponding implementation strategies in more detail. Spangenberg 2002 also provided information about the familiarity and appreciation of the safety campaign, but no information was provided with respect to implemented activities or performance indicators of the proposed behaviour (for example, good housekeeping). The use of drug testing in the workplace, however, has several ethical and legal controversies.

Both multifaceted intervention studies (Spangenberg 2002; Wickizer 2004) have used multiple and continuing interventions targeted on the whole work organisation (that is, workers, staff and employers), implemented by various strategies. Informational and facilitative strategies that influence the safety culture at work sites combined with enforcement such as work site inspection or obliged drug testing, were important activities in these multifaceted interventions. Other studies (for example, Neal 2000) confirmed an association between safety climate and individual safety behaviour.

In summary, for the two multifaceted intervention studies (Spangenberg 2002; Wickizer 2004) we can assume that there was some degree of implementation, however it would have been preferable if the studies had documented this quantitatively as an intermediate measure. For the regulatory studies we do not know what the implementation level was. It is possible that nobody did anything, or only the 'good' companies took action, where compliance was already high in anticipation. It should also be considered that the introduction of regulation could have encouraged companies to pay further attention to injuries, resulting in an apparent increase in incidents due to improve reporting.

Secondary effects and ethical considerations

Although the two regulation studies from the USA (Derr 2001; Lipscomb 2003), reported significant reductions in injury rates in their original studies, the overall injury rate in the USA construction industry also dropped considerably in that time period (BLS 2007; Hoonakker 2005). Reanalysis with autoregressive time series revealed no short term (level) or long term (slope) regulatory intervention effects on the reduction of injuries in the studies. However, reanalysis confirmed the reported intervention effect of a multifaceted safety campaign and the intervention effect of a controlled ITS study concerning a drug-free workplace program on injuries.

None of the included study reported changed behaviour as a secondary outcome measure. One study (Lipscomb 2003) reported a decline in the number of paid lost working days per injury as secondary outcome measure, but reanalysis of the main outcome measure revealed an underlying downward trend of injuries and no intervention effect.

Finally, in case of any drug-testing interventions, there is still the discrepancy between an employer's right to test its (new) workers versus workers' right for privacy and protection against unreasonable drug testing (Altayeb 1992).

Quantity and quality of evaluative research

No randomized controlled trials which assessed interventions for preventing injuries in the construction industry were identified. The methodological quality of all five included ITS studies was poor. Apparently, safety research in construction industry is not easy to perform. However, the magnitude of the problem with a considerably higher risk of fatal and non-fatal injuries in the construction industry warrants more efforts of both industry and researchers to perform higher quality research.

Only few qualified studies were retained out of over 7500 references. No studies were found that evaluated the vast majority of technical, human factors and organisational interventions which are recommended by standard texts of safety, safety consultants and safety courses. Examples of such interventions are: risk analysis, incident and accident analysis, reporting and resolution of dangerous situations, training courses, observation and inspection rounds, confrontation and discussion of hazardous behaviour, improvements to work methods, tools and equipment, toolbox meetings, audits, workplace logistics, preplanning and subcontractor management (coordination and information activities), safer design of buildings and constructions. This does not mean that these interventions are not effective, only that there is no proof as to whether they are or are not.

This review shows that the ITS design offers a good opportunity for the evaluation of rare or stochastic events such as fatal and non-fatal injuries when (randomized) controlled trials are not possible. However, the ITS studies should be analysed in a correct manner (Ramsay 2003). The included ITS studies did not meet the EPOC criteria for statistical analysis (EPOC 2006). To minimize bias due to the influence of time trends and due to autocorrelation among repeated measurements over time, all ITS studies in this review were reanalysed according to the EPOC criteria (EPOC 2006; Ramsay 2003). Since the construction process involves many different tasks, activities, contractors, employers and environmental conditions with different levels of injury risk exposure, future ITS designs in the construction industry, as noted by Spangenberg 2002, should also take into account the variability of the construction process in order to increase the internal validity.

Ideally, the development of an intervention is based on theories and models that illuminate the pathway of how work related injuries can be prevented. The definition and measurement of process indicators, designed for evaluating the implementation of the intervention, are necessary to determine to what extent the proposed intervention has actually been applied. Testing the association of determinants from underlying theories or models with intervention outcomes increases the insight into potentially effective elements of the intervention. Measuring the behavioural change of workers as a direct effect of the intervention along with injuries, provides a better insight into how the intervention works and also strengthens the evidence for an effect on the injury outcome (Robson 2001).

Future research in this area should focus on;
(i) defining indicators for evaluating the implementation of the intervention,
(ii) implementing the interventions in the best possible way,
(iii) measuring the behavioural change of workers as a direct result of the intervention process,
(iv) measuring fatal and non-fatal injuries as main outcome variable for evaluating the effectiveness of the intervention
(v) testing the association of behavioural changes with the main outcome measures.

AUTHORS' CONCLUSIONS

Implications for practice

The three included regulatory studies of trench plus excavation standard and fall arrest standard did not provide evidence of effectiveness of regulations to reduce fatal and non-fatal injuries in the construction industry. There appear to be a need for additional strategies to maximise the compliance of employers and workers to the safety measures as prescribed by regulation. Multifaceted and continuing interventions, such as a targeted safety campaign or a drug-free workplace program, may be effective for reducing injuries in the longer term. Trying to influence the safety culture and the enforcement of the implementation of safety measures at worksites among management and construction workers appear to be important activities in these multifaceted interventions.

Implications for research

In the construction industry, more studies are needed to establish the effect of various safety interventions on both the implementation of safety measures as well as on fatal and non-fatal injuries. Studies with interrupted time series over several years, a high internal validity and a correct statistical analysis are feasible, and therefore, should be applied more often to evaluate the effectiveness of safety interventions on fatal and non-fatal injuries.

POTENTIAL CONFLICT OF INTEREST

None known.

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** Indicates the major publication for the study*

TABLES

Characteristics of included studies

Study	**Derr 2001**
Methods	ITS based upon 5 years before and 5 years after intervention; monthly data Intervention independent of other changes: NOT CLEAR Reliable statistical inference: NOT DONE Intervention unlikely to affect data collection: DONE Blinded assessment of outcome variable: DONE Completeness of data set: NOT DONE Reliable primary outcome measure: DONE
Participants	Construction workers (n= not clearly reported)
Interventions	Fall protection standard issued in 1995 Target: not reported, but probably same as reported in Lipscomb 2003 Form: compulsion by legislation
Outcomes	Fatal falls per 1,000,000 workers (per year)

Characteristics of included studies (*Continued*)

	50 (1990), 48 (1991), 45 (1992), 41 (1993), 45 (1994), 46 (1995), 45 (1996), 48 (1997), 40 (1998), 42 (1999)
Notes	Scaffolds, stairways and ladders were excluded in the standard
Allocation concealment	D – Not used

Study	**Lipscomb 2003**
Methods	ITS based upon 2 years before and 8 years after intervention, quarterly data Intervention independent of other changes: NOT CLEAR Reliable statistical inference: NOT DONE Intervention unlikely to affect data collection: DONE Blinded assessment of outcome variable: DONE Completeness of data set: DONE Reliable primary outcome measure: DONE
Participants	Carpenters (n=16,215)
Interventions	Vertical Fall Arrest Standard issued in 1991 requiring personal protective equipment, fall protection plan, risk reducing activities Target: worker/work team, equipment, workplace, organization Form: compulsion by legislation
Outcomes	Fall related injuries per 100 person-years (per year) 3.85 (1989), 3.15 (1990), 2.85 (1991), 2.80 (1992), 2.31 (1993), 2.15 (1994), 1.86 (1995), 1.21 (1996), 1.58 (1997), 1.45 (1998)
Notes	Only union workers were included (n= not clearly reported)
Allocation concealment	D – Not used

Study	**Spangenberg 2002**
Methods	ITS based upon 3 years before and 3 years during intervention, yearly data Intervention independent of other changes: NOT CLEAR Reliable statistical inference: NOT DONE Intervention unlikely to affect data collection: DONE Blinded assessment of outcome variable: NOT CLEAR Completeness of data set: DONE Reliable primary outcome measure: NOT CLEAR
Participants	Construction workers (n=4,250 man-years) involved in demolition, excavation, tunnels, bridges and finishing
Interventions	Multifaceted safety campaign issued in 1996 including attitudinal and behavioural aspects (e.g., newsletter, best practices, safety inspections, financial safety award, themes on injury risks) Target: worker/work team, organization Form: information, facilitation (feedback), enforcement (inspection)
Outcomes	Injuries per 100 person-years (per year) 2.98 (1993), 3.70 (1994), 6.86 (1995), 5.34 (1996), 3.74 (1997), 4.80 (1998)
Notes	Majority of construction workers had project assignment less than a year
Allocation concealment	D – Not used

Study	**Suruda 2002**
Methods	ITS based upon 6 years before and 6 years after intervention; yearly data Intervention independent of other changes: NOT CLEAR Reliable statistical inference: NOT DONE Intervention unlikely to affect data collection: DONE

	Blinded assessment of outcome variable: DONE Completeness of data set: NOT CLEAR Reliable primary outcome measure: DONE
Participants	Construction workers about 5 million
Interventions	Trench & excavation standard issued in 1990 Target: not reported Form: compulsion by legislation
Outcomes	Fatal injuries per 1,000,000 workers (per year) 15.59 (1984), 16.29 (1985), 13.50 (1986), 13.73 (1987), 10.94 (1988), 10.94 (1989), 9.54 (1990), 5.82 (1991), 5.82 (1992), 6.52 (1993), 7.45 (1994), 5.35 (1995)
Notes	Construction firms fewer than 11 workers were exempt from routine legislative inspections
Allocation concealment	D – Not used

Study	**Wickizer 2004**
Methods	Controlled ITS based upon 3 years before, 3 years during and 1 year after intervention; quarterly data Intervention independent of other changes: NOT CLEAR Reliable statistical inference: NOT DONE Intervention unlikely to affect data collection: DONE Blinded assessment of outcome variable: DONE Completeness of data set: DONE Reliable primary outcome measure: DONE
Participants	Construction workers (at follow-up: intervention group n=3,305 person-years; control group n=65,720 person-years)
Interventions	Drug-free workplace program issued in 1996 including formal policy, drug testing, treatment, worker assistance, education workers, supervisors and managers Target: worker / work team, organization Form: information, education, facilitation (financial incentives), enforcement (drug testing),
Outcomes	Injuries per 100 person-years (per year) Intervention; 29.03 (1994), 28.09 (1995), 26.28 (1996), 24.21 (1997), 18.08 (1998), 20.90 (1999), 20.53 (2000) Control; 30.58 (1994), 27.68 (1995), 25.92 (1996), 26.48 (1997), 26.21 (1998), 25.42 (1999), 26.62 (2000) Change; 1.55 (1994), -0.41 (1995), -0.37 (1996), 2.26 (1997), 7.34 (1998), 4.52 (1999), 6.08 (2000)
Notes	Enrolment in the study was awarded with 5% discount in workers' compensation premiums for up to three years 43% methodological score on internal validity scale of Downs and Black's (Downs 1998) quality checklist of controlled studies
Allocation concealment	D – Not used

Characteristics of excluded studies

Study	**Reason for exclusion**
Altayeb 1992	Before-after study without a control group.
Darragh 2004	Before-after study without a control group.
Dong 2004a	Retrospective cohort study, but measurements did not take place before the intervention.
Gerber 2002	Before-after study without a control group.

Characteristics of excluded studies (*Continued*)

Johnson 2002	Before-after study without a control group.
Kinn 2000	Retrospective cohort study; unclear if measurements were taken before and after the intervention.
Nelson 1997	Retrospective cohort study.
Spangenberg 2005	Not preventive intervention.

ADDITIONAL TABLES

Table 01. Development of the search strategy

Preliminary searches were done in PubMed to define useful terms for the search strategy. This revealed that searches could be made sensitive but not specific enough. We developed the definitions described below.
Search terms for types of participants: working at construction sites
The search term construction is truncated as construction* according to the industry name not as construct*, since many other things can be constructed for example, vectors or plasmids in the biochemistry field. The terms "construction industry" or "construction worker" are not used in order to make the search not too specific.
Many articles mentioned the word building instead of the term construction, which is why the term building* was added as a search term.
It is possible that there are articles including neither construction nor building. This is why the most important job titles (trades) were included in the search strategy used in the study by Koningsveld and Van der Molen (Koningsveld 1997). In addition we added the following job titles that appeared many times in the articles found in the preliminary searches: laborer/labourer and contractor.
The terms construction, building and job titles like carpenter are also used for other purposes such as a surname or in a company or street name (location), and that is why the search words concerning the population are followed by a search tag [tiab] (title abstract) or [tw] (text word).
Search terms for outcome: injury
The primary outcome in the search strategy was defined as an injury and the term is truncated as injur* to make it sensitive enough. Also the terms accident and safety were taken into account. Accident was truncated as accident* to make it sensitive enough.
Search terms for interventions
Intervention in the search strategy was defined as any kind of intervention related to safety management, risk management or accident prevention applied to decrease the rate or severity of injuries. Terms resembling these kinds of interventions were selected for this part of the search strategy.
Search terms for study design
For study design, two search strategies were used to find (cluster) randomized controlled trials and prospective non-randomized controlled trials or interrupted time series; for the discussion section the last strategy, search #7, will also be used to find before-after studies and case-reference studies. For randomized controlled trials we will use the strategy described by Robinson and Dickersin (Robinson 2002) and for non-randomised studies the strategy described by Verbeek et al. (Verbeek 2005).

Table 02. Results from reanalysis of the ITS studies; all outcomes as injuries / 100 p-y.

Study	Pre-int level m(sd)	Change level (SE)	Pre-int slope (SE)	Change slope (SE)	Autocorrelation
Derr 2001	45.80 (3.42)	8.16 (2.18)	-1.97 (0.51)	0.28 (0.67)	-0.64
Lipscomb 2003	3.50 (0.49	0.39 (0.57)	-0.70 (0.35)	0.47 (0.35)	-0.08
Spangenberg 2002	3.34 (2.06)	-3.75 (1.13)	2.17 (0.43)	-2.67 (0.52)	-0.82
Suruda 2002	14.01 (2.09)	-2.18 (1.17)	-1.10 (0.23)	0.76 (0.31)	-0.37
Wickizer 2004: Intervention	27.80 (1.40)	-4.62 (2.43)	-0.79 (0.98)	0.13 (1.01)	-0.70
Wickizer 2004: Control	28.06 (2.35)	2.93 (0.61)	-2.25 (0.24)	2.01 (0.25)	-1.25
Wickizer 2004: Int-Con	0.26 (1.12)	-7.55 (1.85)	-1.50 (0.75)	-1.97 (0.77)	-0.83

Table 03. Characteristics of excluded before-after and retrospective studies

Study ID	Methods	Participants	Interventions	Outcome per 100 py
Altayeb 1992	Before-after study	Construction workers (31 companies, no control group	Drug testing programs issued during 1985-1988 in USA	Number of injuries Before: 11.2 After: 9.1 Absolute change: 2.1
Darragh 2004	Before-after study	Residential construction workers (97 companies, no control group)	Safety education and training program, issued in 1997 in USA (also booklet, focused inspection and financial incentives were used)	Number of injuries: Before: 17.4 After: 14.7 Absolute change: 2.7 Number of lost work day injuries (LWDI) Before: 5.8 After: 3.5 Absolute change: 2.3 Number of LWDI and medical cost Before: 3.8 After: 2.2 Absolute change: 1.6
Gerber 2002	Before-after study	Construction workers (49 companies, no control group)	Drug-testing programs issued during 1985-1999 in USA	Number of injuries Before: 8.9 After: 4.4 Absolute change: 4.5 Number of injuries Before: 8.9 After: 4.4 Absolute change: 4.5
Johnson 2002	Before-after study	Carpenters and drywall tapers from variety of ethnic backgrounds (5 administrators plus 50 workers, no control group)	A job safety program (toolbox, training, stress management techniques) issued in 1998 in USA	Number of injuries Before: 26.8 After: 12.9 Absolute change: 13.9 Number of lost days Before: 23.5 After: 2.4 Absolute change: 21.1
Nelson 1997	Retrospective cohort study	Construction workers (784 employers, control group of 8301 employers)	Washington State fall protection standard, violation during 1991-1992 in USA	Number of fall injuries Before intervention group: 1.8 Before control group: 1.0 After intervention group: 1.4 After control group: 1.0 Absolute change difference between intervention and control group: 0.4

ANALYSES

Comparison 01. Regulation

Outcome title	No. of studies	No. of participants	Statistical method	Effect size
01 Level	3		Effect Size (Random) 95% CI	0.69 [-1.70, 3.09]
02 Slope	3		Effect Size (Fixed) 95% CI	0.28 [0.05, 0.51]

Comparison 02. Safety campaign

Outcome title	No. of studies	No. of participants	Statistical method	Effect size
01 Level			Effect Size (Fixed) 95% CI	Subtotals only
02 Slope			Effect Size (Fixed) 95% CI	Subtotals only

Comparison 03. Drug-free workplace program

Outcome title	No. of studies	No. of participants	Statistical method	Effect size
01 Level			Effect Size (Fixed) 95% CI	Subtotals only
02 Slope			Effect Size (Fixed) 95% CI	Subtotals only

COVER SHEET

Title	Interventions for preventing injuries in the construction industry
Authors	van der Molen HF, Lehtola MM, Lappalainen J, Hoonakker PLT, Hsiao H, Haslam R, Hale AR, Verbeek J
Contribution of author(s)	Henk van der Molen was involved in designing and writing the review. Marika Lehtola was involved in the conception and drafting of the protocol, designing and running the searches, the inclusion of studies, the data extraction and commented on all drafts of the review. Jos Verbeek designed and performed the data-analysis and commented on all drafts. Jorma Lappalainen, Peter Hoonakker, Hongwei Hsiao, Roger Haslam, Andrew Hale commented on all drafts of the review and assisted with the data collection
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Date new studies sought but none found	Information not supplied by author
Date new studies found but not yet included/excluded	Information not supplied by author
Date new studies found and included/excluded	Information not supplied by author
Date authors' conclusions section amended	Information not supplied by author
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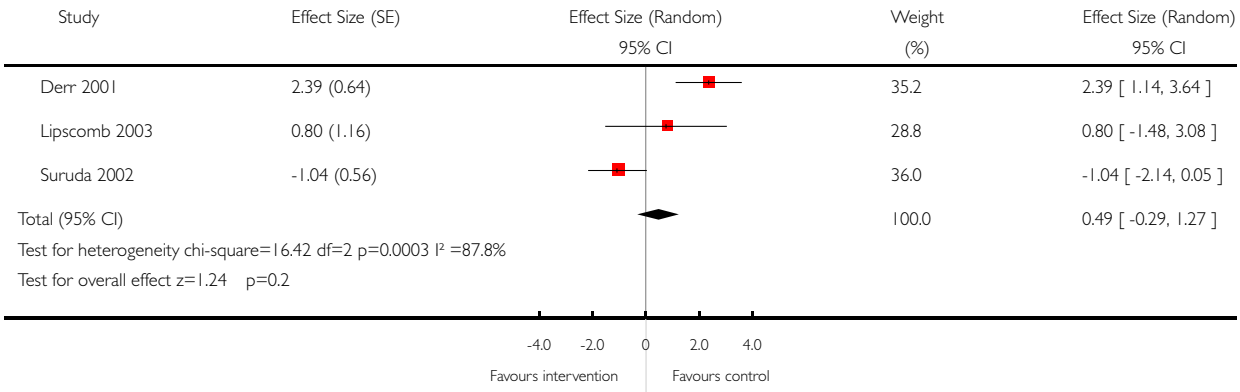
GRAPHS AND OTHER TABLES

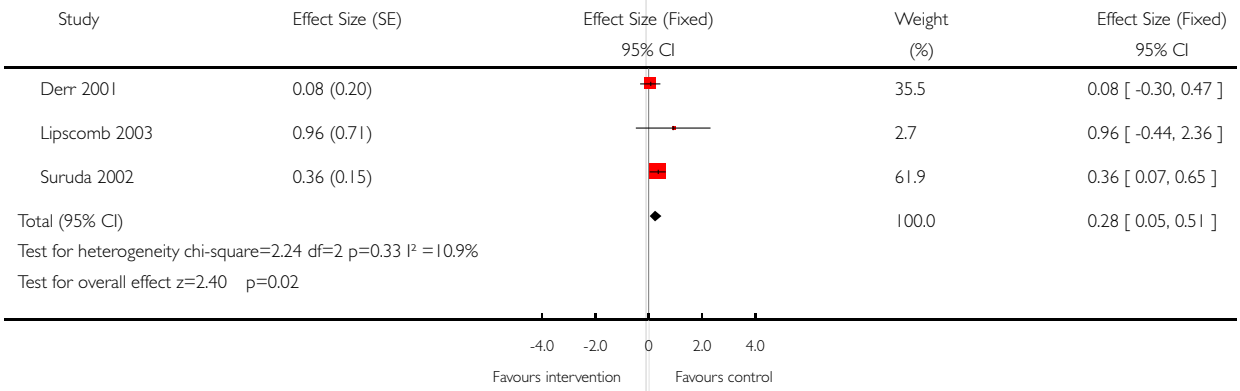
Analysis 01.01. Comparison 01 Regulation, Outcome 01 Level

Review: Interventions for preventing injuries in the construction industry
Comparison: 01 Regulation
Outcome: 01 Level



Analysis 01.02. Comparison 01 Regulation, Outcome 02 Slope

Review: Interventions for preventing injuries in the construction industry
Comparison: 01 Regulation
Outcome: 02 Slope

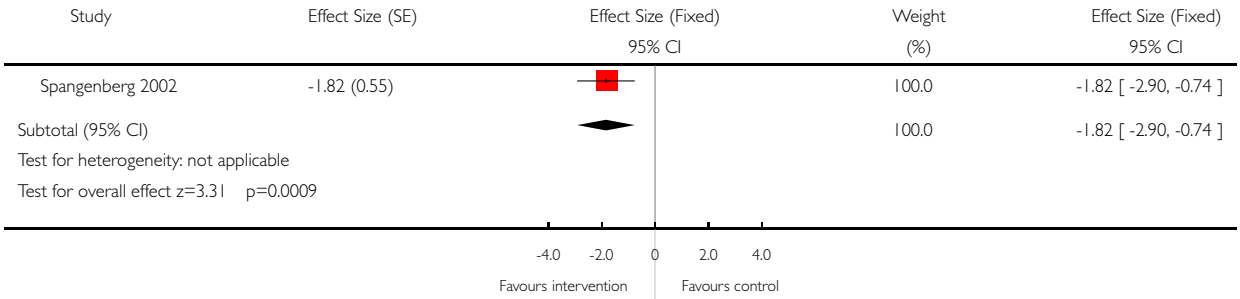


Analysis 02.01. Comparison 02 Safety campaign, Outcome 01 Level

Review: Interventions for preventing injuries in the construction industry

Comparison: 02 Safety campaign

Outcome: 01 Level



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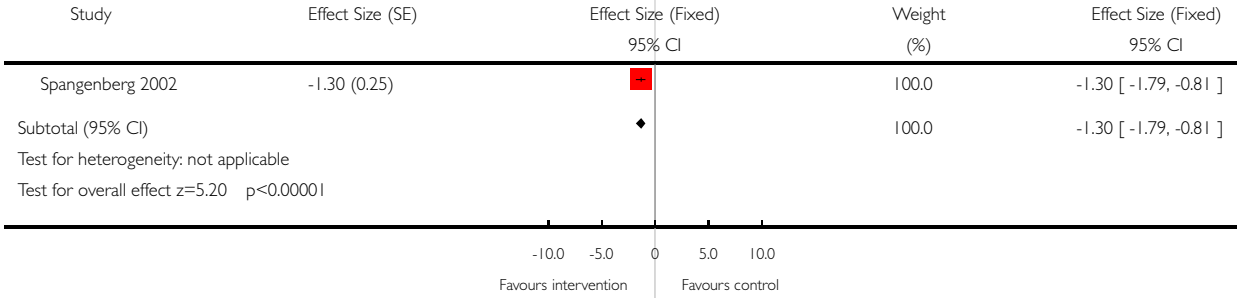
Review: Interventions for preventing injuries in the construction industry

Comparison: 02 Safety campaign

Outcome: 02 Slope

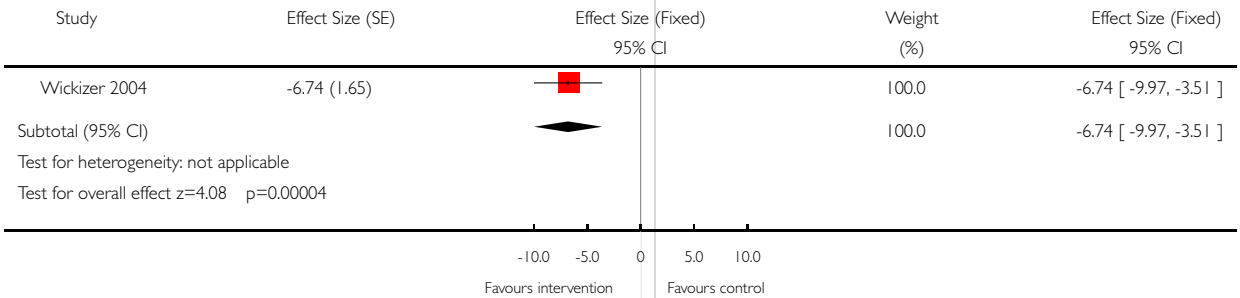


Analysis 03.01. Comparison 03 Drug-free workplace program, Outcome 01 Level

Review: Interventions for preventing injuries in the construction industry

Comparison: 03 Drug-free workplace program

Outcome: 01 Level



Analysis 03.02. Comparison 03 Drug-free workplace program, Outcome 02 Slope

Review: Interventions for preventing injuries in the construction industry

Comparison: 03 Drug-free workplace program

Outcome: 02 Slope