The Effectiveness of Interventions for Preventing Injuries in the Construction Industry
A Systematic Review

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Background: Occupational injury rates among construction workers are the highest among the major industries. A number of injury-prevention interventions have been proposed, yet the effectiveness of these is uncertain. Thus a systematic review evaluating the effectiveness of interventions for preventing occupational injuries among construction workers was conducted.

Methods: Seven databases were searched, from the earliest available dates through June 2006, for published findings of injury prevention in construction studies. Acceptable study designs included RCTs; controlled before–after studies; and interrupted time series (ITS). Effect sizes of similar interventions were pooled into a meta-analysis in January 2007.

Results: Of 7522 titles found, four ITS studies and one controlled ITS study met the inclusion criteria. The overall methodologic quality was low. No indications of publication bias were found. Findings from a safety-campaign study and a drug-free-workplace study indicated that both interventions significantly reduced the level and the trend of injuries. Three studies that evaluated legislation did not decrease the level (ES 0.69; 95% CI=−1.70, 3.09) and made the downward trend (ES 0.28; 95% CI=0.05, 0.51) of injuries less favorable.

Conclusions: Limited evidence was found for the effectiveness of a multifaceted safety campaign and a multifaceted drug program, but no evidence was found that legislation is effective to prevent nonfatal or fatal injuries in the construction industry.
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Introduction

Construction workers are frequently exposed to various types of injury-inducing hazards. Poor construction safety and associated fatal and nonfatal occupational injuries have been reported in many studies around the world.[1–6] In 2003 the fatal injury incidence rates of 4.0 (UK) to 11.7 (U.S.) per 100,000 construction workers were reported.[3,7] The majority of construction fatalities result from falls from heights and from being struck by moving vehicles, while the majority of nonfatal injuries result from falls from heights, from slips and trips on the level, and from being struck by a moving or falling object.[3,8]

The construction industry is an important industry worldwide, in terms of its contribution to both employment and regional and national economies. The costs related to occupational incidents can be substantial. Direct workers' compensation costs due to slips, trips, and falls varied from $0.04 in insulation work to $20.56 in roofing, with an average of $4.3 per $100 payroll costs during a large construction project in the U.S.[9] Indirect costs related to medical expenses, productivity, supervisory, and liability costs increase the financial losses even more.[6,10] Thus, effective interventions to prevent occupational injuries are the basis of an effective health and safety policy to ensure the health of construction workers and to reduce the societal burden related to direct and indirect occupational injury costs.

Various interventions to prevent occupational injuries have been proposed and studied, such as organizational interventions, safety programs, incentives, and legislation.[11–14] However, the effectiveness of these

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Table 1. Methodologic quality

Study	Intervention is independent from other changes	Reliable statistical inference enabled	Intervention was unlikely to affect data collection	Blinded assessment of outcome variable existed	Completeness of the data set taken into account	Reliable primary outcome measure used	Total
Derr (2001)[27]	0	0	1	1	0	1	3/6
Lipscomb (2003)[15]	0	0	1	1	1	1	4/6
Spangenberg (2002)[28]	0	0	1	0	1	0	2/6
Suruda (2002)[13]	0	0	1	1	0	1	3/6
Wickizer (2004)[29]	0	0	1	1	1	1	4/6

interventions on occupational injuries remains unclear.[15] Attempts have been made to summarize the effectiveness of safety interventions in some reviews, but these reviews are not systematically updated, and they typically focus on the prevention of one injury-related event (e.g., falling,[16,17]), or on one source of injury or injury type.[18] This review systematically summarizes the most current scientific evidence on the effectiveness of interventions to prevent the occupational injuries associated with construction work.

Methods

The methods described in the Cochrane Handbook[19] were used to collect the best currently available evidence from evaluation studies on the topic and to report the findings by synthesizing the evidence in the best possible way. If sufficiently homogenous, studies are combined in a meta-analysis whenever statistically possible to get more precise results.[19]

Searching Trials

The search terms *construction workers, injury, safety*, and *study design* were used in the search strategy. The strategy was created by combining the most important job titles[20] with the method of Robinson and Dickersin[21] for RCTs and the method of Verbeek et al. [22] for nonrandomized studies. Seven databases were searched through June 2006: MEDLINE (from 1966); EMBASE (from 1988); OSH-ROM (including NIOSHTIC and HSELINE); the Cochrane Central Register of Controlled Trials; the Cochrane Injuries Group's specialized register; PsycINFO (from 1983); and the Ei Compendex® (from 1990). Also, topic-related websites were searched. Trials in any language were considered for inclusion.

Eligibility of Studies

For inclusion, the study participants had to be construction workers on one of these types of construction sites: building/housing/residential; road/highway/civil engineering; offices/commercial; or industrial installations. All types of interventions that had fatal or nonfatal injuries reported as outcome measure were included. Only RCTs; cluster RCTs; controlled before–after studies; and interrupted time-series (ITS) studies were eligible. Other study designs were considered to be too much prone to bias to be used as evidence of effectiveness.

Methodologic Quality

The quality criteria developed by the Effective Practice and Organization of Care (EPOC) review group were used as a framework for judging the methodologic quality of ITS studies.[23] Checklists, like EPOC's quality criteria, were used for assessing the strengths and weaknesses of the study design, and especially the vulnerability of the study to different biases. Six standard criteria were used for the quality assessment (Table 1), and each criterion was scored with 1 point if it was met and with 0 if it was unclear or not met. The Downs and Black checklist[24] was intended to be used for randomized and nonrandomized studies, but these types of studies were not found.

Data Extraction

Data extraction and all other assessments were done independently.

Measuring Intervention Effect

In order to obtain comparable and reliable effect sizes from ITS studies, data from original papers were extracted and re-analyzed, according to the recommended methods, in December 2006.[25] 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 among individual observations. If a control group was used for the ITS study, the difference in rates between the intervention and the control group was used.

Re-analysis made it possible to estimate regression coefficients corresponding to two standardized effect sizes for each study: a change in level and a change in trend before and after the intervention.[25] 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 trend was defined as the difference between post- and pre-intervention slopes. A negative change in level or trend represents an intervention effect in terms of a reduction in injuries both in the uncontrolled and controlled interrupted time series. Data were standardized by dividing the outcome and SE by the pre-intervention SD as recommended by Ramsay (C. Ramsay, poster presentation, 9th Annual Cochrane Colloquium, 2001), and entered into the Review Manager (RevMan) 4.2 computer program as effect sizes and SEs.

Data Synthesis

Results were pooled in January 2007 for studies that evaluated similar interventions, participants, and outcomes. Where sufficient quantitative data were available, meta-analyses were performed. For interrupted time series, the standardized changes in level and trend were used as effect measures. Meta-analysis was performed, using the generic inverse variance method of RevMan 4.2. If the outcomes were heterogeneous as indicated by an $I^2>50\%$, a random-effects model was used in the meta-analysis; otherwise a fixed-effects model was used.

Results

Selection of Studies Meeting the Inclusion Criteria

Altogether 7522 titles were found from the search of the seven databases (7484), from websites (35) and by the reference-list checking of relevant papers (3). After the titles and abstracts had been screened for eligibility, 55 potential full articles were evaluated more closely. One study is awaiting assessment[26] because of insufficient outcome data. Neither RCTs nor controlled before–after studies were found, but five interrupted time-series studies were identified. Thus, four ITS[13,15,27,28] and one controlled ITS study[29] were included in the review.

Description of Included Studies

Three of the included primary studies[13,15,27] evaluated the injury-reducing effect of legislation; one[28] evaluated a multifaceted safety campaign; and one[29] evaluated a multifaceted drug-free-workplace program (Table 2). Two of the three legislative intervention studies evaluated the intervention effect on fatal injuries and one study on nonfatal injuries. The multifaceted safety campaign and drug-free-workplace program evaluated the intervention effect on nonfatal injuries. Four of the five included studies utilized state or national administrative databases.

The legislative interventions aimed to reduce the risks of falls in general by implementing a vertical fall arrest standard,[15,27] and to reduce the risks of trench cave-in by implementing a trench and excavation standard with a targeted inspection program.[13] The intervention of the multifaceted safety campaign study consisted of many attitudinal and behavioral aspects (e.g., leaflets to new workers; a quarterly published newsletter with safety activities, accident cases that caused injuries, and preventive measures; safety inspections; and financial incentives).[28] The drug-free-workplace program on alcohol and drugs consisted also of different components: a formal written substance-abuse policy, a worker-assistance program for referral to treatment, no termination of employment when a worker agreed to receive treatment, and training for supervisors and managers.[29]

Methodologic Quality of Included Studies

None of the studies could show that their interventions were independent from other changes, or that they had reliable statistical inferences. The highest quality score was 4 points of a maximum of 6, so the aggregate quality score of the included studies was below 67% (Table 1).

Intervention Effectiveness of Included Studies

Three legislation intervention studies[13,15,27] were homogenous enough (study design, participants, intervention, and outcomes) and provided sufficient quantitative data for meta-analysis. Two other studies[28,29] had different intervention types and could not be combined.

Effectiveness of Legislation on Fatal and Nonfatal Injuries

Re-analysis of results of the original studies. While all three studies[13,15,27] that evaluated legislation had a downward trend of injuries over time pre-intervention (Table 3), none of them showed a significant downward change in level or trend. To the contrary, one study[27] showed a significant increase in level, and one[13] showed a significant increase in trend after the intervention.

Meta-analysis of the re-analyzed studies. The three studies were sufficiently homogeneous to be combined in a meta-analysis because the mechanism of the intervention (legislation) was thought to have a similar effect for both fatal and nonfatal injuries. In the meta-analysis, the CI for the effect sizes of changes in level overlapped largely with 0, indicating that there was no significant effect (Figure 1). The considerable heterogeneity in the results can possibly be explained by the much higher initial pre-intervention level of injuries in the Derr et al.[27] study (Table 3). The meta-analysis of the change in trend showed a small but significant effect, indicating an increase in injuries after the intervention.

In conclusion, data from these three low-quality studies indicated that there was no evidence that legislation had an initial effect on the level of injuries, but legislation was associated with a less favorable downward trend than pre-intervention.

Effectiveness of a Safety Campaign on Nonfatal Injuries

Re-analysis of results of the original study. One study[28] evaluated the effect of a multifaceted safety campaign aimed at promoting positive attitudes toward safety and at promoting behavioral safety aspects at work. The study had an upward trend of injuries over time pre-intervention (Table 3). The study showed an initial intervention reduction of 3.75 nonfatal injuries per 100 person-years. A progressive effect of the intervention was observed with a 2.67 reduction in nonfatal injuries per 100 person-years per year. This yielded effect sizes of −1.82 (95% CI=−2.90, −0.74) and −1.30 (95%

Table 2. Characteristics of the included studies

Study	Participants, country	Intervention and form of intervention	Study design	Outcomes and used data points
Derr (2001)[27]	Construction workers in 50 states in U.S. (*n*=not clearly reported)	Fall-protection standard issued in 1995; compulsion by legislation	ITS based on 5 years before and 5 years after intervention	Fatal falls per 1,000,000 workers (per year): 50 (1990;); 48 (1991;); 45 (1992;); 41 (1993); 45 (1994); 46 (1995); 45 (1996); 48 (1997); 40 (1998); 42 (1999)
Lipscomb (2003)[15]	16,215 carpenters in U.S.	Vertical Fall Arrest Standard issued in 1991 requiring personal protective equipment, fall-protection plan, and risk-reducing activities; compulsion by legislation	ITS based on 2 years before and 8 years after intervention	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)
Spangenberg (2002)[28]	Construction workers in Denmark involved in demolition, excavation, tunnels, bridges, and finishing work (*n*=4250 man-years)	Multifaceted safety campaign issued in 1996 including attitudinal and behavioral aspects (e.g., newsletter, best practices, safety inspections, financial safety award, themes on injury risks); information; facilitation (feedback); enforcement (inspection)	ITS based on 3 years before and 3 years after intervention	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)
Suruda (2002)[13]	About 5 million construction workers in 47 states in U.S.	Trench and excavation standard issued in 1990; compulsion by legislation	ITS based on 6 years before and 6 years after intervention	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)
Wickizer (2004)[29]	Construction workers (at follow-up, intervention group: *n*=3305 person-years; control group: *n*=65,720 person-years)	Drug-free-workplace program issued in 1996 including formal policy; drug testing; treatment; worker assistance; education workers; supervisors, and managers; information; education; facilitation (financial incentives); enforcement (drug testing)	Controlled ITS based on 3 years before, 3 years during, and 1 year after intervention	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)

ITS, interrupted time series

Table 3. Results from re-analysis of the ITS studies; all outcomes in number of injuries/100 person-years

Study	Pre-intervention level M (SD)	Change in level (SE)	Pre-intervention trend (SE)	Change in trend (SE)	Autocorrelation
Derr (2001)[27]	45.80 (3.42)	8.16 (2.18)	−1.97 (0.51)	0.28 (0.67)	−0.64
Lipscomb (2003)[15]	3.50 (0.49	0.39 (0.57)	−0.70 (0.35)	0.47 (0.35)	−0.08
Spangenberg (2002)[28]	3.34 (2.06)	−3.75 (1.13)	2.17 (0.43)	−2.67 (0.52)	−0.82
Suruda (2002)[13]	14.01 (2.09)	−2.18 (1.17)	−1.10 (0.23)	0.76 (0.31)	−0.37
Wickizer (2004)[29]: intervention group[a]	27.80 (1.40)	−4.62 (2.43)	−0.79 (0.98)	0.13 (1.01)	−0.70
Wickizer (2004)[29]: control group[a]	28.06 (2.35)	2.93 (0.61)	−2.25 (0.24)	2.01 (0.25)	−1.25
Wickizer (2004)[29]: intervention minus control group[a]	0.26 (1.12)	−7.59 (1.85)	−1.50 (0.75)	−1.97 (0.77)	−0.83

[a]This study was the only one to have a control group, and the end result reporting the change was calculated as injury rate difference in statistical program: injury rate of the intervention group minus injury rate of the control group.
ITS, interrupted time series

CI=−1.79, −0.81) for initial effect and progressive effect, respectively.

Effectiveness of a Drug-Free-Workplace Program on Nonfatal Injuries

Re-analysis of results of the original study. One study[29] showed a significant initial intervention effect of a drug-free-workplace program with a nonfatal-injury rate difference of 7.59 per 100 person-years between the intervention and control group (Table 3). The study had a downward trend of injuries over time pre-intervention. A progressive 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=−10.01, −3.55) and −1.76 (95% CI=−3.11, −0.41) for initial effect and progressive effect, respectively.

Discussion

In this review evidence was found that a multifaceted safety campaign, as well as a multifaceted drug-free-workplace program, reduce nonfatal injuries, but no

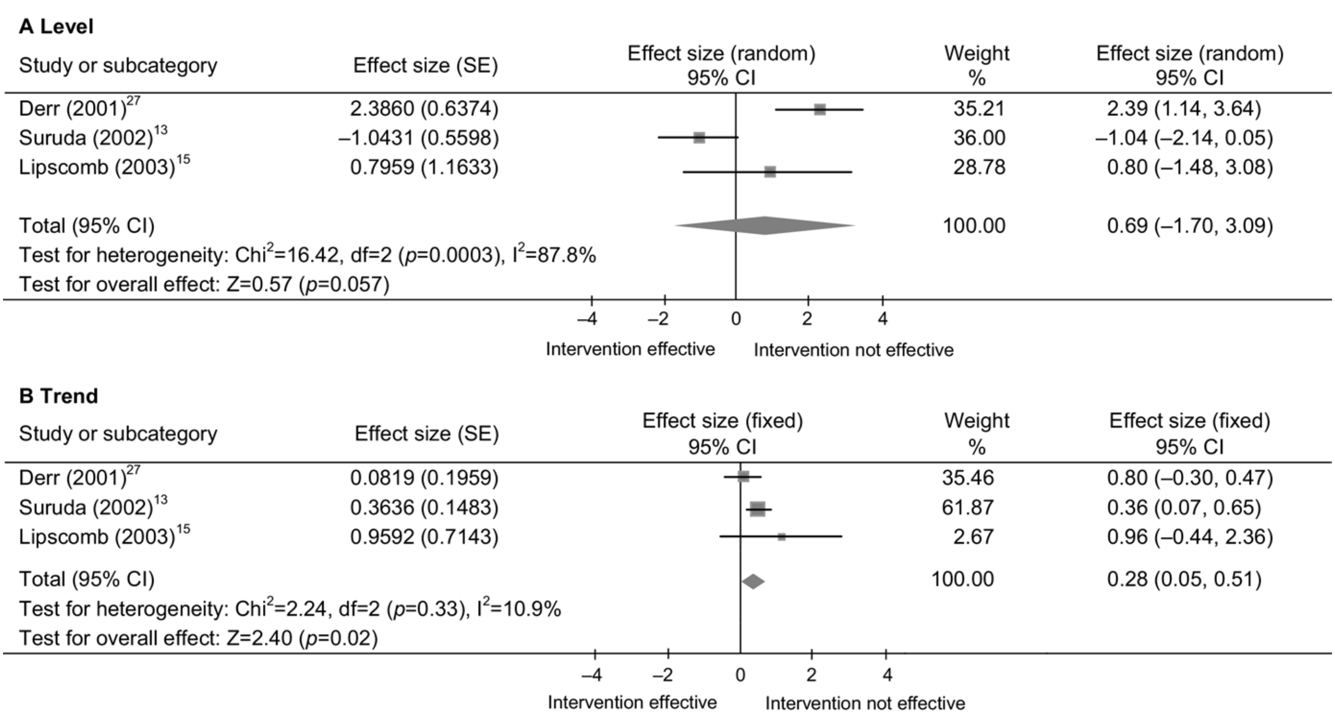

Figure 1. Meta-analysis of the legislation interventions with interrupted time-series design. Outcomes are reported as effect sizes and SE for A Level: Describes the immediate effect of an intervention on annual injury rate, and for B Trend: Describes the long-term effect of an intervention on the annual injury rate.

evidence was found that legislation prevents nonfatal and fatal injuries in the construction industry.

Implementation Level and Strategy

Because of the inadequate description of most of the intervention studies found, it was not possible to characterize all interventions precisely. Another concern was the lack of information about the implementation of the proposed intervention; this incomplete knowledge makes it impossible to draw firm conclusions about the potential effectiveness of the intervention.

No information was available about how and to what extent the legal interventions were implemented at worksites. No information was given about how employers and workers were motivated to comply with the legislation. It could be argued that obligatory legislative interventions are just organizational interventions used to commit or compel employers and workers to reduce the risks for injuries. Lipscomb et al.,[15] for example, stated that informational and educational programs could accompany legislation. Also, in other health and workability studies, it is argued that legislation alone is not powerful enough in today's society to change attitudes and behavior in the desired direction.[30]

Another explanation for not finding an effect could be that legislation is only gradually introduced and implemented, and so does not actually interrupt the time series. Because it is not known how the legislation was introduced to the field or how well they were publicized or enforced, there might exist a so-called gradual diffusion or delayed causation of the intervention.[31] It can be argued that some firms anticipate forthcoming legislation and others lag behind in their implementation. Therefore, the exact point of the intervention can be difficult to determine.

The studies concerning the multifaceted interventions in the safety campaign[28] and the drug-free-workplace program[29] described in more detail the content of their interventions and their corresponding implementation strategies. The Spangenberg et al. study[28] also provided information about the familiarity and receptivity of the safety campaign, but no information was provided with respect to implemented activities or performance indicators for the proposed behavior (e.g., good housekeeping). The use of drug testing in the workplace, moreover, introduces several ethical and legal complications, such as the employer's right to test and the worker's right to privacy.

Both multifaceted intervention studies[28,29] have used multiple and continuing intervention methods. Informational and facilitative strategies that influence the safety culture at worksites, combined with enforcement methods such as worksite inspection or mandatory drug testing, were important activities in these multifaceted interventions. Other studies (e.g., Neal et al.[32]) confirmed an association between safety climate and individual safety behavior.

In summary, for the two multifaceted company studies,[28,29] it can be assumed that there was some degree of implementation, although it would have been better if the studies had documented the degree or measure of implementation quantitatively, as an intermediate measure.

Secondary Effects and Ethical Considerations

Although two of the three legislative studies, which were conducted in the U.S., reported significant reductions in injury rates in their original articles, the nonfatal injury rate in the U.S. construction industry also dropped considerably in that time period.[2] In fact, there was a less-favorable time trend after the intervention, which could be due to better reporting of injuries as a result of increased attention to injuries. Re-analysis with auto-regressive time series revealed no short-term (level) or long-term (trend) legislative intervention effects on the reduction of injuries in the studies. However, re-analysis confirmed the reported intervention effect on injuries of the multifaceted safety campaign and the controlled ITS study concerning a drug-free-workplace program.

None of the included studies reported changed behavior as a secondary outcome measure. One study[15] reported a decline in the number of paid lost-working days per injury as a secondary outcome measure, but re-analysis of the main outcome measure revealed an underlying downward trend of injuries and no intervention effect.

Finally, in the case of any drug-testing interventions, there is still the discrepancy between an employer's right to test its workers—especially newly recruited or probationary employees—versus a worker's right to privacy and protection against unreasonable drug testing.[33]

Other Studies Not Meeting the Selection Criteria

Evaluation studies without a concurrent control group were also systematically searched, as well as case-reference and retrospective studies, in order to gain some degree of perspective from lower-quality studies that would otherwise be excluded from the review because of lack of rigor or nonstandard study design. Five before–after studies[12,33,35–37] without a concurrent control group and one retrospective study[34] with measurements before and after the intervention were found. Among these studies was an additional one on legislation[34] and two on drug testing to prevent nonfatal injuries.[33,35] In addition, there were two studies[12,36] that evaluated the effect of education and training on preventing nonfatal injuries. Finally, there was one study[37] that evaluated an organizational intervention (i.e., a company-wide 5-step health and safety plan) on nonfatal injuries, but it was impossible to extract the outcomes, and the authors were asked for clarification. The results from these studies support the results reported in this review.

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. However, publication bias due to omission of nonpublished negative studies is still conceivable. On the other hand, review of the excluded lower-quality studies revealed that there were also relatively few studies with a reported statistically negative outcome. Therefore, it was assumed that the risk of publication bias was low.

Quantity and Quality of Evaluative Research

No RCTs were found. The methodologic quality was low for all five included ITS studies. Apparently there are existing barriers to conducting high-quality occupational-safety research using these quantitative tools, whether for reasons related to competing demands for medical and public policy analysis or for other undetermined reasons. However, the observable magnitude of the problem, which involves continued and high levels of the risk of fatal and nonfatal injuries in the construction industry, warrants additional efforts; both industry and occupational health researchers could use sophisticated tools and methods to conduct research on this occupationally hazardous industry. No studies were found that evaluated the vast majority of technical factors, human factors, or organizational interventions that are recommended by standard texts of safety and safety consultants as well as safety courses. Commonly used intervention methods include such disciplines and tools as risk analysis, incident and accident analysis, the reporting and resolution of dangerous situations, training courses, observation and inspection rounds, tools and equipment, audits, preplanning, and subcontractor management. This is not to suggest that these intervention methods are not effective, but only to note that there are no study findings to support efficacy or lack of efficacy. For the same reasons, the conclusions derived from the demonstrated effectiveness of the safety campaign and the drug-free-workplace program should not encourage practitioners to concentrate solely on these interventions. What is consistently required is the application of proper study design and well-considered analytic tools to assess efficacy in producing desired outcomes.

This review demonstrates that the ITS design offers a good opportunity for the evaluation of rare or stochastic events like fatal and nonfatal injuries when RCTs are not possible. However, the ITS studies should be analyzed in a correct manner.[25] The included ITS studies did not meet the EPOC criteria for statistical analysis.[23] Because 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 et al,[28] 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 the work-related injuries can be reduced or 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 interventions have actually been applied.[38] Testing the association of determinants from underlying theories or models with intervention outcomes increases the insight into the potentially effective elements of the intervention. Measuring the behavioral change of workers as a direct effect of the intervention process, along with the surveillance of injury rates and frequencies, provides a better insight into how the intervention works and also strengthens the evidence of a causative effect on the injury outcome.[39]

Future research in this area should focus on (1) defining indicators for evaluating the implementation of the intervention, (2) implementing the interventions in the best possible way, (3) measuring the behavioral change of workers as a direct result of the intervention process, (4) measuring fatal and nonfatal injuries as main outcome variables for evaluating the effectiveness of the intervention, and (5) testing the association of behavioral changes with the main outcome measures.

Conclusion

Implications for Practice

Legislation alone is not effective in reducing fatal and nonfatal injuries in the construction industry; additional strategies are necessary, ones that actually increase the compliance of employers and workers to regulatory safety standards. Multifaceted and continuing interventions, like a targeted safety campaign or a drug-free-workplace program, seem to be effective for reducing injuries in the longer term. A 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 the implementation of safety measures as well as on fatal and nonfatal injuries. Studies that incorporate such methods as interrupted time series over several years, a high internal validity, and a correct statistical analysis are feasible; therefore, they should be applied more often to evaluate the effectiveness of safety interventions on fatal and nonfatal injuries.

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