Meta-analysis of studies examining long-term construction injury rates

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Background
The construction industry is one of the employment sectors with the highest risk of injuries.

Aims
To evaluate the injury trend in the construction industry from data published from 1987 to 2010.

Methods
All papers with at least two measurements of injuries within a medium- to long-term period were included. The numbers of fatal and non-fatal injuries were examined in two separate groups: 100 000 workers per year and 200 000 worked hours per year.

Results
All injuries significantly decreased between the first and the second measurement, with fatal injuries decreasing by 35% and non-fatal ones by 33% in workers/year and by 22% in worked hours/year. There was high heterogeneity among the sources of data for workers/year index ($I^2 = 49\%$ for fatal injuries, $99\%$ for non-fatal injuries) but no heterogeneity for worked hours/year index ($I^2 = 0$). Meta-regression analysis showed a significant linear relationship between time and risk reduction for fatal injuries ($r = 0.63; P < 0.001$; a 6% reduction per year); trend reduction for non-fatal injuries was not related to the time taken between the measurements.

Conclusions
Fatal injuries have a reduction trend that depends on large interventions, whereas non-fatal injuries are more prone to episodic changes. Furthermore, while the workers/year index allows easier evaluation of the injury rate variation in a single working environment, the worked hours/year index is better at comparing the injury rate variation in different working environments because it reduces the sources of heterogeneity.

Key words
Construction; fatality rate; injury prevention.

Introduction
Work-related injuries are the result of social and technical failures, and should be preventable. The scientific community aims its prevention strategies at eliminating or reducing the causes of injuries. Therefore, prevention policies and monitoring programmes should be systematically applied to a work environment that is in continuous evolution. This approach is called ‘safety culture’, and it aims to inform and educate those involved in the work activity about the risks and the ways to reduce them [1].

The efficacy of prevention policies in reducing the occurrence of work injuries is often unclear; studies have looked at specific preventive methods and assessed their efficacy, but this has been in limited groups of workers and in specific contexts. When considering the impact of injury prevention policies over time, there is a lack of clear evidence in the scientific literature, and data about cause is limited. For example, the results of a meta-analysis published by the Cochrane Collaboration do not suggest that educational interventions are effective in the prevention of injuries in agriculture [2]. However, a successive meta-analysis, based on more data, highlights the efficacy of prevention programmes, including educational programmes, in reducing work-related injuries in agriculture [3]. Many confounding technical aspects have to be considered before formulating general conclusions from these studies, for example, the methods used for quantifying and reporting injury rates, the time span used to evaluate the effects of preventive programmes and the effect of economic development on the number of worked hours and consequently on the likelihood of injuries. The heterogeneity of the methods of presenting data by different organizations throughout the world also has a pivotal role that must be taken into account before
any comparisons are made. For instance, injury rate, fatal and non-fatal, can be expressed using the 100 000 workers per year index or by using the 200 000 worked hours per year index. It would be useful to evaluate which standardized incidence rate is most appropriate to allow consistency and comparability in studies.

The construction industry has the highest risk of injuries [4]. It therefore requires more effective monitoring because of the number of fatal injuries or permanent disability. Injuries are often multi-factorial and include environmental factors, work organization, tools and procedures used, behavioural factors, limited knowledge about work conditions, lack of experience and skills, inadequate psychological and physical conditions, lifestyle issues (alcohol, drugs and nutrition), among others. Moreover, injury risk is also influenced by factors such as the economic trend, technological innovation, age, seasonality, company size and degree of unionization [5].

The multi-factorial causes of injuries require the use of multiple preventive interventions aimed at addressing the factors that play a key role: legislative guidelines, workplace drug and alcohol policies, workplace inspection and supervision, and safety campaigns. Epidemiological data show that while these interventions are able to reduce the number of injuries in construction, their rate still remains very high [6–8].

Our hypothesis was that an analysis of data collected over the medium to long term (9 years on average for fatal injuries and 6–9 years on average for non-fatal injuries) might provide information on the reduction trend, if any, of the injury rate in this sector; differences evidenced in a temporal trend based on several years should be free from the impact of episodic, short-lived and/or immediate (a few months or days) phenomena (phasic trend) and more sensitive to continuous and prolonged effects (tonic trend) of the adopted measures and policies.

The aim of this meta-analysis was, therefore, to verify the injury trend over a long period and to evaluate the methods to quantify and present the modifications over time, if any, of the injury rates.

**Methods**

A systematic search of papers concerning construction injuries published from January 1987 to April 2010 was performed. Journals interested in this topic have increased since 1987, showing an almost exponential rise until 2010. There was no restriction on language, kind of publication or geographical area. MEDLINE, Nioshtic-2, TOXNET, BioMed Central, PubMed and Google Scholar databases were searched using the keywords injuries and carpenters, injury prevention and building, occupational injury, building injury, injury rate and building, fatality rate, and intervention evaluation.

The 77 114 publications identified were all screened by at least two authors according to the following inclusion criteria: (i) studies about the incidence of fatal and/or non-fatal injuries in populations of building workers and (ii) longitudinal studies describing at least two repeated observations over a long period (not <1 year). Papers that covered the causes of changes in injury rates but not their trend were not included. Fifty-five papers (all published in English and all with data presented in a numeric format) met the inclusion criteria and were consequently included in the review. The main features of these studies are shown in Table 1 (available as Supplementary data at Occupational Medicine Online).

The population comprised building workers (both employees and self-employed) working at building sites for buildings, homes, roads or highways, and public works in general or dedicated to installing plants (for instance, power plants, plumbing and ventilation systems).

We grouped the studies according to the type of injuries (fatal and non-fatal) and the method used for reporting injuries (i.e. the number of fatalities expressed in 100 000 workers per year and the number of non-fatal injuries expressed in either 100 000 workers per year or 200 000 worked hours per year).

When data were presented with different incidence rates from the above-mentioned methods, they were expressed, where possible, in 100 000 workers per year or 200 000 worked hours per year. The distinction between injuries by the number of workers per year and the worked hours per year was maintained because of the lack of a universal criterion for conversion of the two indices. In the USA, the equivalent of 2000 h per worker per year corresponds to a worker employed full time per year; consequently, injuries reported in 2000 worked hours per year correspond to an index of injury in 100 workers per year [9]. In other countries, for example, Denmark, the equivalent of worked hours per year in buildings is 1600 h, and consequently, the same index corresponds to 125 workers per year [10].

Two authors independently studied the data and assessed the study quality. The statistical parameter used was the Mantel–Haenszel risk ratio (RR), which expresses the likelihood of occurrence of injuries in relation to the before/after period [11].

The first analysis concerned fatalities expressed in 100 000 workers per year, the second one concerned non-fatal injuries expressed in 100 000 workers per year and the third one concerned non-fatal injuries expressed in 200 000 worked hours per year.

Some studies reviewed both fatal and non-fatal injuries; therefore, they appear in two analyses. Other studies appear many times in the same analysis because they separately compared the incidence of injuries of the same type in different countries, presenting their respective data individually.
The RR indicated the possible variation of the probability of incurring an injury during the period under examination. The heterogeneity among the studies was evaluated by the index of inconsistency ($I^2$), which refers to the variability or differences among studies in estimating the effect not due to chance. In the presence of a high index of heterogeneity, the RR was assessed with the random effects model. For the RR measures, based on frequencies, a ratio of 1.0 indicated the lack of differences between the before and after measurements. The meta-regression analysis was performed to evaluate the possible relationship between the lapse of time since the preventive interventions and the risk reduction. Because our study did not involve patients and was a meta-analysis, ethical approval was not sought.

**Results**

For all the papers included, the period of time between the first and the second assessment was on average 9 years for fatal injuries and 6–9 years for non-fatal injuries, with 32 of the selected 55 studies dealing with fatal injuries.

In the first assessment, there were 800 fatal injuries (on average 25 deaths per 100 000 workers per year), whereas there were 520 in the second assessment (on average 16 deaths per 100 000 workers per year), with a mean interval of 9.2 years ($SD = 4.66$) between the two assessments and a 35% statistically significant reduction (RR $1.54$ [1.38–1.72] $P < 0.001$) with $I^2 = 49\%$ (Figure 1). In this category, the meta-regression analysis shows a significant linear relationship between the time elapsed and risk reduction ($r = 0.63$; $P < 0.001$), which decreases by 6% per year, during the considered period.

Seventeen of the selected 55 studies looked at non-fatal injuries expressed in 100 000 workers per year. There were 119 050 injuries in the first assessment (7002 non-fatal injuries per 100 000 workers per year on average) and 81 259 in the second assessment (4779 non-fatal injuries per 100 000 workers per year on average) with a mean interval of 8.8 years ($SD = 6.5$) between the assessments.

![Figure 1. Forest plot of the reduction of fatal injuries.](https://academic.oup.com/occmed/article-abstract/62/5/356/1490463/1)
and a 33% statistically significant reduction (RR 1.49 [1.37–1.63] $P < 0.001$) with $I^2 = 99\%$ (Figure 2).

Fifteen of the selected 55 studies dealt with non-fatal injuries expressed in 200 000 worked hours per year. There were 259 injuries in the first assessment (17 injuries for 200 000 worked hours per year on average) and 201 injuries in the second evaluation (13 non-fatal injuries per 200 000 worked hours per year on average). The mean interval between the evaluations was 5.6 years (SD = 3.5). The risk of injury was significantly reduced by 29% (RR 1.29 [1.07–1.55] $P < 0.01$) with no heterogeneity ($I^2 = 0\%$) (Figure 3).

The meta-regression analysis for non-fatal injuries in both methods showed that the reduction of injury risk in relation to the number of years of observation was weak and that the period between the observations was irrelevant in reducing the risk.

**Discussion**

Our analysis of long-term studies of injury rates in the construction industry showed a significant fall in injury and fatality rates. We also found that this reduction, at least for fatal injuries, did not depend on the impact of
episodic, immediate or short-lived phenomena (phasic trend) but was more influenced by continuous and prolonged effects (tonic trend).

Prevention strategies against injuries are many and different [6,7,10,12–26]. The meta-analysis results indicate that data relating to fatal injuries show a progressive and constant decrease over a medium- to long-term period. In particular, the reduction trend seems to be linear over the years, and reduction of deaths progressed by 6% per year (tonic trend). Nevertheless, on analysing the evaluated articles, we found a high heterogeneity (49%) and believe that it may be caused by a number of factors, including the fact that the effects of safety varied from one country to another. For example, fatalities increased in China, whereas they were reduced in other countries during the same period. The reason for this may depend on fast-occurring changes in local working conditions, and it could be a side-effect of major economic development initiatives, which do not coincide with measures upgrading safety policies. This could result in the recruitment of poorly skilled workers with insufficient knowledge of health and safety legislation, and poor implementation of valid preventive regulatory and oversight systems for safety on building sites [27–29]. Other factors include the risk differences depending on the categories of building workers involved and the different impacts of intervention policies in the work market. Often, the type and intensity of information and training activity were not documented [8,9,18,30]. Furthermore, some studies included were longitudinal studies monitoring the frequency of injuries in specific groups of workers after risk reduction programmes had been applied. These studies document their results in limited work situations and in relatively small groups of workers. Other studies were based on epidemiological data of large numbers of workers, often concerning the entire working population involved in the application of policy changes in the risk prevention of injuries even if causes were not investigated. Finally, the studies used more or less cogent and different criteria to define an event as an injury.

Regarding non-fatal injuries expressed in 100 000 workers per year, the included studies were performed in different countries. On examining the papers, we observed that the high heterogeneity (99%) was due to the same causes listed for fatal injuries.

Studies of non-fatal injuries expressed in 200 000 worked hours per year presented no heterogeneity \(P = 0\%\). Considering injury rates by worked hours per year and not by workers per year provides a result that is more similar to the real working situation. We avoided using the same criterion for someone who works 12 h per day and someone who works 8 h per day. We believe that the worked hours per year index is more reliable than the workers per year index and gives results closer to the real rate of injuries. The absence of heterogeneity among the studies in worked hours per year may be explained as follows: studies came largely from similar working environments and countries, they obtained information from the same database, they presented a similar number of samples and 5 of the 15 studies included were carried out by the same research group. We believe that studies using the index worked hours per year are homogeneous because the use of this index is more reliable, even if less simple to handle than the other index. It requires stricter criteria in carrying out the research and the evaluation of fewer but better controlled data.

Regarding meta-regression, the results show that it was not significant for non-fatal injuries. It could show that the period between the observations is irrelevant in reducing the risk of non-fatal injuries and that their trend is more subject to episodic changes (phasic trend) than for fatal injuries. In fact, fatal injuries showed a progressive reduction by 6% per year, and maybe they need a medium- to long-term period to reach a more significant reduction (tonic trend). To reduce the number of non-fatal injuries, daily constant monitoring as well as single major interventions may be necessary.

Despite different methods of detection of injuries, there were significant reductions in injury rates in almost all geographical and organizational contexts. Fatal injuries showed a greater reduction than non-fatal injuries, probably because they require a more strictly applied safety policy, and the number of fatal injuries is more reliable—a death at work is not concealable, whereas a less serious injury might not be reported.

In conclusion, we believe that a result in 100 000 workers per year is a more convenient index. It is easier to evaluate the injury rate variation with a large survey in a single working environment where all workers work the same hours. To compare the results of different studies carried out in different working environments, the 200 000 worked hours per year index is more suitable because it reduces the sources of heterogeneity.

**Key points**

- Analysis of long-term studies of injury rates in the construction industry showed a significant fall in injury and fatality rates.
- Reduction in fatal injuries depended on large interventions, whereas reduction in non-fatal injuries was more subject to episodic changes.
- Evaluation of injury rates within a single working environment is best done using the injuries per workers per year rate, whereas comparing injury rates in different working environments is best done using the worked hours per year index because it reduces the sources of heterogeneity.
Conflicts of interest
None declared.

References


