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Monograph

Fifteen years of American construction occupational safety and health research

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ABSTRACT

The researchers reviewed construction occupational safety and health research published in high-impact, peer-reviewed academic journals between 2002 and 2016 to assess whether research in the field is efficiently targeted to produce evidence-based interventions addressing the industry's most serious occupational hazards. Unlike most previous surveys of the field, this interdisciplinary literature search captured research published in the construction management and engineering literature as well as that in public health and medicine journals. The researchers found 741 articles by US-based lead authors, with falls the most-studied safety hazard (89 articles) and airborne silica exposure the most-studied health hazard (51), both among the deadliest current hazards in construction occupational safety and health, but much asbestos research was sponsored by companies involved in litigation, generating few findings useful for protecting today's workers. The review described important trends in the literature, including increased attention to noise and hearing loss, a growing number of intervention studies, and greater concern for populations at disproportionate risk (e.g., small/residential, Latino/immigrant, younger/older workers, & women working in construction). The National Institute for Occupational Safety and Health (NIOSH) directly or indirectly funded a majority of the published research. Policymakers should understand that most occupational safety and health research depends on NIOSH funding.

1. Introduction

Construction is dangerous. In 2017, 971 construction workers died from work-related injuries in the United States – more than any other industrial sector (BLS, 2017). That year the industry also witnessed more than 80,000 nonfatal injuries severe enough to take workers off the job, at least temporarily. Millions suffer long-term health impairment after years of exposure to health hazards on the job ranging from airborne crystalline silica to excessive noise levels.

Academic research targeting construction occupational health and safety is an essential part of improving occupational safety and health in the building industry. High-quality research is needed to identify the causes of occupational injury and illness and to design and test effective interventions. But are research resources being efficiently applied to the most critical occupational hazards in the American construction industry? Are they committed to the demographic segments of the workforce at greatest risk? Are they testing evidence-based interventions for use in the field?

Answering this question requires a comprehensive review of the field as a whole. Yet while many investigators have published review articles focused on a particular hazard (Flynn and Susi, 2012), there has been no systematic effort to examine and describe the corpus of construction occupational safety and health research as a whole, and to assess how limited research resources are being applied to the most important problems in the field. Furthermore, because a significant portion of the construction occupational safety and health research is published in engineering and construction management journals that are not indexed in PubMed, review articles based on PubMed searches leave out a substantial quantity of peer-reviewed research addressing these hazards.

The authors conducted an extensive and multidisciplinary literature search in order to describe the scope and patterns of construction occupational safety and health research in the United States. The results of this search allow us to answer some basic questions about the state of the field: What construction occupational safety and health problems are under study? Is the research addressing the most critical hazards in the field, and is it yielding interventions that can address these hazards? What do government, the academy, and the private sector respectively contribute to the advance of knowledge in the field?

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2. Material and methods

The search was designed to identify American construction safety and health research published in high-impact, peer-reviewed English language journals of any academic discipline between 2002 and 2016. (Search results from earlier dates yielded far fewer studies, but are not strictly comparable because of technological improvements in search technology and metadata.) To be included in the dataset, articles needed to explicitly reference the construction workforce – for instance, an article on occupational exposure to welding fumes that did not specify that the welders were employed in construction would be excluded. As the research team sought to describe the US construction industry and the US research environment (including funding sources), only articles with a US-based lead author were included. To focus on research appearing in high-impact journals, only articles in journals listed in the *Journal Citation Reports* (Thomson Reuters, 2016) were included – an objective standard of impact that applies across multiple disciplines despite wide their variation in research design and methodology. Finally, only research articles were included in the results, excluding letters, commentaries, and book reviews.

The authors searched four major databases for articles: PubMed, Web of Science, the Applied Science and Technology Index, and the American Society of Civil Engineers (ASCE) Library. Using a variety of broad search terms suited to each database (Table 1), the research team generated an initial list of 5585 articles, of which 741 ultimately met the criteria for inclusion.

The authors then created a list of keywords representing construction occupational hazards, trades, topics, and demographic characteristics of workers participating in the study. Each author separately reviewed all 741 articles, assigning all keywords that applied; afterward, the authors met and reconciled any differences. Finally, the lead author identified and recorded external funding sources for 601 of the articles.

3. Results and discussion

3.1. WHAT problems are researchers studying?

The construction safety and health hazards under study can be grouped under four major hazard domains: safety hazards, health hazards, work-related musculoskeletal disorders, and "wellness" studies focused on topics such as smoking, nutrition and stress (Fig. 1.). Forty-seven percent (47%) of the studies in the sample addressed safety hazards; 41% addressed health hazards; 19% addressed Work-Related Musculoskeletal Disorders (WMSDs); and 12% addressed "wellness" issues such as stress and smoking cessation. (Because many studies covered more than one domain, such as a study of disability in sheet metal workers that cited traumatic injuries, musculoskeletal disorders, and respiratory ailments caused by exposure to dusts and gases (West, 2016), the numbers do not add up to 100%).

Over the period under study, the share of studies addressing wellness issues has more than doubled. In 2002–2006, 7% of the studies addressed wellness issues, but by 2012–2016 18% did. Growing interest in "total worker health" perspectives explain much of this growth (Feltner, 2016). At their best, such approaches can address work environment issues that endanger workers' systemic health, such as job-related stress. At their worst, they can divert scarce occupational health and safety research capacity from occupational hazards to workers' smoking and eating habits off the job.

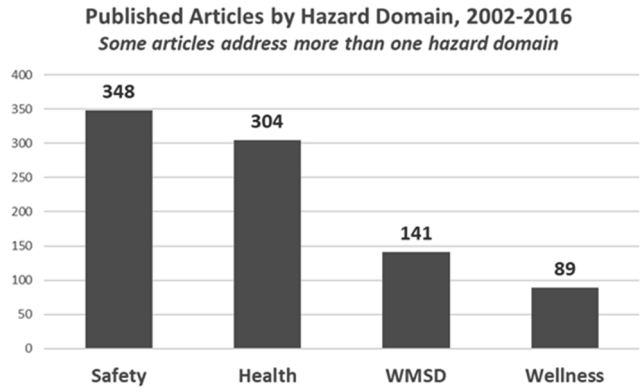

Fig. 1. Construction Occupational Safety and Health Research by Hazard Domain, 2002–2016.

3.1.1. Safety hazards

Most construction occupational fatalities can be traced to four causes: falls; "struck-by" injuries in which a worker is struck by a vehicle or object; "caught-in" injuries, in which a worker is caught in machinery or collapsing materials or buildings; and electrocutions. OSHA designates these as the as the "fatal four" or "focus four," and reports that they were responsible for 59.9% of construction occupational fatalities in 2017 (OSHA, 2019).

Appropriately, most of the published research targeting safety hazards addresses the "focus four." Falls are both the leading cause of construction fatalities, responsible for 386 construction worker deaths in 2017 (BLS, 2017) and the safety hazard examined in the literature during the period under examination, with 89 of the studies addressing fall hazards and prevention. Interest in fall hazards has increased over time, growing from 25% of the published studies in the 2002–2006 period but accounting for 37% of the studies published in 2012–2016.

Sixty studies in the sample addressed struck-by and/or caught-in injuries; it was not possible to separate the two categories clearly because many of these studies focused on a piece of heavy equipment that posed both hazards, such as dump trucks or excavators (McCann, 2006; Shen, 2016). However, notable concentrations of research included road work-zones and nail gun injuries. With dozens of workers suffering fatal struck-by injuries each year, road work-zones are a leading site of construction fatalities (CPWR, 2018). And although nail-gun injuries are seldom fatal, nail guns send more construction workers to the emergency room than any other piece of equipment (Lipscomb et al., 2010). Published research on construction safety is effectively targeted at the most frequent and serious hazards in the industry.

3.1.2. Health hazards

Among health hazards studied, airborne crystalline silica was the most frequent topic of study, accounting for 51 of the articles in the sample (Table 2). Many of these studies measured airborne silica exposures during common construction tasks such as grinding mortar, drilling concrete, or abrasive blasting, or tested the efficacy of different controls. This work creating a solid body of evidence to inform OSHA's new 2016 silica standard, especially its critical Table 1, which lists acceptable dust control methods for each construction task (Beckett and

Table 1
Search Terms by Discipline.

Discipline	Databases	Search Terms
Health and Medicine	PubMed	construction AND (injur* OR illnes* OR fatal* OR health OR safety)
Engineering and Construction Management	ASCE Library, Applied Science and Technology	worker AND (injur* OR illnes* OR fatal* OR health OR safety)
Interdisciplinary	Web of Science	construction AND worker AND (injur* OR illnes* OR fatal* OR health OR safety)

Table 2
Most-Studied Construction Occupational Health Hazards, 2002–2016.

Health Hazard	Published Articles
Silica	51
Asbestos	48
Welding Fumes	42
Noise/Hearing Loss	35
Asphalt	32
Lead	15
Solvents	10

Table 3
Emerging Themes in Construction Occupational Health and Safety Research, 2002–2016.

Date Range	Number of Published Articles		
	Prevention through Design (PtD)	Safety Culture/ Climate	Wellness
2002–2006	3	6	16
2007–2011	7	20	25
2012–2016	14	35	49

Lyons, 2007; Cooper et al., 2012; Shepherd and Woskie, 2013; OSHA, 1926).

Asbestos was the subject of 48 studies, although this number perhaps overstates the quantity and quality of new research produced: several of the papers were funded by parties in litigation and focused on disputes over past exposures (Sheehan, 2011). Other major topics included welding fume exposure, ranging from assessing exposures and exploring neurological and cardiovascular health effects to testing the use of local exhaust ventilation as an engineering control (Flynn and Susi, 2012; Grashow, 2014; Bowler, 2011), and hearing loss, one of the most widespread occupational health hazards in the sector (Masterson, 2016). Rounding out the list of frequently studied construction occupational health topics were asphalt and asphalt fume hazards, lead, and exposure to chemical solvents.

While the Census of Fatal Occupational Injuries (CFOI) (Statistics-a) gives us specific and detailed statistics on construction fatalities caused by traumatic injuries, and sources such as the Survey of Occupational Injuries and Illnesses (SOII) (Statistics-b), workers' compensation claims, and emergency room admissions records provide useful data on non-fatal traumatic injuries, available information on health hazard prevalence is less complete. Nonetheless, it is possible to make a few observations on the targeting of occupational health research.

It is likely that silica was the most prevalent construction health hazard during the period under study. With silica exposures linked to silicosis, lung cancer, COPD and kidney disease, OSHA estimated that the new rule will save the lives of approximately 600 workers each year, and protect the respiratory health of many more, with most of the affected workers employed in construction. Investment in this research has paid off by identifying dust control methods for use incorporation in the rule.

Asbestos historically affected an even larger worker population, but OSHA acted against its use almost immediately after the agency was created in 1971. Although asbestos counts for a substantial share of the current construction occupational safety and health research output, much is of dubious value to worker safety and is instead developed for use in litigation (see below).

3.1.3. Other topics and themes

In order to accommodate both the health and engineering disciplines, the researchers adopted a broad definition of intervention research: development, testing, and dissemination of a program for use in the field to improve construction worker safety. Intervention studies could include testing dust exposures during concrete cutting with a wet saw, creating an app that turns a worker's smart phone into a proximity warning alarm, or designing and testing a fall-prevention training program (Shepherd and Woskie, 2013; Hubbard and Middaugh, 2013; Evanoff, 2016). Nearly one third of the papers (233 of 741) in the sample were intervention studies, and the share increased over time: intervention research accounted for 25% of the studies published in 2002–2006 but 34% of the studies published in 2012–2016.

More than one-fifth of the studies – 167 in all – focused on segments of the workforce who are disproportionate risk of injury or illness on the job. These included those employed by small and/or residential contractors (61 studies), Latino and/or immigrant construction workers (55), older workers (39), younger workers (35), and women working in construction (14). Although less pronounced than the increase in intervention studies, this represents another growth trend in the literature. 18% of the studies published in 2002–2006 focused on populations at disproportionate risk, climbing to 24% by 2012–2016.

Some newer areas of research have come into their own during the period under study (Table 3). Prevention through Design calls for reviewing building plans at the design stage with an eye to minimizing health and safety risks for those who will build and maintain the structure; safety culture and safety climate studies examine the role of a firm's organizational culture in occupational safety and health outcomes (Tymvios and Gambatese, 2016; Schwatka et al., 2016). More controversially, "wellness" studies often focus on the health effects of diet, exercise, and tobacco and alcohol consumption – a research strategy some advocates fear shifts attention away from occupational risks and feeds a "blame the worker" narrative (Lange et al., 2006). All three areas have seen remarkable growth in research output.

It is encouraging to find that a growing share of field research is dedicated to developing, testing and promoting interventions that can improve construction safety and health, a trend one would expect as cumulative achievements in surveillance research complete the picture of construction occupational safety and health. Surveillance has also helped us identify segments of the workforce at disproportionate risk, such as immigrant or young workers, and target them for more intensive investigation. The field has also witnessed a rapid growth of new approaches such as prevention through design, safety culture/ safety climate, and wellness studies. Researchers can expect these fields to yield and test a new generation of interventions in the coming decades.

3.2. WHO is doing the research?

Based on the listed authors for the 741 articles in the database, it appears that at present, between 200 and 300 U.S.-based investigators are actively conducting research for publication in the high-impact academic journals listed in the Journal Citation Reports. Most of the researchers are university-based academics: for 510 of the papers – nearly 70% – the lead author was a university-based researcher.

Among these 510 lead authors, 345 were based in schools of medicine or public health and 145 in schools of Engineering and/or Construction Management, compared to just 20 for all other academic disciplines and programs combined. While the medical and public health school research is distributed widely across the field, addressing both safety and health concerns, most (78%) of the studies generated in Engineering and Construction Management programs focused on safety hazards.

Among university programs, Duke University was the single most prolific: in 46 of the papers reviewed, the lead author was a Duke faculty member or graduate student. Harvard University (43), University of Washington (24), Washington University at St. Louis (20), and University of Massachusetts, Lowell (18) rounded out the top five.

Two institutions outside the university walls made major contributions to the literature during this period. On 69 of the published papers,

Table 4
Leading Journals Publishing Construction Occupational Safety and Health Research, 2002–2016.

Journal Title	Articles Published
American Journal of Industrial Medicine	127
Journal of Occupational and Environmental Health	96
Journal of Construction Engineering and Management	58
Journal of Safety Research	39
Journal of Occupational and Environmental Medicine	34
Annals of Occupational Hygiene	27
Safety Science	26

the lead author worked at the National Institute for Occupational Safety and Health; on 46 more, the lead author was a staff researcher at CPWR – The Center for Construction Research and Training, a nonprofit whose research is supported by NIOSH (see below). The Liberty Mutual Institute for Safety Research, a third institution in this space, generated 10 studies during the period before its closure in 2017. Finally, several studies were conducted by for-profit engineering and environmental consulting firms, usually financed by for-profit corporations whose products or work practices were under examination.

3.3. WHERE is it published?

Just seven journals accounted for more than half the studies in the bibliography, with the *American Journal of Industrial Medicine* by far the leading publication venue for construction safety and health research (Table 4). The list includes two journals which are not routinely indexed in PubMed: the *Journal of Construction Engineering and Management* and *Safety Science*. However, individual NIH-funded studies appearing in these journals are often published in PubMed, in accordance with the NIH Public Access Policy (National Institutes of Health). It is notable that most of the studies published by for-profit environmental consultants with the support of for-profit corporations appeared in a journal not appearing on this list, the *Bulletin of Environmental Contamination and Toxicology*.

3.4. WHO's paying for it?

The authors were able to identify a source of external funding for 601 of the 741 studies in the sample. (The remaining 140 may have had no external support, or did not declare it in the publication.) The great majority of these (411) were supported by the National Institute for Occupational Safety and Health (NIOSH), either because NIOSH staff researchers performed the work themselves or they awarded grant funding to an external researcher to perform it. Much of this research is conducted by or through CPWR, which serves as the National Construction Center under a NIOSH cooperative agreement (the research output is divided between work performed by CPWR staff researchers and that performed by CPWR's external consortium of university-based researchers). Three other government agencies sponsored 20 or more studies in the sample: the National Institute for Environmental Health Sciences, the National Cancer Institute, and the National Science Foundation. In many cases, studies were supported by more than one funder.

One might have expected that construction firms and product manufacturers, who have an economic incentive to improve industry health and safety, might be an important source of funding for construction safety and health research – an assumption that led the Office of Management and Budget to recommend large cuts in NIOSH funding by claiming that "Some [research] activities conducted by NIOSH could be more effectively conducted by the private sector." (OMB, 2019) This did not prove to be the case. The authors identified nearly two dozen published studies citing financial support by for-profit corporations, usually employing researchers at for-profit consulting firms such as Envirosafe or Exponent rather than university-based scholars. Several of these papers were commissioned by product manufacturers engaged in asbestos litigation; others were funded by asphalt and petroleum companies during a time period when OSHA was considering regulations to limit asphalt fume exposure (Clark, 2011; Lange, 2008).

4. Conclusions

The findings of this review describe the breadth of ongoing research in construction safety and health, giving us a better appreciation of the size and scope of research output. For the most part, these studies are focused on the sector's most serious hazards, such as the "focus four" and ubiquitous health hazards such as airborne silica and hearing loss. It is also the case that a growing number of studies are targeted at segments of the workforce identified in surveillance research as being at disproportionate risk, such as small or residential contractors, Latino and immigrant, or younger workers. The body of research contains a growing share of intervention studies and the appearance of innovative new approaches such as Prevention through Design (PtD) and Safety Culture/Climate studies that will inform a new generation of intervention research. The study also confirms the need for interdisciplinary research approaches, covering both health and engineering disciplines, at least when exploring safety hazards, where the literature is split almost evenly between the two fields

The findings also cast a light on the importance of government funding for basic research in occupational safety and health. NIOSH staff and NIOSH-funded external researchers account for the lion's share of the high-quality research in this field. In those select cases in which a private firm supported research, the funder had an apparent financial interest in the outcomes – hardly an environment conducive to impartial data collection and analysis. Policymakers should take this into account when considering budget decisions.

The methodology employed entailed certain limitations. Systematic reviews conducted within a single field often assess the quality of the study – for instance, medical research based on randomized control trials may be considered more definitive than that based on a cohort study. However, such ranking was not feasible with the variety of disciplines and methodologies represented in this review. The authors were limited to a single threshold requirement for quality of research: whether the study was approved for publication in a peer-reviewed journal of its field listed in the Journal Citation Reports. Similarly, the study did not attempt to assess the cumulative state of knowledge of any particular problem under study; the review identified areas of emphasis rather than achievement. If occupational injuries and illnesses remain far too frequent in the construction industry, this study does not indicate whether insufficient research by scholars or insufficient action by practitioners is responsible in any given case.

The results point to promising areas for future study. An increasing share of the research literature has been devoted to developing and testing interventions. While the silica intervention research helped inform OSHA's 2016 silica standard, the current study does not assess the impact of academic research on health and safety in the construction industry; it would be valuable to explore how industry has responded to the research findings. Finally, the impact of private sector research sponsorship on research findings should be explored. Extensive study of the "funding effect" in tobacco and pharmaceuticals has documented that industry-sponsored research has tended to generate findings favorable to the sponsor (Krimsky, 2013; Lexchin, 2003). Although the quantity of funded research in construction occupational safety and health has been limited, it would be valuable to learn whether a similar pattern obtained in industry-sponsored research of the health impacts of asbestos and asphalt.

Institution and ethics approval and informed consent

This project did not rely on human subjects, so was not subject to institutional review.

Authors' contributions

Clayton Sinyai conceived the project, conducted the initial literature search, and prepared the summary findings. Clayton Sinyai and Sang Choi reviewed and classified articles and abstracts and collaborated to identify trends in the literature.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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