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Fatal falls from roofs among U.S. construction workers

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ABSTRACT

Introduction: This study examined trends and patterns of fatal falls from roofs in the U.S. construction industry over an 18-year period (1992–2009), with detailed analysis for 2003–2009. *Methods:* Two large national datasets were analyzed: the U.S. Bureau of Labor Statistics' Census of Fatal Occupational Injuries and the Current Population Survey. *Results:* Roof fatalities accounted for one-third of fatal falls in construction in 1992–2009. A disproportionately high percentage (67%) of deaths from roof falls occurred in small construction establishments (1–10 employees). Roofers, ironworkers, workers employed with roofing contractors, or working at residential construction sites, had a higher risk of roof fatalities. A higher rate of roof fatalities was also found among younger (<20 years) and older (>44 years) workers, Hispanics, and immigrant workers. *Conclusion:* Roof fatalities corresponded with economic cycles and differed among construction subgroups and worksites. Impact on Industry: Prevention strategies should target high-risk worker groups and small establishments.

1. Introduction

Roofing is one of the most hazardous tasks in the construction industry (CPWR - The Center for Construction Research and Training (CPWR), 2008; Fredericks, Abudayyeh, Choi, Wiersma, & Charles, 2005; U.S. Bureau of Labor Statistics (BLS), 2011). According to the BLS (2012a), workers in the roofing industry are over three times more likely to experience fatal occupational injuries when compared to construction workers overall. Falls are the leading cause of workplace fatalities in the roofing industry, accounting for 76% of fatalities between 2003 and 2009 (BLS, 2012b). Fall injuries not only bring suffering to construction workers, but also increase financial burdens to their families, employers, and society. During the period from 2005–2007, the 38 states in the National Council on Compensation Insurance (NCCI) reported that falls from elevations cost insured roofers $54 million per year, about $106,000 per injured roofer, which is much higher than the average cost of falls from elevations of other occupations ($50,000; Occupational Safety and Health Administration (OSHA), 2011).

Falls from roofs occur more frequently than other types of falls, particularly among roofers. Sa, Seo, and Choi (2009) surveyed residential and commercial roofers in the Midwest and found that compared with commercial roofers, residential roofers experienced more injuries due to falls and were less likely to be provided with fall protection devices or have their use enforced by their employers. This study also found that residential roofers were more likely to work for small employers with fewer than 10 employees than their commercial counterparts. Kaskutas et al. (2009) found evidence that use of personal fall arrest systems (PFAS) and monitoring of unguarded floor openings were rare among small establishments in construction. Olbina, Hinze, and Ruben (2011) highlighted that small construction firms, in particular specialty contractors, face challenges in providing their employees with a safe work environment. Studies also found that existence of fall protection programs, enforcement of fall protection device usage, actual use of fall protection devices, type of work, establishment size, and race/ethnicity were significantly associated with fall injuries (Dong, Fujimoto, & Men, 2009; Sa et al., 2009).

While many factors contribute to fall injuries, loss of balance is one of the major causes (Hsiao & Simeonov, 2001). After examining the influence of sloped surfaces on postural balance and adaptation period, Choi (2008) found that workers were experiencing a greater postural instability at an earlier phase of a task on a steeper surface, whereas a significant decrement in postural control on a flat surface existed after working on an inclined (pitched) surface. Wade and Davis (2009) confirmed that individuals are less stable directly after performing tasks on an inclined surface, such as roofs.

Fatal falls from heights during construction work activities are not unique to the United States alone. They are also the largest cause of fatal construction injuries in the United Kingdom, accounting for 44% of the U.K.'s construction fatalities from 1999 to January 2007 (Health & Safety Executive, 2010). Similar to the U.S., falls from

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roofs and through skylights in the U.K. are leading types of fatal construction falls comprising 31% of fatal construction falls from 1999 to 2007.

The prevention of falls from roofs is a common goal for workers, employers, insurance companies, safety and health professionals, and government agencies. Furthermore, it is one of the strategic goals of the National Construction Agenda under the National Occupational Research Agenda (NORA, 2008). However, the current prevalence of falls in the construction industry suggests that causes and prevention of falls are not yet fully understood. There is a desperate need to improve the 'translation' of research findings for safety practitioners and construction workers, especially the prevention and implementation of protection interventions for falls from heights (e.g., roofs).

The purpose of this study was to describe trends and patterns of fatal falls at the national level, and use them to explore possible solutions for the fatal fall injury problem. Patterns and trends of work-related deaths caused by falls from roofs in the U.S. construction industry were examined by analyzing a large national fatality dataset and household survey spanning an 18-year period (1992–2009). Examples of safety practices and recommendations are also discussed. This study, which links injury surveillance data to injury intervention programs, is expected to benefit safety and health researchers, professionals, practitioners, and all construction stakeholders.

2. Methods

2.1. Data sources and terms

Two large nationally representative datasets were analyzed in this study: the Census of Fatal Occupational Injuries (CFOI) and the Current Population Survey (CPS). The numbers of work-related deaths were estimated from the research files of the 1992–2009 CFOI, a data collection by the U.S. Bureau of Labor Statistics (BLS). The CFOI is a federal-state cooperative program that has been implemented in all 50 states and the District of Columbia since 1992 (BLS, 2010a). Data on work-related fatalities are compiled from death certificates, workers' compensation reports, OSHA reports, medical examiner reports, newspaper articles, and other sources. Both the death and work-relatedness of the fatality must be corroborated by at least two data sources, or one data source and a follow-up questionnaire. The 1992–2009 CFOI research files were obtained through a data use agreement with the BLS and used to examine overall trends of fatal falls. Since there were significant changes in industrial and occupational classification systems in 2003, detailed data analyses span from 2003 to 2009 only.

Fatalities in the construction industry were identified according to the 1987 Standard Industrial Classification (SIC) system prior to 2003, and the North American Industry Classification System (NAICS) for 2003 onward. Falls from roofs (event codes 1150–1159 in the BLS' Occupational Injury and Illness Classification System; BLS, 2007) included falls through existing roof openings, roof surfaces or skylights, falls from roof edges, and falls from roofs that were unspecified or not elsewhere classified (n.e.c.). Other fatal falls excluded falls from roofs, but included other falls to a lower level, falls on the same level, jump to a lower level, and unspecified falls. Job locations (job site where the death occurred) were categorized as industrial construction sites, residential construction sites, public buildings, etc. Establishment size represents the number of wage-and-salary workers (excluding self-employed workers) employed at the establishment of the decedent.

To calculate fatality rates, denominators were obtained from the CPS, a large monthly household survey sponsored jointly by the U.S. Census Bureau and the BLS. Fatality rates were defined by deaths per 100,000 full-time equivalent workers (FTEs), assuming that a full-time employee works 2,000 hours per year, or 40 hours * 50 weeks. FTEs were obtained from the CPS and calculated based on the reported hours worked by respondents and the weighted total of construction employment. Since the construction industry was coded and combined as one industry in the CPS data, death rates for construction subsectors could not be computed for this study. Furthermore, decedents under 16 years old were excluded from the rate estimates since the CPS only collects employment information on those who are 16 years or older.

2.2. Data analysis

To measure fatality trends over time, the effects of economic cycles were taken into consideration according to the definition of an economic recession (National Bureau of Economic Research (NBER), 2008). The BLS' employment data were used to demonstrate the start and end of the two recessions during the study period. Average annual percent change of fatal work injuries in construction was tabulated in four periods corresponding to the employment trend and economic cycles. Distributions of fatal falls from roofs among major demographic and employment categories were tabulated and compared with other fatal falls and overall fatalities in construction by analyzing the CFOI data. To calculate the death rate of fatal falls from roofs, the CFOI data and the CPS data were matched by basic demographics (age, race, Hispanic or Latino ethnicity, birthplace, and geographical region) and employment categories (occupation, class of employment, and self-employed classification). Chi-square (χ^2) tests were used to measure whether characteristics of falls from roofs significantly differed from other fall fatalities at the $\alpha = 0.05$ level. Pearson's correlation coefficient analysis was conducted to assess the associations between selected variables of interest.

Critical risk factors associated with falls from roofs were identified from the descriptive analyses and recoded for the multinomial logistic regression model. The dependent variables were composed of three categories: 1) death caused by a fall from a roof, 2) death caused by another type of fall, and 3) death due to other causes rather than a fall injury. The last category, Category 3, was used as the reference point for comparisons. The independent variables included a group of dummy variables in which the youngest (<20 years) and oldest age groups (≥65 years) were combined and compared with other age groups. Dummy variables were also created for high-risk occupations (e.g., roofers and ironworkers), industries (e.g., roofing industry), small establishments (<20 employees), job locations (e.g., residential), geographical regions, etc. Odds ratios (ORs) and 95% confidence intervals (CIs) were calculated to measure the differences in risk between comparison groups. Since some key variables were only available in the CFOI data (e.g., detailed construction subsectors, establishment size, and job locations), the CPS data was not utilized in the regression analysis. All statistical analyses were performed with SAS version 9.2 (SAS Institute, 2010).

3. Results

3.1. Fatality trend in construction

From 1992 to 2009, work-related deaths from injuries totaled 20,498 in the construction industry. Of all construction fatalities during this time period, almost one-third (6,591) were fall fatalities and one-third (2,163) of those were caused by falls from roofs. Following the overall fatal injury trend in construction, both fall fatalities and fatal falls from roofs increased from 1992 to the mid-2000s and decreased in later years.

When economic cycles were considered, fatal injuries coincided with the overall employment trend (see Fig. 1a); the change in fatal falls from roofs was more volatile than the other two categories (i.e., death caused by other types of falls and death due to injuries without falls; see Fig. 1b). From 1992 through 2001, the annual increase for fatal falls

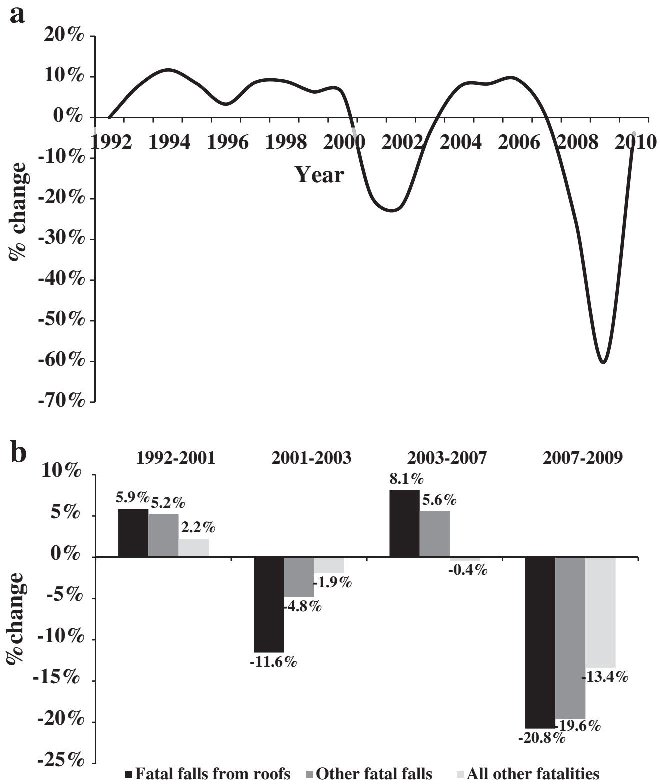

Fig. 1. a. Annual percent change in employment, 1992–2010. b. Annual percent change in work-related deaths in construction, period averages.

from roofs was 5.9%, while the growth for non-fall fatalities was less than half at 2.2%. Other fatal falls also grew considerably at an average of 5.2% year after year during this period. This increased fatality trend coincided with the 10-year economic expansion from March 1991 to March 2001 (NBER, 2001). A decrease in construction fatalities, predominantly among falls from roofs (−11.6%), was observed in 2001–2003, corresponding with the short recession during that period. From 2003–2007, the second half of the most recent economic expansion (U.S. Treasury Department, 2011), fatalities due to falls from roofs increased at a higher annual rate than during the previous expansion (8.1% versus 5.9%). Coinciding with the economic recession which struck in December 2007 (U.S. Treasury Department, 2011), fatal falls from roofs in construction dropped 20.8% annually from 2007 to 2009, while other fatal falls declined by 19.6%, followed by a reduction of 13.4% in non-fall fatalities during the same period.

3.2. Characteristics of fatalities

Characteristics of fatalities in construction from 2003 to 2009 are shown in Table 1. Nearly all construction fatalities occurred among male workers, but patterns of fatalities for all three categories varied among other demographic subgroups. With regard to age, construction workers under 45 years old shared a larger proportion (58%) of fatal falls from roofs, whereas workers aged 55 years and above had a greater percentage of other types of fatal falls (24.4% versus 17.4% of roof fatalities, $p<0.001$). Race characteristics showed that black and other racial minorities were more likely to experience fatal falls from roofs than their white counterparts ($p=0.028$). About 35% of fatal falls from roofs occurred among Hispanic workers even though Hispanic decedents accounted for only one-fourth of all construction fatalities. Similarly, those workers who were foreign-born were more likely to experience fatal falls from roofs (34%) than other types of fatalities ($p=0.002$). Small establishments (1–10 employees) had a disproportionate share of fatal falls in general, with 67% from roofs and 62% from other causes of falls. With regard to injury location, industrial construction had the largest percentage of fatal falls, both from roofs and other causes (42% and 43%, respectively). Fatal falls from roofs in residential construction sites were disproportionately high (34%), given that deaths from all causes in these construction sites made up only 18% of all construction fatalities. For regional characteristics, almost half of all roof fall fatalities occurred in the South.

3.3. Fatality distribution

The distribution of fatal falls from roofs was significantly different ($p<0.001$) from other fatal falls across construction occupations (Table 2). The greatest percentage of roof fall fatalities occurred for roofers (35%), followed by construction laborers (22%) and carpenters (12%). In other fatal falls, however, construction laborers and carpenters accounted for a larger proportion (24% and 15%, respectively). By construction subsector, roofing contractors experienced about 43% of overall roof fall fatalities in construction; over 60% of fatal injuries in roofing contractors were due to falls from roofs. The second-most prevalent sector for roof fatalities was residential building construction (15%). This sector also experienced the greatest percentage of other fatal falls (14%; see Table 2). In terms of types of roof falls from 2003 to 2009, almost half of roof fatalities (46%) were falls from roof edges (Fig. 2). Falls through roof openings and roof surfaces

Table 1
Characteristics of fatalities in construction, 2003-2009.

Characteristics	Fatal falls from roofs (N=875)	Other fatal falls (N=1,844)	All fatalities (N=8,123)	*p*-value*
Age				<0.001
16-19	4.1%	1.8%	2.7%	
20-24	9.0%	6.5%	8.9%	
25-34	20.3%	18.2%	20.9%	
35-44	24.3%	22.2%	23.7%	
45-54	24.6%	26.7%	24.6%	
55-64	13.6%	16.5%	13.8%	
65+	3.8%	7.9%	5.4%	
Gender				0.280
Male	99.3%	99.6%	98.6%	
Race				0.028
White	81.7%	85.7%	84.1%	
Black	5.9%	5.3%	7.2%	
Other	12.3%	9.0%	8.7%	
Hispanic origin				<0.001
Hispanic	34.5%	28.0%	25.3%	
Foreign-born	33.5%	27.7%	23.0%	0.002
Self-employed	21.3%	18.6%	15.5%	0.298
Establishment size [a]				<0.001
1-10 employees	67.1%	61.8%	52.3%	
11-19 employees	10.7%	7.9%	9.3%	
20-49 employees	11.5%	12.1%	13.9%	
50-99 employees	4.6%	7.1%	7.9%	
100+ employees	6.1%	11.1%	16.7%	
Location				<0.001
Industrial construction sites	41.6%	42.9%	30.5%	
Residential construction sites	34.3%	25.3%	18.0%	
Public building	8.5%	6.6%	5.2%	
Other locations	15.0%	24.5%	46.3%	
Region				0.049
South	49.3%	44.2%	47.7%	
West	17.9%	18.2%	19.3%	
Midwest	16.3%	19.2%	19.3%	
Northeast	16.3%	18.4%	13.7%	
Total	**100%**	**100%**	**100%**	–

Source: Numbers were generated by the authors with restricted access to the U.S. Bureau of Labor Statistics' Census of Fatal Occupational Injuries. The views expressed here do not necessarily reflect the views of the BLS.
Note: [a] Self-employed workers and cases without establishment size information were excluded.
* *p*-values reflect chi-square tests for the characteristic variables between falls from roofs and other fatal falls.

Table 2
Distribution of fatalities by construction occupations and subsectors, 2003-2009.

	Fatal falls from roofs (N=875)	Other fatal falls (N=1,844)	All fatalities (N=8,123)	*p-value**
Selected Occupations				<0.001
Roofer	35.1%	3.9%	5.9%	
Construction laborer	21.6%	23.5%	24.3%	
Carpenter	12.3%	15.3%	8.3%	
Foreman	7.7%	6.7%	8.5%	
Construction manager	4.8%	4.5%	5.4%	
Painter	3.5%	7.8%	3.7%	
Ironworker	2.4%	6.0%	2.7%	
Heating A/C mechanic [b]	2.1%	1.7%	1.9%	
Helper	1.6%	0.9%	1.3%	
Welder	1.4%	1.8%	1.7%	
Brickmason	1.0%	3.0%	1.5%	
Sheet metal worker	0.9%	1.0%	0.5%	
Other	5.6%	23.9%	34.3%	
Selected subsectors				<0.001
Roofing Contractors	43.1%	4.8%	7.5%	
Residential Building Construction	14.6%	14.0%	10.1%	
Commercial/Institutional Building Construction	7.0%	6.3%	4.8%	
Structural Steel and Precast Concrete Contractors	4.0%	6.2%	3.0%	
Painting and Wall Covering Contractors	3.9%	7.7%	3.9%	
Framing Contractors	3.7%	4.6%	2.0%	
Plumbing, Heating/Air-Conditioning Contractors	3.7%	5.0%	5.6%	
Site Preparation Contactors	1.6%	2.6%	8.2%	
Industrial Building Construction	1.4%	2.3%	1.6%	
Masonry Contractors	1.3%	5.0%	3.3%	
Drywall and Insulation Contractors	1.3%	5.0%	2.1%	
Electrical Contractors	0.8%	7.5%	7.1%	
Other	13.8%	29.0%	40.9%	
Total	**100%**	**100%**	**100%**	

Source: Numbers were generated by the authors with restricted access to the U.S. Bureau of Labor Statistics' Census of Fatal Occupational Injuries. The views expressed here do not necessarily reflect the views of the BLS.
Note: [b] The full occupation title is Heating, Air Conditioning, and Refrigeration Mechanics and Installers.
* *p*-values reflect chi-square tests for the occupation/subsector between falls from roofs and other fatal falls.

caused nearly 18% of roof fatalities and 14% were due to falls through skylights.

3.4. Fatality rates

When risk was measured by death rate, the rate of fatal falls from roofs was 1.16 per 100,000 FTEs for the entire construction industry from 2003–2009 (Table 3). The youngest (16 to 19 years) and oldest (65 years and older) age groups had the highest rates of roof fatalities, 2.48 and 2.43 per 100,000 FTEs, respectively. Racial minorities were also found to have a higher risk than white workers. In addition, Hispanic workers, immigrants, and self-employed workers all had higher rates of roof fatalities in general. With regard to region, the rate of fall decedents from roofs in the South was 1.41 per

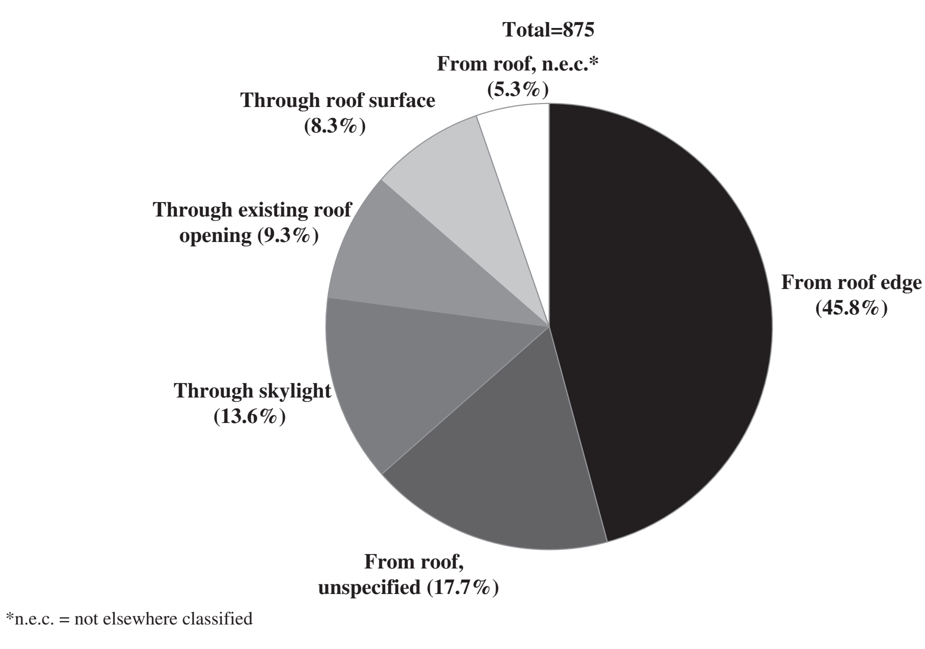

Fig. 2. Types of fatal falls from roofs, 2003–2009.

Table 3
Rate of fatal falls from roofs by selected characteristics, 2003-2009 average.

Characteristics	Rate per 100,000 FTEs	95% CI		Risk Index*
		LB	UB	
Age				
16-19	2.48	2.34	2.64	**2.13**
20-24	1.13	1.10	1.16	0.98
25-34	0.90	0.89	0.91	0.77
35-44	1.04	1.02	1.05	0.89
45-54	1.24	1.22	1.25	**1.06**
55-64	1.57	1.54	1.61	**1.35**
65 and over	2.43	2.29	2.58	**2.09**
Race				
White	1.05	1.05	1.05	0.90
Black	1.21	1.17	1.25	**1.04**
Other	3.45	3.31	3.59	**2.97**
Hispanic ethnicity				
Hispanic	1.79	1.76	1.82	**1.54**
Non-Hispanic	0.95	0.94	0.95	0.81
Country-born				
Foreign-born	1.82	1.79	1.84	**1.56**
Native	0.99	0.98	0.99	0.85
Employment type				
Wage-and-salary	1.06	1.04	1.07	0.91
Self-employed	1.17	1.17	1.18	**1.01**
Region				
South	1.41	1.40	1.43	**1.22**
West	0.87	0.86	0.88	0.75
Northeast	1.19	1.17	1.21	**1.02**
Midwest	0.98	0.96	1.00	0.84
All construction	1.16	1.14	1.19	1.00

Source: Numbers were generated by the authors with restricted access to the U.S. Bureau of Labor Statistics' Census of Fatal Occupational Injuries. The views expressed here do not necessarily reflect the views of the BLS. Rates were calculated using the Current Population Survey.
Note: Rate = number of deaths per 100,000 full-time equivalent workers.
* The average risk of fatal falls from roofs for the construction industry was used as the reference (risk = 1).

100,000 FTEs, about 22% higher than construction as a whole. By occupation, roofers had an extremely high rate at 20.53 per 100,000 FTEs (Table 4).

Table 4
Rate of fatal falls from roofs by selected occupations, 2003-2009 average.

	Rate per 100,000 FTEs	95% CI		Risk Index*
		LB	UB	
Selected occupations				
Roofer	20.53	19.41	21.78	17.67
Ironworker	6.35	5.65	7.25	5.47
Helper	2.13	2.02	2.33	1.83
Construction laborer	2.07	1.96	2.11	1.78
Sheet metal worker	1.77	1.63	1.98	1.52
Welder	1.77	1.59	1.93	1.52
Foreman	1.11	1.08	1.14	0.96
Carpenter	1.11	1.08	1.13	0.95
Heating A/C mechanic[c]	0.88	0.84	0.93	0.76
Painter	0.81	0.80	0.86	0.70
Brickmason	0.67	0.63	0.72	0.58
Construction manager	0.63	0.62	0.65	0.54
All construction	1.16	**1.14**	**1.19**	**1.00**

Source: Numbers were generated by the authors with restricted access to the U.S. Bureau of Labor Statistics' Census of Fatal Occupational Injuries. The views expressed here do not necessarily reflect the views of the BLS. Rates were calculated using the Current Population Survey.
Note: Rate = number of deaths per 100,000 full-time equivalent workers.
[c] The full occupation title is Heating, Air Conditioning, and Refrigeration Mechanics and Installers.
* The average risk of fatal falls from roofs for the construction industry was used as the reference (risk = 1).

3.5. Contributing factors to roof fatalities

Table 5 shows the results from Pearson's correlation coefficient (r) analyses. For fatal falls from roofs, significant positive associations were found for roofers, Hispanic ethnicity, self-employed status, and residential sites; while significant negative associations were observed with establishment size and job tenure. The correlation coefficient matrix also indicated that roofers, the occupation with the highest risk of falls from roofs, were more likely to be younger ($r = -0.039$, $p < 0.001$), Hispanic ($r = 0.086$, $p < 0.001$), and work in residential construction ($r = 0.115$, $p < 0.001$). In the South, fall decedents from roofs tended to be of Hispanic origin ($r = 0.105$, $p < 0.001$), younger ($r = -0.046$, $p < 0.001$), and have shorter tenures with their current employer ($r = -0.084$, $p < 0.001$).

Results from the multinomial logistic regression model are presented in Table 6. After adjusting for other risk factors, the odds of experiencing a fatal fall from a roof versus a non-fall fatality were significantly higher for Hispanic workers when compared with non-Hispanic workers (OR = 1.24, 95% CI: 1.02 - 1.50). Self-employed workers were also more likely to have a roof fatality when compared with wage-and-salary workers (OR = 1.45, 95% CI: 1.15–1.83). Compared with other occupations, deaths among roofers were 5.3 times more likely to be caused by falls from roofs. With regard to construction subsectors, the highest odds of roof fatalities were found in the roofing industry (OR = 12.85, 95% CI: 9.38 - 17.59) followed by the residential industry (OR = 2.03, 95% CI: 1.56–2.63). Working at residential sites also had higher odds of roof fatalities than at other construction sites (OR = 1.80, 95% CI: 1.45–2.22). In addition, small establishments (<20 employees) had significantly greater odds of fatal falls from roofs than mid-sized or larger establishments with 20 or more employees (OR = 1.27 for establishments with 1–10 employees and OR = 1.42 for establishments with 11–19 employees).

The difference between roof fatalities and non-fall fatalities was not significant in the selected dummy age groups and geographic regions when controlling for other factors, but was significant in other comparison groups (Table 6). The construction occupations examined in the model had significantly higher odds of other fatal falls, particularly for ironworkers (OR = 6.23, 95% CI: 4.63–8.38), sheet metal workers (OR = 4.29, 95% CI: 2.21–8.35), and carpenters (OR = 3.16, 95% CI: 2.62–3.83). Those working as roofers had a higher risk of other fatal falls in addition to falls from roofs (OR = 1.83, 95% CI: 1.22–2.75). Conversely, no significant difference was found in establishments with 11–19 employees, the residential industry, and the roofing industry when comparing other fatal falls with non-fall fatalities. This suggests that fatal falls in these subgroups were mainly caused by falls from roofs.

4. Discussion

4.1. Key findings

This study examined the trends and patterns of fatal falls from roofs in construction from 1992 to 2009. The results indicated that fatality trends in construction corresponded with economic cycles in the past two decades, with roof fatalities being the most sensitive to economic changes, in particular to housing markets during this period. Although overall rates of fatal injuries in the U.S. construction industry gradually declined since 1992, results from trend analyses suggested that the recent decline in roof fatalities was appreciably attributed to the economic downturn during 2007–2009. In terms of risk, roofers, ironworkers, construction helpers, and construction laborers were the four most dangerous occupations with the highest death rates for falls from roofs. Multinomial logistic regression results suggested that working as a carpenter, sheet metal worker, or welder also significantly increased the odds of fatal falls from roofs after controlling for possible confounders. With regard to construction

Table 5
Pearson correlation coefficients and p-values of fatal falls from roofs and independent variables.

Variables (Prob>|r| under H0: Rho = 0)	Falls from roofs	Age	Establishment size	Roofer	Hispanic	Job tenure	Southern region	Self-employed	Residential site
Falls from roofs	1.000	−0.020	**−0.023**	**0.430**	**0.075**	**−0.045**	0.011	**0.056**	**0.147**
		0.066	0.041	<.001	<.001	0.036	0.342	<.001	<.001
Age	−0.020	1.000	**0.028**	**−0.039**	**−0.240**	**0.299**	**−0.046**	**0.213**	−0.017
	0.066		0.010	0.001	<.001	<.001	<.001	<.001	0.126
Establishment size	**−0.023**	**0.028**	1.000	−0.013	**0.032**	0.010	**0.027**	**−0.152**	**−0.068**
	0.041	0.010		0.227	0.004	0.653	0.017	<.001	<.001
Roofer	**0.430**	**−0.039**	−0.013	1.000	**0.086**	−0.030	−0.006	0.016	**0.115**
	<.0001	0.001	0.227		<.001	0.163	0.562	0.161	<.001
Hispanic	**0.075**	**−0.240**	**0.032**	**0.086**	1.000	**−0.122**	**0.105**	**−0.060**	**0.088**
	<.001	<.001	0.004	<.001		<.001	<.001	<.001	<.001
Job tenure	**−0.045**	**0.299**	0.010	−0.030	**−0.122**	1.000	**−0.084**	**0.120**	**−0.070**
	0.036	<.001	0.653	0.163	<.001		<.001	<.001	0.001
Southern region	0.011	**−0.046**	**0.027**	−0.006	**0.105**	**−0.084**	1.000	−0.013	**−0.053**
	0.342	<.001	0.017	0.562	<.001	<.001		0.253	<.001
Self-employed	**0.056**	**0.213**	**−0.152**	0.016	**−0.060**	**0.120**	−0.013	1.000	**0.168**
	<.001	<.001	<.001	0.161	<.001	<.001	0.253		<.001
Residential site	**0.147**	−0.017	**−0.068**	**0.115**	**0.088**	**−0.070**	**−0.053**	**0.168**	1.000
	<.001	0.126	<.001	<.001	<.001	0.001	<.001	<.001	

Source: Numbers were generated by the authors with restricted access to the U.S. Bureau of Labor Statistics' Census of Fatal Occupational Injuries. The views expressed here do not necessarily reflect the views of the BLS.

subsectors, the odds of fatal falls from roofs were higher for roofing and residential construction than any other construction sector. In addition, workers who were younger than 20 years or older than 44 years, racial minorities, Hispanics, and immigrant workers had a higher death rate of falls from roofs than the construction industry overall. Other risk factors included being self-employed, working at residential construction sites, and being employed in small establishments with fewer than 20 employees.

4.2. Study limitations

The research results must be taken into consideration with a few limitations of this study. The first limitation is that numerators (i.e., fatalities) and denominators (i.e., employment) cannot be linked in various ways. For instance, employment data in construction subsectors are not available in the CPS since the construction industry is coded as one industry in this dataset. Although employment data on construction subsectors are available in other data sources, such as the Current Employment Statistics (CES) and the County Business Patterns (CBP), neither the CES nor CBP contains data on worker demographics, which are essential in computing death rates for subpopulations. On the other hand, the death rates reported in this study may be either underestimated or overestimated since self-reported hours worked derived from household surveys may not be accurate, affecting rate calculations (CPWR, 2010).

Another limitation to note is that some critical information that could influence the rate of falls from roofs (e.g., industry breakdowns,

Table 6
Multinomial logistic regression on fatalities in construction, 2003–2009.

Characteristics	Odds Ratio Estimates							
	Fatal falls from roofs vs. non-fall fatalities				Other fatal falls vs. non-fall fatalities			
	Point Estimate	95% CI		Pr>ChiSq	Point Estimate	95% CI		Pr>ChiSq
Demographics								
Age (16-19/65+ vs. 20–64 years old)	1.236	0.912	1.673	0.171	**1.285**	**1.056**	**1.564**	**0.012**
Hispanic (vs. non-Hispanic)	**1.235**	**1.020**	**1.495**	**0.030**	**1.312**	**1.152**	**1.495**	**<.0001**
South (vs. other regions)	1.090	0.919	1.292	0.321	**0.847**	**0.757**	**0.948**	**0.004**
Occupation								
Roofer (vs. other occupations)	**5.317**	**3.690**	**7.662**	**<.0001**	**1.830**	**1.218**	**2.748**	**0.004**
Carpenter (vs. other occupations)	**4.305**	**3.258**	**5.688**	**<.0001**	**3.163**	**2.616**	**3.825**	**<.0001**
Laborer (vs. other occupations)	**1.724**	**1.377**	**2.157**	**<.0001**	**1.154**	**1.002**	**1.328**	**0.047**
Ironworker (vs. other occupations)	**5.644**	**3.413**	**9.333**	**<.0001**	**6.225**	**4.627**	**8.376**	**<.0001**
Sheet metal worker (vs. other ccupations)	**3.816**	**1.485**	**9.805**	**0.005**	**4.290**	**2.205**	**8.347**	**<.0001**
Welder (vs. other occupations)	**2.271**	**1.176**	**4.387**	**0.015**	**1.668**	**1.108**	**2.512**	**0.014**
Industry								
Roofing industry (vs. other subsectors)	**12.845**	**9.380**	**17.590**	**<.0001**	1.391	0.974	1.988	0.070
Residential industry (vs. other subsectors)	**2.027**	**1.564**	**2.626**	**<.0001**	1.196	0.988	1.448	0.066
Employment								
Self employed (vs. wage-and-salary)	**1.451**	**1.154**	**1.826**	**0.002**	**1.236**	**1.055**	**1.448**	**0.009**
Establishment size 1–10 (vs. size 20+)	**1.265**	**1.052**	**1.521**	**0.013**	**1.418**	**1.256**	**1.600**	**<.0001**
Establishment size 11–19 (vs. size 20+)	**1.422**	**1.023**	**1.976**	**0.036**	1.016	0.802	1.286	0.898
Location								
Residential sites (vs. other sites[d])	**1.797**	**1.454**	**2.222**	**<.0001**	**1.701**	**1.459**	**1.984**	**<.0001**

Source: Numbers were generated by the authors with restricted access to the U.S. Bureau of Labor Statistics' Census of Fatal Occupational Injuries. The views expressed here do not necessarily reflect the views of the BLS.
Note: [d] Other sites include industrial sites, public buildings, street and highway, and other locations.

job location information) was only available in the CFOI data. As a result, only the CFOI data were utilized in the multivariate analyses. Finally, none of the data sources used in this study provided information regarding working conditions and environments, safety and health trainings, availability of fall prevention equipment, or other work organization and safety climate factors. Thus, the real risk of falls from roofs may not be fully captured in this study.

4.3. Industry impact

4.3.1. Enforcing OSHA regulations

This study added evidence that falls from roofs are the leading cause of work-related deaths among residential construction workers. Previous research illustrated that lack of specific fall prevention methods and regulations may contribute to the higher rates of fall deaths in residential construction (Kaskutas et al., 2009; Lipscomb, Dale, Kaskutas, Sherman-Voellinger, & Evanoff, 2008; Sa et al., 2009). To reduce roof injuries, it is imperative to enforce OSHA regulations. OSHA's guidance document, Fall Protection in Residential Construction (2012), describes various project-specific methods that residential construction employers may be able to use to prevent fall-related injuries and fatalities at various points in the residential construction process. Under OSHA regulations (29 CFR 1926.501(b)(13)), workers engaged in residential construction six feet or more above lower levels must be protected by conventional fall protections (e.g., guardrail systems, safety net systems, or PFAS) or other types of fall protection measures (OSHA, 1995). According to OSHA, fall protections must meet and be used in accordance with applicable OSHA requirements.

4.3.2. Strengthening fall protection programs in the roofing industry

While roof injuries occur among many construction occupations and sectors, this study confirmed that roofing and residential construction sectors have a much higher risk of falls from roofs than any other construction sectors. All roofing contractors should have a written fall protection program that specifies what type of fall protection is provided, provides adequate training for workers, and enforces fall protection programs. Exposed sides and edges should be protected with guardrails, safety nets, or personal fall protection systems. Alternative fall protection methods (e.g., safety lines and safety monitoring systems) should only be used when standard fall protection methods are not feasible or present a greater danger. Additional methods that reduce or eliminate fall exposures should also be considered, such as fabrication of roof components on ground levels and later positioned mechanically. Roof openings must be securely covered with material of adequate strength and marked with “HOLE” or “COVER,” or protected with a guardrail system as required by OSHA (29 CFR 1926.502(i)(4)) (OSHA, 1995). When installing or removing opening covers or guardrails, workers should be protected with PFAS. Skylights must be guarded with protective screens or guardrails (29 CFR 1926.501(a)(4)) and PFAS should be used when installing or removing skylights. Furthermore, weak roof surfaces should be identified and marked when possible.

4.3.3. Evaluating Effectiveness of Training

Although resources such as fall prevention programs and protective equipment are necessary, they are less effective without adequate training. Many Hispanic or Latino construction workers lack English language abilities (CPWR, 2008), which could result in not understanding proper working procedures and lead to serious injuries to themselves or others. Lipscomb et al. (2008) studied the challenges in residential fall prevention through a series of focus groups with union apprentice carpenters at various levels of training. Their findings indicate that apprentices often do not apply safety principles they have been taught in the actual work environment, illustrating how attempts to prepare workers through training alone can fall short. The findings also demonstrate the importance of measuring more than just knowledge when evaluating training effectiveness.

4.3.4. Developing fall protection equipment

It is imperative to aid design engineers and safety professionals in assessing the effectiveness of existing PFAS to mitigate potential risks of falls in the construction industry. For instance, Goh and Love (2010) conducted a study evaluating the capacity of fall arrest energy absorbers in relation to the weight of heavy workers to provide recommendations for improvements in current fall arrest standards. Their study recommended that current fall arrest standards be reviewed to account for the increasing weight of workers. Not only should the test mass be increased in accordance with the weight of heavy workers, but the review should also consider the influence of other parameters such as the damping effect of the human body, G-force, and acceleration duration. In addition, fall protection mechanisms need to be easy to install, cost effective, and serve dual purposes (e.g., a specialized net to catch nails and other debris).

4.4. Future studies

The National Construction Agenda has strategic safety goals designed to address the “top 10 problems” in construction safety and health (NORA, 2008). In addition to reformation of design for safety and prevention issues and training issues described above, improved surveillance for hazards and outcomes is needed in order to achieve the NORA goals. For example, future research could implement the revised BLS coding system and CFOI data (BLS, 2010b) to verify these findings. Case studies or project-based studies could also be conducted to complement the methodology and findings of this current study.

Research is also needed on effectiveness of fall protection equipment and methods for steep sloped roofs such as single-family residences. Researchers have reported that both construction workers and managers expressed that lack of use of PFAS was primarily due to its negative impact on productivity and comfort. Yet, the objective measure of impact on productivity and safety measures as a result of the use of a restrictive safety device has not been extensively studied. It is critical to study the influence of different types of PFAS on productivity and safety during residential roofing construction (Choi, Griinke, & Lederer, 2006). The effectiveness of the guardrail system (Bobick, McKenzie, & Kau, 2010), perception of loss of balance (Choi, 2005, 2008; Choi & Fredericks, 2008), and vertical structures as visual cues (Simeonov, Hsiao, & Hendricks, 2009) in fall prevention have not yet been thoroughly examined and validated. Long-term and large-scale studies are needed to address their implications in fall prevention. In addition, the Hierarchy of Fall Hazard Control Methods (Weisgerber & Wright, 1999), which establishes a hierarchy of fall protection measures and has been extensively adopted in U.K. (Health & Safety Executive, 2007), British Columbia, Canada (WorkSafeBC, 2005), and Australia (National Code of Practice for the Prevention of Falls in General Construction, 2008), should be considered when planning work at heights.

Further study is also needed to understand why the South has more fall fatalities from roofs. For instance, environmental factors such as heat, humidity, and related fatigue could be examined. In addition to communication and training barriers, research is needed to determine additional causes for the higher rate (50%) of fatal falls among Hispanic and foreign-born workers, such as less experience with large buildings and a higher prevalence of a “fear of falling.”

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References

Bobick, T. G., McKenzie, E. A., & Kau, T. Y. (2010). Evaluation of guardrail systems for preventing falls through roof and floor holes. *Journal of Safety Research*, *41*(3), 203–211.

Choi, S. D. (2005). Ratings of perceived loss of balance: A potential safety monitoring technique for workers walking/working on sloped surfaces. *Journal of Safety, Health and Environmental Research*, *2*(1), 1–26.

Choi, S. D. (2008). Postural balance and adaptations in transitioning sloped surfaces. *International Journal of Construction Education and Research*, *4*(3), 189–199.

Choi, S. D., & Fredericks, T. K. (2008). Surface slope effects on shingling frequency and postural balance in a simulated roofing task. *Ergonomics*, *51*(3), 330–344.

Choi, S. D., Griinke, D., & Lederer, M. (2006). Fall protection equipment effects on productivity and safety in residential roofing construction. *Journal of Construction Research*, *7*(1/2), 149–157.

CPWR - The Center for Construction Research and Training (2008). *The Construction Chart Book: The U.S. Construction Industry and its Workers* (4th edition). Silver Spring, MD:CPWR.

CPWR - The Center for Construction Research and Training (2010). Work-related fatal and nonfatal injuries among U.S. construction workers, 1992–2008. Silver Spring, MD. http://www.cpwr.com/rp-cpwrreports2.html

Dong, X., Fujimoto, A., & Men, Y. (2009). Fatal falls among Hispanic construction workers. *Accident Analysis and Prevention*, *41*, 1047–1052.

Fredericks, T. K., Abudayyeh, O., Choi, S. D., Wiersma, M., & Charles, M. (2005). Occupational injuries and fatalities in the roofing contracting industry. *Journal of Construction Engineering and Management*, *131*, 1233–1240.

Goh, Y. M., & Love, P. (2010). Adequacy of personal fall arrest energy absorbers in relation to heavy workers. *Safety Science*, *48*(6), 747–754.

Health & Safety Executive (2007). *The work at height regulations 2005: A brief guide.* Suffolk, England: Health & Safety Executive (Retrieved from, http://www.hse.gov.uk/pubns/indg401.pdf)

Health & Safety Executive (2010). *Health and safety in roof work.* Suffolk, England: Health & Safety Executive (Retrieved from, http://www.hseni.gov.uk/hsg33_roof_work.pdf)

Hsiao, H., & Simeonov, P. (2001). Preventing falls from roofs: A critical review. *Ergonomics*, *44*, 537–561.

Kaskutas, V., Dale, A. M., Nolan, J., Patterson, D., Lipscomb, H. J., & Evanoff, B. (2009). Fall hazard control observed on residential construction sites. *American Journal of Industrial Medicine*, *52*, 491–499.

Lipscomb, H. J., Dale, A. M., Kaskutas, V., Sherman-Voellinger, R., & Evanoff, B. (2008). Challenges in residential fall prevention: Insight from apprentice carpenters. *American Journal of Industrial Medicine*, *51*, 60–68.

National Bureau of Economic Research (NBER) (2001). *The business-cycle peak of March 2001.* Cambridge, MA: The National Bureau of Economic Research (Retrieved from http://www.nber.org/cycles/november2001/)

National Bureau of Economic Research (NBER) (2008). *Determination of the December 2007 peak in economic activity.* Cambridge, MA: The National Bureau of Economic Research (Retrieved from http://www.nber.org/cycles/dec2008.html)

National Code of Practice for the Prevention of Falls in General Construction (2008). Australian Workplace Safety Standards Act. (2005). Retrieved from. http://www.safeworkaustralia.gov.au/sites/SWA/AboutSafeWorkAustralia/WhatWeDo/Publications/Documents/247/NationalCodeofPractice_PreventionOfFalls_GeneralConstruction_2008_PDF.pdf

National Occupational Research Agenda (NORA) (2008). *National construction agenda for occupational safety and health research and practice in the U.S. construction sector.* : National Institute for Occupational Safety and Health (NIOSH) (Retrieved from http://www.cdc.gov/niosh/nora/comment/agendas/construction/pdfs/ConstOct2008.pdf)

Occupational Safety and Health Administration (OSHA) (1995). *Part 1926: Safety and Health Regulations for Construction – Subpart M: Fall Protection.* Washington, D.C.: Occupational Safety and Health Administration (Retrieved from http://www.osha.gov/pls/oshaweb/owasrch.search_form?p_doc_type=STANDARDS&p_toc_level=1&p_keyvalue=1926)

Occupational Safety and Health Administration (OSHA) (2011). *Workers' compensation costs of falls in construction.* Washington, D.C.: Occupational Safety and Health Administration (Retrieved from http://www.osha.gov/doc/topics/residentialprotection/workerscomp.ppt)

Occupational Safety and Health Administration (OSHA) (2012). *OSHA guidance document: Fall protection in residential construction.* Washington, D.C.: Occupational Safety and Health Administration (Retrieved from http://www.osha.gov/doc/guidance.pdf)

Olbina, S., Hinze, J., & Ruben, M. (2011). Safety in roofing: Practices of contractors that employ Hispanic workers. *Professional Safety*, *56*(4), 44–52.

Sa, J., Seo, D. C., & Choi, S. D. (2009). Comparison of risk factors for falls from height between commercial and residential Roofers. *Journal of Safety Research*, *40*(1), 1–6.

Simeonov, P. I., Hsiao, H., & Hendricks, S. (2009). Effectiveness of vertical visual reference for reducing postural instability on inclined and compliant surfaces at elevation. *Applied Ergonomics*, *40*(3), 353–361.

SAS Institute (2010). *SAS/STAT 9.2 User's Guide*, *1-7*, SAS Publishing, Cary, NC: SAS Institute Inc.

U.S. Bureau of Labor Statistics (BLS) (2007). Occupational Injury and Illness Classification system. 2007. Retrieved from. http://www.bls.gov/iif/oiics_manual_2007.pdf

U.S. Bureau of Labor Statistics (BLS) (2010a). Injuries, illnesses, and fatalities: Census of Fatal Occupational Injuries (CFOI). Retrieved from. http://www.bls.gov/iif/oshfat1.htm

U.S. Bureau of Labor Statistics (BLS) (2010b). Occupational Injury and Illness Classification system, 2007. Retrieved from. http://www.bls.gov/iif/oiics_manual_2010.pdf

U.S. Bureau of Labor Statistics (BLS) (2011). News release: National Census of Fatal Occupational Injuries in 2010 (Preliminary Results). Retrieved from. http://www.bls.gov/news.release/pdf/cfoi.pdf

U.S. Bureau of Labor Statistics (BLS) (2012a). Fatal work injuries, 2009. Retrieved from. http://www.bls.gov/iif/oshwc/cfoi/cfch0008.pdf

U.S. Bureau of Labor Statistics (BLS) (2012b). *Occupational injuries/illnesses and fatal injury profiles, 2003–2009; Fatal occupational injuries by selected worker characteristics and selected industry, all U.S., all ownerships, 2003–2009.*

U.S. Treasury Department (2011). Recession evaluator graphic. Retrieved from. http://sbcmag.info/news/2011/oct/recession-evaluator-graphic

Wade, C., & Davis, J. (2009). Postural sway following prolonged exposure to an inclined surface. *Safety Science*, *47*(5), 652–658.

Weisgerber, F. E., & Wright, M. C. (1999). Elements of a Fall Safety through Design Program. *Proceedings of the 2nd International Conference, CIB W99, Implementation of Safety and Health on Construction Sites* (pp. 867–874). Rotterdam, Netherlands: Balkema Publishers.

WorkSafeBC (2005). *Occupational Health and Safety (OHS) Regulation: Part 11 – Fall protection.* British Columbia, Canada: WorkSafeBC (Retrieved from http://www2.worksafebc.com/Publications/OHSRegulation/Part11.asp)

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