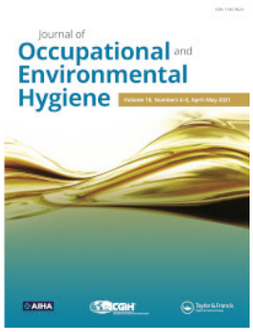

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Injury inequalities among U.S. construction workers

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ABSTRACT

This study explores racial/ethnic inequalities in work-related injuries among U.S. construction workers. Data from the 2004–2017 National Health Interview Survey were used to estimate work-related injuries by race/ethnicity in construction. Disparities in demographic, socioeconomic, and injury status among construction workers were examined by race/ethnicity. Injury differences were also evaluated in multiple logistic regression analyses controlling for potential confounders. Compared to white, non-Hispanic workers, minority workers were more likely to have lower socioeconomic statuses (e.g., lower educational attainment, lack of health insurance coverage, and family income below the poverty level), which considerably increased the likelihood of work-related injuries. The odds of work-related injuries were 70% higher among racial/ethnic minorities than white, non-Hispanics in construction. Injuries were also more severe among minorities than white, non-Hispanic workers. Among workers with a work-related injury, nearly 85% of Hispanics reported missing at least one workday due to injury, 45.6% higher than the proportion of 57.9% for their white, non-Hispanic counterparts. After adjusting for major demographic and socioeconomic factors, the work-related injury difference between race/ethnicity was no longer statistically significant. However, the odds of work-related injury remained significantly higher among workers who were younger (35–54 years vs. $\geq$ 55 years: aOR = 2.2, 95% CI: 1.3–3.6); male (aOR = 5.3, 95% CI: 2.9–9.8); not college-educated (aOR = 1.5, 95% CI: 1.0–2.2); had a family income below the poverty threshold (aOR = 1.8, 95% CI: 1.2–2.8); or held a blue-collar occupation (aOR = 2.0, 95% CI: 1.2–3.4). These findings suggest that the injury differences between race/ethnicity were strongly associated with demographics and socioeconomic inequalities in these worker groups. The identified injury disparities should be reduced or eliminated, following the hierarchy of controls paradigm.

KEYWORDS

Minority; occupation; socioeconomic; work-related

Introduction

Racial and ethnic inequalities in the U.S. are reflected in a variety of areas; most notable being in health (Shavers and Shavers 2006; Singh et al. 2017), wealth (Brown 2016; Maroto 2016), education (Noguera 2017), and employment (Slack and Jensen 2009). Similar to the nation overall, racial and ethnic inequities have been observed in the construction industry (Mishel 2017)—an industry with a high risk of work-related injuries and illnesses (Kachan et al. 2012). Despite progresses, studies show that minority workers in construction still lag behind their white, non-Hispanic counterparts in education, wage rates, family income, health insurance coverage, pension plans, training, and unionization (The Center for Construction Research and Training (CPWR) 2018; National Institute of Occupational Safety and Health and American Society of Safety Engineers (NIOSH and ASSE) 2015; Mishel 2017). Disparities in occupational safety and health were also identified (Anderson et al. 2000; Dong et al. 2010; CPWR 2018). While the gap in injury rates has decreased over the years, rates of fatal falls remain higher among Hispanic construction workers than non-Hispanics (Dong et al. 2009; CPWR 2018). Disparities in injury severity were also found, with minorities missing significantly more workdays due to injury/illness than non-Hispanic whites (Strong and Zimmerman 2005; Dong et al. 2010). Furthermore, research has shown that the risk of work-related injuries and illnesses are more likely to be underestimated among minority workers than white, non-Hispanics because of non- or under-reporting (Lipscomb et al. 2006; Shannon et al. 2009).

Researchers have attempted to explain why such disparities exist. One study reported that Hispanic

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workers employed in residential construction in North Carolina did not always receive personal protective equipment (PPE) as required by law (Grzywacz et al. 2012). Another study found that Hispanic trainees tended to value job security over speaking up about safety issues, as speaking up may threaten their employment (Shrestha and Menzel 2014). Studies also examined workplace characteristics related to safety, including physical demands of the job, job security, job tenure, training, and company size (Dong et al. 2009; Arcury et al. 2014). Lack of bilingual skills among construction workers and employers may also affect worker safety (Flynn 2014). A report from the Associated General Contractors of America (AGC Diversity and Inclusion Council 2018) pointed out that employers may group Hispanics together, regardless of English ability, construction experience, country of origin, education level, and time in the U.S. Although information on workplace discrimination is often missing, one study found that Hispanic workers were more likely to experience racial discrimination and harassment than non-Hispanic, whites (Shannon et al. 2009).

While the aforementioned studies evaluated racial/ethnic disparities from different perspectives, factors were often examined individually and geographically rather than collectively and nationally. Given the persistent disparities in occupational safety and health among construction workers, further investigation of the factors driving these disparities is needed to inform prevention efforts. To this end, the current study explored race and ethnicity inequalities in work-related injuries among construction workers by analyzing a large, nationally representative population survey. Injury inequalities and their associations with demographic and socioeconomic factors were examined. In addition, potential factors underlying injury inequities were measured and discussed through this study.

Methods

This study analyzed the 2004–2017 National Health Interview Survey (NHIS) data. The NHIS is a nationally representative, cross-sectional household survey conducted annually by the National Center for Health Statistics (NCHS). The NHIS gathers demographic, employment, and other health-related information from the civilian, non-institutionalized U.S. population. More information about the survey is available from https://www.cdc.gov/nchs/nhis/index.htm. The NHIS sample adult (aged 18 or older) file and injury file were downloaded from the IPUMS NHIS database (Blewett et al. 2019), and linked by the survey ID at the individual level. As the NHIS data are publicly available, this study was exempt from human subjects review.

Construction workers were respondents who reported construction as their primary industry, regardless of their occupation and employment status when the survey was conducted. Occupations were recoded as *blue-collar* (i.e., construction trades and production occupations) or *white-collar* (i.e., managerial, professional occupations, and office workers). *Injuries* were defined as incidents that occurred and received medical advice or treatment in the past three months. Since very few construction workers (n = 18) experienced more than one injury in the 3-month period, only the respondent's first reported injury was included in the tabulations. If the activity reported was "working at a paid job" or "unpaid work" when the injury occurred, a *work-related injury* (WRI) was counted.

Race/ethnicity was self-reported and regrouped as "Hispanic", "white, non-Hispanic", "black, non-Hispanic", and "other, non-Hispanic" (i.e., Asian, American Indian/Alaskan Native, or multiracial). To increase statistical reliability, race/ethnicity was dichotomized ("white, non-Hispanic" vs. "racial/ethnic minority") for the regression analyses. *Family income* was denoted as a poverty level threshold (at or above vs. below) based on the U.S. Census Bureau's poverty threshold in the year prior to the survey. *Health insurance coverage* was defined as having a general health insurance plan, either public or private. Fourteen years of the NHIS data between 2004 and 2017 were pooled together to increase sample size and statistical power. The NHIS survey weights, strata, and clusters were used in all statistical analyses to account for the complex survey design. Injury estimates were annualized using the survey weight multiplied by four for injured workers. Demographics, socioeconomic characteristics, and injury status were stratified by race/ethnicity. Chi-square tests were employed to measure if differences in injury characteristics between minority and white, non-Hispanic workers were statistically significant at the $a = 0.05$ level. Pearson correlation coefficients were calculated to assess relationships between injury status (WRI vs. non-WRI), race/ethnicity, and other demographic and occupational characteristics. Three logistic regression models were developed to estimate unadjusted and adjusted odds ratios (ORs or aORs) of work-related injuries and their 95% confidence intervals (CIs). Model 1 included race/ethnicity only to estimate unadjusted ORs; Model 2 added work-related characteristics, including occupation; and Model 3 added demographic and socioeconomic factors, such as age, gender, education, and poverty

Table 1. Characteristics of construction workers, National Health Interview Survey (NHIS), average of 2004–2017.

Characteristic	All (N = 24,144) Sample dist. %	SE	Hispanic (N = 5,946) Sample dist. %	SE	White, Non-Hispanic (N = 15,334) Sample dist. %	SE	Black, Non-Hispanic (N = 1,880) Sample dist. %	SE	Other, Non- Hispanic[A] (N = 984) Sample dist. %	SE
Demographic										
Age group										
18–29	18.9	0.4	27.5	0.8	16.6	0.5	13.7	1.1	18.3	1.8
30–39	21.0	0.3	30.9	0.8	17.9	0.4	18.0	1.3	22.6	1.9
40–49	22.0	0.3	22.7	0.7	21.8	0.4	22.2	1.1	20.3	1.7
50–59	18.4	0.3	10.8	0.5	20.5	0.4	22.3	1.1	18.1	1.4
60+	19.8	0.3	8.1	0.4	23.2	0.4	23.9	1.1	20.7	1.6
Female	10.0	0.2	4.8	0.3	11.7	0.3	8.1	0.8	12.3	1.5
Below poverty threshold	13.6	0.3	24.2	0.7	9.2	0.3	23.1	1.3	15.6	1.5
Education										
College graduate or more	10.5	0.3	4.7	0.4	12.5	0.4	7.2	0.8	14.5	1.5
Some college or associates	27.5	0.4	15.5	0.7	31.4	0.5	26.6	1.3	29.0	1.8
High school or GED	37.0	0.4	29.0	0.9	39.4	0.5	39.3	1.4	37.7	2.1
Some high school	15.3	0.3	22.4	0.7	12.7	0.3	20.0	1.1	12.7	1.5
<9th grade	9.7	0.3	28.4	0.7	4.0	0.3	7.0	0.7	6.1	1.0
NHIS interview language										
English only	88.3	0.4	49.7	1.0	99.5	0.1	99.9	0.1	96.2	0.7
Spanish only	7.2	0.3	32.0	0.9	0.1	0.0	0.0	0.0	0.1	0.1
Other[B]	4.5	0.2	18.2	0.7	0.4	0.1	0.1	0.0	3.7	0.7
Born outside U.S.	21.4	0.5	74.8	0.8	4.5	0.2	11.6	1.1	28.3	2.0
Work-related										
Employment status										
Employed	70.2	0.4	81.9	0.6	67.8	0.5	58.2	1.5	63.4	2.0
Unemployed	6.1	0.2	6.0	0.4	5.6	0.2	10.0	1.0	8.0	1.1
Not in labor force[C]	23.7	0.4	12.1	0.6	26.6	0.4	31.8	1.4	28.6	2.0
Self-employed	21.8	0.4	15.1	0.6	24.8	0.4	15.4	1.0	17.7	1.6
Blue-collar worker	77.8	0.4	90.6	0.5	72.9	0.5	87.1	1.0	74.9	1.8
Occupation group										
Construction/extraction	67.3	0.4	81.9	0.7	62.1	0.5	73.6	1.3	63.7	2.0
Management/professional	15.3	0.3	6.4	0.5	18.9	0.4	8.3	0.8	16.4	1.5
Farming/other production	10.2	0.3	8.1	0.5	10.5	0.3	12.8	1.1	11.0	1.3
Services/sales/clerical	7.2	0.2	3.6	0.3	8.5	0.3	5.3	0.7	9.0	1.3
Health insurance coverage										
Insured	70.1	0.4	42.5	1.0	78.6	0.4	70.0	1.3	79.3	1.6
Injury status										
Not injured	88.5	0.5	92.2	0.7	87.0	0.6	90.0	1.5	91.5	1.5
WRI	3.9	0.3	3.8	0.5	4.0	0.4	3.4	1.3	3.4	1.0
Non-WRI	7.6	0.4	4.0	0.6	9.0	0.5	6.6	1.1	5.1	1.3
Total (weighted)	**100% (14.2 million)**		**22.3% (3.2 million)**		**68.0% (9.7 million)**		**6.1% (0.9 million)**		**3.6% (0.5 million)**	

Abbreviations and acronyms: dist., distribution; SE, standard error; WRI, work-related injury; non-WRI, injury unrelated to work
Wald chi-square test of differences in characteristics by race/ethnicity statistically significant at $p < 0.0001$ for all categories.
[A]Includes Asian, American Indian/Alaskan Native, multiple races, and persons for whom race was not releasable due to confidentiality or other reasons.
[B]Includes combination of English and Spanish, or any other language.
[C]Defined as individuals who did not have a job and were not looking for one in the last week.

level. All statistical analyses were performed using SAS (V. 9.4, SAS Institute, Cary, NC).

Results

From 2004–2017, more than 24,000 NHIS respondents reported that the construction industry was their primary industry, representing over 14 million workers (weighted, including all employment statuses) annually during the study period (Table 1). Of these, 68.0% reported they were white, non-Hispanic; 22.3% were Hispanic; and 9.7% were other minorities. Worker demographics varied by race/ethnicity ($p < 0.0001$). Hispanic workers were younger (58.4% < 40 years), more likely to be male (95.2%), and had lower levels of education. Nearly 30% (28.4%) of Hispanic workers had

Table 2. Characteristics of injuries among construction workers who were injured while employed.

	All injured workers				Hispanic				White, Non-Hispanic				Other, Non-Hispanic[A]				p value[B]	
	WRIs (N = 238)		Non-WRIs (N = 283)		WRIs (N = 62)		Non-WRIs (N = 48)		WRIs (N = 150)		Non-WRIs (N = 210)		WRIs (N = 26)		Non-WRIs (N = 25)		WRIs	Non-WRIs
Injury characteristic	%	SE	%	SE	%	SE	%	SE	%	SE	%	SE	%	SE	%	SE		
All injuries																		
Missed 1+ workdays	65.9	2.2	54.0	2.0	84.3	4.9	66.7	3.2	57.9	2.5	52.0	2.5	83.8	4.8	49.4	7.3	**<0.0001**	**0.011**
Employment status when injured																		
Part-time	6.1	0.8	8.1	1.0	10.0	2.9	12.0	1.4	4.0	0.8	5.8	1.2	13.3	2.6	28.0	4.6	**<0.0001**	**<0.0001**
Full-time	93.9	0.8	91.9	1.0	90.0	2.9	88.0	1.4	96.0	0.8	94.2	1.2	86.7	2.6	72.0	4.6		
Body part																		
Limb/shoulder/hip	62.5	2.4	63.6	2.0	50.2	5.7	66.5	4.1	65.8	2.9	62.5	2.6	66.0	7.3	70.1	4.0	0.149	0.402
Back/trunk/head/neck	37.5	2.4	36.4	2.0	49.8	5.7	33.5	4.1	34.2	2.9	37.5	2.6	34.0	7.3	29.9	4.0		
Type																		
Fracture, sprain, strain, or twist	46.7	2.4	46.9	2.2	40.2	5.0	63.4	3.8	48.0	2.7	44.0	2.5	52.2	11.0	44.7	7.5	0.160	**<0.0001**
Cut or bruise	31.4	2.4	23.1	1.9	43.1	5.1	25.1	3.6	28.3	2.6	22.8	2.4	26.4	7.3	22.2	6.0		
Other	21.9	1.2	29.9	2.3	16.7	3.2	11.5	2.3	23.7	1.9	33.2	2.8	21.4	4.4	33.1	4.7		
Occurred in industrial or construction area	44.9	2.6	0.7	0.0	42.9	4.5	1.8	0.1	46.9	3.0	0.6	0.0	33.4	7.1	–		0.300	–
Falls																		
Fall injury	21.3	2.9	18.5	1.4	20.4	5.6	14.3	1.7	23.4	3.2	18.8	1.5	6.5	1.3	24.5	7.2	**0.016**	0.137
Source of falls																		
Escalator	3.2	0.1	7.8	0.6	6.7	0.0	14.7	0.0	2.3	0.1	7.6	0.7	–		–		–	
Level ground or curb	18.5	0.8	39.5	2.5	16.7	0.0	23.6	0.0	19.7	1.2	41.6	3.1	–		40.3	0		
Ladder/scaffolding	37.7	1.7	12.1	0.1	61.7	0.0	–		31.3	1.8	15.1	0.2	31.3	0	–			
Building/other structure	19.5	0.9	2.3	2.3	4.3	0.0	–		23.0	1.4	2.9	2.9	39.5	0	–			
Other	21.1	3.6	38.3	0.4	10.7	0.0	61.7	0.0	23.7	4.5	32.8	0.5	29.2	0	59.7	0		
Cause of falls																		
Slip, trip, or stumble	44.7	2.0	67.4	2.5	33.8	0.0	35.8	0.0	46.9	2.8	69.2	3.1	68.7	0	94.0	0		–
Bump or shove by person or object	5.7	0.3	7.7	0.1	6.7	0.0	2.5	0.0	5.6	0.3	9.2	0.1	–		–			
Loss of balance, fainting, or seizure	18.0	0.8	6.8	2.1	34.1	0.0	14.8	0.0	13.1	0.8	6.4	2.6	31.3	0	–			
Other	31.6	3.1	18.1	1.4	25.3	0.0	46.9	0.0	34.4	3.9	15.2	1.8	–		6.0	0		

Symbols and acronyms: %, percent; WRI, work-related injury; Non-WRI, injury unrelated to work; SE, standard error

Table includes only the first injury reported per worker, the first body part reported per injury, and the first injury type reported per body part.

[A]Includes black, Asian, American Indian/Alaskan Native, multiple races, and persons for whom race was not releasable due to confidentiality or other reasons.

[B]Wald chi-square test used to calculate p values to assess whether injury characteristics differed by race/ethnicity, for WRIs and non-WRIs individually.

not reached 9th grade, over 7 times the percentage of white, non-Hispanic workers (4.0%). Nearly one in four Hispanic and black workers had a family income below the poverty threshold (24.2% and 23.1%, respectively), compared to less than one in 10 (9.2%) white, non-Hispanic workers. Hispanic workers were also less likely to have health insurance coverage. Only 42.5% of Hispanic workers had health insurance compared to 78.6% of their white, non-Hispanic counterparts ($p < 0.0001$). Moreover, three-fourths (74.8%) of Hispanic workers were born outside of the U.S., and about half (50.2%) completed the NHIS interview in a language other than English.

Employment characteristics also varied by race/ethnicity ($p < 0.0001$). Hispanic and black, non-Hispanic workers were more likely to have blue-collar occupations (> 87%), while white, non-Hispanic workers were more likely to have management or professional occupations (18.9%) and be self-employed (24.8%). Overall, 11.5% of construction workers in the sample experienced injuries annually. Injury status differed significantly among racial and ethnic worker groups ($p < 0.0001$). Compared to minority workers, white, non-Hispanic workers had a higher rate for both work-related and non-work-related injuries.

Table 2 presents injury characteristics by race/ethnicity among workers who experienced an injury while employed. Injuries were more severe among minority workers than white, non-Hispanic workers. Among those with a work-related injury, 84.3% of Hispanic workers and 83.8% of other minority workers missed at least one workday due to an injury, which was significantly higher than the 57.9% among their white, non-Hispanic counterparts ($p < 0.0001$). Fall injuries were common in construction, accounting for more than 20% of work-related injuries. Ladders/scaffolding were the most frequently reported source of WRI falls (37.7%), and were responsible for nearly

Table 3. Pearson correlation coefficients between race/ethnicity, injury status, and characteristics of construction workers who were injured while employed.

Characteristic[A]	Race/ethnicity	Work-related injury	Age	Education	Male	Below poverty level	Blue-collar occupation	Self-employed	Full-time status
Work-related injury	**0.12**[C]								
Age	**−0.13**[C]	−0.07							
Education	**−0.24**[B]	**−0.18**[B]	**0.14**[C]						
Male	−0.01	**0.20**[B]	**−0.13**[C]	**−0.18**[B]					
Below poverty level	**0.25**[B]	0.07	−0.07	**−0.19**[B]	0.02				
Blue-collar occupation	**0.12**[C]	**0.21**[B]	**−0.21**[B]	**−0.31**[B]	**0.43**[B]	**0.12**[C]			
Self-employed	−0.02	−0.08	**0.26**[B]	0.01	0.02	0.00	**−0.10**[D]		
Full-time status	**−0.10**[D]	0.06	**−0.19**[B]	0.01	**0.13**[C]	**−0.24**[B]	0.01	**−0.20**[B]	
Uninsured	**0.24**[B]	0.06	**−0.22**[B]	**−0.27**[B]	**0.12**[C]	**0.19**[B]	**0.21**[B]	0.04	−0.07

Notes: Race/ethnicity: racial/ethnic minority vs. white, non-Hispanic; Injury status: work-related vs. unrelated to work; Gender: male vs. female; Poverty level: below poverty level vs. at or above poverty level; Blue-collar occupation: blue-collar vs. white collar; Self-employment: self-employed vs. wage-and-salary; Employment status: full-time vs. part-time; Health insurance: uninsured vs. insured.
[A]All variables are binary except for age (continuous) and education (ordinal).
[B]$p < 0.0001$, [C]$p < 0.01$, [D]$p < 0.05$.

Table 4. Multivariable logistic regressions of work-related injuries (WRIs) among construction workers who were injured while employed.

	Model 1			Model 2			Model 3		
Characteristic	OR	95% CI		aOR	95% CI		aOR	95% CI	
Race/ethnicity									
White, Non-Hispanic		Reference			Reference			Reference	
Racial or ethnic minority[A]	**1.7**	**1.2**	**2.3**	**1.6**	**1.1**	**2.3**	1.4	0.9	2.1
Blue-collar occupation									
No					Reference			Reference	
Yes				**2.4**	**1.6**	**3.8**	**2.0**	**1.2**	**3.4**
Self-employed									
Yes					Reference			Reference	
No				1.2	0.9	1.7	1.2	0.9	1.7
Employment status									
Part-time					Reference			Reference	
Full-time				1.4	0.8	2.4	1.7	0.9	3.1
Age group									
55+								Reference	
35–54							**2.2**	**1.3**	**3.6**
18–34							1.4	0.9	2.2
Sex									
Female								Reference	
Male							**5.3**	**2.9**	**9.8**
Education									
Any college								Reference	
No college							**1.5**	**1.0**	**2.2**
Family income									
At or above poverty threshold								Reference	
Below poverty threshold							**1.8**	**1.2**	**2.8**
Health insurance coverage									
Yes								Reference	
No							1.1	0.7	1.6

Acronyms: CI, Confidence Interval; OR, Odds Ratio; aOR, Adjusted Odds Ratio
Statistically significant odds ratios ($p < 0.05$) are bolded.
[A]Includes Hispanic, black, Asian, American Indian/Alaskan Native, multiple races, and persons for whom race was not releasable due to confidentiality or other reasons.

two-thirds (61.7%) of work-related fall injuries among Hispanic workers.

Table 3 presents Pearson correlation coefficients between race/ethnicity, injury status, and other characteristics of construction workers who were injured while employed. Being a racial/ethnic minority was significantly correlated with increased work-related injury, younger age, lower education, living below the poverty level, blue-collar occupation, working part-time, and being uninsured ($p < 0.05$). In addition, WRIs were significantly correlated with blue-collar occupation, lower education, and being male

($p < 0.0001$). Furthermore, blue-collar occupation, younger age, and being male were all significantly correlated with one another ($p < 0.01$). Although nearly half of the correlation coefficients between WRIs and selected variables were statistically significant, the relatively weak correlations suggest that other important determinants of WRIs (e.g., specific workplace hazards and exposure scope) were not captured.

Results from multivariable logistic regressions are displayed in Table 4. Model 1 suggests that the odds of having a WRI were 70% higher among racial/ethnic minorities compared to white, non-Hispanic workers (OR = 1.7, 95% CI: 1.2–2.3) without controlling for possible confounders. After adjusting for occupational factors in Model 2, the difference in odds of WRI between race/ethnicity slightly decreased but remained statistically significant (OR = 1.6, 95% CI: 1.1–2.3). After more demographic and socioeconomic variables were added to Model 3, the WRI difference between race/ethnicity was no longer statistically significant (aOR = 1.4, 95% CI: 0.9–2.1). However, WRI odds remained significantly higher among workers who were younger (35–54 years vs. $\geq$ 55 years: aOR = 2.2, 95% CI: 1.3–3.6); male (aOR = 5.3, 95% CI: 2.9–9.8); not college-educated (aOR = 1.5, 95% CI: 1.0–2.2); had a family income below the poverty threshold (aOR = 1.8, 95% CI: 1.2–2.8); or held a blue-collar occupation (aOR = 2.0, 95% CI: 1.2–3.4).

Discussion

This study illustrates that patterns of injuries varied by race and ethnicity among U.S. construction workers. While white, non-Hispanic construction workers were more likely to report any kind of injury, the proportion of injuries that were work-related was significantly higher among workers who were racial/ethnic minorities. Compared to white, non-Hispanic workers, minority workers in construction were more likely to have lower socioeconomic status (e.g., lower educational attainment, lack of health insurance coverage, and family income below the poverty level), which considerably escalated the odds of work-related injuries. When occupation and other factors were constant, the effects of education and poverty were still found. Despite no direct measure of workplace exposure in this study, this finding suggests that poverty and lower educational attainment can be a marker for more dangerous work exposures, since workers with lower socioeconomic status are more likely to take high-risk jobs, have nonstandard work arrangements (e.g., day laborers and temporary workers), and be employed in small construction companies, which often have limited safety protections (Benach and Muntaner 2007; Smith et al. 2010; GAO 2015; Ringen et al. 2018; CPWR 2019; Yang et al. 2020).

Although information by detailed occupation is unavailable in this study, the results show that racial/ethnic minorities were more likely to be employed in blue-collar occupations, and the odds of work-related injuries for workers in those occupations were double that of their white-collar counterparts after controlling for major confounders. These findings are consistent with previous research using different data sources (Anderson et al. 2000; Goodrum and Dai 2005; Dong et al. 2007, 2010, 2014; Smith and DeJoy 2012; Stanbury and Rosenman 2014). The study also found higher odds of work-related injuries among younger and male construction workers. This could result from a lack of experience and training among young workers, as well as gender differences in occupational distributions in construction (Iacuone 2005; Flynn and Sampson 2012; Tucker and Turner 2013; Stergiou-Kita et al. 2015; CPWR 2018; Breslin et al. 2019). These vulnerabilities may be compounded among Hispanic workers who are more likely to be young, male, and comprise an increasing proportion of the construction workforce (NIOSH and ASSE 2015; CPWR 2018, 2020b).

The identified higher risks among vulnerable construction workers should be reduced or eliminated by a hierarchy of controls. Elimination and substitution are the most effective methods of reducing workplace hazards at the design or development stage (NIOSH 2015). The Prevention through Design (PtD) paradigm initiated by NIOSH (2013) is the optimal method of mitigating occupational health risks, eliminating hazards at the design stage regarding tools, materials, equipment, and systems. PtD interventions such as parapet walls and non-fragile skylights can inexpensively eliminate fall hazards. This especially benefits vulnerable construction workers since they are more likely to suffer from fall injuries (Dong et al. 2013; CPWR 2018).

Safety and health policies are also critically important. For instance, OSHA's Temporary Worker Initiative (TWI) has recommended that "the temporary staffing agency and the host employer set out their respective responsibilities for compliance with applicable OSHA standards in their contract" (OSHA 2014). States can pass legislation placing the responsibility of worker safety and health on both parties to ensure OSHA's requirements, such as injury and illness

recordkeeping, hazards communication, and safety and health training (Yang et al. 2020). This approach is crucial given that vulnerable workers in construction are disproportionally employed in nonstandard work arrangements (CPWR 2016, 2019).

Employers should apply engineering controls to reduce workplace risks before relying on training as a control strategy. For example, guardrails may protect all workers on a worksite from fatal and non-fatal falls, and exhaust systems and wetting systems may reduce dust from drywall sanding and welding fumes. Employers should also provide personal protective equipment (PPE) to workers when necessary, such as personal fall arrest systems (PFAS). Research found that among decedents who had been on the job for just one week in construction, 54% of fatalities were from falls. Moreover, lack of access to PFAS was as high as 70% in residential building and roofing sectors, which typically employ a large number of young and Hispanic workers (Dong et al. 2017; CPWR 2018).

Training is low in the hierarchy as an administrative control; however, effective training is a key component of any health and safety management program, and can reduce injury disparities by reaching Hispanic and minority workers. This study found that more than 70% of Hispanic construction workers were foreign-born and about half received the NHIS survey in non-English languages. Thus, effective training programs, such as OSHA 10 hr and 30 hr training, hazard-specific safety procedures (e.g., fall prevention, electrical safety), and toolbox safety trainings (Williams et al. 2010; Schoenfisch et al. 2017; Caban-Martinez et al. 2018; Eggerth et al. 2018; Olson 2019; CPWR 2020a) should consider language barriers among Hispanic workers and their potential lack of basic knowledge in construction activities/tasks and safety procedures in the U.S. (Brunette 2005; Orrenius and Zavodny 2009; Flynn 2014). In particular, trainings for new immigrant workers should be culturally appropriate and carefully translated (Brunette 2005; O'Connor et al. 2005; Menzel and Gutierrez 2010; CPWR 2018). Moreover, safety and health interventions should empower workers to understand their rights, workplace regulations, and how to report and respond to occupational hazards (Menzel and Gutierrez 2010; Williams et al. 2010).

Furthermore, employee involvement in developing occupational safeguards may be especially effective in improving workplace safety, as workers can incorporate ongoing ideas, feedback, and hands-on experience into the intervention process (Becker and Morawetz 2004; Brunette 2005; Williams et al. 2010; Evia 2011; Zuluaga et al. 2016). Mentoring relationships between inexperienced and experienced workers can also be an effective way to transfer safety knowledge within a culturally masculine framework, and may particularly benefit younger workers (Flynn and Sampson 2012; Sokas et al. 2019).

Several limitations of this study should be addressed. Most importantly, workplace hazards and exposures were not directly and fully measured. The NHIS injury reporting period only covers three months, limiting the number of injuries that could be analyzed. While short reporting periods might reduce recall bias, injuries occurring within three months may not represent the real risk at workplaces across a year. Moreover, the current study confirms injuries may be underreported by racial/ethnic minorities in the survey (McInerney 2015). Such reporting bias likely occurs because the NHIS only captures injuries requiring medical advice or treatment, yet racial/ethnic minorities are less likely to seek medical care (Dong et al. 2007; O'Hara and Caswell 2013). This may explain the lower prevalence of injuries and higher injury severity among minority construction workers. Finally, while the NHIS is a large survey, the sample size of construction workers was still limited for subgroup analyses even though multiple years of data were pooled together. As a result, differences among detailed racial and ethnic groups and geographic areas could not be distinguished.

Despite its constraints, this study expands the current literature examining injury disparities by race/ethnicity in construction from a broader view of occupational safety and health (Dong et al. 2007, 2010, 2011). In addition to demographics, the rich information from the NHIS permits the study to examine work-related injuries among construction workers with different socioeconomic statuses. Such information is typically absent in studies using BLS injury data, workers' compensation claims, or data from emergency rooms (Anderson et al. 2000; Dong et al. 2009; Schoenfisch et al. 2010). Furthermore, the association between socioeconomic issues and workplace safety has not been addressed in previous research using national survey data (Dong et al. 2010; Kachan et al. 2012; Gu et al. 2016). The higher odds of work-related injuries observed among workers with lower socioeconomic status demonstrate the root of injury inequality, and promote principles of health equity and social justice beyond workplace interventions (Baron et al. 2013; Seabury et al. 2017; NORA Construction Sector Council 2018; Peiró et al. 2020).

Conclusion

This study confirms that racial/ethnic disparities exist in the construction industry. Compared to white, non-Hispanic construction workers, minority construction workers had lower socioeconomic statuses and were more likely to hold blue-collar jobs. Injuries among racial/ethnic minorities were 70% more likely to be work-related than their white, non-Hispanic counterparts in construction. However, such differences diminished after controlling for major demographic and socioeconomic factors. The results indicate that demographics and socioeconomic inequalities between races/ethnicities may underlie injury differences among construction workers. The identified injury disparities should be reduced or eliminated by a hierarchy of controls in the construction industry and beyond.

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Disclosure

The authors declare no conflicts of interest.

Disclaimer

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Notes on contributors

Samantha Brown: Inquired and analyzed data, created tables, interpreted results, drafted manuscript, and approved the final version before submission.

Raina D. Brooks: Conducted literature review, drafted manuscript, and approved the final version before submission.

Xiuwen Sue Dong: Designed the study, interpreted the results, drafted and revised the manuscript critically for important intellectual content, and agreed to be accountable for all aspects of the work.

References

AGC Diversity and Inclusion Council. 2018. The business case for diversity and inclusion in the construction industry. Arlington (VA): The Associated General Contractors of America. https://www.agc.org/sites/default/files/Files/Advocacy/AGC%20Report%20on%20Biz%20Case%20for%20D%26I%20FINAL%20OCT%202018_Small.pdf.

Anderson JTL, Hunting KL, Welch LS. 2000. Injury and employment patterns among Hispanic construction workers. J Occup Environ Med. 42(2):176–186. doi:10.1097/00043764-200002000-00016

Arcury TA, Summers P, Carrillo L, Grzywacz JG, Quandt SA, Mills TH. 2014. Occupational safety beliefs among Latino residential roofing workers. Am J Ind Med. 57(6):718–725. doi:10.1002/ajim.22248

Baron SL, Steege AL, Marsh SM, Menéndez CC, Myers JR, Centers for Disease Control and Prevention (CDC). 2013. Nonfatal work-related injuries and illnesses — United States, 2010. MMWR Suppl. 62(3):35–40.

Becker P, Morawetz J. 2004. Impacts of health and safety education: Comparison of worker activities before and after training. Am J Ind Med. 46(1):63–70. doi:10.1002/ajim.20034

Benach J, Muntaner C. 2007. Precarious employment and health: developing a research agenda. J Epidemiol Community Health. 61(4):276–277. doi:10.1136/jech.2005.045237

Blewett LA, Rivera DJ, King ML, Williams KCW. 2019. IPUMS health surveys: National Health Interview Survey, Version 6.4 [dataset]. IPUMS. [accessed 2020 Oct 14]. doi:10.18128/D070.V6.4

Breslin FC, Dollack J, Mahood Q, Maas ET, Laberge M, Smith PM. 2019. Are new workers at elevated risk for work injury? A systematic review. Occup Environ Med. 76(9):694–701. doi:10.1136/oemed-2018-105639

Brown TH. 2016. Diverging fortunes: racial/ethnic inequality in wealth trajectories in middle and late life. Race Soc Probl. 8(1):29–41. doi:10.1007/s12552-016-9160-2

Brunette MJ. 2005. Development of educational and training materials on safety and health: targeting Hispanic workers in the construction industry. Fam Commun Health. 28(3):253–266. doi:10.1097/00003727-200507000-00006

Caban-Martinez AJ, Santiago KM, Stillman J, Moore KJ, Sierra DA, Chalmers J, Baniak M, Jordan MM. 2018. Physical exposures, work tasks, and OSHA-10 training among temporary and payroll construction workers. J Occup Environ Med. 60(4):e159–e165. doi:10.1097/JOM.0000000000001267

Center for Construction Research and Training (CPWR). 2016. Hispanic employment and business owners in the

U.S. construction industry. Silver Spring (MD): CPWR. https://www.cpwr.com/wp-content/uploads/publications/publications_1st-Quarter-2016_1.pdf.
Center for Construction Research and Training (CPWR). 2018. Construction chart book (6th ed.). Silver Spring (MD): CPWR. https://www.cpwr.com/research/data-center/the-construction-chart-book/.
Center for Construction Research and Training (CPWR). 2019. Nonstandard work arrangements in the construction industry. Silver Spring (MD): CPWR. https://www.cpwr.com/wp-content/uploads/publications/Quarter1-QDR-2019_0.pdf.
Center for Construction Research and Training (CPWR). 2020a. Toolbox talks. Silver Spring (MD): CPWR. https://www.cpwr.com/research/research-to-practice-r2p/r2p-library/toolbox-talks/.
Center for Construction Research and Training (CPWR). 2020b. Coronavirus and health disparities in construction. Silver Spring (MD): CPWR. https://www.cpwr.com/wp-content/uploads/publications/DataBulletin-May2020.pdf.
Dong XS, Choi SD, Borchardt JG, Wang X, Largay JA. 2013. Fatal falls from roofs among U.S. construction workers. J Safety Res. 44:17–24. doi:10.1016/j.jsr.2012.08.024
Dong XS, Fujimoto A, Ringen K, Men Y. 2009. Fatal falls among Hispanic construction workers. Accid Anal Prev. 41(5):1047–1052. doi:10.1016/j.aap.2009.06.012
Dong XS, Fujimoto A, Ringen K, Stafford E, Platner JW, Gittleman JL, Wang X. 2011. Injury underreporting among small establishments in the construction industry. Am J Ind Med. 54(5):339–349. doi:10.1002/ajim.20928
Dong XS, Largay JA, Choi SD, Wang X, Cain CT, Romano N. 2017. Fatal falls and PFAS use in the construction industry: findings from the NIOSH FACE reports. Accid Anal Prev. 102:136–143. doi:10.1016/j.aap.2017.02.028
Dong XS, Men Y, Ringen K. 2010. Work-related injuries among Hispanic construction workers—evidence from the Medical Expenditure Panel Survey. Am J Ind Med. 53(6):561–569. doi:10.1002/ajim.20799
Dong XS, Ringen K, Men Y, Fujimoto A. 2007. Medical costs and sources of payment for work-related injuries among Hispanic construction workers. J Occup Environ Med. 49(12):1367–1375. doi:10.1097/JOM.0b013e31815796a8
Dong XS, Ringen K, Welch L, Dement J. 2014. Risks of a lifetime in construction part I: traumatic injuries. Am J Ind Med. 57(9):973–983. doi:10.1002/ajim.22363
Eggerth DE, Keller BM, Cunningham TR, Flynn MA. 2018. Evaluation of toolbox safety training in construction: the impact of narratives. Am J Ind Med. 61(12):997–1004. doi:10.1002/ajim.22919
Evia C. 2011. Localizing and designing computer-based safety training solutions for Hispanic construction workers. J Constr Eng Manage. 137(6):452–459. doi:10.1061/(ASCE)CO.1943-7862.0000313
Flynn MA. 2014. Safety and the diverse workforce. Prof Saf. 59(6):52–57.
Flynn MA, Sampson JM. 2012. Trench safety-using a qualitative approach to understand barriers and develop strategies to improve trenching practices. Int J Constr Educ Res. 8(1):63–79. doi:10.1080/15578771.2011.633973
Government Accountability Office (GAO). 2015. Contingent workforce: size, characteristics, earnings, and benefits. Report No: GAO-15-168R. Washington (DC): U.S. Government Accountability Office. https://www.gao.gov/assets/670/669899.pdf?mod=article_inline.
Goodrum PM, Dai J. 2005. Differences in occupational injuries, illnesses, and fatalities among Hispanic and non-Hispanic construction workers. J Constr Eng Manage. 131(9):1021–1028. doi:10.1061/(ASCE)0733-9364(2005)131:9(1021)
Grzywacz JG, Quandt SA, Mills T, Marín A, Summers P, Lang W, Evia C, Arcury TA. 2012. Employer provision of personal protective equipment to Latino workers in North Carolina residential construction. New Solut. 22(2):175–190. doi:10.2190/NS.22.2.e
Gu JK, Charles LE, Andrew ME, Ma CC, Hartley TA, Violanti JM, Burchfiel CM. 2016. Prevalence of work-site injuries and relationship between obesity and injury among U.S. workers: NHIS 2004-2012. J Safety Res. 58:21–30. doi:10.1016/j.jsr.2016.06.001
Iacuone D. 2005. Real men are tough guys: hegemonic masculinity and safety in the construction industry. J Mens Stud. 13(2):247–266. doi:10.3149/jms.1302.247
Kachan D, Fleming LE, LeBlanc WG, Goodman E, Arheart KL, Caban-Martinez AJ, Clarke TC, Ocasio MA, Christ S, Lee DJ. 2012. Worker populations at risk for work-related injuries across the life course. Am J Ind Med. 55(4):361–366. doi:10.1002/ajim.21994
Lipscomb HJ, Loomis D, McDonald MA, Argue RA, Wing S. 2006. A conceptual model of work and health disparities in the United States. Int J Health Serv. 36(1):25–50. doi:10.2190/BRED-NRJ7-3LV7-2QCG
Maroto M. 2016. Growing farther apart: racial and ethnic inequality in household wealth across the distribution. SocScience. 3(34):801–824. doi:10.15195/v3.a34
McInerney M. 2015. Examining differences by ethnicity in the propensity to file for workers' compensation insurance. Washington (DC): U.S. Department of Labor, Office of the Assistant Secretary for Policy, Chief Evaluation Office, Department of Labor Scholars Program. https://www.dol.gov/sites/dolgov/files/OASP/legacy/files/2015_DOL_Scholars_Paper_Series_McInerney_Report.pdf.
Menzel NN, Gutierrez AP. 2010. Latino worker perceptions of construction risks. Am J Ind Med. 53(2):179–187. doi:10.1002/ajim.20735
Mishel L. 2017. Diversity in the New York City union and nonunion construction sectors. Washington (DC): Economic Policy Institute. https://www.epi.org/publication/diversity-in-the-nyc-construction-union-and-nonunion-sectors/.
National Institute for Occupational Safety and Health (NIOSH). 2013. Prevention through design. https://www.cdc.gov/niosh/topics/ptd/.
National Institute for Occupational Safety and Health (NIOSH). 2015. Hierarchy of controls. https://www.cdc.gov/niosh/topics/hierarchy/default.html.
National Institute of Occupational Safety and Health and American Society of Safety Engineers (NIOSH and ASSE). 2015. Overlapping vulnerabilities: the occupational health and safety of young immigrant workers in small construction firms. Report No.: 2015-178. Cincinnati (OH): U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for

Occupational Safety and Health, DHHS (NIOSH). https://www.cdc.gov/niosh/docs/2015-178/default.html.
Noguera PA. 2017. Introduction to racial inequality and education: patterns and prospects for the future. Educ Forum. 81(2):129–135. doi:10.1080/00131725.2017.1280753
NORA Construction Sector Council. 2018. National occupational research agenda for construction. Washington (DC): U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute of Occupational Safety and Health, DHHS (NIOSH). https://www.cdc.gov/nora/councils/const/agenda.html.
O'Connor T, Loomis D, Runyan C, Abboud d. S J, Schulman M. 2005. Adequacy of health and safety training among young Latino construction workers. J Occup Environ Med. 47(3):272–277. doi:10.1097/01.jom.0000150204.12937.f5
O'Hara B, Caswell K. 2013. Health status, health insurance, and medical services utilization: 2010. Report No.: P70-133RV. Washington (DC): U.S. Department of Commerce, Economics and Statistics Administration, Census Bureau. https://www.census.gov/prod/2012pubs/p70-133.pdf.
Olson R. 2019. Using mobile phone marketing technology to increase safety meeting frequency among small residential construction companies. Silver Spring (MD): CPWR. https://www.cpwr.com/wp-content/uploads/publications/Oregon-Using-Mobile-Phone-Tech-to-Increase-Safety-Meetings-CPWR-final-report-2019_11.1.19.pdf.
Orrenius PM, Zavodny M. 2009. Do immigrants work in riskier jobs? Demography. 46(3):535–551. doi:10.1353/dem.0.0064
Occupational Safety and Health Administration (OSHA). 2014. Protecting temporary workers. https://www.osha.gov/temporaryworkers.
Peiró JM, Nielsen K, Latorre F, Shepherd R, Vignoli M. 2020. Safety training for migrant workers in the construction industry: a systematic review and future research agenda. J Occup Health Psychol. 25(4):275–295. doi:10.1037/ocp0000178
Ringen K, Dong XS, Goldenhar L, Cain CT. 2018. Construction safety and health in the USA: lessons from a decade of turmoil. Ann Work Expo Health. 62(Suppl 1):S25–S33. doi:10.1093/annweh/wxy069
Schoenfisch AL, Lipscomb HJ, Shishlov K, Myers DJ. 2010. Nonfatal construction industry-related injuries treated in hospital emergency departments in the United States, 1998–2005. Am J Ind Med. 53(6):570–580. doi:10.1002/ajim.20829
Schoenfisch AL, Lipscomb H, Sinyai C, Adams D. 2017. Effectiveness of OSHA outreach training on carpenters' work-related injury rates, Washington State 2000–2008. Am J Ind Med. 60(1):45–57. doi:10.1002/ajim.22665
Seabury SA, Terp S, Boden LI. 2017. Racial and ethnic differences in the frequency of workplace injuries and prevalence of work-related disability. Health Aff (Millwood). 36(2):266–273. doi:10.1377/hlthaff.2016.1185
Shannon CA, Rospenda KM, Richman JA, Minich LM. 2009. Race, racial discrimination, and the risk of work-related illness, injury, or assault: findings from a national study. J Occup Environ Med. 51(4):441–448. doi:10.1097/JOM.0b013e3181990c17
Shavers VL, Shavers BS. 2006. Racism and health inequity among Americans. J Natl Med Assoc. 98(3):386–396.
Shrestha PP, Menzel NN. 2014. Hispanic construction workers and assertiveness training. Work. 49(3):517–522. doi:10.3233/WOR-131728
Singh GK, Daus GP, Allender M, Ramey CT, Martin EK, Perry C, De Los Reyes AA, Vedamuthu IP. 2017. Social determinants of health in the United States: addressing major health inequality trends for the nation, 1935-2016. Int J MCH Aids. 6(2):139–164. doi:10.21106/ijma.236
Slack T, Jensen L. 2009. Race, ethnicity, and underemployment in nonmetropolitan America: a 30-year profile. Rural Sociol. 67(2):208–233. doi:10.1111/j.1549-0831.2002.tb00101.x
Smith CK, Silverstein BA, Bonauto DK, Adams D, Fan ZJ. 2010. Temporary workers in Washington State. Am J Ind Med. 53(2):135–145. doi:10.1002/ajim.20728
Smith TD, DeJoy DM. 2012. Occupational injury in America: an analysis of risk factors using data from the General Social Survey (GSS). J Safety Res. 43(1):67–74. doi:10.1016/j.jsr.2011.12.002
Sokas RK, Dong XS, Cain CT. 2019. Building a sustainable construction workforce. Int J Environ Res Public Health. 16(21):4202. doi:10.3390/ijerph16214202
Stanbury M, Rosenman KD. 2014. Occupational health disparities: a state public health-based approach. Am J Ind Med. 57(5):596–604. doi:10.1002/ajim.22292
Stergiou-Kita M, Mansfield E, Bezo R, Colantonio A, Garritano E, Lafrance M, Lewko J, Mantis S, Moody J, Power N, et al. 2015. Danger zone: men, masculinity and occupational health and safety in high risk occupations. Saf Sci. 80:213–220. doi:10.1016/j.ssci.2015.07.029
Strong LL, Zimmerman FJ. 2005. Occupational injury and absence from work among African American, Hispanic, and non-Hispanic white workers in the national longitudinal survey of youth. Am J Public Health. 95(7):1226–1232. doi:10.2105/AJPH.2004.044396
Tucker S, Turner N. 2013. Waiting for safety: responses by young Canadian workers to unsafe work. J Safety Res. 45:103–110. doi:10.1016/j.jsr.2013.01.006
Williams Q, Ochsner M, Marshall E, Kimmel L, Martino C. 2010. The impact of a peer-led participatory health and safety training program for Latino day laborers in construction. J Safety Res. 41(3):253–261. doi:10.1016/j.jsr.2010.02.009
Yang RY, Williamson MW, Steward S, Brown KS, Greeberg H, Shakesprere J. 2020. Reimagining workplace protections: a policy agenda to meet independent contractors' and temporary workers' needs. Washington (DC): Urban Institute. https://www.urban.org/sites/default/files/publication/103331/reimagining-workplace-protections_0.pdf.
Zuluaga CM, Namian M, Albert A. 2016. Impact of training methods on hazard recognition and risk perception in construction. In: Proceedings of the Construction Research Congress; 2016 Jun 2–May 31; San Juan (PR): American Society of Civil Engineers; p. 2861–2871. doi:10.1061/9780784479827.285