ELSEVIER

Capture–Recapture Estimates of Nonfatal Workplace Injuries and Illnesses

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PURPOSE: We examine reporting of nonfatal injury and illness reporting for the two most important sources of such data in the United States: workers' compensation data and the Bureau of Labor Statistics' (BLS) annual Survey of Occupational Injuries and Illnesses.
METHODS: We linked individual case records from establishments reporting to the BLS with individual cases reported to workers' compensation systems in six states for 1998–2002 and used capture–recapture analysis to estimate the proportion of injuries reported. Data are for private sector workers and exclude mining, railroad and water transportation, temporary employment agencies, membership organizations, and small agricultural establishments.
RESULTS: For injuries and illnesses eligible for income benefits, using conservative assumptions, we estimate that workers' compensation systems in the six states missed over 180,000 lost-time injuries in the sampled industries, that the BLS survey missed almost 340,000, and that about 69,000 injuries were unreported to either system.
CONCLUSIONS: Underreporting of nonfatal occupational injury and illness is substantial in both systems, but particularly in the Survey of Occupational Injuries and Illnesses. Using both sources improves coverage but falls far short of an accurate count for four of the six states. Reporting rates vary widely, so we cannot infer them for the entire United States.
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KEY WORDS: Capture–recapture, Occupational health, Injury, Surveillance.

INTRODUCTION

This study estimates the level of reporting for the two most commonly used sources of state and national data about nonfatal injuries and illnesses in the private sector in the United States. These are state workers' compensation data and the Survey of Occupational Injuries and Illnesses (SOII). The SOII is an annual, nationally representative survey of approximately 165,000 private industry establishments conducted by the U.S. Department of Labor, Bureau of Labor Statistics (BLS).

Injury and illness reporting systems provide data used to prioritize efforts to prevent occupational injuries and illnesses. Reported injury rates also are used to measure the success or failure of prevention efforts. Yet, studies over the last two decades have concluded that injuries are underreported in both systems (1–6).

In a recent study focusing on musculoskeletal disorders, Biddle and Roberts (7) concluded that less than 60% of eligible workers filed for workers' compensation income benefits. Many said they did not file because of the availability of other benefits such as sick leave. Morse et al. (8) conducted a random-digit-dial survey in Connecticut to determine the period prevalence of work-related upper-extremity musculoskeletal disorders. Of cases in which a medical provider identified the condition as work-related, only 21% of respondents said that they had filed for workers' compensation benefits (8). A study by Lakdawalla and Reville based on the National Longitudinal Survey of Youth indicates that 55% of reported occupational injuries result in workers' compensation claims (9). Finally, Smith et al. (10) use National Health Interview Survey data and derive injury rates for private industry that are 1.4 times the BLS estimates.

Although originally developed in wildlife biology and demography, capture–recapture methods have been used to generate improved estimates of drug use, homelessness, infectious diseases, and diabetes (11). In the occupational health and safety arena, they have been used to estimate occupational fatality rates (12–14), asthma prevalence (15), silicosis prevalence (16), carpal tunnel incidence (17), the incidence of work-related musculoskeletal disorders (18, 19), and the period prevalence of occupational diseases (20). A 1998 capture–recapture study in the Netherlands concluded that employers had reported only 35.6% of workplace injuries to the government (21).

The first capture–recapture study to estimate overall nonfatal occupational injury and illness rates in a U.S. state was published in 2006 (22). For cases involving more than 7 lost

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Selected Abbreviations and Acronyms

BLS = Bureau of Labor Statistics
SIC = Standard Industrial Classification
SOII = Bureau of Labor Statistics Survey of Occupational Injuries and Illnesses

workdays, this study applies capture–recapture methods to individual Michigan workers' compensation and SOII records. Rosenman et al. (22) conclude that BLS and workers' compensation data account respectively for only 32% and 66% of injuries and illnesses in Michigan. Our work extends this research to six additional states.

METHODS

Data

We obtained data for 1998–2001 from the SOII and for all reported paid workers' compensation cases from Minnesota, New Mexico, Oregon, Washington, Wisconsin, and West Virginia. Both datasets include name, gender, and age of the injured worker; length of service at the establishment (for five states); date of injury; days of lost work; days of restricted work; nature of injury; part of body affected; state or federal employer identifier; employer name and address; and four-digit industry code (Standard Industrial Classification [SIC]).

Establishments in mining and railroad transportation do not report directly to the BLS for its annual survey, so their reporting patterns may differ from those of industries reporting directly to the BLS. State and local government and agricultural establishments with fewer than 11 employees are not surveyed for the BLS national estimates. The water transportation industry is covered by its own workers' compensation system. Injuries to workers from temporary employment agencies may be reported to the BLS by one entity and to workers' compensation by another. Finally, membership organizations have spotty coverage by workers' compensation programs. We exclude these industries from our analysis, reducing coverage in favor of analyzing industries with relatively uniform reporting requirements.

Creating Comparable Samples

The SOII case-specific data includes cases in which workers do not return to work for at least one full day after the day of the injury. In contrast, some workers' compensation databases include cases involving medical costs but without lost work time. Others report only injuries that involve permanent disability or cross a threshold for lost work time, typically 3 or 7 days. Only these lost-time cases are, in principle, reported both to the BLS and to all workers' compensation systems. We therefore exclude cases that do not meet a state's definition of a lost-time injury.

For establishments with more than 30 days-away-from-work injuries, the BLS requires employers to report only injuries occurring on certain dates. Because cases outside these dates are not in the BLS sampling frame, we keep only those unlinked workers' compensation cases with dates of injury occurring during the BLS sampling period. To be conservative, we keep linked workers' compensation cases, even if the reported date of injury lies outside the BLS sampling frame.

Both the BLS and the participating states allowed us to analyze their data under stringent confidentiality rules. The protocol was approved by the Boston University Institutional Review Board and the Washington State Department of Labor and Industries Institutional Review Board.

Linking Workers' Compensation and BLS Cases

We link workers' compensation claims to BLS-reported injuries using data elements common to both sources, including employer identifier, employer name, employer address, employer zip code or city, worker's first initial, worker's last name, sex, date of injury, and date of birth or age at injury. We first linked records deterministically, considering two injuries to be matched if identical on eight of these items. This procedure accounted for 90–95% of all linked cases.

For remaining unlinked cases, we applied probabilistic record linkage using Linkpro 3.0 (© InfoSoft, Inc.) (23–25). After potential matches were ranked by Linkpro, two coders determined whether cases are linked. Within states, concordance between coders measured by Cohen's kappa ranged between 0.79 and 0.84. Where the coders differed, we applied a decision rule (available on request) to determine whether a pair was linked.

Accounting for Establishment Sampling

The BLS surveys a sample of establishments (business units at a single location) within each state. Workers' compensation reporting systems typically report by firm, not by establishment. As a consequence, we can identify firms in the workers' compensation data that report to BLS, but we cannot identify reporting and non-reporting establishments within those firms. For multi-establishment firms (e.g., fast food chains or manufacturers with several plant locations), this differential reporting presents a challenge: in such firms, an injury may be unrecorded by BLS because an establishment failed to report or because the establishment was not included in the BLS subsample.

To address this, we use quarterly employment information from the BLS longitudinal database of establishments and firms to derive for each firm the proportion of

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employment in establishments reporting to the SOII. We assume homogeneity of injury rates and reporting rates across all establishments within a firm. Under this assumption, we impute the number of workers' compensation injuries reported by establishments that are not in the BLS sample and adjust the weights of the unmatched workers' compensation cases accordingly to account for the expected number of unlinked workers' compensation injuries reported by unsampled establishments in multi-establishment firms. Table 1 presents the weighted and unweighted frequencies in the BLS and workers' compensation datasets. The weighted frequency corresponds to the number of reported injuries represented by the analyzed samples.

Capture-Recapture Analysis

Capture–recapture methods are used in epidemiology to enumerate difficult-to-count populations using multiple, overlapping, but incomplete data sources. A typical application is estimation of disease incidence or prevalence. The conceptual framework underling capture-recapture methodology is simple, and thorough treatments are available (26). The most straightforward analysis uses only basic probability theory to estimate the number of unknown cases, while relying on several assumptions. In brief, these assumptions are a closed population, source independent capture probabilities, and homogeneous probability of ascertainment in each source. Extensions and improvements to the basic methods are available as needed to address violations of these underlying assumptions.

Capture–recapture methods generally assume homogeneous probability of capture within each source. However, probability of reporting to each source may be associated with case-level factors. To address this issue, we use a multinomial logistic model to estimate covariate-dependent capture probabilities for one or both sources, conditional upon being observed (20, 27). The resulting model accounts for heterogeneity in capture probability explained by observed covariates. Covariates include employment size categories, 1-digit industry code (SIC), age, sex, job tenure, and categories for part of body injured and nature of injury.

TABLE 1. Frequency of reported occupational injuries and illnesses: time off work longer than workers' compensation waiting period, 1998–2001

	WA	WV	OR	WI	NM[a]	MN
Workers' compensation						
Weighted frequency[b]	200,254	45,645	106,585	176,799	23,259	112,251
Unweighted frequency	39,726	14,120	25,873	61,576	4,408	22,169
BLS						
Weighted frequency[b]	110,312	37,191	75,978	152,069	16,950	117,154
Unweighted frequency	16,321	7,720	12,752	42,494	3,158	20,783

Data are for private sector workers and exclude mining, railroad and water transportation, temporary employment agencies, membership organizations, and agricultural establishments with fewer than 11 employees.
[a]New Mexico has a 7-day waiting period. The other states have 3-day waiting periods.
[b]Using BLS sampling weights.

Sensitivity to Positive Source Dependence

Our basic estimates rely on the assumption of source independence, yet we expect positive source dependence. Reporting to both systems is strongly influenced by employers. In some workplaces, the same individual may be responsible for filling out the BLS survey and for filing workers' compensation claims. Even if this is not the case, an employer may believe that a workplace injury that is not a compensable workers' compensation claim should not be reported to the BLS. Moreover, unless an injured worker reports an injury to a supervisor, it will very rarely enter either system (28). Despite likely positive source dependence, we cannot estimate the degree of dependence of the two sources without additional assumptions or a third data source (29). For this reason, we do a sensitivity analysis of the potential effects of varying degrees of source dependence.

RESULTS

Capture-Recapture Estimates

Table 2 displays estimates of injury reporting for cases meeting the workers' compensation lost-time threshold, without adjusting for heterogeneity of capture probability related to observed covariates and assuming source independence (26). Table 3 shows estimates based on a logistic model with the following covariates: the worker's age, sex, length of service (for five states), part of body injured, nature of injury, 1-digit industry code (SIC), and employer size class. Adjusting for heterogeneity has little impact on the estimates. We focus on reporting rates, so we report only percentages in this and subsequent tables. Confidence intervals were calculated using 1000 bootstrap samples.

Both BLS and workers' compensation reporting vary substantially among states. Because the BLS annual survey is a national program with a single set of reporting guidelines, this considerable interstate variation is unexpected. Further, states that have little underreporting to their state workers' compensation system may have relatively high underreporting to the BLS survey and vice versa.

Sensitivity to Source Dependence

If the data exhibit positive source dependence, estimates of underreporting based on source independence will be biased downward. To show the impact of different assumptions about positive source dependence, we provide results of a sensitivity analysis in Table 4. As the odds ratio increases,

TABLE 2. Crude capture–recapture estimates of workplace injury and illness reporting: lost-time cases, 1998–2001, no source dependence

		Workers' compensation		
		No report	Report	Total
Washington				
BLS	No report	5,159 (2%)	95,590 (45%)	100,749 (48%)
	Report	5,648 (3%)	104,664 (50%)	110,312 (52%)
	Total	10,807 (5%)	200,254 (95%)	211,061 (100%)
West Virginia				
BLS	No report	1,070 (2%)	11,597 (23%)	12,667 (25%)
	Report	3,143 (6%)	34,048 (68%)	37,191 (75%)
	Total	4,213 (8%)	45,645 (92%)	49,858 (100%)
Oregon				
BLS	No report	13,042 (10%)	47,086 (35%)	60,128 (44%)
	Report	16,479 (12%)	59,499 (44%)	75,978 (56%)
	Total	29,521 (22%)	106,585 (78%)	136,106 (100%)
Wisconsin				
BLS	No report	23,778 (10%)	65,316 (27%)	89,094 (37%)
	Report	40,585 (17%)	111,484 (46%)	152,069 (63%)
	Total	64,363 (27%)	176,799 (73%)	241,163(100%)
New Mexico				
BLS	No report	6,115 (17%)	12,023 (34%)	18,138 (52%)
	Report	5,714 (16%)	11,236 (32%)	16,950 (48%)
	Total	11,829 (34%)	23,259 (66%)	35,088 (100%)
Minnesota				
BLS	No report	19,738 (11%)	36,335 (21%)	56,073 (32%)
	Report	41,238 (24%)	75,916 (44%)	117,154 (68%)
	Total	60,976 (35%)	112,251 (65%)	173,227 (100%)

Rows and columns may not add correctly because of rounding. 95% confidence intervals extend less than 1.5 percentage points from the point estimates for all states but New Mexico, where they extend less than 3 percentage points.

positive source dependence increases, and the estimated coverage of the two sources declines.

DISCUSSION

This study estimates ascertainment of occupational injuries and illnesses by state workers' compensation systems and by the BLS. Under the conservative assumption of source independence, the SOII captures at most 76% of injuries and illnesses in all six states. For workers' compensation, ascertainment is less than 80% in four states. Assuming source independence, we estimate that workers' compensation systems in the six states missed over 180,000 lost-time injuries in the sampled industries, that the BLS survey missed almost 340,000, and that about 69,000 injuries were unreported to either system. Positive source dependence (OR = 5) increases the estimated number of missed lost-time injuries and illness in these industries to more than 450,000 for workers' compensation and more than 610,000 for the BLS survey. Assuming source independence, tabulating injuries and illnesses from both sources increases ascertainment to at least 84% in all six states without relying on capture-recapture analysis. Positive source dependence (OR = 5) reduces minimum estimated ascertainment to 57%.

We do not know the primary reasons for underreporting or for the substantial variation in ascertainment by state. Azaroff et al. (28) document many possible explanations. To be reported, conditions must be diagnosed and ascertained, and this is rare for chronic occupational disease (28, 30, 31). If undiagnosed, neither system will report them. Very limited reporting has also been documented for upper extremity cumulative trauma disorders, also chronic conditions (8, 18, 31). In addition, ascertainment by workers' compensation systems can be affected by employer policies about reporting or contesting claims, worker concerns about retaliation for claim filing, and stigma associated with claim filing. Interstate variation in workers' compensation reporting can be affected by laws that make it easier or more difficult to receive benefits and by the level of benefits. The two states in this study with the highest workers' compensation reporting rates both have exclusive

TABLE 3. Capture-recapture estimates of workplace injury and illness reporting adjusted for capture heterogeneity: lost-time cases, 1998–2001, no source dependence

Percent reported to:	WA	WV	OR	WI	NM[a]	MN
Workers' compensation	93%	91%	77%	75%	67%	65%
BLS	55%	76%	56%	65%	51%	68%
Either						
Adjusted estimate	96%	97%	88%	92%	84%	87%
Crude estimate	98%	98%	90%	91%	83%	89%

Calculations assume source independence and are adjusted for age, sex, job tenure, industry, establishment size, body part injured, and nature of injury. 95% confidence intervals extend less than 1.5 percentage points from the point estimate for all states but New Mexico, where they extend about 3 percentage points.
[a]New Mexico has a 7-day waiting period. The other states have 3-day waiting periods.

TABLE 4. Estimates of reporting for six states adjusted for capture heterogeneity: sensitivity to assumptions about source dependence

Percent reported to:	Odds ratio[a]	WA	WV	OR	WI	NM[b]	MN
Workers' Compensation	1	93%	91%	77%	75%	67%	65%
	3	88%	88%	67%	67%	53%	57%
	5	84%	85%	61%	61%	45%	52%
Bureau of Labor Statistics	1	55%	76%	56%	65%	51%	68%
	3	53%	73%	49%	58%	43%	58%
	5	52%	71%	45%	53%	37%	53%
Either	1	96%	97%	88%	92%	84%	87%
	3	90%	93%	76%	81%	67%	74%
	5	86%	90%	68%	74%	57%	67%

[a]The ratio of the odds that an injury is reported to workers' compensation if it is reported to BLS to the odds that an injury is reported to workers' compensation if it is not reported to BLS. This ratio equals one for source independence and is greater than one for positive source dependence. Confidence intervals increase with odds ratios. For OR = 5, 95% confidence intervals extend less than 1.5 percentage points from the point estimate for Minnesota and Wisconsin, about 3.5 points for New Mexico, and less than 2.5 points for the other states.
[b]New Mexico has a 7-day waiting period. The other states have 3-day waiting periods.

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state funds, whereby all workers' compensation insurance is sold by one public insurer. In other states, workers' compensation claim data are gathered by the state from many insurers and third-party administrators. Although we lack evidence, on its face, this extra reporting step provides additional opportunities for case data to be lost.

The BLS survey faces a different set of issues. Unlike the handling of workers' compensation cases, entering injuries and illnesses into the Occupational Safety and Health Administration (OSHA) log (on which the BLS survey is based) is generally a minor task for the responsible person. That person may not have taken the time to become familiar with the reporting rules, and the workplace may not have an effective system for providing injury information to the responsible individual. Moreover, employers may fear that high injury rates will trigger an OSHA inspection. In addition, injuries reported after submission of the BLS survey (usually early in the year following the injury) will not be captured. Finally, unlike in workers' compensation, injured workers do not lose benefits if an injury is not recorded in the OSHA log, so they lack incentives to provide information or to check whether it is recorded.

Interstate differences in ascertainment by the BLS SOII may be caused by differences in state laws regarding compensability and the (incorrect) assumption that injuries not eligible for workers' compensation should not be recorded on the OSHA log. Boden and Ruser (32) have shown that laws that make it more difficult to file workers' compensation claims reduce BLS reports of days-away-from-work injuries by 10%. However, reporting rates in the same state may be high in one system and low in the other. Other state differences, including the ways in which data are gathered before forwarding to the BLS, should be explored. Because we have studied only 6 states, the substantial interstate variation in reporting does not allow us to generalize our findings to the entire United States.

Messiou and Zaidman (33) compared injury reporting on the OSHA logs with workers' compensation claims in Minnesota. They did not estimate the degree of underreporting in the two systems. Rather, by comparing these two data sources for a subsample of establishments, they identify reasons for disparities in reporting. These include omission of disputed workers' compensation cases from the OSHA log, not updating the log after the initial entry, and not reporting some paid workers' compensation cases on the OSHA log because the employer does not think they are work-related.

Maier and Reinke use the Oregon Population Survey to estimate workers' compensation reporting (34). They estimate that 61% of injuries in 2002 and 54% of injuries in 2001 are reported. These percentages are lower than our estimate based on source independence, but they are close to our 61% estimate based on source dependence with an odds ratio of 5. Using data from the 2002 Washington State Behavioral Risk Factor Surveillance System survey, Fan et al. (35) examine workers' compensation reporting in that state. They estimate that only 52% of injured workers filed a workers' compensation claim. This is far below our lowest estimate for Washington, which is 84% (Table 4). One difference between these analyses and ours is that the survey studies include both injuries involving time lost from work and those without lost time. Our analysis focuses only on cases involving more than 3 days of lost time. Injured workers with little or no time off work may be much less likely to file workers' compensation claims than those who have lost several days from work (36). Because the great majority of workplace injuries involve little or no lost time, including these injuries could substantially reduce the estimated reporting rate.

Another recent study addresses the degree of ascertainment of workplace injuries and illnesses by workers' compensation and the BLS survey or the OSHA logs. Rosenman et al. (22) did a capture-recapture study comparing the BLS survey and workers' compensation reporting in Michigan. They found only 32% ascertainment by the BLS, about half the lowest ascertainment among the six states in this study. For workers' compensation, they found 66% ascertainment, at the low end of the range in our states.

We cannot tell whether the difference in reporting between this study and the Rosenman et al. study is caused by interstate reporting differences or by differences in data and methods. Rosenman et al. may have applied more stringent linkage criteria, but we think that this is unlikely to have caused substantial differences in the number of linked cases. Perhaps more important is how the two studies handled the difference between reporting units for the BLS annual survey and workers' compensation. The BLS annual survey is done on an establishment basis, but workers' compensation data is typically reported on an employer basis for multi-employer sites. Rosenman et al. used available data (company name, address, EIN) to decide whether two establishments were identical. We do not believe that the available data permit us to distinguish accurately and consistently among individual establishments in multiestablishment companies. Instead, we used the method described above to account for this issue. Although our results indicate less underreporting than the Rosenman et al. study, they are consistent with Smith et al. who conclude that BLS private industry injury estimates are about 70% of those based on the National Health Interview Survey (10).

For four of six states, estimated reporting assuming source independence is less than 80% for the workers' compensation system and 65% or less for the BLS SOII. However, our two sources are very likely to exhibit positive source dependence, so these estimates probably substantially overestimate ascertainment. For example, assuming moderately positive source dependence (OR = 3), median ascertainment

of the two sources is 67% and 55%, respectively. Despite likely positive source dependence, we know that: (i) estimates based on source independence are better than the incidence derived from each source alone, (ii) they are better than estimates derived from adding the number of cases reported to either source or to both, and (iii) they are a lower-bound estimate of the true number of cases and therefore provide an upper-bound estimate of the percent of cases reported by each source. Thus, capture–recapture estimates that assume source independence provide improved incidence estimates, despite their downward bias.

This study and others raise questions about the adequacy of these two sources as surveillance tools for occupational injuries and illnesses. Tabulating cases that appear in at least one source would improve ascertainment but would still fall far short of an accurate count for four of the six states in this study. Also, inferences from these data sources about the variation in injury rates across states should be made with great caution, if at all, because reporting varies substantially. Further study would be valuable in helping to understand the reasons for differential reporting between sources and among states.

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