Serious Injury and Fatality Investigations Involving Pneumatic Nail Guns, 1985–2012

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Background *This article examines serious and fatal pneumatic nail gun (PNG) injury investigations for workplace, tool design, and human factors relevant to causation and resulting OS&H authorities' responses in terms of citations and penalties.*
Methods *The U.S. Occupational Safety and Health Administration (OSHA) database of Fatality and Catastrophe Investigation Summaries (F&CIS) were reviewed (1985–2012) to identify n = 258 PNG accidents.*
Results *79.8% of investigations, and 100% of fatalities, occurred in the construction industry. Between 53–71% of injuries appear to have been preventable had a safer sequential trigger tool been used. Citations and monetary penalties were related to injury severity, body part injured, disabling of safety devices, and insufficient personal protective equipment (PPE).*
Conclusions *Differences may exist between construction and other industries in investigators interpretations of PNG injury causation and resulting citations/penalties. Violations of PPE standards were penalized most severely, yet the preventive effect of PPE would likely have been less than that of a safer sequential trigger.* Am. J. Ind. Med. 59:164–174, 2016. Published 2016. This article is a U.S. Government work and is in the public domain in the USA.

KEY WORDS: pneumatic nail gun; traumatic injury; struck by; accident investigation; trigger safety

SCOPE OF THE PROBLEM

As pneumatic nail gun (PNG) use and associated productivity increased in the 1970s and 1980s through the present [Niemiec, 1989; Haun, 2011], an increasing number of medical case reports described resulting traumatic injuries [Peterson and Dixon, 1976; Lyons, 1983; Edlich et al., 1986; Freeman and Ainscow, 1994; Lee and Sternberg, 1996; Hoffman et al., 1997]. The first surveillance study describing nail gun injuries was conducted by the Washington State Department of Labor and Industries [Baggs et al., 1999, 2001] and reported that the overall compensable nail gun injury incidence rate in the building construction industry sector (Standard Industrial Classification 15) was 77.9/10,000 full-time equivalent (FTE) workers/year. However, the incidence rate within the state's industry risk classification for more specific jobs in wood frame building construction was 205.8/10,000 FTE.

In an analysis of workers compensation claims among Ohio union carpenters (1994–1997) and North Carolina Home Builders' employees (1996–1999), Dement et al. [2003] reported PNG injury rates among residential construction carpenters in Ohio and North Carolina equivalent to 132 cases/10,000 FTE and 91 cases/10,000 FTE, respectively. Mean medical payments per claim were $1,497 in North Carolina and in Ohio the mean workers' compensation cost per paid lost-time injury was $9,237. Text field narratives were analyzed for a subset of claim descriptions (n = 185) and at least 68% of cases appear to have been related to unintentional nail gun discharge or misfire.

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Lipscomb et al. [2003] investigated all acute work-related injuries (n = 783) occurring during 1999–2001 among a cohort of St. Louis, MO union apprentice carpenters (n = 5,137) working in the home building industry. Investigators interviewed 586 carpenters and collected detailed information regarding work-related injuries. Nearly 14% (80) of the injuries involved nail gun use. The overall nail gun injury rate based on hours worked in the residential sector for this time period (37 months) was 2.1/200,000 hours. The rate for less experienced apprentice carpenters was three times higher (3.7/200,000 hours) than that for journey-status carpenters (1.2/200,000 hours). The authors concluded that two-thirds of nail gun injuries equipped with a contact actuation trigger could have been prevented if a sequential actuation trigger system had been used.

The largest surveillance study of nail gun injuries involved the analysis of injuries treated in hospital emergency departments between 2001 and 2005 using the Consumer Product Safety Commission's (CPSC's) National Electronic Injury Surveillance System (NEISS) and the NEISS occupational injury supplement, NEISS-Work [Lipscomb and Jackson, 2007]. During these years, the estimated average number of work-related nail-gun injuries ranged from 19,300 to 28,600, with an annual average of 22,200. The body regions injured were the hands/fingers—58%; upper extremities (excluding hands/fingers)—8%; lower extremities—24%; and other regions—10%. The NEISS-Work database does not include information describing the type of nail gun or the trigger system.

PNEUMATIC NAIL GUN TRIGGER SAFETY

In general industry, PNG use is regulated under Occupational Safety and Health Administration (OSHA) "*machine guarding—point of operation guarding*" regulation [29 CFR 1910.212(a)(3)(ii)], which does not specifically require a "safety device" (29 CFR Part 1926, Safety and Health Regulations for Construction). However, Federal OSHA established minimum requirements for working with portable pneumatic tools in the construction industry under 29 CFR 1926.302(b)(3) as follows: "*All pneumatically driven nailers, staplers, and other similar equipment provided with automatic fastener feed, which operate at more than 100 p.s.i. pressure at the tool shall have a safety device on the muzzle to prevent the tool from ejecting fasteners, unless the muzzle is in contact with the work surface*."

The state of California's PNG regulation (§1704. Pneumatically Driven Nailers and Staplers) exceeds those of Federal OSHA by including additional requirements such as: prohibiting the disabling of any operating control (part b), requiring tool disconnection from compressed air during maintenance or when clearing a jam (part c), requiring that the hose be secured when working on sloped roofs steeper than 7:12 (part d), requiring a Code of Safe Practices for PNG use (part f), and requiring training prior to using the tool and after an operator has been observed using it unsafely or sustains an injury using one (part g.3). Employer training must include instructing workers on the hazards related to "each mode of actuation" for PNGs (part g.4).

All PNGs (other than light duty tools) incorporate a safety engineering control requiring that the contact tip of the nail gun (i.e., nose, safety tip, workpiece contact) be depressed against the lumber before a nail can be fired [American National Standard Institute, 2002]. At least two distinct modes of actuation are available [NIOSH/OSHA, 2011]. The modes of actuation prescribe the sequence dependence (or lack thereof) between the workpiece contact and the finger trigger. The contact actuation trigger (CAT) mechanism allows nails to be fired when the operator pushes the nail gun tip against the lumber to be fastened, either before or after depressing the trigger. With the full sequential actuation trigger (SAT), the workpiece contact (tip) must first be pushed against the lumber before the trigger is depressed to fire a nail, and the same sequence must be repeated to fire subsequent nails. The SAT mechanism is known to reduce risk of injury due to unintended actuation [see NIOSH/OSHA, 2011].

Prior surveillance studies have quantified the prevalence of nail gun injuries in construction building trades and characteristics/factors leading to these injuries [Dement et al., 2003; Lipscomb et al., 2003, 2008]. It is known that the majority of nail gun injuries are puncture wounds to the hands and fingers [Lipscomb et al., 2010] and do not require in-patient hospitalization. However, federal and state plan OSHA accident investigation reports represent an opportunity to evaluate more serious outcomes involving nail gun injuries. These reports include a narrative injury description, more detailed than in other data sources, including an assessment of causal factors conducted by investigating authorities. This article reports an analysis of cases in the Fatal and Catastrophe Investigation Summaries (F&CIS) database in the 27-year period 1985–2012 involving PNGs. The purpose of the analysis was to summarize Federal and state plan OSHA investigations of serious and fatal PNG injuries by occupation and industry, the nail gun user activity and nail trajectory in the incident, and the relevance of a sequential actuation trigger in preventing the incident. Further, we explored Federal and state plan OSHA investigators' interpretations of the attributed human factors issue in causation and authorities' responses in terms of issuance of citations and associated monetary penalties levied. This was examined for the construction sector, where the majority of these incidents have occurred, and other industry sectors.

METHODS

Data Source

Employers in all states must report work-related fatalities and injury incidents requiring in-patient hospitalization of three or more employees, with the latter defined as a catastrophe.[1] Twenty-one states and one territory manage their own private and public sector occupational safety and health enforcement agencies (OSHA-approved "state plans"). These State Plans adopt and enforce regulations at least as protective as Federal OSHA, with some promulgating regulations that are more protective. California and Utah are two State Plans that have more stringent regulations requiring employers to report incidents that result in serious injury to one or more workers [California Code of Regulations, 2014a; Utah Labor Code, 2014].

Fatality and Catastrophe Investigation Summaries (OSHA 170 form) are submitted after Federal or State Plan OSHA conducts an inspection in response to a fatality or catastrophe. The summaries provide a description of the incident, including events leading to the incident and causal factors. The OSHA IMIS F&CIS database contains records related to Federal and State OSHA work-related accident investigation and job site safety and health inspections. The database includes Federal and State OSHA accident investigation records containing the following information: OSHA-170 form, standards cited, citations issued, penalties assessed, and an abstract summarizing the circumstances surrounding the injury incident. At the time of this analysis the IMIS database was publicly accessible through the web: (https://www.osha.gov/pls/imis/accidentsearch.html). We did not obtain IRB approval for this secondary analysis of a data set that was publicly accessible and did not contain personally identifying information.

Search Strategy and Data Analysis

The OSHA Integrated Management Information System (IMIS) Fatality and Catastrophe Investigation Summaries (F&CIS) database [OSHA, 2015] was broadly queried for the word "nail" in any of the text fields, which included event description, event keyword, or abstract summary. A total of 1,598 investigations containing "nail" were found for the period 1985–2012. These report summaries were manually reviewed by three of the authors from which 260 cases were deemed, by consensus, to be traumatic injuries in which the injury victim was struck by a discharged nail from a pneumatic nail gun. Two cases were excluded: one of the cases was a duplicate and another involved two separate injuries. A final set of $n = 258$ investigation cases was analyzed. Variable totals in sums among variables are due to incomplete or missing data in the coded fields.

Data fields coded by the investigating authority (Compliance Safety and Health Officer, CSHO) included location of site (state), establishment size, SIC and NAICS identifier, occupational classification (SOC) of injured worker, body part injured, degree of injury (fatality, hospitalization, non-hospitalization), violation type, issuance of citation(s), and assessed penalties. The F&CIS database also contains coded fields in which the CSHO documents a single human factor, selected from a pick list, deemed by the CSHO to have influenced the injury event. According to OSHA, human factors are "*. . .what the worker involved, other worker(s) or the employer did or failed to do that caused the incident. For example, improper or dangerous work procedures were used, safety procedures were not followed or personal protective equipment was not worn when required. Included is any work activity or procedure for such under the direct control of the worker, fellow worker(s) and employer*" [OSHA, 1984].

To further characterize injury circumstances, three of the authors (BDL, JTA, SDH) independently reviewed the narrative text summary for the investigation, and coded each case for the following variables: injury victim; operator activity; nail trajectory; work surface; PNG safety training; PNG safety disabled; and lack of a sequential trigger system. This process resulted in full agreement among the three authors for 75% of these variable codings; and for over 98% of codings there was at least partial agreement (two of three authors agreed). The cases without full agreement were discussed to derive a consensus coding.

Lack of a sequential trigger system indicates that a non-sequential trigger system was determined to have been used and that the injury/fatality would have been prevented with a full SAT system. In other words, these are cases in which a restrictive sequential trigger operation would have controlled the hazard, but the nail gun was not equipped with such a system or that system was not in use. Examples of representative case narratives assigned to these categories can be found in the Appendix.

Construction sector investigations and resulting citations were analyzed for the data field documenting the applicable standard and the violation severity (other than serious, serious, and willful). Over 90 unique standards were identified as the basis for citation in construction sector

[1] As of Jan 1, 2015 Federal OSHA reporting requirements were changed so that an in-patient hospitalization of one or more employees must be reported within 24 hours of the incident.

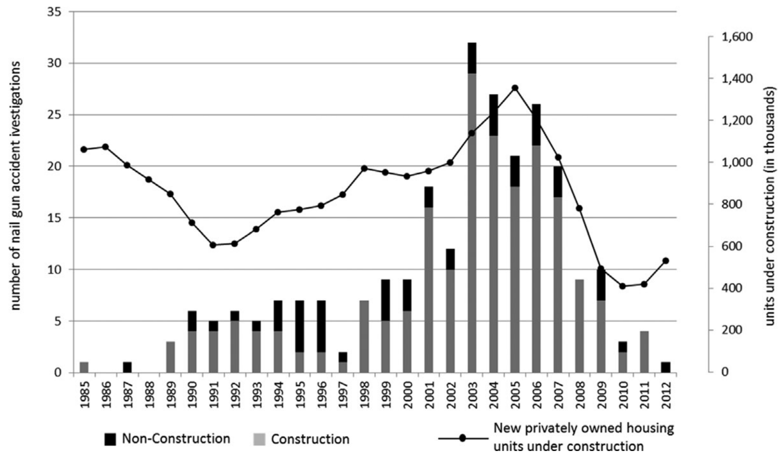

FIGURE 1. Fatality and catastrophe investigation cases (N = 258) involving pneumatic nail gun injuries, shown by year, 1985–2012, and by construction (■) and non-construction sectors (■). (Solid line shows new privately owned housing units under construction, with axis on right. Source: U.S. Census Bureau).

accidents. These standards were classified broadly as those applicable to pneumatic nail guns,[2] personal protective equipment,[3] training,[4] and other standards.

Monetary penalties issued for citations contained in the F&CIS dataset were inflation adjusted, indexed to 2013 real dollars, using the BLS general Consumer Price Index for the time period. Thus, the inflation-adjusted monetary penalties are directly comparable over the analysis time period.

Generalized linear models were used to test for the main effects of the F&CIS variables coded by CSHO's and variables from the narrative text analysis on the likelihood of citation issuance and the resulting monetary penalty. Pairwise contrasts were conducted between the levels of an independent variable. A separate model was used for each combination of independent and dependent variables. $P < 0.05$ was considered statistically significant. The SAS (Version 9.3, SAS Institute, Inc., Cary, NC) procedure PROC GENMOD was used. The binomial distribution with an identity link function was used for the dependent variable of issuance of a citation (1 = one or more citations, 0 = no citation). If the variance of a level of an independent variable was 0, the level was not included in the model, so that the model could be estimated. The inflation-adjusted monetary penalty was summed for all issued citations per investigation, and the gamma distribution with an inverse link function was used for the continuous variable inflation-adjusted total penalty. Fourteen 0 values for inflation-adjusted penalty were not included in the analysis. Only positive values were included because the gamma distribution is not defined at 0.

RESULTS

Accident Investigation Overview

The N = 258 cases were summarized by those in the construction industry (SIC 15-17) versus other industries. Most PNG-related accident investigations occurred in the construction industry and occurred during the early to mid 2000s peak in residential building activity (see Fig. 1). The general trend aligns with that of residential building activity during this time period, as shown in Figure 1. State OSHA plans conducted 92% (n = 238) of all PNG-related accident investigations, with the California state plan accounting for 81.5% (n = 194) Utah 2.1% (n = 5) of the State OSHA Plan inspections; 39 incidents were also investigated by other State OSHA agencies (AZ, MD, MI, NC, NV, OR, and VA) as fatality/catastrophe inspections, although they only resulted in one hospitalized injury. Investigations conducted under State plans were for accidents resulting in in-patient hospitalization (n = 200), non-hospitalization (n = 32) injuries, and one fatality. In five cases, severity was not coded. Of the OSHA State Plan accident investigations, 96% were conducted as fatality/catastrophe investigations that are initiated when an employer contacts OSHA. In two cases, no location (state) was documented. PNG injuries involving a hospitalization accounted for 82% of non-fatal injuries. Nine of the 18 investigations conducted by Federal OSHA were fatality investigations and represented 90% of the fatality investigations. All fatal injuries occurred in the construction sector.

[2] Examples: Federal OSHA 1926.302(b)(3); CCR (California) Subchapter 4, Article 28, section 1704, Pneumatically Driven Nailers and Staplers.

[3] Examples: Federal OSHA 1910.132,1910.133; CCR (California), Subchapter 7, Article 10, section 3382, Eye and Face Protection.

[4] Examples: CCR (California) Subchapter 4, Article 3, section 1510, Safety Instructions for Employees; 1509(e). Conduct "*toolbox or tailgate safety meetings, or equivalent*; 3203(a)(7)(b) *Provide training and instruction to all new employees*."

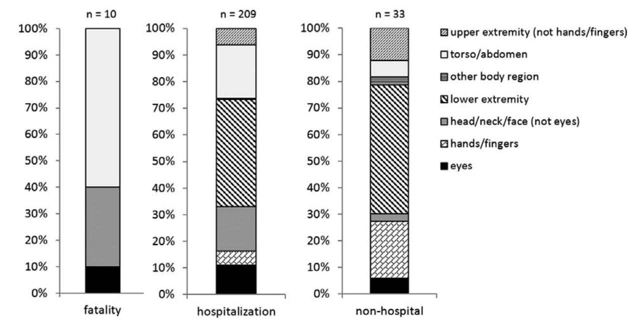

FIGURE 2. Percentage of injuries by affected body part grouped by injury severity. The full height of the bar represents 100%, but counts differ by degree of injury (severity). In six cases, no body region was coded.

Most (76.7%) injuries were puncture wounds. Foreign body in eye, fractures, and cut/laceration accounted for 6.2%, 5.4%, and 3.5% of all injuries, respectively. The lower extremity was the body region most frequently injured (38.9%); followed by the torso/abdomen (19.5%), head/neck/face (15.2%), eyes (10.1%), hands/fingers (7.0%), and upper extremity, other than hands/fingers (6.6%) (see Fig. 2). Head/neck/face, eye, and torso injuries are clearly associated with higher severity. Lower extremity, upper extremity, and hand/fingers are inversely associated with severity.

Most investigations occurred in the General Building Contractors-Residential (SIC 152) and Carpentry Work (SIC 1751) construction sectors, accounting for, respectively, 22% and 37.6% of the total investigations. Lumber and Wood Products (SIC 24) manufacturing accounted for 39.6% of non-construction investigations. More than 55% of all investigations occurred among carpentry occupations (in construction and other industries) and 12.0% occurred among construction laborers.

The human factor codes most frequently documented were (see Table I) a misjudgment of hazardous situation (36.6%), operational position not appropriate for task (11.3%), and safety devices removed or inoperative (8.2%), in addition to other factors (23.7%). The overall Chi-square test indicates that the attributed human factor differed between construction and non-construction sector investigations ($X^2_{10} = 22.53$, $P = 0.013$). Misjudgment of hazardous situation ($X^2_1 = 49.19$, $P < 0.001$) and malfunction of neuromuscular system ($X^2_1 = 11.26$, $P < 0.001$) appear disproportionately assigned in construction sector investigations. Operational position not appropriate for task ($X^2_1 = 5.83$, $P = 0.016$) appears disproportionately assigned to non-construction sector investigations. Proportion of investigations in which safety devices removed or inoperative was assigned did not differ between construction and non-construction sectors.

Text Analysis of Accident Descriptions Narrative

Injury Victim. In 77.7% of the cases, the injury victim was the nail gun operator (user), and in 22.2% of the cases the victim was a co-worker/bystander who was not the user of the nail gun.

Operator Activity. Fewer than one-third (30.3%) of the injuries occurred while the operator was engaged in a nailing activity, that is, when actually intending to fire a nail. Slips, trips, and falls (STF) were described in 13.6% of summary narratives and were coded as such by the authors. This was in spite of only one investigation coded by the CSHO with an event type as a fall. All of the case narratives for which we coded an STF were also coded to have been resulting from a lack of a sequential actuation trigger system, that is, preventable with the SAT.

Work Surface. In 63% of all narrative summaries, the work surface was described. For construction sector cases, the distribution was 32% occurring on level floor, 13% on

TABLE I. Human Factor Influence Assigned by CSHO Grouped by Construction Sector Investigations and Other Sector Investigations

Contributing human factor	Construction		Non-construction		Total	
Misjudgment of hazardous situation	81	(39.5%)	13	(25.0%)	94	(36.6%)
Operational position not appropriate for task	21	(10.2%)	8	(15.4%)	29	(11.3%)
Malfunction of neuromuscular system or perception system	14	(6.8%)	1	(1.9%)	15	(5.8%)
Safety devices removed or inoperative	13	(6.3%)	8	(15.4%)	21	(8.2%)
Insufficient or lack of engineering controls, housekeeping program, or written work practices program	6	(2.9%)	4	(7.7%)	10	(3.9%)
Insufficient or lack of protective work clothing and equipment	6	(2.9%)	2	(3.8%)	8	(3.1%)
Distracting actions by others	5	(2.4%)	0	(0.0%)	5	(1.9%)
Malfunction of procedure for securing operation, warning of hazardous situation, or lock-out tag-out	2	(1.0%)	3	(5.8%)	5	(1.9%)
Defective equipment: knowingly used	1	(0.5%)	2	(3.8%)	3	(1.2%)
Other	51	(24.9%)	10	(19.2%)	61	(23.7%)
	205	(100%)	52	(100%)	257	(100%)

ladders, 13% on roofs, 3% on structural members, and 39% other or unknown due to insufficient information. Non-construction investigation cases were distributed as 60% level floor, 4% ladders, 4% roofs, and 32% other or unknown.

PNG Safety Training. In 95% of cases, PNG safety training was not described in the report summary. Prior safety training was affirmed positively (nail gun operator had received training) for eight (3.1%) cases and affirmed negatively (no training of the nail gun operator) for six (2.3%) cases.

PNG Safety Disabled. The safety contact was clearly described as disabled in 3.5% (n = 9) of the narrative descriptions. In another 5% of cases, it was determined that the safety was probably disabled. No information in the remaining 91.5% of cases suggested that the safety device was disabled.

Nail Trajectory. Narrative summaries indicated that nearly half (49%) of the injuries occurred when the nail gun made direct contact with the victims' body, unintentionally firing a single nail. In 12.8% of cases, victims were struck from a nail ricochet (nail bounces off of a surface into the victim), 9.7% of cases described airborne nails striking the victim without ricochet, and 7.4% described a "double-fire"—when the PNG recoiled and a second unintended nail was fired. For the direct contact mechanism of injury, 23.8% of cases were injuries to a bystander, and 76.2% were to the operator.

Lack of a Sequential Actuation Trigger. From the investigation summary narrative descriptions, it was determined that the lack of a full sequential actuation trigger safety feature was a causal factor in 53.5% of the cases and was not a factor in 19.5% of cases. In the remaining 27% of cases, lack of a sequential trigger system was coded as either a "probable" causal factor (17.2%) or as not discernable (9.8%) due to insufficient information.

Citations and Penalties

There were 325 citations issued in construction industry investigations and 122 in non-construction industry investigations. One or more State Plan or Federal OSHA citations were issued in 130 of the construction accident investigations and 30 of the non-construction investigations. These resulted in 299 and 109 initial penalties, respectively. Table II describes citations issued in the investigations involving nail gun injuries and resulting monetary penalties. Final levied penalties are often reduced from the initial, with this reduction derived from a number of factors including smaller employer size, good faith, and history of no prior citations.

Among the 205 construction sector investigations, 25 had one or more citations for violations of personal protective equipment (PPE) standards—16 of those cases involved ricochet/airborne nails, three involved direct contact with the nail gun workpiece safety contact, and six were unclear in the description of nail trajectory. Four of these 25 had been coded as preventable with a full SAT, 14 as not preventable, and seven with insufficient information to determine the effect the full SAT would have had. Eighteen of the 25 PPE citations involved eye or head/neck/face injuries (consistent with the high percentage of ricochet/airborne nails). Fifteen (60%) of the citations for PPE-related standards were injuries resulting from deliberate nailing activity, although, overall, the activity of deliberately driving a fastener comprised 30% of these cases.

TABLE II. Citations Issued and Penalties Levied in Investigations

	Construction (SIC 15,17)	Non-construction
Investigations	205	53
Citations issued	325	122
Establishments given one or more citation	130	30
Initial penalties	299	109
Final penalties	268	97
Establishments given one or more penalties	117	29
Final penalties per investigation	1.31	1.87
Range in non-zero penalties (in 2013 USD)	\$56–\$16,319	\$46–\$13,321
Mean penalty (in 2013 USD)	\$1,056	\$1,312
Median penalty (in 2013 USD)	\$313	\$403

There were 22 investigations with citations for non-compliance with PNG standards in construction accidents (16 with monetary penalties). Of these, 18 cited California code of regulations 1704 Pneumatically Driven Nailers and Staplers, one cited Michigan Construction Safety Standard R 408.41937 Powered Staplers and Nailers, and three cited federal OSHA 1926.302(b)(3). Among the 13 construction sector investigations associated with a human factor code of safety devices removed or inoperative, eight were cited for violation of a PNG standard. In only one of the 22 construction accidents with a citation for violation of a PNG standard was the accident deemed to have been NOT preventable with a full SAT. Nine of 22 were coded as preventable with a SAT, and 12 were associated with insufficient information in the accident description. Only one citation for violation of a PNG standard was associated with an operator activity of (deliberate) nailing. Of the 22 citations, 10 involved direct contact by the victim with the nail gun safety tip, nine involved unknown nail trajectory, and three involved an airborne nail.

The median initial and final penalties for a PNG standard violation in the construction sector were, respectively, \$969 and \$568 (in 2013 US dollars). Four initial penalties

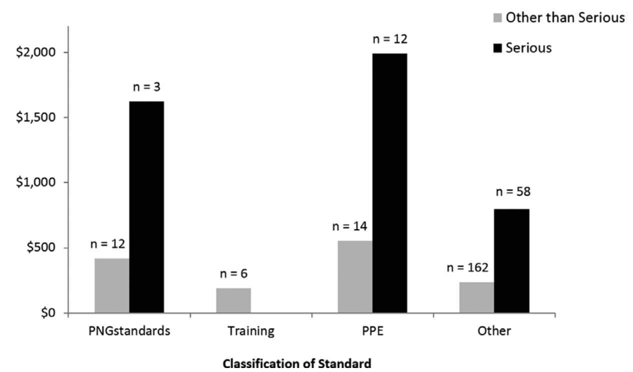

FIGURE 3. Median monetary penalty by classification of standards for construction sector inspections. There were 268 final penalties assessed. One willful violation of PNG standards was issued (not shown). (Penalties adjusted to 2013 dollars).

exceeded $22,000. Median initial and final penalties for PPE-related standards were $2,098 and $678 and for training-related standards were $243 and $189. The six resulting penalties for training standards violations in the construction industry were all violations of California Code of Regulations Standards. Figure 3 shows, for construction Industry inspections, the median penalty by the applicable standard as classified by pneumatic nail gun standard, training standard, PPE standard, or other standard and the seriousness of the violation. There was a single penalty ($5,637) in the category of a willful violation that is not shown on the graph. However, 15 of the 73 penalties for serious violations exceeded the amount of this willful violation.

Issuance of citation, on a per investigation unit (n = 258), was modeled (Generalized Linear Model) with the binomial distribution. The analysis did not distinguish single versus multiple citations per investigation. Higher likelihood of citation was predicted by part of body injured ($\chi^2_6 = 19.07$, $P = 0.004$), degree of injury ($\chi^2_2 = 6.05$, $P = 0.049$), and human factor ($\chi^2_9 = 25.82$, $P = 0.002$). See Table III for the percentages of cases issued citations by these variables. Nail trajectory ($\chi^2_4 = 8.91$, $P = 0.06$) did not reach 0.05 level of significance, but nail ricochet injuries (75.8%) were more likely to be issued a citation than direct contact with safety tip (58.7%) or double fire (42.1%). Lack of a full sequential trigger was not related to the issuance of a citation.

Inflation-adjusted monetary penalty was related to the accident human factor documented by the CSHO ($\chi^2_{10} = 29.35$, $P < 0.01$). Higher penalties were associated with "Malfunction of Neuro-Muscular System or Perception System" and "Safety Devices Removed or Inoperative." Lower penalties were associated with "Insufficient or Lack

TABLE III. Factors Predictive of Issuance of Citation in Investigations

	N (cases)	Cases issued citation (%)	95%CI
Part of body injured			
Eye	26	92.3	(82.1, 102.6)
Head/neck/face	39	69.2	(54.7, 83.7)
Lower extremity	100	61.0	(51.4, 70.6)
Upper extremity	17	58.8	(35.4, 82.2)
Torso	50	50.0	(36.1, 63.9)
Hand/finger	18	44.4	(21.5, 67.4)
Degree of injury			
Fatality	10	70.0	(41.6, 98.4)
Hospitalization	209	64.6	(58.1, 71.1)
Non-hospitalization	33	42.4	(25.6, 59.3)
Human factor			
Insufficient or lack of protective work clothing and equipment[a]	8	100.0	—[a]
Safety devices removed/inoperative	21	95.2	(86.1, 104.3)
Insufficient or lack of engineering controls, housekeeping program, or written work practices program	10	90.0	(71.4, 108.6)
Malfunction of neuromuscular system or perception system	15	80.0	(59.8, 100.2)
Equipment in use or procedure for handling material not appropriate for operation or process	6	66.7	(29.0, 104.4)
Defective equipment: knowingly used	3	66.7	(13.3, 120.0)
Distracting actions by others	5	60.0	(17.1, 102.9)
Misjudgment of hazardous situation	94	52.1	(42.0, 62.2)
Operational position not appropriate for task	29	51.7	(33.5, 69.9)
Malfunction of procedure for securing operation, warning of hazardous situation, or lock-out tag-out	5	40.0	(−2.9, 82.9)

[a]All eight cases coded as "insufficient or lack of protective work clothing and equipment" were issued citations and were thus not included in the model (0 variance).

of Engineering Controls, Housekeeping Program, or Written Work Practices Program" and "Misjudgment of Hazardous Situation." Other factors related to total monetary penalty were occupational group ($\chi^2_6 = 12.9, P = 0.04$) with Roofers receiving the lowest penalty and Woodworkers the highest; degree of injury ($\chi^2_3 = 15.0, P < 0.01$) with fatalities receiving significantly higher penalties than hospitalizations, and those significantly higher penalties than non-hospitalizations; industry classification (SIC) ($\chi^2_8 = 27.6, P < 0.01$) with lumber manufacturing receiving the highest total penalty and non-residential building and roofing the lowest. Non-construction total monetary penalties were higher than those in the construction sector ($\chi^2_1 = 6.62, P = 0.01$). Factors unrelated to monetary penalty were as follows: number in establishment, part of body injured, victim (nail gun operator vs bystander), operator activity, nail trajectory, work surface, and lack of a full sequential trigger.

DISCUSSION

The OSHA F&CIS database provides a perspective on high severity PNG injuries investigated by Federal and State Plan OSHA and how these authorities responded (e.g. citations, and penalties). The F&CIS database contains mostly injury investigations conducted by State OSHA agencies, with California making up the majority of investigations. The small number of Federal OSHA PNG injury investigations can be explained by the difference in Federal and certain State OSHA Plan requirements for reporting the occurrence of a serious, but non-fatal injury. Per 29 CFR 1904.39(a), Federal OSHA and the most State Plan OSHAs require employers contact OSHA to report all "in-patient hospitalization of three or more employees as a result of a work-related incident" [OSHA 2014]. California and Utah State OSHA Plans have promulgated standards exceeding this requirement such that employers report a fatality or a single serious injury requiring hospitalization [California Code of Regulations, 2014b; Utah Labor Code, 2014]. California's large economy, large construction sector, and enhanced reporting requirement explain this state's predominance in the data set.

The OSHA F&CIS database provides insight into how Compliance Safety and Health Officers (CSHO) have characterized injury causation for serious PNG injuries and how violations associated with, but not necessarily the cause of, serious PNG accidents have been penalized. CSHOs frequently attributed one of the "human factor" codes that, while not a root cause, appears to be suggestive of worker error, for example, misjudgment of hazardous situation or malfunction of neuromuscular system or perception system. Other potential human factor influences that could have been attributed included insufficient or lack of engineering controls (identified in only one construction and three non-construction cases) and equipment in use not appropriate for operation or process (identified in only two construction cases). In spite of the fact that over half of nail gun injuries were preventable with a full sequential actuation trigger system (engineering control), insufficient or lack of engineering controls was identified in only 1.1% of cases.

The human factor was classified by the investigating CSHO as "safety devices removed or inoperative" in 8.2% (n = 21) of cases, although only described in the summary text narrative in 3.5% of cases. From review of accident description narratives, we coded two cases as "safety disabled" that were not assigned to the applicable human factor code by the CSHO. Overall, agreement was high between those cases classified positively by the authors as having safety devices disabled and those coded by the investigating CSHO with the applicable human factor code. Nail gun manufacturers place high emphasis on the fact that safety devices on the tool should not be modified or disabled. This factor appeared to be involved in 3.5–8.5% of the cases in the F&CIS. It is not clear whether any of these injuries were preventable with a sequential actuation trigger mechanism.

In spite of the uncertainties in coding from the narratives, and that only one human factor can be documented when the injury may be of multi-factor causation, there are informative trends in how the human factors codes were assigned. Non-construction sector investigations tended to be more often coded with a human factor as *operational position not appropriate for task* and either *insufficient or lack of engineering controls, housekeeping program*, or *written work practices programs*. Conversely, construction sector investigations tended to disproportionately attribute *misjudgment of hazardous situation* or *malfunction of the neuromuscular or perception systems*. This may reflect underlying differences between the construction and manufacturing sector investigations in terms of perceptions about injury causation and the responsibility of the nail gun user in preventing them. Construction sector investigations, in which worksites are non-fixed, may more often implicate worker "errors" and manufacturing sector investigations, with fixed worksites, may more often implicate work process/procedural deficiencies.

Nail gun safety training is described as an important component in nail gun injury prevention programs, particularly so by the nail gun manufacturers trade association [American National Standard Institute, 2002]. Yet in 94% of the investigation report summaries, safety training of the nail gun user, either in the affirmative or negative, was not mentioned. A non-random sample of 15 full investigation reports revealed that three of the full reports did contain information about user training. Thus, our analysis of accident summaries likely under-represents the frequency in which safety training (or lack thereof) is documented in investigations. Nonetheless, few citations were written for violations of PNG safety standards (Federal and California), PNG training standards (California), or construction training standards (Federal and State OSHA standards); and when penalties were issued for violations of training standards, the median penalty for these violations was less than $200.

By way of comparison, the median penalty associated with PPE-related standards was nearly three times higher than that for training standards (for other than serious violations), and the penalties for serious violations of PPE-related standards were 10 times higher than the penalties for citations related to training standards. It is unclear how effective PPE would have been in preventing or reducing the severity of many of these injuries. If PPE could be assumed to have prevented all eye and head injuries that would account for 65 injuries (~25%) in this dataset and possibly 40% (4) of the fatal injuries. (We assume that no torso/abdomen, upper extremity, or lower extremity injuries would have been prevented with PPE).

Conversely, it appears that a greater percentage of injuries would have been prevented had the PNG been equipped with a sequential actuation trigger so that hazards were controlled at their source. In most cases, the summary report provided sufficient description of injury events to distinguish between intentional nail discharge, regardless of trigger mechanism, and unintended nail discharge associated with the contact actuation trigger system. Our findings suggest that the lack of a sequential actuation trigger mechanism was responsible for unintentional discharge in 53.5–70.7% of the injuries and 70% of the fatal injuries. This is consistent with estimates of 65–69% reported by Dement et al. [2003] and Lipscomb et al. [2003]. Knowledge that the SAT is a safer trigger system and more effective in reducing nail gun injury hazards at their source has yet to be embodied in non-voluntary standards applicable in the United States. Nor does it appear to be reflected in citations or severity of penalties levied in fatal or catastrophic nail gun accidents.

The F&CIS database represents the higher severity nail gun injuries with the majority resulting in hospitalization. It is known that hand/finger injuries represent a much larger proportion of all occupational nail gun injuries treated in Emergency Departments [MMWR, 2007] than their proportion in this data set, because hand/finger injuries are less likely to require in-patient hospitalization. Thus, the present data set should not be considered representative of all PNG injuries.

The results of the abstract narrative text provide injury event details not available in the IMIS data fields. It is important to consider that in nearly one-quarter of these higher severity accidents, the injury victim was a coworker or "bystander," and not the user of the PNG. Only 33% of the injuries could be attributed to an operator activity involving intentional nail discharge or movement/positioning of the PNG in preparation for nailing. Almost 50% of injuries occurred when a PNG discharged a nail unintentionally after the tip of the nail gun made direct contact with the body of the user or a bystander and discharged a nail (excluding double fires).

A limitation of this analysis of investigation report summaries is that more contextual information may be available in the full report narratives that is not captured in the text analysis of the summaries. The authors obtained a sub set (n = 15) of full investigation reports of PNG-related accident investigations conducted by Federal or California OSHA (2002–2009) courtesy of Duke University. The full reports contain more detailed descriptions of the injury events than the publicly accessible summary narratives. The informal review of these 15 full investigation reports revealed cases in which additional, more detailed, information clarified uncertainty in coding or resulted in changes to the authors' initial coding. For example, in 7 of the 15 cases for which full reports were obtained, the summary report contained insufficient information to determine whether the lack of sequential trigger system was a causal factor. The full reports contained enough information to change the coding of six uncertain cases to yes, and one to no. This suggests that our analysis of report summaries may actually under-represent the percentage of cases in which lack of sequential trigger system was a causal factor.

CONCLUSION

The results of the present analysis corroborate the increased risk of traumatic injury involving nail guns that are not equipped with a full sequential actuation trigger (SAT). The analysis indicates that the primary injury mechanism among the most severe (fatal and catastrophic) nail gun injuries is the unintended actuation from direct contact of the victim with the workpiece safety contact (tip) of a contact actuation trigger. In spite of this, citations and higher monetary penalties were associated with cases of ricochet nail trajectories and appear to have been directed at (lack of) use of PPE and eye injuries, perhaps suggesting a belief that this mechanism of injury is more preventable. Citations for training standards have been issued less frequently, with minimal penalty severity, in spite of the emphasis often placed on training as a component of a nail gun injury prevention program.

Until recently, PNG injury prevention recommendations primarily focused on maintaining the functionality of the "safety tip" and providing safety training to operators (ANSI SNT-101-2002; OSHA/1926.302.b.3; California Code of Regulations, Section 1704.g). In 2011, NIOSH and OSHA jointly published *Nail Gun Safety: A Guide for Construction Contractors* that acknowledged the increased risk of traumatic injury due to the unintentional firing of the PNG using the CAT mechanism. In recognition of this risk, NIOSH and OSHA provided the recommendation to: “Use the full sequential trigger—The full sequential trigger (i.e., SAT) is always the safest trigger mechanism for the job. It reduces the risk of unintentional nail discharge and double fires—including injuries from bumping into co-workers.”

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APPENDIX

Example of lack of a sequential trigger system determined to be a definitive causal factor:

> “. . . The owner was standing holding a pneumatic nail gun. As the owner turned, the employee backed into him, causing the gun to actuate and shoot a nail into the employee’s lower back. He was hospitalized.”

(Represents direct contact with the workpiece tip while the trigger was already actuated. This is preventable with a full sequential actuation trigger).

Example of lack of a sequential trigger system determined to NOT have been a causal factor (two examples):

> "... The coworker was nailing the cross studs and Employee #1 was bent over to nail the header onto the jack of the wall panel. The coworker shot a nail in the plate that should have gone into the cross stud but, instead, came out through the top of the plate, nicking the cross stud. The nail flew across the work area and struck Employee #1 in the middle of his chest. ... The safety clip was in place and working properly. The nail possibly was fired into the wood at a bad angle, or when the nail went into the first piece of wood it possibly hit a knot or something that caused it to exit the top. The nail was not bent and, apparently, came straight through the wood."

> "... Employee #1, a carpenter, was using a pneumatic nail gun to nail cross- braces between floor joists at a construction project. He was standing on a ladder on the first floor of the building, and leaning into the floor joist to the second level. Employee #1 was holding the nail gun over the joist and pointing it back toward himself, with the joist between the nailer and himself. When he fired the gun a nail it passed through the joist but missed a second board that would have stopped it. The nail entered Employee #1's chest and punctured his heart. He was transported to the hospital for treatment."

(These represent cases with airborne nails that could have been released in this manner with any trigger actuation system.)

Example in which the lack of a sequential trigger system was a probable causal factor is as follows:

> "Employee #1 was using a nail gun to repair pallets. One nail did not go all the way in and he decided (to) hammer it in manually. As Employee #1 set aside the nail gun, he had the pressure trigger down as if he were ready to activate it. The nail gun struck the top of his boot, causing him to pull the trigger and shoot himself in the foot. Employee #1 sustained a puncture injury, but did not required hospitalization."

(The narrative above appears contradictory, first describing the trigger as initially depressed, then a subsequent pull of the trigger. Having the trigger depressed prior to making work piece, tip contact would not have actuated a full sequential trigger system. It was determined to be unclear, but probable, that this trigger was a contact actuation system).

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