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Prevention of Traumatic Nail Gun Injuries in Apprentice Carpenters: Use of Population-Based Measures to Monitor Intervention Effectiveness

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Introduction *Nail guns are responsible for a significant injury burden in residential construction. Risk, based on hours of work, is particularly high among apprentice carpenters due in part to more frequent exposure to tool use.*

Methods *Nail gun injuries were evaluated over 3 years among carpenters enrolled in two apprenticeship programs in the Midwest (2.3 million residential work hours observed) following initiation of training and a voluntary ANSI standard change calling for safer sequential triggers on framing nailers. Injury rates, based on hours of tool use, were calculated yearly. Rates and adjusted rate ratios were calculated with Poisson regression. Attributable risk percent (AR%) and population attributable risk (PAR%) were calculated yearly for modifiable independent risk factors for injury including lack of training in tool use and type of trigger mechanism on tools being used.*

Results *As apprentices received training and safer trigger mechanisms became more widespread, injury rates decreased significantly (31%). While school training and hands-on mentoring were both important, injury rates were lowest among apprentices who received both. Although injury rates changed over the observation period, the relative risk comparing trigger mechanisms did not; contact trip triggers consistently carried a twofold risk.*

Conclusions *Although training and safer trigger use both increased, because of the relative prevalence of training and trigger exposures in this population, the engineering solution consistently had the potential to make more difference in population risk. Our findings demonstrate the utility of observational methods including measures of population–based risk in monitoring intervention effectiveness and making recommendations that lead to injury reduction.* Am. J. Ind. Med. 51:719–727, 2008.

INTRODUCTION

Pneumatic nail guns and fasteners for wood frame construction, which became commercially available in the 1960's, are now a standard tool in wood frame construction. Residential carpenters, the primary users of the tool, are particularly difficult to study; consequently safety issues of individuals in this sector of the construction industry have received less attention than their commercial counterparts. Although there is now considerable data documenting injury risk associated with the use of these tools [Baggs et al., 1999, 2001; Dement and Lipscomb, 1999; Lipscomb et al., 2003a,b, 2006; Lipscomb and Jackson, 2007], the risk associated with their use had not received much attention for several decades. Until the late 1990's, reports

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were largely limited to case reports or case series in trauma journals [Wu et al., 1975; le Nobel and Wing, 1987; Kizer et al., 1995].

Injuries from nail guns occur under a variety of circumstances including accidental discharges, gun double fires, nails which ricochet and become airborne, and penetration of the receiving structure [Edlich et al., 1986; Beaver and Cheatham, 1999]. Work by Lipscomb et al. [2003a, 2006] documented particularly high rates of injury among apprentice carpenters. We now know that lack of any training and the type of trigger mechanism on the tools are both independent risk factors for nail gun injuries [Lipscomb et al., 2006]. The tools are easy to use and these high injury rates, based on total hours of work, in part reflected greater use of the tools among relatively unskilled apprentices. In any event, unskilled workers who have the tools in their hands the most bear a significant proportion of the injury burden from these tools. The vast majority of injuries involve puncture wounds to the hand or fingers [Baggs et al., 1999; Dement et al., 2003; Lipscomb et al., 2003a; Lipscomb and Jackson, 2007]. However, there are increasing reports of serious, devastating, and fatal injuries [Nadesen 2000; Brodwater, 2007; Department of Labor, US OSHA, 2007] associated with the use of these tools.

The primary safety device to prevent accidental discharge of pneumatic nail guns is the trigger mechanism which works in combination with a contact element located in the nose of the gun [ANSI, 1983]. Common triggering configurations on these tools include contact trip and sequential triggers. The more common contact trip design allows nails to be discharged from the tool anytime the nose and the trigger mechanism are both depressed. Workers are able to hold the trigger down and rapidly fire the tool to ''bump or bounce nail.'' In contrast, the sequential design requires that the nose be depressed before the trigger in order to discharge a nail, making it more difficult to unintentionally discharge nails. Sequential triggers can also prevent injuries that occur following recoil of the gun; with a contact trigger the nose may contact a surface after recoil inadvertently discharging if the user's finger is still on the trigger.

Most pneumatic nail gun manufacturers have offered sequential triggers as an option on new equipment for a number of years, and many have provided retrofit kits to allow existing guns to be converted to sequential actuation. However, the majority of guns have been sold with contact trip trigger mechanisms. The International Staple Nail and Tool Association (ISANTA) sponsored a voluntary change in the ANSI standard for pneumatic tools effective in May 2003 [ANSI, 2003]. The new standard involves tool safety labels and changes in the actuation system of the majority of framing nailers, specifically ''most of the larger (framing) tools will be shipped with sequential actuation systems.'' However, some tools continue to be sold with contact trip systems, tools with sequential triggers can be shipped with a contact trigger in the same box, buyers may request a contact trip trigger be placed on their tool, and there are hundreds of thousands of tools already in the workplace that continue to be used.

These analyses focus on evaluating the effect of training in nail gun use received by apprentice carpenters and the type of trigger on the tools they use in preventing acute injuries. Both must be evaluated in the context of the 2003 voluntary standard change.

METHODS

Site of Work

This work was conducted in collaboration with the Carpenters' District Council of Greater St. Louis and Vicinity (CDC-GSV) and the Homebuilders Associations in St. Louis and S. Illinois. This geographic area is one of few regions in the country with a large unionized residential workforce. The CDC-GSV represents residential carpenters who work for contractors of varying size, including a number of small to medium sized residential contractors who can be particularly difficult to incorporate into research and intervention efforts.

Data Sources and Collection Methods

Between 2005 and 2007 data were collected from apprentice carpenters enrolled in the apprenticeship programs affiliated with the CDC-GSV (Carpenters Joint Apprenticeship Program, St. Louis, Missouri and Southern Illinois Carpenters Training Center, Belleville, Illinois). Union carpenters typically spend 4 years in apprenticeship training. During that time they are enrolled in formal classroom and supervised shop training for 2-week periods twice a year with the remainder of their time in the field.

One day per week for 6 months each year ($\sim$24 times), two journeymen carpenters on the research team went into classrooms at the training centers and asked apprentices to complete a short written questionnaire anonymously. Collection of data was intentionally limited to 6-month periods each year (2005, 2006, and 2007) to avoid querying any given carpenter more than once each year. Participation was after informed consent; all procedures were approved by the institutional review boards at Duke University Medical Center and the Center for Construction Research and Training (AFL-CIO).

Since carpenters can work in the non-union sector prior to joining the union, apprentices where asked to report both time in the trade and in the union apprenticeship program. To provide estimates of time at risk, the apprentices were asked to report the hours they worked in residential carpentry and an estimate of the usual hours of nail gun use each week over the last year. They were asked to specifically

report on the triggering mechanism on the tools they used and their estimate of hours of nail gun use with each trigger mechanism in a typical week in the last year. Each carpenter was asked to report any nail gun injuries they had experienced including the date of their most recent injury. Apprentices who reported injuries were queried further about their most recent injury including the type of tool and trigger mechanism involved, and the circumstances surrounding the injury. While the focus of this evaluation is prevention of acute traumatic injuries, because of concern raised about the potential to increase risk of musculoskeletal injuries with sequential trigger use, we specifically asked about any musculoskeletal problems experienced as well.

In response to earlier research findings [Dement et al., 2003; Lipscomb et al., 2003a,b] the carpenters' apprenticeship program first initiated nail gun training for early apprentices in January of 2002. Influenced by resources and competing demands, the form of the training has varied over time from the original classroom presentation with slides, demonstration, and hands-on instruction and supervised tool use, to more basic classroom instruction covering use and safety principals. Some received supervised instruction at school in later years, while others did not.

Each carpenter was asked about nail gun training, and injured carpenters were specifically asked whether they had training before their injury occurred. Analyses of data collected in 2005 to explore risk factors have been previously reported [Lipscomb et al., 2006]. Because of the wider variety of training experiences reported outside the apprenticeship program than we had anticipated, the questionnaire was modified to capture more detail about training experiences in 2006 and 2007. Options included classroom training through the apprenticeship program, toolbox talks, video training, hands-on mentoring at school or on site, required contractor training, talks by manufacturers' representatives, and product information; they were not limited to training received after becoming an apprentice.

Analytical Approach

Our analytical approach to these data was very similar to that described for the earlier analyses of data from 2005 [Lipscomb et al., 2006]. Crude injury rates (incidence density) based on the report of injuries in the last year were calculated per 200,000 hr of residential carpentry work. Confidence intervals for all rates were calculated assuming a Poisson distribution [Haenszel et al., 1962]. Rates were calculated separately for injuries that required medical care, lost time from work, or either of these to approximate OSHA recordable cases.

Injuries were further restricted to those that occurred when the apprentice was using the tool (as opposed to a coworker) to estimate rates of injury per 10,000 hr of reported tool use in order to define injuries and time at risk on the same basis. In the event that a carpenter had experienced more than one injury in the last year, analyses were only based on the report of the most recent injury. Crude injury rates and rate ratios as well as adjusted rate ratios were calculated using Poisson regression [Nizim, 2000] after stratifying hours of tool use and injuries by covariates of interest including time in the union, time in the trade, trigger mechanism on the tool, and type of training in tool use before injury. Variables were retained in the multivariate models if they were independent risk factors based on likelihood ratio statistics or if their removal changed other risk factors 15% or more. Using these criteria, no variables were dropped from the model with a *P*-value of less than 0.10 (Type III statistic, SAS, Version 8.2).

As intermediate measures of interest, the proportion of hours of tool use with each trigger mechanism and proportion of hours of tool use with training before an injury were calculated by year. Using these figures, attributable risk percent (AR%), and the population attributable risk percent (PAR%) [Hennekens and Buring, 1987] were calculated to estimate the impact of the modifiable factors we were exploring, namely trigger configuration and training, associated with injury risk in this population of apprentice carpenters. Because we are using incidence density rates, we used the population proportion of time exposed as our measure of prevalence for these calculations. Separate analyses were conducted for each year, and the findings in 2006 and 2007 were compared to those previously reported for 2005 [Lipscomb et al., 2006].

Data from the questionnaires were entered and stored in an ACCESS database [Microsoft, 1997] created in EpiInfo Version 3.3.2 [CDC, 2005] and transferred to SAS Version 8.2 [SAS Institute, 1999–2001] for analyses. All procedures were approved by the Institutional Review Boards at Duke University Medical Center and the Center for Construction Research and Training (CPWR), AFL-CIO.

RESULTS

The proportion of workers reporting a nail gun injury in the preceding 12-month period (period prevalence) as well as any nail gun injuries declined markedly among these apprentice carpenters between 2005 and 2007. The greatest declines were seen between 2005 and 2006 (Fig. 1). While the overall rates of injuries, based on hours worked, followed a similar pattern (Table I), the rate of injuries resulting in medical care and lost time from work increased.

Only 20% of these work-related injuries in 2006 and 2007 were reported as a workers' compensation injury (this item was not asked in 2005). Consistently, 11–12% of injuries resulted from a tool being used by another worker.

Yearly injury rates, based on reported hours of tool use, and adjusted rate ratios are presented in Tables II and III, respectively. In both tables the data are stratified by time in the trade, union tenure, training, and trigger mechanism. In

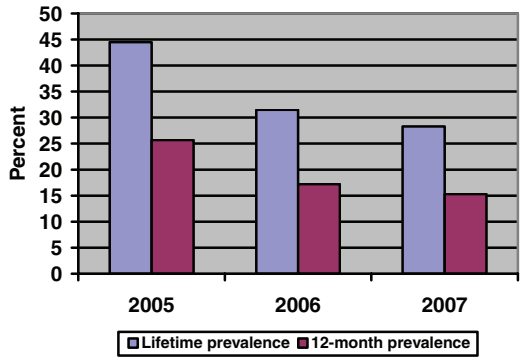

FIGURE 1. Reported prevalence of nail gun injuries by year among apprentice carpenters, Carpenters District Council of Greater St. Louis and Vicinity, 2005–2007. Twelve months prevalence limited to individuals who worked residential hours in the last year. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

2006 and 2007, we evaluated more specifically the effects of different types of training received prior to injury. In 2006, only school training remained in the multivariate model while other types of training did not. In 2007, while school-based training and hands-on mentoring had comparable effects there was a significant interaction of their effects with individuals who had neither of these types of training at particularly high risk (RR 3.7; 95% CI 2.5, 5.3) compared to those who had both. Time in the trade was dropped from the 2007 model based on a *P*-value of 0.33 for the likelihood ratio statistic, indicating lack of significance of this class variable (SAS Type III statistic).

Although based on small numbers especially for sequential trigger injuries, it is of note that musculoskeletal injuries associated with repetitive trauma occurred at rates of 0.41(95% CI 0.27, 0.60) per 10,000 hr of contact trip tool use (n = 26) and 0.11 (95% CI 0.04, 0.28) per 10,000 hr of sequential trigger use (n = 6).

The proportions of hours of tool use with a contact trip trigger and prior to having received training are presented by year in Table IV. The yearly attributable risk estimates (AR% and PAR%) for lack of training and contact trip trigger use based on these figures are presented in Figure 2a,b. The AR%, which represents the proportion of injuries that could have been prevented among the exposed, decreased for both trigger mechanism and training over time. The PAR% dropped over 50% for training between 2005 and 2006; this was due to a decreased relative risk measure in 2006 since the proportion of apprentices with training before injury did not increase that year. The PAR% for trigger mechanism has steadily decreased as the proportion of hours of tool use with a sequential trigger increased. However, based on the fact that the majority of apprentices are now receiving some training before they are injured and nearly half of the hours of tool use continue to be with tools with the contact trigger mechanism, the greatest future prevention effect in this population would come through more use of tools with the safer, sequential trigger.

DISCUSSION

Through this work we sought to better understand factors that contributed to injuries from pneumatic nail guns, one of the more common acute traumatic injury hazards of residential carpenters. Specifically, we sought to evaluate the effectiveness of training in tool use and the trigger mechanisms on tools being used within the context of an industry-sponsored voluntary standard change that went into

TABLE I. Apprentice Carpenters Working Residential, Their hours Worked, Frequency of Nail Gun Injuries Reported, and Rates of Nail Gun Injuries per 200,000 hr Worked by Year, Carpenters District Council of Greater St. Louis and Vicinity, 2005–2007

	2005	2006	2007
Number of carpenters	654	818	490
Hours of residential work	814,287	976,759	548,043
Number of injuries	168	141	75
Rates (95% CI)			
Overall injury rate	41.3 (35.3, 48.4)	28.8 (24.3, 34.0)	27.3 (19.9, 36.9)
Rate of injuries resulting in			
Medical care	9.6 (6.9, 13.1)	8.6 (6.1, 11.7)	15.3 (10.9, 20.8)
Missed work time[a]	6.6 (4.3, 9.6)	5.7 (3.7, 8.3)	9.9 (6.5,14.5)
Beyond day of injury[b]	n.a.	4.5 (2.8, 6.8)	5.1 (2.8, 8.6)
Medical or lost time	10.3 (7.4, 14.0)[a]	9.0 (6.6, 12.1)[b]	16.8 (12.2, 22.5)[b]

n.a., not available.
[a]Lost time not confirmed to be beyond day of injury.
[b]Lost time was confirmed beyond day of injury.

TABLE II. Stratified Crude Rates (95% CI) of Self-Inflicted Nail Gun Injuries per 10,000 hr of Tool Use by Year Among Apprentice Carpenters, Carpenters District Council of Greater St. Louis and Vicinity, 2005–2007

	2005	2006	2007
Time in union			
<1-year	4.4 (3.1, 6.0)	4.1 (2.9, 5.6)	2.5 (1.8, 3.5)
1 to <2 years	3.0 (2.2, 4.0)	1.9 (1.4, 2.6)	2.4 (1.7, 3.4)
2+ years	2.0 (1.4, 2.5)	1.2 (0.69, 1.9)	1.4 (1.7, 3.4)
Time in trade			
<1-year	6.5 (4.4, 9.4)	5.8 (3.7, 8.7)	3.6 (2.2, 5.9)
1 to <2 years	2.7 (2.2, 3.4)[a]	2.5 (1.7, 3.6)	2.1 (1.3, 3.4)
2 to <5 years		1.6 (1.1, 1.2)	1.7 (1.2, 2.5)
5+ years	1.9 (1.1, 3.0)	1.4 (0.67, 2.6)	1.9 (1.2, 2.9)
Trigger mechanism			
Contact	3.6 (2.9, 4.4)	2.9 (2.3, 3.7)	2.8 (2.1, 3.7)
Sequential	1.6 (1.0, 2.4)	1.4 (0.94, 2.0)	1.5 (1.1, 2.1)
Any training			
Yes	2.2 (1.8, 2.8)	1.9 (1.5, 2.4)	1.8 (1.4, 2.3)
No	6.1 (4.5, 8.1)	3.0 (2.0, 4.3)	3.9 (2.5, 6.2)
Types of training[b]			
School			
Yes	—	1.9 (1.5, 2.5)	1.6 (1.2, 2.1)
No	—	2.9 (2.1, 3.9)	2.9 (2.2, 3.9)
Contractor			
Yes	—	1.3 (0.59, 2.5)	1.7 (0.9, 2.0)
No	—	2.3 (1.9, 2.9)	2.1 (1.7, 2.x)
Manufacturer talk			
Yes	—	1.5 (0.82, 2.5)	1.3 (0.70, 2.5)
No	—	2.3 (1.9, 2.9)	2.2 (1.8, 2.7)
Toolbox talk			
Yes	—	1.6 (1.0, 2.4)	1.7 (1.2, 2.4)
No	—	2.4 (1.9, 3.0)	2.2 (1.8, 3.1)
On site/hands on			
Yes	—	2.1 (1.5, 3.8)	1.6 (1.2, 2.2)
No	—	2.3 (1.7, 3.0)	2.7 (2.0, 3.6)
No school or hands-on	—	—	3.7 (2.5, 5.3)
Only school	—	—	2.2 (1.4, 3.6)
Only hands-on	—	—	2.0 (1.3, 3.1)
Both	—	—	1.3 (0.8, 1.9)

[a]Strata not defined as finely in 2005; represents 1 to <5 years.
[b]Detail not available in 2005.

TABLE III. Adjusted Rate Ratios (95% CI) of Self-Inflicted Nail Gun Injuries by Year Among Apprentice Carpenters, Carpenters District Council of Greater St. Louis and Vicinity, 2005–2007

	2005	2006	2007
Time in union			
<1-year	1.7 (0.92, 3.3)	2.1 (1.0, 4.3)	1.8 (0.84, 3.7)
1 to <2 years	1.6 (0.92, 2.6)	1.2 (0.60, 2.3)	1.7 (0.81, 3.5)
2+ years	1	1	1
Time in trade			
<1-year	2.7 (1.2, 5.9)	2.6 (1.2, 5.9)	
1 to <2 years[a]	1.4 (0.79, 2.7)	1.9 (0.88, 4.0)	
2 to <5 years		1.3 (0.62, 2.6)	
5+ years	1	1	
Trigger mechanism			
Contact	2.0 (1.2, 3.3)	2.0 (1.3, 3.1)	1.9 (1.1, 3.4)
Sequential	1	1	1
Any training			
Yes	2.9 (1.9, 4.4)	2.1 (1.4, 3.0)	2.0 (1.2, 3.3)
No	1	1	1
Types of training[b]			
School			
Yes		1	
No		2.7 (1.8, 4.2)	
Contractor			
Yes			
No			
Manufacturer talk			
Yes			
No			
Toolbox talk			
Yes			
No			
On site/hands on			
Yes			
No			
Neither school nor hands-on			2.7 (1.3, 5.9)
Only school			1.8 (0.75, 4.3)
Only hands-on			1.6 (0.72, 3.6)
Both			1

[a]Strata not defined as finely in 2005; represents 1 to < 5 years.
[b]Detail not available in 2005.

effect nationwide in 2003. Our findings demonstrate considerable progress in the control of this injury risk among the carpenters we studied.

The data convincingly demonstrate the effectiveness of training in preventing injuries among apprentice carpenters—even though, in this case, their training took many different forms. The occupational health community often speaks to the importance of training, but we are less often able to demonstrate that it really matters [Rivara and Thompson, 2000]. Here it appears that it is not only important, but that more is better. The fact that we found apprentice school training and hands-on mentoring to be of essentially equal importance is important, with broader implications for training unskilled carpenters in a non-union sector where there is no formal apprenticeship training. However, it is of particular note that the greatest protection was afforded when apprentices received both classroom training and hands-on instruction.

In each year of our analyses, tools with contact trip triggers consistently carried twice the risk of those with sequential triggers. Additionally, as the proportion of hours of tool use with sequential triggers increased, injury rates declined. Diffusion of tools with the safer trigger into the hands of workers remains a challenge. We have seen some progress in this regard, but 4 years after the voluntary standard went into effect nearly half of nailing time among these apprentices continues to be done with the more dangerous trigger. This is in a geographic area of the country where there has been considerable attention to this safety hazard through newsletters to workers and contractors and media coverage. This raises concern about the effect of voluntary industry-sponsored standards such as this one. Granted, the standard as written is weak, calling for *shipment* of framing nailers with sequential triggers rather than their *use*. This wording has allowed manufacturers to comply with the standard while shipping an alternative contact trip trigger in the same box.

Carpenters typically provide their own hand tools, but power tools such as nail guns are more often provided by the contractor for whom the carpenter works. This makes workers dependent upon the decision of their employers to provide the safer tool.

We are aware of concerns about the potential for trading an acute injury hazard for musculoskeletal problems associated with the need for regular triggering of guns with sequential actuation. Because work-related musculoskeletal disorders can be even more challenging to track than acute injuries, we specifically asked for reports of these conditions from the apprentices we surveyed. While we acknowledge, this is based on a very small number of observations, to date we do not see evidence that this is the case and in fact we see musculoskeletal problems reported among carpenters using contact trip tools more often.

In the fast-paced residential sector of the construction industry, workers, as well as contractors, have expressed concerns about slowing the pace of work with the use of tools with sequential triggers. We recently evaluated this concern and, under controlled conditions, found negligible differences ($<1\%$) in building times [Lipscomb et al., 2008]. Regardless, if regulation that called for the safer trigger was in place and enforced, all would be using the same tool and productivity would not be an issue.

Nail gun injuries are much more prevalent than we thought and many, even those resulting in medical care or lost time from work beyond the day of injury, often go unreported. Injury incidence rates, measured over a 3-year period of data collection from earlier surveillance among a well-defined cohort of 5,000 residential carpenters in this area defined the reported injury incidence rates among apprentices at 3.7 (95% CI 2.7–4.9) per 200,000 hr worked [Lipscomb et al., 2003a]. Throughout the project period, the rates were stable for the overall population studied and among apprentices. In addition, our overall rates were precisely the same as those reported in wood frame construction in the State of Washington [Baggs et al., 1999, 2001], adding to our confidence in the reliability of our baseline measures. However, we recognized in the first year of directly surveying apprentices that these rates were gross under-estimates of the true burden of injury with many injuries going unreported. Of note, the injury rates from nail guns resulting in paid lost time from work or medical care (based on hours of work, not hours of tool use) are higher than those recognized in BLS reports for the construction trades in recent years for all injuries [BLS, 2006]. Both the rate of injuries resulting in lost work time and those resulting in medical care increased among these apprentices during our 3 years of observation, while overall injury rates declined. We believe this reflects attention to these injuries in the apprenticeship school including discussions of seeking appropriate medical care.

Limitations and Strengths

We recognize that there are both limitations and strengths to this work. The apprenticeship schools are primarily responsible for skills training; safety is incorporated into many aspects of training, but there are always competing demands for limited school time. Consequently, training offered to these apprentices changed over time and continues to do so. Different instructors have been involved, presentations were modified based on shorter class schedules, other training needs, etc. We made no attempt to assess differences in teachers or methods employed in school beyond specific questions that allowed us to assess hands-on instruction, which could have been at school or on a job site, in years 2 and 3. However, we are attempting to assess effectiveness, which means how an intervention works in the real world situation, and this is the reality in which these instructors and apprentices work.

The data we analyzed came from a series of cross-sectional surveys with apprentices over a 3-year time period. Asking for recall of injuries and time at risk over the last year allowed us to estimate injury rates. We analyzed our data in each year using Poisson regression as you would approach cohort data, electing to present the findings stratified by year. Effect measures for training, particularly, but also time in the trade varied over the 3-year period. We also knew we surveyed a number of the same carpenters each year, but because the data were collected anonymously they could not be linked on an individual basis. The creation of separate models for each year avoided the need to account for more than one observation per person in each mathematical model.

Methodologically, cross-sectional data are not viewed as robust as longitudinal data or randomized designs in assessing effectiveness of interventions for a number of reasons. However, in this case, we believe these serial cross-

TABLE IV. Proportion of Hours of Tool Use With Contact Trigger and no Training by Year, 2005–2007

	2005	2006	2007
No training	18.0%	23.0%	11.6%
Contact trip trigger	64.5%	51.6%	41.3%

sectional data are quite strong, providing an efficient way to evaluate and monitor the effects of interventions for this particular injury problem in this population. We knew from the outset that apprentice carpenters were at high risk of injury [Lipscomb et al., 2003a] and we knew that part of their risk was conferred by their high exposure to these tools. As apprentices, working through a 4-year training program their risk would decrease with increasing experience, training, and exposure. Following a cohort of apprentices would not have been useful in determining whether very early apprentices rates of injuries decreased. Alternatively, we could have created a dynamic cohort allowing new members in each year; that would have been logistically more complicated, requiring identified data for no significant gain.

Neither training nor trigger design could be randomized among these apprentices considering the factors influencing each—contractors hiring them, small work sites, and significant potential for cross-over to name a few. In fact, the very complex and highly dynamic nature of these workplaces may challenge the validity of randomization. Additionally, the ANSI standard change, which provided important context for this evaluation, was effective in May 2003 nationwide. Considering all these issues, we believe the approach we took was reasonable and provides considerable information about the interventions.

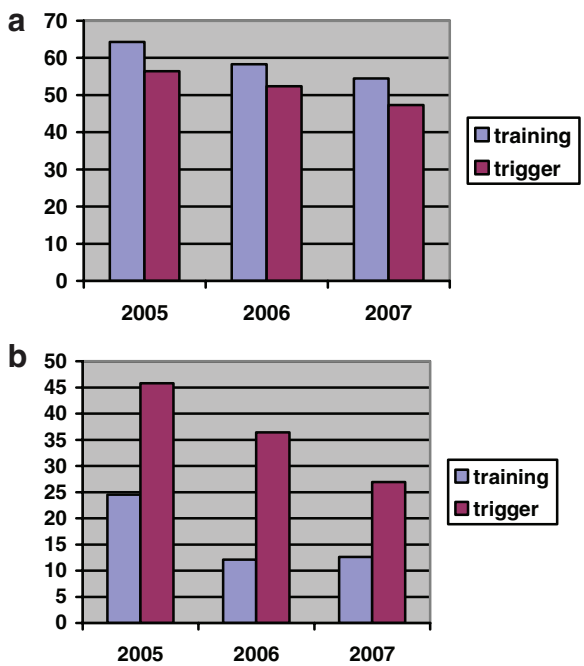

FIGURE 2. Attributable risk percent and population attributable risk percent for trigger mechanism and training, 2005–2007 apprentice carpenters. **a**: Attributable risk percent by year for training and trigger type. **b**: Population attributable risk percent for training and trigger type. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

Our research design focused on evaluating only two modifiable risk factors for injury; we know there are others including speed of work in this fast-paced industry, as well as quality and nature of building material including knots in wood and increasing use of dense building materials such as laminated beams. This is important to remember as we follow injury trends further over time as changes could affect the picture.

In this industry, the ability to directly measure exposures such as actual hours of tool use by carpenters over a year is not realistic. We relied on self-report from apprentices to capture their injury experiences and exposure information on tool use. We recognize that there will be error in such reports. However, we know of no reason that reporting errors should be more likely for one trigger type than the other. Thus, while our rate measurements may not be entirely accurate, the measures of relative risk should be reasonable.

The consistency of the data from these self-reports of apprentices over 3 different years is quite reassuring. For example, the proportion of nailing done by apprentices on residential sites was consistently reported each year and the hours of work they reported are what we expected based on previous formal reports from the union [Lipscomb et al., 2003a,b,c]. Stratified rate estimates based on hours of tool use are similar in each year. Although injury rates declined, the relative risk measures for trigger mechanism were constant over 3 years as one would expect.

It can be difficult to gain access to residential construction workers, particularly in large enough numbers to evaluate training effectiveness over a period of time. This evaluation built directly on our surveillance work over the last 9 years that has focused on occupational safety issues of residential construction workers in this district council of the United Brotherhood of Carpenters and Joiners of North America. The importance of sustained collaboration that allowed continued access to workers and partners with interest in intervening cannot be minimized.

CONCLUSIONS

Despite the demonstration of decreasing injury rates with increasing training and use of the sequential triggers, acute nail gun injury rates remain unacceptably high among these apprentice carpenters. There are no regulations that define minimal training requirements for the use of

pneumatic nail guns or that require use of the safer sequential triggering mechanism, despite data indicating that there should be. Particularly in the absence of regulation, continued emphasis on increasing both is needed. However, depending on the type and quality of training available and the relative prevalence of training and safer trigger use in any given population, one intervention may warrant more attention than the other. In this particular group of apprentice carpenters, consistently, increasing the use of the sequential trigger would have more future impact on the injury experience of the group. The relative value of training in preventing injuries has been and continues to be less than half that of switching to tools with the sequential trigger. It would be helpful to evaluate the diffusion of both in other areas of the country where focus on this particular injury problem has not been as great as it has been in this area. In light of the fact that much residential construction in the U.S. is done under conditions in which training may be less likely (non-union settings, growing immigrant workforce including non-English speakers) than among these union carpenters, the use of the safer sequential trigger is clearly warranted.

Special work groups, like these residential carpenters, need surveillance and intervention trials as well as subsequent evaluations that are specific to their workforce, such as the one we have presented. Combining their experiences with all other construction workers masks the significance of the problems they face and the exposures that are particular to these workers.

Lastly, our findings demonstrate the usefulness of observational methods in evaluating the effectiveness of interventions and making recommendations for continued injury reduction. PAR% measures have been overlooked in much of the occupational safety literature. We believe this example demonstrates their usefulness in monitoring intervention effectiveness and in the setting of priorities for continued reduction of injuries. This is particularly true when more than one modifiable factor independently contributes to injury risk for groups of workers as is often the case.

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