DISSERTATION

NOISE EXPOSURE IN STEEL STUD CONSTRUCTION: NOISE CHARACTERIZATIONS AND TOOL LIMIT GUIDANCE FOR COMMERCIAL FRAMERS

Submitted by

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ABSTRACT

NOISE EXPOSURE IN STEEL STUD CONSTRUCTION: NOISE CHARACTERIZATIONS AND TOOL LIMIT GUIDANCE FOR COMMERCIAL FRAMERS

Noise exposure in construction is well-demonstrated to be hazardous to hearing, with high rates among construction workers of occupational noise-induced hearing loss. This study focused on an under-studied population of construction workers: Commercial framers who cut and install steel studs as their primary task. This study used personal noise dosimetry and task assessments to characterize the noise exposures of this population, and to develop implementable recommendations to decrease hazardous occupational noise exposure for this population of workers. Sound pressure levels of common power saws at the framers' hearing zone was hazardous, with L_{eq} log-transformed means of 107.2 dBA and L_{peak} means of 120.1 dBC during saw use. Noise dose among this population ranged from 5.8 – 61.4% of the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) and from 63.9 – 823.2% for the National Institute for Occupational Safety and Health (NIOSH) recommended exposure limit (REL). Mean ambient noise dose equivalent at the study sites was 1.4% for OSHA PEL criteria and 12.4% for NIOSH REL criteria. Overall, installers had significantly lower REL doses than cut persons ($p = 0.016$). Octave band analysis showed a slight upward trend of higher sound pressure levels at higher frequencies. Recommendations for task limitations were developed for isolated use of power saws, the powder-actuated tool (PAT) nailer, and the impact driver. Generalized cuts of steel studs without hearing protectors were limited to 13 – 14 cuts per worker per day for any saw and any stud type. Shots with the PAT nailer were limited to <2 shots per day

per worker without hearing protectors, 10 – 13 shots per day with foam earplugs, 27 – 34 shots per day with earmuffs, and 86 – 108 shots per day with double hearing protection (earplugs plus earmuffs).

ACKNOWLEDGEMENTS

I want to give a huge thank you to Dr. Bill Brazile for teaching me more about Environmental Health than I ever could have imagined. We had a lot of challenges to overcome, but we had a lot of fun and made it all happen with a better project than I could have possibly expected. To my excellent advisor and my very good friend – I appreciate all that you've done for me and your words will never be forgotten.

To all of my committee members, I thank you for your advice, your leadership, and your help as we wandered through this immensely fun journey together.

DEDICATION

This dissertation is dedicated to my wonderful family who stood by my side as I toiled away day and night. Thank you to my wife, Heather, and my son, Edan, for bearing with me no matter how crazy the journey. Your support, understanding, and encouragement helped make this project a major success and I will always be thankful that you continued to cheer me on through all of the challenges. Love you!

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Introduction, Purpose and Scope

Construction workers are exposed to hazardous noise as a daily part of their job, a statement that is well-demonstrated in numerous studies that show high rates of occupational noise-induced hearing loss among this population (Kerr et al., 2002; Neitzel et al., 1999). This occupational illness is not a surprise, considering the loud and powerful tools they use on a daily basis to construct buildings from durable materials that are engineered to last for decades or longer. Ironically, despite the high noise exposures of construction workers in general (Kerr et al., 2002; Neitzel et al., 1999; Seixas et al., 2001), the Occupational Safety and Health Administration (OSHA) has provided standards for noise exposure in construction that are less protective than those for general industry. The National Institute for Occupational Safety and Health (NIOSH) does not distinguish between general industry and construction, and recommended exposure limits (RELs) are the same for all occupational groups. The lower protective standards of OSHA are demonstrated in significantly higher noise doses with REL criteria as opposed to OSHA permissible exposure limit (PEL) criteria (Bejan et al., 2011; Seixas et al., 2005).

This study was designed to understand the noise exposures of a specific group of construction workers: Commercial framers who cut and install steel studs as their primary occupational tasks. Anecdotally, this group of workers is the source of much of the noise on a construction site, and the tools they use demonstrate this well. They use power saws to cut and modify steel stud framing members dozens of times each day, producing noise that can be heard well outside of the construction site. They use powder-actuated tool (PAT) nailers dozens of times each day, a tool that uses a powder cartridge similar to a firearm to drive a nail into steel and concrete. Their work involves numerous other power tools that produce substantial noise energy during these manipulations, and the outcome is daily hazardous noise exposure.

This study investigated the noise exposures of steel stud framers on active construction sites during the summer of 2023. In total, 42 workers were sampled, including 37 framers and 5 supervisors, at 6 different construction sites during the course of 10 workdays. Buildings that were under construction during the sampling periods included a combination of new-build projects and renovation projects of between 3,150 ft^2 (300 m^2) and 200,000 ft^2 (18,000 m^2), and from 1 to 5 stories tall.

Sampling schemes included primarily noise dosimetry studies of the workers as they conducted their normal daily tasks. Additional investigations included assessing cutting-time durations of various steel studs and analyzing tasks associated with various work assignments as part of the workers' duties. These samples were used to characterize the noise exposures the workers received from the various tools they use on a daily basis, to assess the noise dose the workers received from those noise exposures, and to then construct recommendations on tool use limits to help decrease hazardous noise exposures in this group of workers. The specific aims for the study were to 1) Characterize noise exposures from the various power saws the workers used to cut steel studs, 2) Describe the noise dose steel stud framers receive during a typical workday of cutting and installing steel studs, 3) Characterize the noise exposure of commercial framers from their daily task assignments in relation to their daily noise dose, and 4) To develop use limits to commonly-used loud framing tools. Enjoy.

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Chapter 1: Power saw noise levels during steel stud cutting tasks on commercial construction sites: A tool characterization from a worker exposure standpoint[1]

Summary

Construction framers who cut and install steel studs as part of their daily tasks are exposed to hazardous noise levels during their work shift in large part due to the power saws they use to cut steel studs. This investigation characterizes the noise exposure of workers who use power saws to cut steel studs on active construction sites. Further, the length of time that it takes to cut common types of studs on a commercial construction site are presented, which is a direct association to the amount of noise exposure the workers receive from using the power saws. In general, power saws found on the study sites had the following log-transformed mean metrics during cutting of steel studs: A-weighted equivalent continuous sound pressure level (L_{Aeq}) of 107.2 dB, A-weighted fast response maximum sound level (L_{AFmax}) of 108.5 dB, and C-weighted peak sound level (L_{Cpeak}) of 120.1 dB. Three of the saws – the chopsaw, the cut-off saw and the grinder – had similar noise levels, whereas the cordless circular saw had higher noise

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levels for all metrics. In general, among all saw types and all sizes of studs found at these study sites, it took on average from 2.5 sec to as much as 57.7 sec to cut each stud, exposing the worker to hazardous noise levels numerous times during a typical workday.

Introduction

Commercial construction in the United States typically uses steel studs as the primary framing components for interior and exterior building walls. Steel studs used in commercial construction in the U.S. commonly come in web sizes (the dimensional width of the stud) between 1.625 – 12.0 inches (41 – 305 mm). Flange sizes (the dimensional depth of the stud) commonly range from 1.0 to 2.5 inches (25 – 64 mm). Common thicknesses of the steel material are 18 mil (0.454 mm), 27 mil (0.683 mm), 30 mil (0.753 mm), 33 mil (0.835 mm), 43 mil (1.088 mm), 54 mil (1.366 mm), 68 mil (1.720 mm) and 97 mil (2.454 mm). [All steel stud soft metric conversions are adapted from the Steel Stud Manufacturers Association (2002).] Various other less common sizes and thicknesses may also be used. Steel studs typically arrive at a jobsite in various lengths that require the stud to be cut to a size suitable for installation. Light thickness studs such as 18 – 30 mil (0.454 – 0.753 mm) can be cut by hand with a pair of snips, however heavier thicknesses require the use of power saws for cutting. Almost exclusively, these power saws use a circular rotating blade or abrasive cut-off wheel to cut these studs quickly and efficiently, an important factor in construction where production quotas are common.

Saw selection on a jobsite is based on a number of factors. In many cases, based on convention and industry practices, the framing company may supply centrally-located saws for worker use. In other cases, the individual framer may supply their own saw, leaving the saw selection entirely up to the worker's preference and budget. If the saw produces sparks during the cutting process, a "hot work" permit may be required, which requires the implementation of certain specific fire protection controls (NFPA, 2024). A cutting tool may be specified by the building owner that reduces noise during construction, such as in an occupied hospital, or at times a quieter tool may be selected as a hazard control for the workers.

To construct a wall in a commercial building, a component called a “track” – a U-shaped piece of steel with similar dimensions as the stud – is fastened to the floor and the ceiling first, with the stud ends placed into the top and bottom track flanges and screwed into place (Fig. 1.1). Steel stud framers often work in pairs. A “cut person” operates the saw to cut the stud to the correct length, and then connects the stud to the track mounted on the floor. An “installer” works from a powered lift to measure and install the stud at the ceiling. While framer pairs are common, other framers may be assigned ad hoc tasks throughout the jobsite, including installing pre-fabricated door frames, building box beams for window openings, installing grid wires to

Fig. 1.1. Example of steel stud framing. Vertical studs are attached to the track mounted on the floor.

support suspended ceilings, correcting problems, installing support hardware, and numerous other tasks in which a worker may not be exclusively dedicated to using a saw, but may still use one consistently during the course of a day. With the exception of installers who are often confined to a lift without access to a saw, most framers on a commercial jobsite therefore use the saw numerous times throughout the workday.

In the U.S., occupational noise exposure limits are set by the Occupational Safety and Health Administration (OSHA) for workers in general industry and, with less protective limits, for workers in construction. The National Institute for Occupational Safety and Health (NIOSH) has provided its own recommendations for lower exposure limits in an effort to help protect the hearing of such workers who have notably high occurrences of occupational hearing loss (Kenney & Ayer, 1975; Kerr et al., 2003; Leensen & Dreschler, 2015; NIOSH, 1998; Seixas et al., 2012). Presently, the OSHA permissible exposure limit (PEL) for noise in construction is 90 dBA time-weighted average (TWA) for an 8-hour work shift with a 5-dB exchange rate (OSHA, 1970), with no action level to encourage decreasing exposures nor administration of a hearing conservation program prior to reaching the PEL. NIOSH provides a more-protective recommended exposure limit (REL) of 85 dBA TWA and 3-dB exchange rate (NIOSH, 1998).

Table 1.1. Saw and blade/cut-off wheel information for the power saws used to cut steel studs at the study sites.

Saw Type	**Saw Manufacturer**	**Saw Model**	**Blade/Cut-off Wheel Type(s)**
Chopsaw	DeWalt	D28710/15	Hilti 436732 Drywall Stud Cutting Wheel DeWalt DWA8001 Metal Cutting Wheel
Cordless Circular Saw	Hilti	SCM 22-A	Hilti SCBM MU 6.5” 40t Blade
Cut-off Saw	DeWalt	DCS690	DeWalt DWAFV8918 Cutoff Wheel
Grinder	DeWalt	DCG412	DeWalt DW8062 Cutoff Wheel

Fig. 1.2. Examples of each saw type that was used at the study sites. A = Chopsaw; B = Cut-off Saw; C = Grinder; D = Cordless Circular Saw.

The researchers of this study investigated steel stud framers at a total of six different active construction sites over the course of ten days to characterize the noise levels produced by locally-common power saws used to cut steel studs. The power saws used on the study sites were generally described as a chopsaw, a cordless circular saw, a cut-off saw, and a grinder. Three of the saw types used abrasive cut-off wheels as the cutting media, and a fourth saw-type used a metal-cutting blade (Fig. 1.2; Table 1.1).

While power saws used for cutting steel studs are anecdotally loud, little is known about their noise level production on the jobsite or the noise exposures of the workers who use them. The researchers aimed to characterize the field-based sound levels received at the worker's hearing zone from common power saws found on construction sites used to cut steel studs.

Materials and Methods

All sampling was performed on volunteers at commercial construction sites. Institutional Review Board approval was received prior to any recruitment. Volunteers with informed consent were recruited at commercial construction sites that were actively in the framing stage and using steel studs as framing materials. Only volunteers who were framing with steel studs as their primary job for the work shift were selected for the study.

Job Site Characteristics

Job sites where volunteers were recruited were commercial buildings under construction or renovation. All sites were opportunistically selected based on availability and willingness of the framing contractor to allow noise sampling of their employees. Sites were a combination of new-build projects and renovation projects of between 3,150 ft^2 (300 m^2) and 200,000 ft^2 (18,000 m^2), and were from 1 to 5 stories tall. Volunteer participants spent the entirety of their work shift performing framing tasks with steel studs during the sampling periods.

Noise Dosimetry

Noise samples were obtained through personal dosimetry with one of two noise dosimeters (Larson-Davis Spark model 706RD and Larson-Davis Spartan model 730, Depew, NY, USA). The Spartan dosimeters were enabled with 1/1 octave band filters and 12-second event sound recording for 6 of the 10 study days. All dosimeters were set to record with A-frequency weighting at the following settings for the virtual dosimeters in each device: (1) OSHA PEL criteria (90 dB criterion level, 90 dB threshold, 5-dB exchange rate, slow response), and (2) NIOSH REL criteria (85 dB criterion level, 80 dB threshold, 3-dB exchange rate, slow response). Peak data were recorded with C-frequency weighting. All data were integrated and logged at 1-second resolution. Dosimetry data were collected from the start of the work day until the end of the work day with lunch break data excluded. Morning and afternoon breaks were included in the calculations because this was considered part of the work day. Calibration of each dosimeter was performed before and after each sampling day using Larson-Davis CAL150/200 calibrators (Depew, NY, USA).

A dosimeter was attached to each participant's shoulder with the microphone near the participant's hearing zone (i.e., two-foot-wide sphere surrounding the head). As framers typically carry the stud on their shoulder, the non-dominant shoulder was used to attach the dosimeter to avoid the worker carrying a stud on the dosimeter microphone. Dosimetry data were downloaded via the dosimeter PC-based software (PCB Piezotronics G4 LD Utility for the Larson-Davis Spartan dosimeters, and PCB Piezotronics Blaze for the Larson-Davis Spark dosimeters, Depew, NY) and exported to spreadsheets for analysis.

Concurrent with dosimetry, the researchers observed and documented times and descriptions of the tasks being performed by each participant. These observational data were then used to compare with the dosimetry data to develop a dB "signature" for saw cuts performed throughout the work day, i.e., the dB signatures were visually identified in the dosimetry time-stamped data.

Saw Noise Characterization and Cutting-Time Evaluations

All noise dosimetry data were collected on workers using power saws which they normally used on a jobsite. No modifications to a worker's daily routine or tool selection were performed for the purpose of this study to ensure that normal working conditions were recorded. Power saws were evaluated as generalized categories of tool type, not by manufacturer or age. Saws were categorized as "chopsaw," "cordless circular saw," "cut-off saw," and "grinder." Saw models and paired blade/cut-off wheel configurations used by the workers in this study are shown in Table 1.1. Examples of each saw are shown in Fig. 1.2.

Dosimeter clocks were synched with a smartphone clock used on site. Times, saw type and stud type were recorded when a participant used a saw. Dosimeter data logs were reviewed and compared with both documentation from observed cut times and dB "signatures" of the saw cuts which were clearly discernible from ambient noise in the data logs. Saw cut dB levels were compiled based on A-weighted, fast-response maximum sound level (L_{AFmax}) dB >90 during the cut, or L_{CPeak} dB >100 if L_{AFmax} was not available, and recorded in a spreadsheet. The thresholds were chosen to distinguish the saw noise from the background noise and were verified with observed cutting times. All saw cuts from all participants, regardless of the number of cuts performed, were included in the noise characterization data compilation to ensure the highest number of data points with the widest variation in stud/saw/worker combinations were included.

Cutting times were observed and logged for various types and sizes of steel stud and track used in the study. Length of cutting time was measured with a smart phone stopwatch, with the stopwatch started when the worker pulled the saw trigger to start the saw, and the time stopped when the worker released the trigger at the end of each cut. Note that track framing components were not a primary focus of this study, but have similar dimensions and noise metrics as studs. For simplicity where this paper refers to cutting steel studs, the analysis also includes track components.

Statistical Analysis

All data from the dosimeters were exported into Microsoft Excel (ver. 16.76) spreadsheets. Statistical analyses were performed using R Statistical Software (v. 4.3.1; R Core Team, 2023) with EnvStats package (Millard, 2013).

Means of all noise metrics, L_x, were calculated as log-transformed means as shown in Eq. 1.1, as described in International Organization for Standardization (ISO) 9612:2009.

$$L_{x(avg)} = 10log_{10}\left(\frac{1}{N}\sum_{i=1}^{N}10^{0.1L_{xi}}\right) \quad \text{(Eq. 1.1)}$$

where:

$L_{x(avg)}$ is the log-transformed mean of all L_{eq}, L_{max} or L_{peak} data for a specific saw

L_{xi} is the individual 1-second measured L_{eq}, L_{max} or L_{peak} for the event

i is the 1-second sample number

N is the total number of 1-second measurements

Results

For the saw characterizations, a total of 23 construction workers were sampled at 6 sites over the course of 10 days. Across all study sites, 4 different power saws were used by the workers to cut steel studs (Table 1.1). In all, a total of 9,527 1-second noise samples of power saw use were recorded by the participant dosimeters.

Violin plots with medians of all data for L_{Aeq}, A-weighted, slow-response maximum sound level (L_{ASmax}), L_{AFmax}, and L_{Cpeak} of each saw are shown in Fig. 1.3. Log-transformed mean values for each saw category are reported in Table 1.2. Of particular note, the central tendencies for all metrics of the cordless circular saw are conspicuously higher than all other saws. Note that the cordless circular saw used a metal-cutting blade whereas all other saws used an abrasive cut-off wheel.

Table 1.2. Log-transformed means for each saw category used in the study and the log-transformed mean of all saw noise data combined.

Saw	Mean L_{Aeq} (dB)	Mean L_{ASmax} (dB)	Mean L_{AFmax} (dB)	Mean L_{Cpeak} (dB)
Chopsaw	106.3	107.1	108.3	118.9
Cordless Circular Saw	110.4	111.3	116.2	125.2
Cut-off Saw	105.9	106.6	107.5	118.3
Grinder	104.7	105.5	106.7	117.8
All Saw Data Combined	107.2	108.1	108.5	120.1

The length of time to cut specific stud sizes by saw type is reported for those that were evaluated during the study (Table 1.3). Time data for cutting track is reported separately in Table A1 of Appendix A, but is not a focus of this study and is not evaluated specifically. Due to the large number of stud/saw combinations and the inability to directly monitor every stud cut, as well as numerous other variables (e.g., cutting multiple studs at once), not all stud/saw combinations are reported. In general, per saw type: The means for the cordless circular saw and the cut-off saw were faster than the mean for all saws combined; the means for the chopsaw and the grinder were slower than the mean for all saws combined. On average, per general stud size: Larger dimensional studs took longer to cut than smaller dimensional studs, with the exception of 8-inch (203 mm) studs which were only cut with the cordless circular saw during the study period. For a specific comparison, using 6-inch 43 mil (152 mm, 1.088 mm) studs as an example, the mean time to cut this stud size with the chopsaw was 8.4 seconds and the mean time to cut this stud size with the cordless circular saw was 6.7 seconds. Similarly for 6-inch 54 mil studs (152 mm, 1.366 mm), the chopsaw took on average 28.9 seconds to cut a single stud whereas the cut-off saw took on average 8.7 seconds to cut the same stud size.

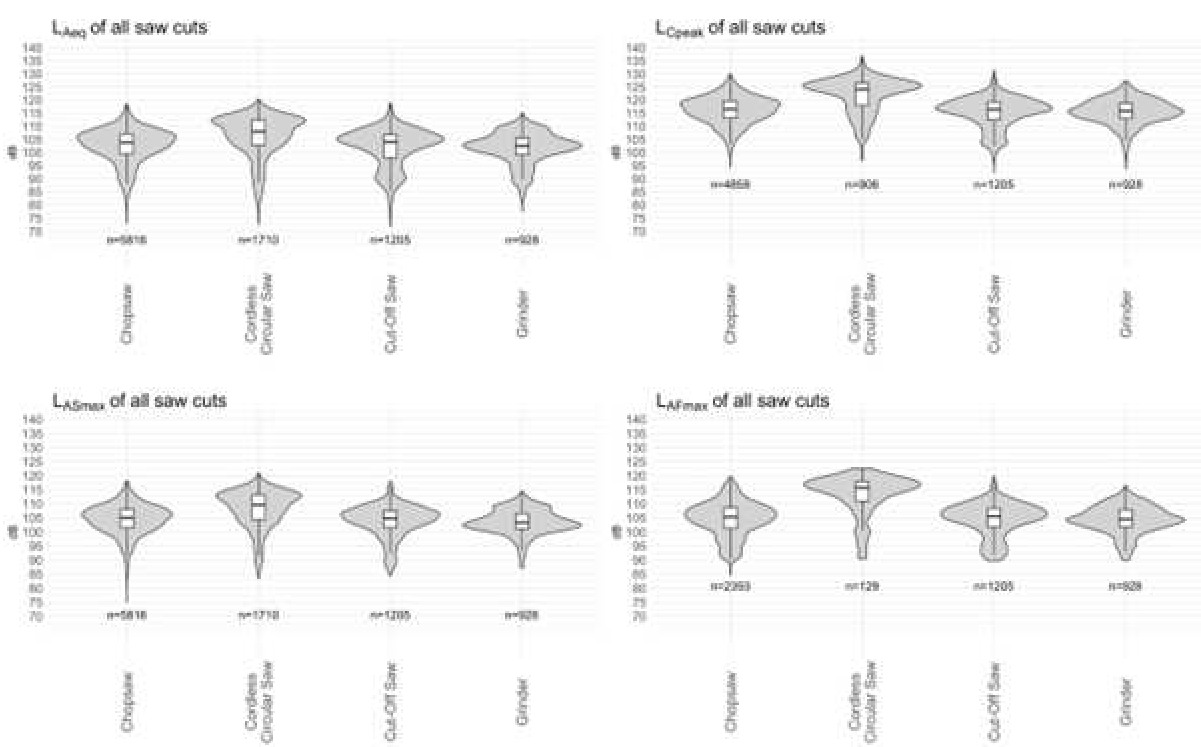

Fig. 1.3. Box plots of dosimetry metrics for each power saw found on each jobsite for the study. Data presented as: L_{Aeq} (A-weighting L_{eq}); L_{Cpeak} (C-weighting L_{peak}); L_{ASmax} (A-weighting, slow response L_{max}); L_{AFmax} (A-weighting, fast response L_{max}).

*Boxplots: Horizontal line = median, boxes = interquartile range (IQR), whiskers = 1.5*IQR. Each sample (n) = 1 second.*

Based on all data collected for this study, the chopsaw comprised 56.9% of total saw usage (Table 1.4). All other saws were used in ranges from 5.8 – 26.2% of the recorded time.

Discussion

Construction workers are well-documented to be exposed to excessive levels of noise in their work (Kerr et al., 2002; Lewkowski et al., 2018; Neitzel et al., 1999; Suter, 2002), and the noise produced when power saws are used to cut steel studs may be enough to cause occupational noise-induced hearing loss, especially in relation to the time it takes to cut each stud. The data presented in this study demonstrate that steel stud framers are exposed to hazardous levels of noise, with extensive L_{Aeq} recordings above 100 dB and numerous peak excursions above 120-dBC during their typical workday (Fig. 1.3). For illustrative purposes, the noise metrics and dB plot shape of a representative cut of a steel stud with a chopsaw, recorded in the field among background noise, is shown in Fig. 1.4.

Table 1.3. Cutting times (sec) to cut steel studs based on the web size and thickness of each stud, per saw type observed. Dimension = stud web measurement; N = sample size of the specific stud type/saw combination; SD = standard deviation; (-) = no event observed.

			Seconds to Cut One Stud at a Time				Seconds to Cut Two Studs at a Time			
Tool	**Dimension**	**Thickness**	**N**	**Mean**	**SD**	**Range**	**N**	**Mean**	**SD**	**Range**
Grinder	3.625 inch (92 mm)	54 mil (1.366 mm)	14	23.2	5.4	11.6-30.7	-	-	-	-
Chopsaw	3.625 inch (92 mm)	18 mil (0.454 mm)	3	4.5	1.9	2.5-6.4	5	5.8	2.7	3.4-10.2
Chopsaw	3.625 inch (92 mm)	33 mil (0.835 mm)	3	2.5	0.8	2.0-3.4	-	-	-	-
Chopsaw	6 inch (152 mm)	33 mil (0.835 mm)	13	9.7	3.5	4.5-18.0	-	-	-	-
Chopsaw	6 inch (152 mm)	43 mil (1.088 mm)	32	8.4	3.4	3.7-15.3	18	18.4	4.4	12.5-32.0
Chopsaw	6 inch (152 mm)	54 mil (1.366 mm)	14	28.9	11.3	11.0-45.0	1	82.2	0	82.2-82.2
Chopsaw	6 inch (152 mm)	97 mil (2.454 mm)	6	57.7	26.1	34.4-106.0	-	-	-	-
Chopsaw	8 inch (203 mm)	33 mil (0.835 mm)	12	11.0	4.3	6.5-22.1	6	15.9	2.8	13.4-21.0
Cordless Circular Saw	3.625 inch (92 mm)	30 mil (0.753 mm)	1	6.1	0	6.1-6.1	8	10.0	2.8	6.8-14.0
Cordless Circular Saw	3.625 inch (92 mm)	43 mil (1.088 mm)	-	-	-	-	8	10.3	2.2	6.5-13.0
Cordless Circular Saw	6 inch (152 mm)	30 mil (0.753 mm)	5	9.8	1.3	8.0-11.2	6	15.0	2.9	10.8-19.4
Cordless Circular Saw	6 inch (152 mm)	33 mil (0.835 mm)	2	7.5	6.3	3.1-12.0	-	-	-	-
Cordless Circular Saw	6 inch (152 mm)	43 mil (1.088 mm)	25	6.7	3.2	2.8-17.3	-	-	-	-
Cordless Circular Saw	8 inch (203 mm)	33 mil (0.835 mm)	1	5.0	0	5.0-5.0	-	-	-	-
Cordless Circular Saw	8 inch (203 mm)	43 mil (1.088 mm)	3	8.3	2.1	6.0-10.0	-	-	-	-
Cut-Off Saw	3.625 inch (92 mm)	54 mil (1.366 mm)	3	4.7	2.9	3.0-8.0	-	-	-	-
Cut-Off Saw	6 inch (152 mm)	54 mil (1.366 mm)	6	8.7	1.1	7.6-10.6	-	-	-	-
Cut-Off Saw	10 inch (254 mm)	54 mil (1.366 mm)	8	15.7	5.2	9.7-27.3	5	29.5	3.2	25.8-34.0

The noise metric data shown in Fig. 1.3 represents all 1-second dosimeter logs > 90 dBA from the time the saw operator pulled the saw trigger and initiated the cut, to the end of the cut when the saw trigger was released. This data recording included not only the noise level produced during the cut (~105 – 130 dBA), but also the noise level of the saw prior to or following contact with the stud when the blade/cut-off wheel was rotating but not touching the stud (~90 – 95 dBA). The saw itself produces a relatively continuous noise, but the contact of the blade/cut-off wheel with the stud creates a complex noise that likely contributes to high L_{Amax}

Table 1.4. For all sites that used power saws for cutting steel studs, the percentage of time each saw was used among all saws. Percentages are based off of number of studs cut that were documented with each saw during the study period.

Saw Used	Number of Cuts	Percentage
Chopsaw	389	56.9
Cordless Circular Saw	179	26.2
Cut-off Saw	76	11.1
Grinder	40	5.8
Total	684	100.0

and L_{Cpeak} dB as shown in Fig. 1.3. While this study does not attempt to understand the changes in physical properties of the saw blade/cut-off wheel or the metal of the stud during the cut, the stochastic frictional forces of the saw blade/cut-off wheel while in contact with the stud have been described as creating vibration of the blade/cut-off wheel against the sides of the kerf as the metal is being cut, which may contribute to numerous impact peaks while cutting (Tönshoff et al., 1981). As such, noise from cutting steel studs is classified as complex.

Of the four types of power saws found in use at the six study sites for this investigation, three have visually similar noise levels while cutting a generalized steel stud, and a fourth saw, the cordless circular saw, has conspicuously higher levels for all noise metrics (Fig. 1.3, Table

1.2). L_{Aeq} data in Fig. 1.3 show average sound energy received by the exposed worker, integrated over 1 second, and assuming continuous noise (PCB Piezotronics, 2013). The instantaneous peaks in noise energy that are captured by the L_{peak} detector in the dosimeter occur so briefly (in milliseconds) that they have little effect on an L_{eq} integration calculation, even with very high peaks such as 130 dB (Qiu et al., 2020; Zhang et al., 2022). L_{max} metrics overcome some limitations of L_{eq} calculations for complex noise by reporting the maximum levels of the noise during the measurement interval based on root-mean-square time weighting calculated from either slow detector (1.0 sec) response or fast detector (0.125 sec) response (NIOSH, 1998; PCB Piezotronics, 2013). The difference in this resolution is illustrated in Fig. 1.4 where all metrics for a single saw cut are plotted over each other.

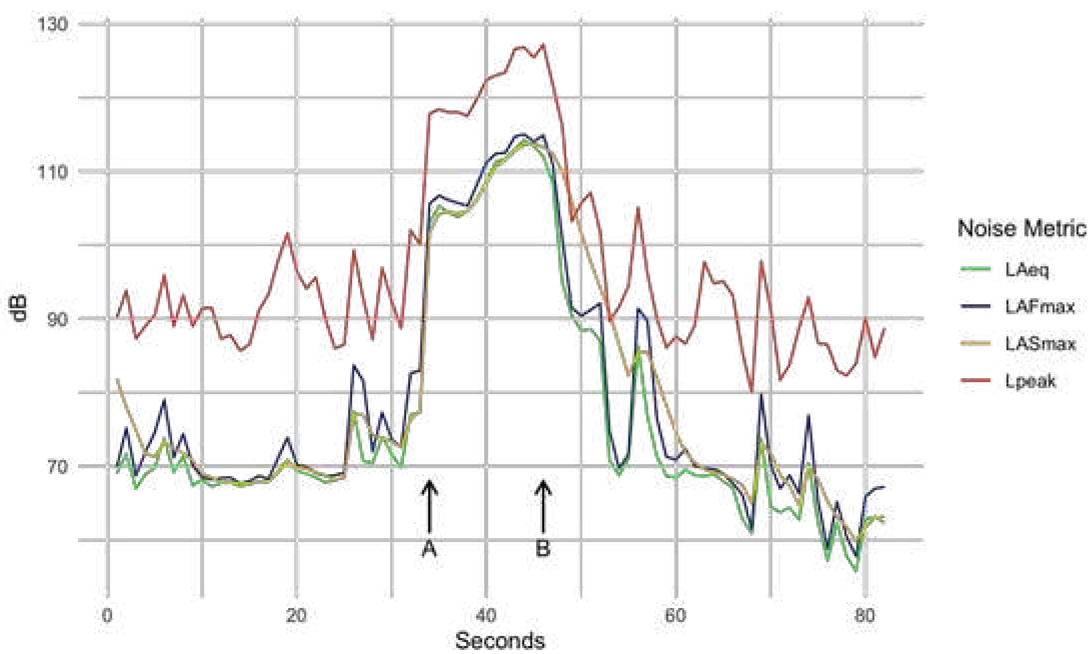

Fig. 1.4. Plot of noise metrics for a representative steel stud cut with a chopsaw, taken from a dosimeter log. Stud cut was a 6” 43 mil (152 mm, 1.088 mm) stud. Point A on the plot indicates the approximate time the saw was started and the cut initiated. Point B indicates the approximate time the cut was finished and the saw trigger was released, with the saw motor winding down afterward. L_{Aeq} = sound pressure level (SPL) equivalent with A frequency weighting; L_{AFmax} = A frequency-weighted, fast-response root-mean-squared (RMS) maximum SPL; L_{ASmax} = A frequency-weighted, slow-response RMS maximum SPL; L_{peak} is the instantaneous peak SPL with C frequency weighting.

While both slow and fast time weighting L_{max} calculations can account for peaks that are essentially ignored in L_{eq} calculations, of the methods currently available, logarithmic averaging of fast time-weighted data (0.125-sec resolution) may provide a more accurate and conservative assessment of noise exposure from complex noise from cutting steel studs, as demonstrated in Table 1.2 and Fig. 1.3, where $L_{AFmax} > L_{ASmax} > L_{Aeq}$. This progression is logical as more instantaneous peaks (as indicated in L_{Cpeak} data) are accounted for in faster-response time weighting calculations. This is especially important in exposures where higher noise levels, and impact/impulse noise in particular, have been shown to be more damaging to hearing structures than lower noise levels (Henderson & Hamernik, 1986; Neitzel et al., 1999; NIOSH, 1998; Xin et al., 2023; Zhang et al., 2021).

Using the violin plots in Fig. 1.3 as a visual example, the numerous L_{Cpeak} values above 120 – 130 dB in this study have the potential to cause lasting damage that is not accounted-for by L_{eq} calculations (Goley et al., 2011; Kelsall, 2006), nor are these damaging instantaneous exposures properly accounted-for by OSHA TWA PELs. Although the NIOSH TWA RELs do not directly account for complex noise that reaches high instantaneous L_{peak} levels, their recommendations are based on more conservative metrics that help offset the effects of short-duration, high intensity noise by using a 3-dB exchange rate and lower criterion level with a threshold that is far more protective than OSHA's controversial 5-dB exchange rate and 90 dB criterion level with 90 dB threshold (Kerr et al., 2002).

All four saw types observed in this study produced noise levels that could exceed a 100% REL dose over the course of a workday and be hazardous to a worker's hearing (NIOSH, 1998). While this characterization is not intended to compare or contrast the hazards of using each specific type of saw, Fig. 1.3 visually indicates that the cordless circular saw had higher noise levels than all other saws. Of note with this saw, it was the only saw to use a metal-cutting blade as opposed to an abrasive cut-off wheel (Table 1.1; Fig. 1.5). Because no sites in this study used the cordless circular saw with a cut-off wheel, it is unknown whether the higher noise levels of this saw are due to the blade, or to the saw itself. Interestingly, this saw also had generally faster cutting times of all saw types (Table 1.3). Again, it is unknown if the blade used with this saw contributed to the cutting speed, or if it was a factor of other variables such as saw power, saw geometry, or cutting style of the saw operators. It is worth noting that several workers anecdotally stated the cordless circular saw was the loudest saw they used on a jobsite, however they often chose it for its portability and ease of use. From a production standpoint, portability in a saw is an important factor, not only for general cutting tasks throughout the workday, but also

Fig. 1.5. Detail of the metal-cutting blade on the cordless circular saw.

for specific tasks that may be located far from the erected chopsaw stations at a large construction site. Portability at the expense of noise exposure needs to be carefully weighed, however, with other power saw options potentially providing a choice that is less hazardous to hearing.

Regarding saw usage, the chopsaw was used the most during the study by a wide margin at 56.9% of total number of studs cuts (Table 1.4). This trend could be attributed to personal preference, convenience, or availability of equipment at the study sites. While chopsaws are less portable than other saw options, they are dependable, consistent, inexpensive, and do not require a supply of batteries. They are also generally set up on a work table, and therefore provide a relatively better ergonomic cutting surface at a solid work station for less fatigue and higher convenience during multiple cuts (Das & Sengupta, 1996). As shown in Table 1.2, this widely-used saw has similar noise levels as the grinder and the cut-off saw, and therefore likewise presents hazardous levels of noise, with L_{AFmax} log-transformed means at 108.3 dB and L_{Cpeak} log-transformed means of 118.9 dB. For a framer with extended use of a chopsaw on a project, the worker is at severe risk for occupational noise-induced hearing loss from this heavily-used tool, with few quieter options available.

Stud cutting times are shown for all studs found on the study sites (Table 1.3). Due to the high variability in cutting times, comparing efficiency among saws for different stud types is challenging and would require additional investigations. It must be noted that there are too many combinations and variables to factor in each individual saw with each stud type for the scope of this paper. However, it was noted during observations of cutting tasks that the general length of time to cut any specific stud size appeared to vary by a number of factors, including the experience of the person operating the saw, the aggressiveness of the saw operator while making the cut, the attentiveness of the saw operator while making the cut, and the cutting style of the saw operator (e.g., pushing hard vs. bouncing vs. cutting slowly with pauses every few seconds).

Other physical variables of the blade/cut-off wheel or stud may cause variations in cut times, but are beyond the scope of this study.

As a case in point, one saw operator was observed making 8 identical, consecutive cuts using a chopsaw on a single 6" 54 mil (152 mm, 1.366 mm) stud. Each cut time ranged widely, from ~23-45 seconds, without any immediately discernible change in cutting technique. This leads one to believe there could be physical differences in the properties of the stud or the cut-off wheel, or subconscious changes in cutting style by the saw operator between cuts, or even fatigue of the saw operator. The wide variation in cut times in this study emphasizes the need for additional field-based research on construction tasks where variability can be high.

In reference to the cutting times displayed in Table 1.3, the cordless circular saw, while substantially louder than the other saws, had faster mean cutting times for the same stud size than other saws. This presents a question on whether a faster saw decreases the overall noise exposure by subjecting the worker to shorter-duration – but more intense – sound energy. Due to the logarithmic nature of dB values and the equal energy hypothesis, it should be noted that every 3 dB presents a doubling of noise energy, and therefore a doubling of noise exposure (NIOSH, 1998). Thus, if a saw cuts a stud exactly twice as fast, but is more than 3 dB louder, the shorter, louder cut may actually be more damaging to hearing. In this study, the cordless circular saw is on average >4 dB louder than all saws for all metrics (Table 1.2), so it would need to cut a stud >2x faster to offset the excess noise exposure. Based on stud cutting times presented in Table 1.3, the cordless circular saw cutting at >2x faster than other saws does not appear to be a trend, except in comparison with the grinder. Thus, in the instance of the cordless circular saw used in this study with a metal cutting blade that is louder than other saws, its increased speed at cutting does not generally decrease noise exposure, and conversely likely increases overall noise exposure in the user. Alternatively, the cut-off saw cuts studs faster than other saws in some instances with similar mean noise metrics (Tables 1.2 & 1.3). Thus, this saw has the potential to not only cut faster, but can decrease noise exposure in the saw operator when compared to using other saws. This presents a dilemma, however, in that increased production may lead to additional studs cut throughout the day, thereby adding to unintended additional noise exposure.

Although hearing protectors can be worn to reduce the effects of loud noise when other control methods are not feasible, and hearing protectors of various brands and styles were available to the workers at all study sites, some workers chose not to use any hearing protectors while using the saws. The nature of commercial framing work can make full-time use of hearing protectors challenging (Suter, 2002), where workers commonly must communicate with each other over long distances, such as yelling from a lift near a 30-ft (10-m) ceiling down to the saw operator at the floor level. To spend the time to insert foam ear plugs intermittently, which may take 20 seconds to insert properly, for a saw cut that takes only 10 seconds to complete, may be seen as an inconvenience by the worker. With a potential lack of education on the irreversible effects of noise-induce hearing loss, workers are oftentimes making the wrong decision and choosing speed or convenience at the expense of hearing.

The circular saw with metal cutting blade (Fig. 1.5), despite its high noise levels, presents an interesting case in that this blade type did not produce sparks during the cutting process at these study sites. This decrease in fire hazard therefore meant that a hot work permit was not required for use with this saw, where a permit may otherwise be mandated that specifies training for the operator and fire suppression equipment nearby (i.e., a fire extinguisher) to prevent a fire from the sparks produced by the cutting process (NFPA, 2024). In some instances, hot work permit requirements may not be able to be fulfilled, leaving the workers to rely on the louder equipment that does not produce sparks while cutting studs.

As noted above, workers stated that, at times, they preferred to use the cordless circular saw due to its portability, despite its increased noise levels. These anecdotes, combined with the noise data from the saws, suggest that the workers may prioritize production and convenience over noise exposure. Supervisors have stated that they provide occupational hazard education during pre-shift safety meetings, some of which were observed by the authors of this paper. However, the workers themselves continue to place insufficient priority on their own hearing protection. While production quotas are very common in commercial construction, the priorities the workers themselves have seemingly placed on production over noise exposure suggests that the workers may need additional or more targeted training to understand the irreversible effects of noise-induced hearing loss (Lusk et al., 1998; Neitzel et al., 2008; Seixas et al., 2011). Without understanding the permanent effects of hazardous noise exposure, workers will continue to place their hearing at risk while working to support themselves and their families. When combined with other sources of noise on a construction site, commercial framers are at a heightened risk of overexposure to noise and, subsequently, high potential for occupational noise-induced hearing loss.

Recommendations

Due to the complex nature of construction noise, and the inability of current exposure limits to fully account for impulse/impact noise exposure, continuing development of kurtosis adjustments to apply to complex noise exposures in construction may help decrease occupational noise-induced hearing loss (Qiu et al., 2020; Xin et al., 2023; Zhang et al., 2021; Zhang et al., 2022; Zhao et al., 2010). Kurtosis adjustment techniques, while still in preliminary stages of development, have the potential to take the hazards of instantaneous impulse/impact noise into account in regards to worker noise exposure (Goley et al., 2011; Hamernik et al., 2003; Qiu et al., 2013; Qiu et al., 2020). As such, the authors of this study encourage continued development of field-applicable kurtosis adjustments.

Although this study did not include saw purchase decisions in the investigation, understanding the reasons for particular saw purchases could help steer education and training plans for framing companies to help purchasers procure quieter, less hazardous power saws for their workers. By purchasing quieter tools and requesting quieter tools from manufacturers, increased demand can help drive innovation in quieter, less-hazardous tools and make them more available and at lower costs.

To help protect steel stud framers from occupational noise-induced hearing loss, targeted education and training is important to consider. Although pre-shift safety meetings address issues of jobsite hazards including noise exposure, workers continue to be non-compliant with hearing protector use. Safety and education programs need to target these non-compliant workers to help them understand the risks to their hearing.

The authors hope these data can be used to explore engineering controls to substantially reduce noise exposure in commercial framers. Ideally, these data can be used by power tool manufacturers to produce power tools that have lower noise levels which present less risk to hearing in commercial steel stud framers.

Conclusion

The data in this study demonstrate that power saws may vary in their noise level production and cutting efficiency while cutting steel studs on commercial construction sites. A common theme among all saws used in commercial framing is the high noise levels of the saws while cutting steel studs. Although the cordless circular saw has higher noise levels than all the other saws in this study, it must be emphasized that these data demonstrate that all saws observed at these study sites produced hazardous noise levels for the saw operator, exposures which likely contribute at least some component to occupational noise-induced hearing loss (Leensen & Dreschler, 2015; Neitzel et al., 1999; Suter, 2002).

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Chapter 2: Power tool effects on noise dose of steel stud framers on commercial construction sites

Summary

The construction industry is well-documented as having high sources of hazardous noise on the job. Framers who cut and install steel studs on commercial construction sites use numerous power tools throughout the course of their normal workday and have the potential to be exposed to levels of noise that can lead to occupational noise-induced hearing loss. This study assessed the noise dose of commercial steel stud framers and characterized the noise of various tools that lead to this high noise dose. Controversy exists, however, as to the level of protection offered by the Occupational Safety and Health Administration (OSHA)-mandated permissible exposure limit (PEL) versus the National Institute for Occupational Safety and Health (NIOSH) recommended exposure limit (REL) for noise exposure. This study demonstrates this difference, where the mean noise dose for the steel stud framers in the study had a mean PEL dose of 27.6% and a mean REL dose of 340.7% for the same workers, due strictly to differences in dose calculation criteria. As a comparison, ambient equivalent noise doses were 1.4% for PEL criteria and 12.4% for REL criteria. Of task assignments during the workday, workers who were assigned primarily as cut persons had significantly higher noise exposures than workers who were assigned as installers ($p = 0.016$). Octave band analysis was conducted for full-day exposures and indicated an upward trend of higher noise exposures at higher frequencies. Overall, among all steel stud framers involved in the study, all but two ($n=37$) had noise doses above the REL 100% dose (range 63.9 – 823.2%), indicating exposure to hazardous levels of noise during their normal workday.

Introduction

Excessive noise exposure is the leading cause of occupational hearing loss in most industries. Workers exposed to loud continuous and impulse noises throughout their work shift cause irreversible damage to the inner ear and subsequent noise-induced hearing loss. The construction industry, with its reliance on loud power tools as a primary part of most trades, is over-represented in regards to hearing loss from occupational noise (Hattis, 1998; Kerr et al., 2002; Neitzel et al., 1999; Neitzel et al., 2011). By the nature of cutting and modifying durable building materials, the tools that perform these tasks must be powerful enough to cut and fasten steel, concrete, wood and other robust materials. It has been a long-standing tradition, however, that powerful tools for these tasks must also be loud, even though loudness may not equate to power. While quiet tools for many tasks do exist, the industry and manufacturers have not yet embraced quiet tools, and these safer alternatives have not yet become prevalent. As such, powerful tools are still loud tools, requiring workers who use these tools to rely on personal protective equipment (PPE) such as foam ear plugs and other hearing protectors to protect their hearing. However, as the National Institute for Occupational Safety and Health (NIOSH) hierarchy of controls demonstrates, PPE is the least favorable method to prevent a worker exposure to any hazard, including noise (Meinke et al., 2022; Morris & Cannady, 2019). Instead of relying on PPE to be worn consistently and properly, other preferable methods of hazard mitigation should be implemented (Meinke et al., 2022; Neitzel et al., 2008), such as substituting a quieter tool or implementing engineering or administrative controls. The construction industry, however, has been slow to adopt hazard controls other than PPE for noise exposures (Lewkowski et al., 2018; Neitzel & Seixas, 2005). In an industry that now commonly has morning stretching exercises to reduce musculoskeletal injuries, it is unfortunate that hearing loss prevention has not become more prevalent.

In the construction industry in the United States, interior partition walls within buildings, and often exterior walls of smaller buildings, are typically constructed with framing members called "studs." For commercial buildings, these studs are comprised of steel, as is shown from one of the study sites in Fig. 2.1, as opposed to wood studs used in the U.S. residential building

Fig. 2.1. Typical commercial construction that uses steel stud framing. This photo is taken of one of the study sites.

industry. The steel studs used for commercial buildings allow for a more durable building material for heavier use in the commercial setting, and are also resistant to pests, fire, and water. Cutting these studs for installation is typically performed by the framer on site with a rotary saw, a pair of aviation snips, or a hydraulic cutter, depending on the thickness of the steel. Whereas cutting steel studs with snips or a hydraulic cutter make no noise above ambient, rotary saws of all forms produce SPLs high enough to be hazardous to hearing in a short period of time (see Chapter 1).

Exposure limits from various agencies exist to protect the workers' hearing. In construction, the Occupational Safety and Health Administration (OSHA) requires hearing protector use when the time-weighted average (TWA) of the shift exceeds 90 dBA using a 5-dB exchange rate and a 90-dBA threshold for their permissible exposure limit (PEL). Conversely, NIOSH has a more conservative and more protective recommended exposure limit (REL) of 85 dBA TWA using a 3-dB exchange rate and 80-dBA threshold. The difference between using a 3-dB or a 5-dB exchange rate leads to substantial differences in TWA noise doses, in addition to the 85 dBA vs. 90 dBA criterion level (Lusk et al., 1998; Seixas et al., 2001; Suter, 1992). Overall, by relying on the OSHA PEL as opposed to the NIOSH REL, employers and their workers are following the bare minimum requirement to minimize noise exposure, but numerous studies have shown the OSHA PEL is not protective enough to prevent occupational noise-induced hearing loss in construction workers which is estimated at 25% occurrence by following the OSHA PEL as opposed to an 8% rate of noise-induced hearing loss by using the NIOSH REL criteria (Bejan et al., 2011; Lusk et al., 1998; NIOSH, 1998).

Further, both the OSHA and NIOSH exposure limits were established for continuous noise, as opposed to impulsive or complex noise exposures. Commercial framers are exposed to both continuous noise as well as numerous impulse and impact noises during their workday (Kerr et al., 2002; Lusk et al., 1998; Qiu et al., 2020). Numerous studies have shown the damaging effects of impulse and impact noise on hearing loss (Henderson & Hamernik, 1986; Neitzel et al., 1999; NIOSH, 1998; Xin et al., 2023; Zhang et al., 2021), however there are currently no additional regulations nor recommendations to account for exposure to complex noise in the occupational setting.

Various studies on workers' noise exposures in the construction industry have shown the hazards of occupational exposure to various power tools and construction tasks (Kerr et al., 2002; Lewkowski et al., 2018; Neitzel et al., 1999; Suter, 2002). Various construction tools have been characterized with respect to sound energy production, and numerous studies have demonstrated the noise-induced hearing loss prevalent among construction workers. This study aims to add to the knowledge of construction worker noise exposure by 1) Describing the noise dose steel stud framers receive during a typical workday of cutting and installing steel studs, and 2) Characterizing the noise exposure of commercial framers from their daily tasks in relation to their daily noise dose. Characterizations are based on field data from active construction sites and noise exposures of experienced commercial framers using their normal day-to-day tools to complete their job tasks.

Materials and Methods

All sampling was performed on volunteers at opportunistically available commercial construction sites. Institutional Review Board approval was received prior to any recruitment. Volunteers with informed consent were recruited at active commercial construction sites. Only volunteers who were framing with steel studs as their primary job for the work shift were selected for the study.

Jobsite Characteristics

Jobsites where volunteers were recruited were commercial buildings under construction or renovation in Colorado. All sites were opportunistically selected based on availability. Sites were a combination of new-build projects and renovation projects of between 3,150 ft^2 (300 m^2) and 200,000 ft^2 (18,000 m^2) and from 1 to 5 stories tall. Volunteer participants spent the entirety of their work shift performing framing tasks with steel studs during the sampling periods.

Noise Dosimetry

Noise samples were obtained through personal dosimetry with one of two noise dosimeters (Larson-Davis Spark model 706RD and Larson-Davis Spartan model 730, Depew, NY, USA). The Spartan dosimeters were enabled with 1/1 octave band filters and 12-second event sound recording for 6 of the 10 study days. All dosimeters were set to record A-weighted equivalent continuous sound pressure level (L_{Aeq}) at the following settings for the virtual dosimeters in each device: (1) OSHA PEL criteria (90 dB criterion level, 90 dB threshold, 5-dB exchange rate, slow response), and (2) NIOSH REL criteria (85 dB criterion level, 80 dB threshold, 3-dB exchange rate, slow response). Peak sound pressure level data were recorded with C-frequency weighting (L_{Cpeak}). All data were integrated and logged at 1-second resolution. Dosimetry data were collected from the start of the work day until the end of the work day with lunch break data excluded. Morning and afternoon breaks were included in the calculations because this was considered part of the work day and breaks were taken within the active jobsite. Calibration of each dosimeter was performed before and after each sampling day using Larson-Davis CAL150/200 calibrators (Depew, NY, USA).

Dosimeters were attached to the participant's shoulder with the microphone near the participant's hearing zone (i.e., two-ft (0.61 m) diameter sphere surrounding the head). As framers typically carry framing components on their shoulder, the non-dominant shoulder was used to attach the dosimeter to avoid interference with the dosimeter microphone. Dosimetry data were downloaded via the dosimeter PC-based software (PCB Piezotronics G4 LD Utility for the Larson-Davis Spartan dosimeters, and PCB Piezotronics Blaze for the Larson-Davis Spark dosimeters, Depew, NY) and exported to spreadsheets for analysis.

Tool Usage and Noise Characterizations

Concurrent with dosimetry, the researchers observed and documented times and descriptions of the tasks being performed by each participant. These observational data were then used to compare with the dosimetry data log to develop a dB "signature" for tool use throughout the work day, i.e., the dB signatures were visually identified in the dosimetry time-stamped data.

All tools use was based on the workers' own power tools which they normally used on a jobsite. No modifications in a worker's daily routine or tool selection were performed for the purpose of this study to ensure normal working conditions were recorded. Tools were evaluated as generalized categories of tool type, not by manufacturer or age.

Saw Cuts

Operating durations and event counts were observed and recorded in a field notebook for types and sizes of steel studs that were cut. Length of cutting time was measured with a smart phone stopwatch (iPhone 14, Apple), with the stopwatch started when the worker pulled the saw trigger to start the saw, and the time stopped when the worker released the trigger at the end of each cut. Dosimeter data logs were reviewed and compared with both documentation from observed tool use times and dB "signatures" of the tool use which were clearly discernible from ambient noise in the dosimeter data logs. Saw cut dB levels were compiled into a spreadsheet based on all A-weighted fast response maximum sound level (L_{AFmax}) dBs >90 dB during the cut. The 90-dBA threshold was chosen to distinguish between the saw noise and background noise. Note that track framing components are included in all data, however due to their smaller total number of cuts and their similarity in dimensions to studs, for simplicity where this paper refers to cutting steel studs, the analysis also includes track components. Saws were categorized as "chopsaw," "cordless circular saw," "cut-off saw," and "grinder."

PAT Nailer

PAT nailer usage times were recorded in a field notebook using a smartphone clock synched with the dosimeter clock. When a worker fired a shot, the type of cartridge and the time of the shot was recorded and later compared and confirmed with the dosimeter log. For dosimeters that had event sound recording capability, the sound recording was also used to verify the PAT shot within the dosimeter data logs. Shots within the dosimeter data logs were easily discernible from the background noise due to high and instantaneous L_{peaks} ~138 dBC.

Impact Driver

The impact driver usage time was recorded in a field notebook using a smartphone clock synched with the dosimeter clock. For dosimeters that had event sound recording capability, the sound recording was used to pinpoint the impact drive use within the dosimeter data logs. Only instances of L_{Fmax} > 90 dBA were used for the study to ensure the impact driver noise was discernible from background noise. This dB threshold also coincided with louder noise the tool produced when the impact mechanism auto-engaged.

Ambient noise measurements

A dosimeter was set up at each site to record the ambient L_{eq}, L_{max} and L_{peak} at each study site as a TWA and an equivalent personal noise dose. The dosimeter was set to record at the start of the shift and continued running until the end of the work shift. Each ambient measurement dosimeter was placed on a tripod at ~5.0 ft (~1.5 m), approximately the height of the hearing zone, and was placed approximately 100 ft (35 m) from the saw.

Statistical Analysis

All data from the dosimeters were exported into Microsoft Excel (ver. 16.76) spreadsheets. Statistical analyses were performed using R Statistical Software (v. 4.3.1; R Core Team, 2023) with EnvStats package (Millard, 2013).

Means of all noise metrics, L_x, are calculated as log-transformed means as shown in Eq. 2.1, as described in International Organization for Standardization (ISO) 9612:2009.

$$L_{x(avg)} = 10log_{10}\left(\frac{1}{N}\sum_{i=1}^{N}10^{0.1L_{xi}}\right) \quad \text{(Eq. 2.1)}$$

where:

$L_{x(avg)}$ is the log-transformed mean of all L_{eq}, L_{max} or L_{peak} data for a specific saw

L_{xi} is the individual 1-second measured L_{eq}, L_{max} or L_{peak} for the event

i is the 1-second sample number

N is the total number of 1-second measurements

Pairwise t-testing was performed to compare the effect of task assignment on noise dose, as the data did not satisfy ANOVA homogeneity of variance (as tested with Levene's test). A significance level of 0.05 was used for all statistical tests.

Results

This study aimed to characterize the noise dose and associated common occupational noise exposures of commercial steel stud framers during their typical workday. Noise dosimetry samples were collected from a total of 40 workers at 6 different construction sites over 10 different workdays.

Exposure limit doses of all workers are reported in Fig. 2.2 with summary statistics of all worker exposure limits reported in Table 2.1. A conspicuous difference is visible between the

Table 2.1. Permissible exposure limit (PEL) and recommended exposure limit (REL) summary statistics for all framers in the study. Based on full-day work shifts.

	Mean Dose (%)	Dose SD	Dose Range (%)	TWA (dBA)
PEL Dose	27.6	13.1	5.8 – 61.4	80.0
REL Dose	340.7	212.9	63.9 – 823.2	89.6

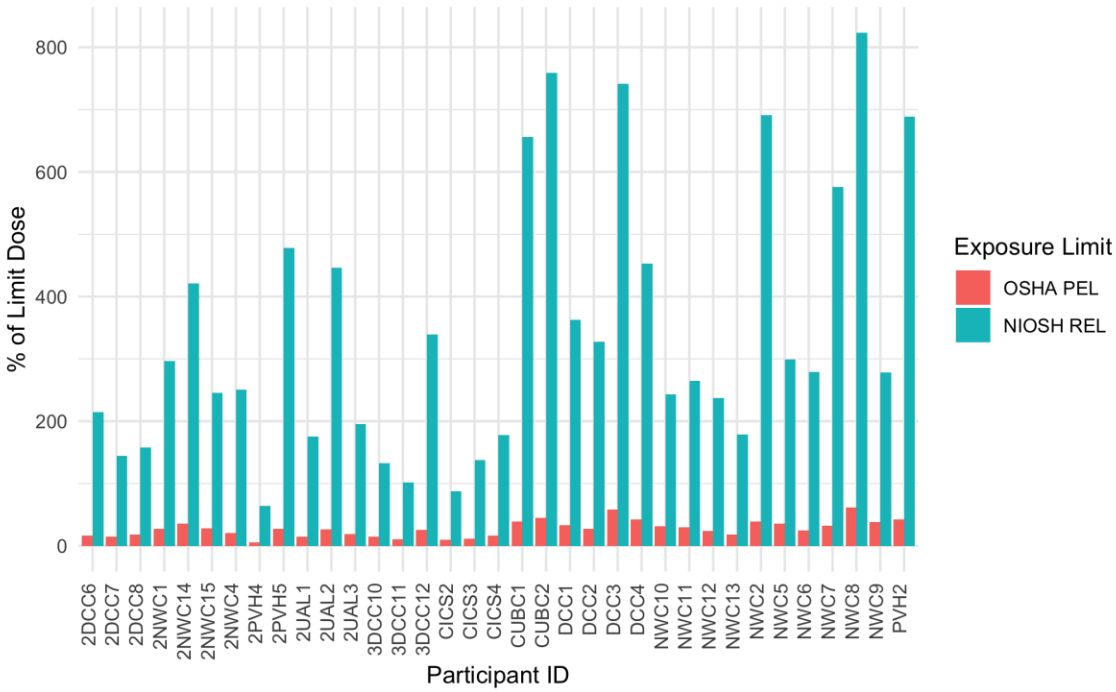

Fig. 2.2. Dose percentage of each framer, for NIOSH Recommended Exposure limit (REL) and OSHA permissible exposure limit (PEL). Shown for each worker that participated in the study.

OSHA PEL and the NIOSH REL doses for the workers. Overall, the mean PEL dose for all workers (excluding supervisors) was 27.6% (range 5.8% to 61.4%), whereas the mean REL dose was 340.7% (range 63.9% to 823.2%). The equivalent mean PEL TWA for all workers was 80.0 dBA and the mean REL TWA was 89.6 dBA. For comparison, the ambient mean OSHA PEL TWA for all study sites was 48.5 dBA (equivalent PEL dose = 1.4%) and mean NIOSH REL TWA was 71.5 dBA (equivalent REL dose = 12.4%; Table 2.2).

Breaking down exposures by assignment (ad hoc, cut person, installer, supervisor), Fig. 2.3 shows box plots for each work assignment with the ambient dose equivalent included for comparison. Overall, for assignment dose medians, cut person > ad hoc > installer > supervisor. Cut person assignment had the widest dose range of all tasks, with a PEL range from 14.5 – 61.4% dose (SD = 14.7) and REL range from 175.6 – 823.2% dose (SD = 236.5). Supervisors

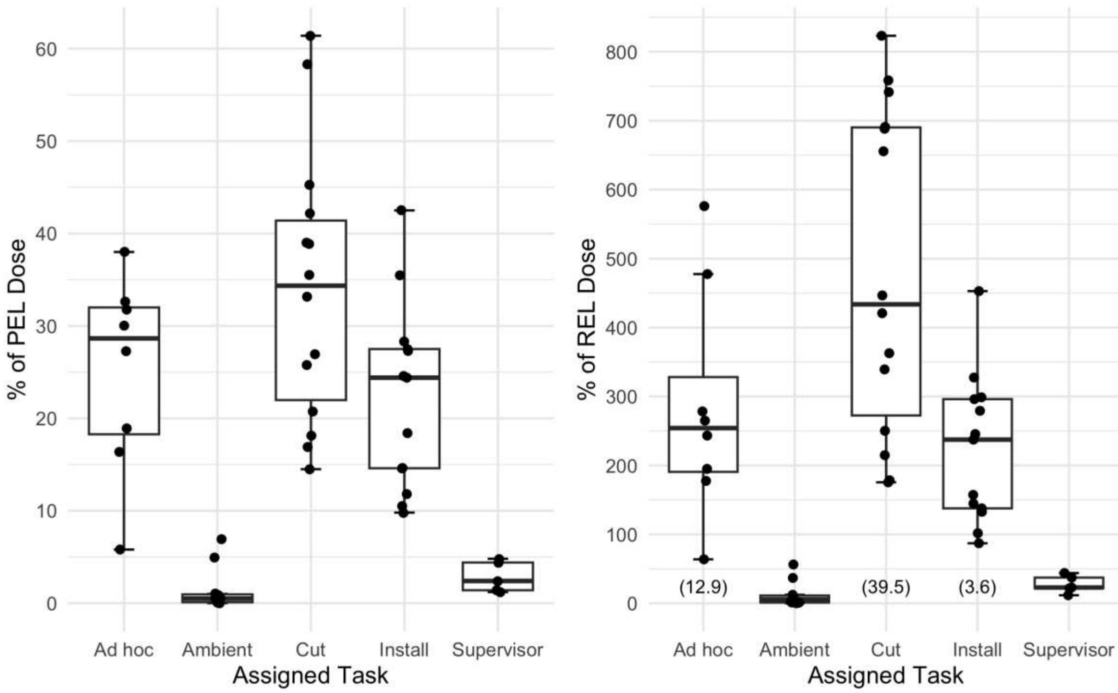

Fig. 2.3. Percent of permissible exposure limit (PEL) and recommended exposure limit (REL) dose for each worker task assignment, plus supervisor and ambient for comparison. Number in ( ) indicates mean number of saw cuts for that task assignment. Boxplot Horizontal line = median, boxes = interquartile range (IQR), whiskers = 1.5*IQR.

had the narrowest range and had no statistically meaningful difference in means to ambient ($p = 0.81$), which corresponds well with their duties that placed them away from direct use of power tools. Paired samples t-test results show that, among framing task assignments (cut, install, ad hoc), there was a statistically significant difference in noise dose only between cut and install tasks ($p = 0.016$; Fig. 2.4 and Table 2.3).

Table 2.2. Ambient time-weighted average (TWA) summary statistics based on permissible exposure limit (PEL) criteria and recommended exposure limit (REL) criteria. Ambient area monitoring was sampled during full-day work shifts with a noise dosimeter.

	Mean (dBA)	Mean dose equivalent (%)	Range (dBA)
Ambient TWA (PEL)	48.5	1.4	<40 – 71.3
Ambient TWA (REL)	71.5	12.4	56.8 – 82.8

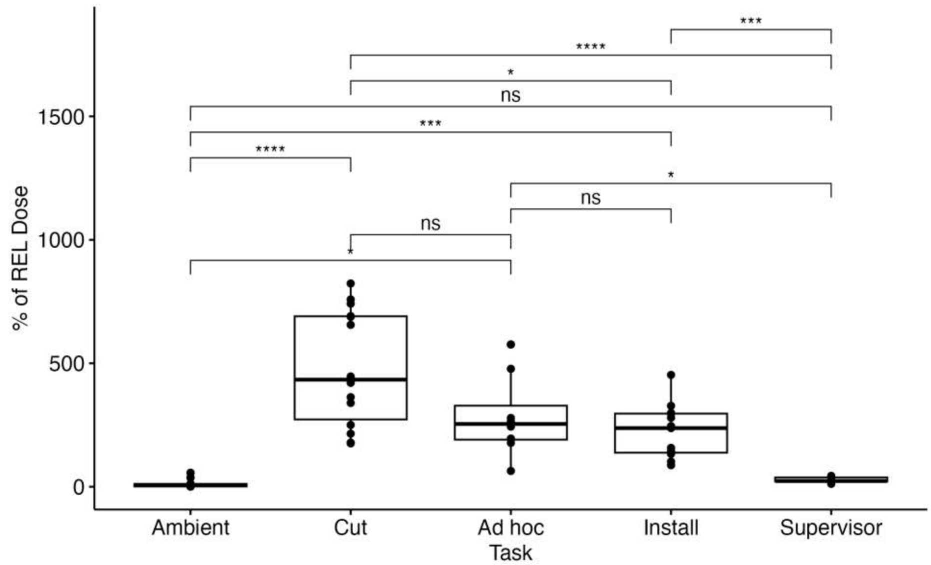

Fig. 2.4. Significance levels of pairwise t-test comparisons of REL dose by work task assignment. A significance level of 0.05 is used; p-value adjustment with Bonferroni correction.

For tool characterizations from the workers' standpoint (i.e., noise data collected from a dosimeter placed on the worker's shoulder in the hearing zone), see Fig. 2.5 for violin plots of metrics for all commonly-used power tools on the study sites. Of note are high median L_{Cpeaks} for PAT nailers, which have short duration impulsive sound. All tools in general have high median

Table 2.3. Pairwise t-test results for comparisons between tasks and recommended exposure limit (REL) noise dose. p.adj = Bonferroni correction.

y	group1	group2	n1	n2	statistic	df	p	p.adj	p.adj.signif
REL Dose	Ad hoc	Ambient	8	11	4.62290025	7.11938250	0.002	0.023	*
REL Dose	Ad hoc	Cut	8	14	-2.28800806	18.94527850	0.034	0.338	ns
REL Dose	Ad hoc	Install	8	13	0.93700753	10.64564525	0.37	1	ns
REL Dose	Ad hoc	Supervisor	8	5	4.36170638	7.13529260	0.003	0.032	*
REL Dose	Ambient	Cut	11	14	-7.40069650	13.19034857	4.76E-06	4.76E-05	****
REL Dose	Ambient	Install	11	13	-6.97533354	12.79263635	1.06E-05	0.000106	***
REL Dose	Ambient	Supervisor	11	5	-1.92434987	10.78249556	0.081	0.811	ns
REL Dose	Cut	Install	14	13	3.70641095	18.40492163	0.002	0.016	*
REL Dose	Cut	Supervisor	14	5	7.15700451	13.21497166	6.75E-06	6.75E-05	****
REL Dose	Install	Supervisor	13	5	6.45658026	12.86900629	2.25E-05	0.000225	***

L_{AFmax} values, with the saws, the PAT nailer and the reciprocating saw visually standing out with higher medians than the others. Whereas all of the power saws have hazardous levels of noise from L_{AFmax}, the cordless power saw stands out visually as among the highest of all saws used (Fig. 2.5).

Table 2.4. L_{Aeq} and L_{Cpeak} exceedance ranges. Mean instances of samples where the worker was exposed to noise exceeding the range of noise levels. Each mean value is the mean number of seconds (L_{Aeq}) or samples (L_{Cpeak}) that were logged within the defined range. Based off of 28,800 sec/workday (8-hour day). L_{Aeq} = dBA; L_{Cpeak} = dBC. (-) = <0.1%.

Statistic	<90 dB	90 to 95 dB	95 to 100 dB	100 to 105 dB	105 to 110 dB	110 to 115 dB	115 to 120 dB	120 to 125 dB	125 to 130 dB	130 to 135 dB	135 to 140 dB	140 to 145 dB	145 to 150 dB	> 150 dB
Mean L_{Cpeak} (# of occurrences)	19143 (66.5%)	6092 (21.2%)	3914 (13.6%)	2072 (7.2%)	1241 (4.3%)	735 (2.6%)	449 (1.6%)	220 (0.8%)	92 (0.3%)	28 (0.1%)	13 -	8 -	6 -	1.3 -
Mean L_{Aeq} (sec)	27780 (96.6%)	1147 (4.0%)	567 (2.0%)	292 (1.0%)	147 (0.5%)	49 (0.2%)	13 -	3 -	0 -	0 -	0 -	0 -	0 -	0 -

Fig. 2.5. Noise metrics for each tool used by the workers in the study. Sample size indicates number of 1-second samples the dosimeter recorded for each tool. For boxplots: Horizontal line = median, boxes = interquartile range (IQR), whiskers = 1.5*IQR.

Octave band analysis for full-shift dosimetry is shown in Fig. 2.6. Overall, there is an upward trend of exposure for higher frequencies than lower frequencies, with an isolated peak at 500 Hz.

Mean exposures for 5-dB ranges of worker L_{Aeq} and L_{Cpeak} are shown in Table 2.4 based on 28,800 seconds for a typical 8-hour workday. For L_{Aeq} data, the workers spent on average 7.7% of their day at L_{Aeq} >90 dB, 3.7% of their day at L_{Aeq} >95 dB, 1.7% of their day at L_{Aeq} >100 dB, and 0.7% of their day at L_{Aeq} >105 dB, with small percentages at L_{Aeq} up to 125 dB. LCpeak data show 51.6% of all recorded 1-second noise intervals having L_{Cpeaks} >90 dB, with decreasing numbers of events as L_{Cpeak} dBs increase. Of note, there were on average ~368 L_{Cpeak} events >120 dB per worker, and on average ~148 events >125 dB per worker.

Discussion

A large discrepancy exists between the OSHA mandated PEL and the NIOSH suggested REL for noise exposure in construction. Where the NIOSH REL is based on scientific evidence that provides more protective guidance toward worker hearing conservation (NIOSH, 1998), the OSHA PEL uses an antiquated formula that assumes – but does not assure – that construction workers will recover from noise exposure throughout their workday due to the intermittency of their type of work (Seixas et al., 2005; Suter, 1992). The noise doses the commercial steel stud framers received during a typical day of work, according to the more-protective NIOSH REL, ranged from 63.9% to 823.2% dose, with a mean dose of 340.7%. This compares sharply with the OSHA PEL dose for the same workers which ranged from 5.8% to 61.4% with a mean dose of 27.6%. None of the workers exceeded the OSHA PEL, however all but two of the workers exceeded the NIOSH REL.

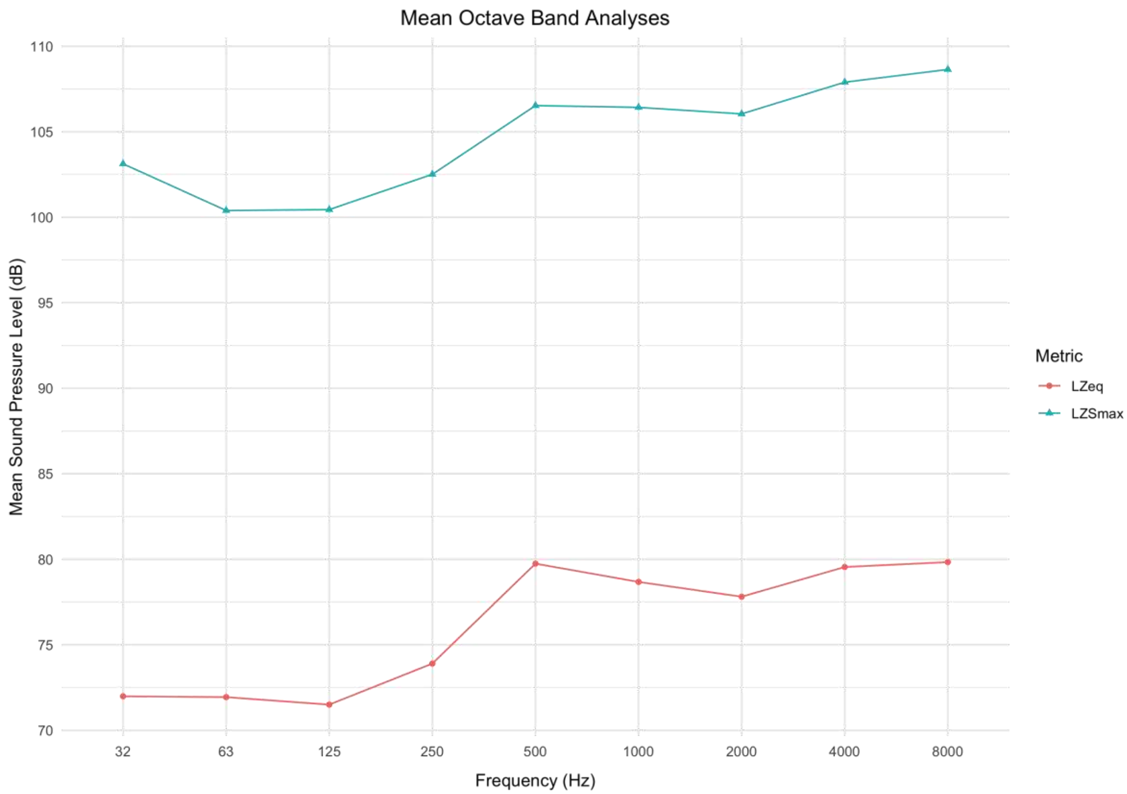

Fig. 2.6. Octave band spectra for L_{Zeq} and L_{ZSmax} for average full-day shifts. Mean is compiled of all workers who wore a dosimeter with an octave band filter for the day (n=19).

This greater than 12-fold difference in average noise dose between OSHA and NIOSH limits is striking, and is attributed to the differences in TWA calculation criteria between the two agencies. OSHA's 5-dB exchange rate has attracted criticism for decades (NIOSH, 1998; Seixas et al., 2001), especially in regards to construction noise exposures. OSHA allows a less-protective 90-dB criterion level with 90-dB threshold vs. NIOSH's recommended 85-dB criterion level with 80-dB threshold. This difference allows OSHA calculations to completely ignore any sound energy below 90 dBA, a hazardous allowance in which chronic sound energy between 80 – 90 dB has been shown to be metabolically damaging to the hearing structures of the inner ear, especially in the presence of impulse/impact noise (Eggermont, 2017; NIOSH, 1998; Qiu et al., 2020). NIOSH's criteria for noise exposure calculations takes these lower-level noise hazards into account to further reduce chronic occupational noise exposures.

One of the biggest issues regarding the noise doses these workers receive, for both NIOSH and OSHA, is accounting for the increased hazards of complex noise. Complex noise has components of both continuous (or steady) noise, and also impulsive noise, which is comprised of instantaneous high energy noise peaks under one second in duration. This impulsive noise is often on the order of milliseconds, with SPLs that can reach 130 – 140 dB or more. In contrast to chronic mid-level noise exposure that causes metabolic damage to hearing structures of the inner ear, impulse/impact noise can cause mechanical damage to the cochlea which can lead to noise-induced hearing loss above what is expected based on the equal energy hypothesis (Lataye & Campo, 1996; Seixas et al., 2005).

Because these impulsive noises are on the order of milliseconds, they have little effect on integrated L_{eq} calculations, and as such are not well accounted-for by occupational noise standards (Qiu et al., 2020; Seixas et al., 2005; Zhao et al., 2010). NIOSH recommendations are much more conservative and protective than OSHA standards, and although don't directly take complex noise into account in their calculations, may indirectly account for these noises through more conservative criteria (NIOSH, 1998; Suter, 2017). While other methods have been investigated to attempt to include impulsive noise exposure in occupational settings, so far kurtosis adjustments show the most promise (Qiu et al., 2020; Zhang et al., 2022; Zhao et al., 2010). The kurtosis adjustments take the outlying high energy impulsive noises into account and add a dB penalty to the L_{eq}, thereby accounting for the harmful effects of complex noise. While kurtosis adjustments are still years from implementation, other methods need to be adopted in the meantime to protect workers' hearing who are exposed to high level impulsive noise during their daily work. One such option can be a fixed dB penalty added to the TWA based on L_{peak} and/or L_{Fmax} exposures, as was part of past ISO standards, but were later removed without comment (Qiu et al., 2020; Suter, 2017).

OSHA's PEL for construction is less protective than the PEL for general industry, specified as such due to the intermittent nature of construction noise exposure. While there is some evidence of hearing recovery from intermittent noise exposure (Seixas et al., 2005; Suter, 2017), actual protective effects and lower rates of hearing damage are unknown and dubious (Qiu et al., 2020; Suter, 1992; Suter, 2017), potentially leading to higher rates of hearing loss in construction workers due to unsuspected overexposure. Many studies demonstrate the high rates of hearing loss in construction workers (Greenspan et al., 1995; Kenney & Ayer, 1975; Kerr et al., 2002; Neitzel et al., 1999; Suter, 2002), and reliance on an undemonstrated recovery from intermittent high energy noise exposures is putting risk of unnecessary hearing loss to millions of construction workers every year.

The noise dose of the framers in this study came from a number of powerful and loud power tools they use to cut and install steel studs as the primary part of their job. As shown in Fig. 2.5 which lists all of the tools evaluated for this exposure characterization, tools include power saws, impact drivers, hammer drills, powder-actuated nailguns, screwguns, and rotary cut-off saws. Many of these power tools are commonly known to be loud, however there are very few alternative quiet options available for framing work and framers are left to rely solely on hearing protectors to protect their hearing. Of the tools evaluated for this study, a few stand out as particularly loud (Fig. 2.5), notably the power saws which are characterized in Chapter 1, and the PAT nailers. Currently, few options are available to reduce noise exposures while cutting steel studs, two examples being hydraulic cutters and hand-held aviation snips, both of which have severe limitations to daily use. Some PAT manufacturers state they offer quieter or noise-suppressed tools, however none of the manufacturers list noise metric data on their site, nor do they appear to be independently evaluated for noise reduction as of the time of this writing.

Table 2.5. Usage time of common tools (in sec) for all workers who used the given tool during their workday. PAT = powder-actuated tool.

	Mean	SD	Min	Max
Saw cuts	371.5	323.4	8	1105
PAT nailer	36.7	32.1	7	114
Impact Driver	206	7.5	37	439

Of the tools listed in Fig. 2.5, the most commonly-used tools by the workers in this study were the power saws, the impact driver, and the PAT nailer, based on number of seconds per tool used, per worker, per day (Table 2.5). The saws and the PAT nailer stand out as some of the loudest tools used by the workers, as is noted in Fig. 2.5. Due to the complex noise produced by the saw, and the impulse noise in particular produced by the PAT nailer, L_{eq} underestimates the noise exposure from these tools, as is demonstrated in high L_{AFmax} and L_{Cpeak} data.

The PAT nailer is unique in that there are different strengths of powder cartridges that can be used with the tool. For this study, the workers used only the red and yellow powder cartridges. The yellow powder cartridge is designed primarily to shoot fasteners into solid concrete. The red powder cartridge is a more powerful cartridge designed primarily to shoot nails through steel beams or into hardened concrete. Additionally, an extension pole can be used with the PAT nailer to reach ceilings for rapid installation of hangers without the need for a ladder or lift. The PAT with extension pole used by workers in this study used an adjustable length extension pole to shoot nails into a 12-ft (3.6m) high ceiling which was ~7 ft (2.1m) from the workers' hearing zone. For this study, the PAT with extension pole was used only with yellow powder cartridges. Fig. 2.5 shows the noise metrics for the PAT nailer for each cartridge type. Unexpectedly, the yellow and red powder cartridges had similar medians for each noise metric, but the yellow cartridge had a smaller spread of data (SD of red cartridge = 8.3; SD of yellow cartridge = 3.8; SD of PAT with extension pole = 6.9). One limitation to these data is the large number of confounders with respect to the PAT nailer. Because the PAT nailer requires two hands to use and also requires significant inline force to be applied to the tool to overcome its safety mechanism, use of the tool often required various body contortions which may have caused the worker to unintentionally cover the dosimeter microphone. Other confounders included the inability to discern which of two side-by-side workers fired a PAT, and whether the PAT was fired on the dosimeter side of the body or the opposite side of the body, affecting the impulsive sound energy reaching the microphone.

The impact driver is a ubiquitous tool among steel stud framers, and is used for every screw that is driven into a steel stud. The impact driver looks similar to an electric drill or screwgun, but gets its name from a rotational impacting mechanism in the tool that ensures a higher torque is applied to the fastener. The mechanism produces an impact sound each time it engages within the tool, and as such produces several impact sounds each time a fastener is driven into a stud. As the tool is typically used in close proximity to the operator's hearing zone, a framer can be exposed to hundreds of these impact noises each day. Fig. 2.5 summarizes impact driver noise from the workers in the study. This estimation is likely an underestimation as each instance of use was not necessarily recorded by the dosimeter due to latent intervals between event sound recordings. While the median L_{Aeq} was one of the lowest among the power tools used by the workers in the study (median = 94.0 dB, log-transformed mean 98.5 dB), it had extensive use (mean = 206 sec, range = 37 – 439 sec; Table 2.5). This use combined with hazardous L_{Aeq}, and concerning L_{Cpeak} (median = 111.4 dB, log-transformed mean 117.6 dB) exposures adds an accumulative source of concerning noise exposure that increases the REL dose among this population of construction workers.

Saws used to cut steel studs are loud and have relatively high noise levels, in particular while the rotating blade is in contact with the steel stud. The noise produced during the cut is described as complex due to the blade vibrations against the kerf causing high L_{peak} dBs. This noise exposure is noticeable in Fig. 2.3 which compares the PEL and REL dose for various task assignments of commercial framers. As installers are often confined to a scissor or boom lift and do not have access to power saws during much of their workday, post-hoc testing demonstrates they have significantly lower mean noise doses throughout the day ($p = 0.016$; Fig. 2.4). Alternatively, cut persons have higher median and mean noise doses, and a much wider range of noise exposure that reaches over 800% of the NIOSH REL dose. Ad hoc assignments vary for each workday, and as such, ad hoc workers may not use a saw as much as an assigned cut person who is expected to use a saw throughout the course of an entire day. The number of cuts each worker made per day based off of task assignment is presented in Fig. 2.3. The average number of studs a cut person cut was 39.5 per day, and the average number of studs an installer cut was 3.6 studs per day. Mean REL doses of 495.3% for the cut person and 270.9% for the installer indicate that noise exposure from other sources adds to the overall noise dose of the workers beyond saw noise alone.

With a mean cutting time of 428.0 sec per day (range 13.0 – 1105.0 sec), saw noise can add a substantial component to noise exposure, in particular where log-transformed mean L_{eq} values at the hearing zone range from 104.7 – 110.4 dBA. However, as is also seen in the high REL doses of installers that average ~9% as many cuts as cut persons, saw noise is clearly not the only hazardous noise source of these workers.

As such, a combination of various sounds from various other power tools used in much smaller amounts throughout the workday are likely adding enough noise to the workers' noise doses to increase the REL. Many of these tools were used in various small amounts throughout the framer's workday, as can be seen in the sample sizes in Fig. 2.5. All produce L_{eq} values with medians above 90 dB, with L_{peak} levels in some instances exceeding 130 dBC. While some of these tools are used in lesser amounts than the saws and the impact driver, they likely collectively contribute considerable amounts of sound energy to workers' daily exposures.

As indicated by high L_{AFmax} values in Fig. 2.5, the complex nature of the noise produced by many of these power tools includes impact/impulse components along with the continuous noise produced by numerous power tools in use around each worker. This complex noise has been shown in animal and human studies to be more hazardous to hearing than continuous noise exposure alone at the same sound pressure level (Hamernik et al., 2003; Zhao et al., 2010). Where continuous noise at lower, repeated exposures causes metabolic damage to the hearing structures of the ear, impulse/impact noise can cause physical damage to the cochlea from high level bursts of sound energy (Attias et al., 2004; Le et al., 2017). This is where caution must be used when interpreting L_{eq} vs. L_{max} vs. L_{peak} exposures in construction. The stochastic nature of construction noise makes interpretation difficult, and even further makes the OSHA PEL underestimate noise exposure in construction workers, even despite a possible, though unproven, recovery from intermittent noise exposures.

Octave band analysis indicates that for all framers who participated in the study, there is a trend of higher noise exposure toward higher frequencies. Considering that these workers are working with light gauge metal, a trend toward higher frequencies coincides with previous studies that show metal fabrication work commonly produces high noise energy in the higher frequencies of human hearing (Dabirian et al., 2020; Kenney & Ayer, 1975; Reinhold et al., 2014). This octave band trend is especially important to consider for exposure in the 1000 – 4000 Hz range where overexposure can cause noise-induced hearing loss in the essential range of human voice communication, and also highlights the need to ensure hearing protectors for commercial framers adequately attenuate noise in the higher frequencies (Neitzel & Seixas, 2005; Reinhold et al., 2014; Suter, 2002). The cause of the peak at 500 Hz (Fig. 2.6) is unknown and further investigations are needed to understand the source of this peak.

As Fig. 2.7 and Table 2.4 show, the percentage of the workday this population was exposed to hazardous levels of noise is worrisome. Due to the exponential nature of L_{eq} dBs, the higher ranges of these exposure are the most concerning, despite proportionately small instances

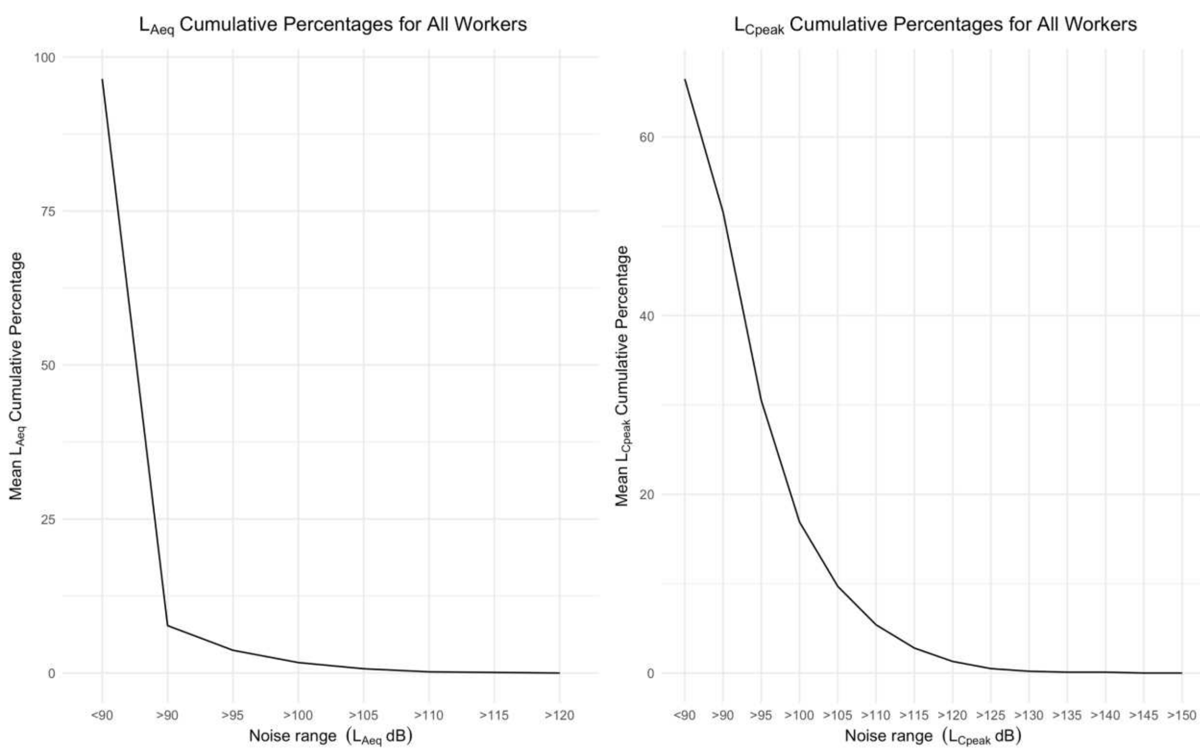

Fig. 2.7. Exceedance plots for mean L_{Aeq} and L_{Cpeak} exposures for all workers in the study, indicating the percentage of time a worker was exposed above each noise level during their workday. Based on 28,800 samples (seconds) per 8-hour workday.

of exposures. Taking the middle of the 100 – 105 dBA range at 102.5 dBA, the NIOSH REL allows for 8.4 minutes of exposure. Likewise, taking the mean of the 105 – 110 dBA range at 107.5, the NIOSH REL allows for only 2.6 minutes of exposure. As Table 2.4 shows, the L_{eq} mean for the workers was 4.9 minutes (292 sec) in the 100 – 105 dBA range, and 2.4 minutes (146 sec) in the 105 – 110 dBA range. Based on the NIOSH recommended limits, the mean time in the 105 – 110 dBA range from this study nearly meets 100% of the REL dose based on those 2.4 minutes alone. Add to that the 57% of the REL met within the 100 – 105 dBA range, and these high energy exposures indicate a strong likelihood for noise-induced hearing loss on the job in just a small part of the day. Add in exposures from the rest of the day and the high REL doses are not surprising.

As expected, L_{Cpeak} values reach higher dB than L_{Aeq} dB values, and likewise the mean number of these peaks are concerning. With 10% of all samples for the average workday having impact noise >105 dBC, and ~367 peaks >120 dBC per day, the impulse/impact exposure needs to be strongly considered in the overall exposures of this population. Because impulse/impact noise has been shown to be more damaging to hearing, and because higher dB noise has also been shown to be more damaging to hearing (Henderson & Hamernik, 1986; Neitzel et al., 1999; NIOSH, 1998), these workers are receiving numerous high-energy assaults on the ears every day, putting them at greater risk for occupational noise-induced hearing loss. Furthermore, these L_{peak} data are only showing the highest instance of an impulse/impact noise per sample second, and does not account for multiple impulse/impact sounds that occur during the same second but may be lower dB, thereby likely underestimating the true number of impact/impulse noises the workers are exposed to each day. Even if there is some evidence of recovery from intermittent noise exposure, the mean exposures in the higher dB ranges are enough to be concerned with noise-induced hearing loss in a short period of time in this occupation.

Construction workers in general are exposed to hazardous noise from the power tools they use to cut and install building components during the construction of a building, and commercial steel stud framers are no exception. Although the workers in this study all remained within the limits of the OSHA PEL during their workday, all workers except two far exceeded the NIOSH REL, a recommendation based on more protective limits and lower acceptable rates of occupational noise-induced hearing loss. Of particular concern are the power saws, the PAT nailers, and the impact drivers the framers use on a daily basis. Even more, as is shown in the difference between cutting and installing assignments, numerous other noises are present in the occupation far above the ambient noise of the construction site that produce hazardous noise to the steel stud framer. These noises may come from repeated use of impact drivers, use of other power tools throughout the day such as hammer drills, and other uncharacterized noise such as banging on metal studs with a hammer. Limitations of this investigation include small sample sizes and the inability to fully characterize all noise exposures including all instances of impact driver use, and non-power tool noise such as striking steel studs with a hammer. To protect the hearing of this population of workers, further research should be conducted that includes larger sample sizes and further characterizes all noise exposures among assignment groups. Additionally, sampling worksites that are not using power saws, such as sites that can cut light-gauge studs with snips, or are using a hydraulic cutter, can help estimate noise exposure in the absence of power saws.

Conclusion

Commercial framers who cut and install steel studs as their primary task may be exposed to hazardous levels of noise during their workday, according to NIOSH recommended exposure limits. Conversely, less-protective OSHA permissible exposure limits show that these same workers are below allowable limits, however numerous studies show that the OSHA noise PEL is under-protecting construction workers. This is demonstrated in other studies that indicate construction workers have high rates of hearing loss. Of particular concern are exposures to noise from power saws used to cut steel studs, the PAT nailer used to fasten framing components, the impact driver used to drive screws into steel studs, along with numerous other power tools that cumulatively add to the REL dose, but are used in smaller percentages by this population of workers during the course of their normal workday. Although this investigation is targeted at commercial steel stud framers, these findings can likely be applied to other construction trades as well, such as mechanical system installers, electricians, and framers in residential construction.

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Chapter 3: Task limit recommendations to decrease noise exposure in commercial steel stud framers

Summary

Commercial framers who work primarily with steel studs during the construction of buildings are exposed to hazardous levels of noise on the job, and are at risk of occupational noise-induced hearing loss. This paper provides recommended limits to common commercial framing tasks based on estimated tool operating durations and estimated tool A-weighted equivalent continuous sound pressure level (L_{Aeq}) means. For generalized cutting of steel studs using common saws, the recommended range is 13 – 14 cuts per worker per day without hearing protectors. For the powder-actuated tool (PAT) nailer, recommended use limits are <2 shots without hearing protectors, 10 – 13 shots with foam earplugs, 27 – 34 shots with earmuffs, and 86 – 108 shots with double hearing protectors (foam earplugs plus earmuffs). Lastly, for the impact driver, the recommended use limit is 486 – 533 screws driven into metal studs per day.

Introduction

Excessive noise exposure is the leading cause of occupational hearing loss in many industries (Campo et al., 2013). Workers exposed to loud continuous and impulse/impact noises throughout their work shift cause irreversible damage to the inner ear, most commonly through over-stimulation and metabolic overload of inner ear hair cells which leads to oxidation and irreversible apoptotic death of the hair cells (Eggermont, 2017).

Within occupational noise exposures, the construction industry is over-represented in on-the-job noise-induced hearing loss (Neitzel et al., 1999; Seixas et al., 2012). By the nature of cutting and modifying durable building materials, the tools that perform these tasks must be powerful enough to cut and fasten steel, concrete, wood and other robust materials, however it has also been a long-standing tradition that powerful tools for these tasks must also be loud. While quiet tools for many tasks do exist, industry and manufacturer buy-in has not yet become prevalent. As such, powerful tools are still loud tools, requiring users to rely on inconsistent protection from personal protective equipment (PPE) such as foam ear plugs and other hearing protectors to limit hazardous noise exposures.

As the National Institute for Occupational Safety and Health (NIOSH) hierarchy of controls demonstrates, PPE is the least favorable method to prevent a worker exposure to any hazard, including noise. Instead of relying on PPE to be worn consistently and properly, better methods of hazard mitigation are eliminating the noise, substituting a quieter tool, engineering controls, or if none of the above are feasible, administrative controls. (Meinke et al., 2022; Morris & Cannady, 2019). When a quiet tool is used through elimination, substitution or engineering controls, PPE is not required because the sound pressure levels (SPLs) are low enough to minimize damage to the hearing structures of the inner ear. By eliminating the need for hearing protectors altogether, worker monitoring of PPE is no longer necessary and hearing conservation programs as required by the Occupational Safety and Health Administration (OSHA) can be eliminated. In the absence of feasible engineering controls, administrative controls may be implemented, such as limiting operational time with a loud tool. Due to the current limited availability of quiet tools in the commercial framing industry, administrative controls are a better option than relying strictly on PPE which requires employer and employee buy-in, training for proper use, and monitoring for compliance.

In the construction industry in the United States, commercial buildings are typically constructed with steel stud framing members, as opposed to wood studs used in the U.S.

residential building market. The steel studs used for commercial buildings allow for a more durable building material for heavier commercial use, but also are resistant to pests, fire, water, and are more cost-effective. These steel studs are galvanized to prevent corrosion, and come in various sizes and thicknesses to allow for various design specifications. Typically, steel studs come in nominal 4-inch (92 mm), 6-inch (152 mm) and 8-inch (203 mm) web sizes (widths), with steel thicknesses ranging from 18 to 97 mil (0.454 to 2.454 mm). [All steel stud soft metric conversions are adapted from the Steel Stud Manufacturers Association (2002).] Cutting these studs for installation is typically performed by the framer on site with a rotary saw (Fig. 3.1), although for very light-gauge studs a pair of aviation snips (aka "tin snips" or just "snips") may be used. On certain jobsites, a hydraulic cutter is used, however very high cost and limitations in deliverability make this an improbable solution for most framing contractors. Whereas cutting steel studs with snips or a hydraulic cutter make no noise above ambient, rotary saws of all forms produce SPLs high enough to require PPE use in a short period of time to maintain a worker below the NIOSH recommended exposure limit (REL). Other installation tools likewise produce

Fig. 3.1. Examples of each saw type that was used at the study sites. A = Chopsaw; B = Cut-off Saw; C = Grinder; D = Cordless Circular Saw.

high SPLs, such as the powder-actuated tool (PAT) nailer and the impact driver, neither of which have reliably quiet options (Fig. 3.2).

Exposure limits from various agencies exist to protect the workers' hearing. In construction, OSHA requires hearing protector use when the time-weighted average (TWA) of the shift exceeds 90 dBA using a 5-dB exchange rate for their permissible exposure limit (PEL). Conversely, NIOSH has a more conservative and more protective REL of 85 dBA TWA using a 3-dB exchange rate. The difference between using a 3-dB vs. a 5-dB exchange rate leads to

Fig. 3.2. Typical common tools used by framers in the study. Powder-actuated tool (PAT) nailer (left) and impact driver (right).

substantial differences in TWA noise calculations, in addition to the 85 dBA vs. 90 dBA criterion level and a 90-dB vs. 80 dB threshold. Overall, by relying on the OSHA PEL as opposed to the NIOSH REL, employers and their workers are following the bare minimum requirement to minimize noise exposure, despite studies that have shown the OSHA PEL is not protective enough to prevent occupational noise-induced hearing loss (Bejan et al., 2011; Lusk et al., 1998).

Further, both the OSHA and the NIOSH exposure limits were established for continuous noise, as opposed to impulse noise (a sudden release of energy) or impact noise (two objects banging against each other), with the exception of a ceiling limit of 140 dBA. Commercial framers are exposed to both continuous noise as well as numerous impulse and impact noises during their workday (Kerr et al., 2002; Lusk et al., 1998). While the NIOSH REL does not specifically account for impulse and impact noise in the TWA calculations, its more protective criteria compensate at least partially for this complex noise due to its conservative nature alone.

Specific guidelines to limit hazardous noise exposures in commercial framing do not currently exist, and although substitution or engineering controls would be ideal, development of administrative task limitations is the next best option. This paper aims to develop administrative controls to limit hazardous noise exposure in commercial framers who cut and install steel studs as part of their daily duties. Specifically, controls to limit noise exposure from using a rotary saw to cut steel studs, a powder actuated tool PAT nailer, and an impact driver are examined, and limits are calculated to help keep workers below recommended exposure limits.

Materials and Methods

All sampling was performed on volunteers at opportunistically-available commercial construction sites. Institutional Review Board approval was received prior to any recruitment. Volunteers with informed consent were recruited at active commercial construction sites. Only volunteers who were framing with steel studs as their primary job for the work shift were selected for the study.

Jobsite Characteristics

Jobsites where volunteers were recruited were commercial buildings under construction or renovation in Colorado. All sites were opportunistically selected based on availability. Sites were a combination of new-build projects and renovation projects of between 3,150 ft^2 (300 m^2) and 200,000 ft^2 (18,000 m^2) and from 1 to 5 stories tall. Volunteer participants spent the entirety of their work shift performing framing tasks with steel studs during the sampling periods.

Tool Noise Characterization

All tool use was based on the workers' own power tools which they normally used on a jobsite. No modifications in a worker's daily routine or tool selection were performed for the purpose of this study to ensure normal working conditions were recorded. Power tools were evaluated as generalized categories of tool type, not by manufacturer or age.

Noise samples of tool sound pressure levels from the worker's standpoint were obtained through personal dosimetry with one of two noise dosimeters (Larson-Davis Spark model 706RD and Larson-Davis Spartan model 730, Depew, NY, USA). The Spartan dosimeters were enabled with 1/1 octave band filters and 12-second event sound recording for 6 of the 10 study days. All dosimeters were set to record with A-frequency weighting at the following settings for the virtual dosimeters within each device: (1) OSHA PEL criteria (90 dB criterion level, 90 dB threshold, 5-dB exchange rate, slow response), and (2) NIOSH REL criteria (85 dB criterion level, 80 dB threshold, 3-dB exchange rate, slow response). Peak data were recorded with C-frequency weighting (L_{Cpeak}). All data were integrated and logged at 1-second resolution. Calibration of each dosimeter was performed before and after each sampling day using Larson-Davis CAL150/200 calibrators (Depew, NY, USA).

Dosimeters were attached to the participant's shoulder with the microphone near the participant's hearing zone (i.e., two-foot-diameter sphere surrounding the head). As framers typically carry framing components on their shoulder, the non-dominant shoulder was used to attach the dosimeter to avoid interference with the dosimeter microphone. Dosimetry data were downloaded via the dosimeter PC-based software (PCB Piezotronics G4 LD Utility for the Larson-Davis Spartan dosimeters, and PCB Piezotronics Blaze for the Larson-Davis Spark dosimeters, Depew, NY) and exported to spreadsheets for analysis.

Tool Usage Evaluations

Concurrent with dosimetry, the researchers observed and documented times and descriptions of the tasks being performed by each participant. These observational data were then used to compare with the dosimetry data log to develop a dB "signature" for tool use throughout the work day, i.e., the dB signatures were visually identified in the dosimetry time-stamped data.

Saw Cuts

Duration times and event counts were observed and recorded in a field notebook for types and sizes of steel studs that were cut. Length of cutting duration was measured with a smart phone stopwatch (iPhone 14, Apple), with the stopwatch started when the worker pulled the saw trigger to start the saw, and the time stopped when the worker released the trigger at the end of each cut. Dosimeter data logs were reviewed and compared with both documentation from observed tool use times and dB "signatures" of the tool use which were clearly discernible from ambient noise in the dosimeter data logs. Saw cut dB levels were compiled into a spreadsheet based on all A-weighted fast response maximum sound level (L_{AFmax}) dBs >90 dB during the cut. The 90-dBA threshold was chosen to distinguish between the saw noise and background noise. Note that track framing components are included in all data, however due to their smaller total number of cuts and their similarity in dimensions to studs, for simplicity where this paper refers to cutting steel studs, the analysis also includes track components. Saws were categorized as "chopsaw," "cordless circular saw," "cut-off saw," and "grinder."

PAT Nailer

PAT nailer usage times were recorded in a field notebook using a smartphone clock synched with the dosimeter clock. When a worker fired a shot, the type of cartridge and the time of the shot was recorded and later compared and confirmed with the dosimeter data log. For dosimeters that had event sound recording capability, the sound recording was also used to verify the PAT shot within the dosimeter data logs. Shots within the dosimeter data logs were easily discernible from background noise due to high and instantaneous L_{peaks} ~138 dBC.

Impact Driver

The impact driver usage time was recorded in a field notebook using a smartphone clock synched with the dosimeter clock. For dosimeters that had event sound recording capability, the sound recording was used to pinpoint the impact driver use within the dosimeter data logs. Only instances of L_{Fmax} >90 dBA were used for the study to ensure the impact driver noise was discernible from background noise. This dB threshold also coincided with louder noise the tool produced when the impact mechanism auto-engaged. Durations of each impact-driven screw were calculated within the Excel spreadsheet, with overall screw driving time under impact calculated from 4026 screws driven during the course of the study.

Statistical Analysis

All data from the dosimeters were imported into the dosimeter proprietary PC software (Larson-Davis Blaze and G4) and exported to Microsoft Excel spreadsheets. Statistical analyses were performed using R Statistical Software (v. 4.3.1; R Core Team, 2023) with EnvStats package (Millard, 2013).

Means of all noise metrics, L_x, are calculated as log-transformed means as shown in Eq. 3.1, as described in International Organization for Standardization (ISO) 9612:2009.

$$L_{x(avg)} = 10log_{10}\left(\frac{1}{N}\sum_{i=1}^{N}10^{0.1L_{xi}}\right) \quad \text{(Eq. 3.1)}$$

where:

$L_{x(avg)}$ is the log-transformed mean of all L_{eq}, L_{max} or L_{peak} data for a specific saw

L_{xi} is the individual 1-second measured L_{eq}, L_{max} or L_{peak} for the event

i is the 1-second sample number

N is the total number of 1-second measurements

Occupational noise exposure allowable durations are calculated from Eq. 3.2, as described in the NIOSH Criteria for a Recommended Standard: Occupational Noise Exposure (NIOSH, 1998).

$$T_{min} = \frac{480}{2^{(L-85)/3}} \qquad \text{(Eq. 3.2)}$$

where:

T_{min} is the allowable duration of exposure

L is the level of exposure, L_{Aeq}

Allowances for impulse noise (Eq. 3.3) are adapted from Murphy & Tubbs (2007) and are used to calculate allowable shots from the PAT nailer.

$$N = 10^{(140-PI)/10} \qquad \text{(Eq. 3.3)}$$

where:

N is the total allowable number of shots

PI is the peak SPL (dB)

Hearing protectors are derated as described by NIOSH for effective noise levels in dBA following Eq. 3.4 (NIOSH, 1998).

$$NRR_d = (NRR * df) - 7 \quad \text{(Eq. 3.4)}$$

where:

NRR_d is the derated NRR for the hearing protector

NRR is the NRR listed by the hearing protector manufacturer

df is the derating factor as specified by NIOSH

for foam earplugs, $df = 0.5$

for earmuffs, $df = 0.75$

Simple linear regression was used to test if REL noise dose was significantly predicted by the number of cuts a worker performed with a power saw each day. Multiple linear regression was used to test if number of cuts, PAT shots, and impact driver seconds significantly predicted REL dose. A significance level of 0.05 was used for all statistical tests.

Results

To investigate first whether limiting number of saw cuts has an impact on REL dose, the relationship was analyzed with a simple linear regression model. The fitted regression model for REL dose predicted by number of cuts was: REL dose = 188.031 + 7.728*(number of cuts) and the relationship was statistically significant: $R^2 = 0.49$; $F_{(1,21)} = 20.3$; $p < 0.001$ (Fig. 3.3). Note that saw noise was not the sole noise exposure leading to the REL dose for these workers.

Table 3.1. Summary statistics for the number of seconds each worker used commonly used tools. PAT = powder-actuated tool; SD = standard deviation.

Tool	Mean	Median	SD	Range
Saw cuts	428.0	405	324.4	13 – 1105 (sec)
PAT nailer	40.1	30	32.6	7 – 114 (shots)
Impact Driver	387.4	370	230.3	16 – 877 (sec)

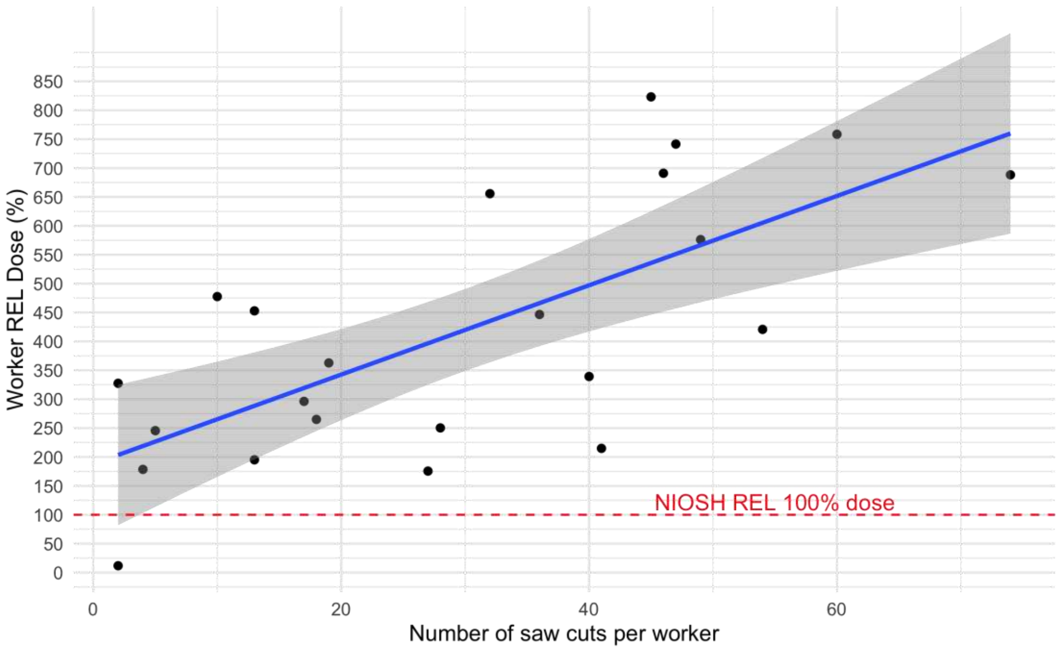

Fig. 3.3. REL dose as predicted by number of cuts made. Shading represents 95% confidence interval. Red dashed line indicates a 100% dose of the NIOSH recommended exposure limit (REL). $F_{(1,21)} = 20.3$; $p < 0.001$; $R^2 = 0.49$.

For workers who used a power saw during their workday, they used one on average for 428 seconds (range = 13 – 1105 sec) per worker per day to cut steel studs (Table 3.1). For all workers combined and for all types of studs (generalized among all stud sizes and thicknesses, and saw types; Table 3.2), the average time to cut a steel stud was 12.8 sec/stud. Based on time allowance calculations for the NIOSH REL TWA from Eq. 3.2, the amount of time a worker can be exposed to the range of L_{eq} saw noise levels from Chapter 1 and stay below the 100% NIOSH REL dose is presented in Table 3.2. With a 95% confidence interval L_{Aeq} of 107.0 – 107.3 dB for all saws, this equates to a limit of: 13 – 14 cuts without hearing protectors, 103 – 110 cuts with foam earplugs (assumed NRR of 32 dB, derated per NIOSH guidelines to 9 dB of attenuation, Eq. 3.4), and 275 – 293 cuts with earmuffs (assumed NRR of 27 dB, derated to 13.25 dB per NIOSH guidelines, Eq. 3.4). Specific cut limit recommendations are presented in Table 3.2.

Table 3.2. Allowable time for each saw type, and cut limits for each instance to remain below the NIOSH recommended exposure limit (REL), with and without specified hearing protectors. Seconds allowed is calculated from Eq. 3.2 from the mean L_{Aeq} of the tool. Sound pressure levels provided with 95% confidence interval. L_{Aeq} = A-weighted equivalent continuous sound pressure level; HPD = hearing protective device.

Stud/Saw Combination	L_{Aeq} (dB)	Mean cutting time (sec)	(Time allowed)[3] Max # of cuts to REL no HPD	(Time allowed)[3] Max # of cuts with foam earplugs[1]	(Time allowed)[3] Max # of cuts with earmuffs[2]
Any saw type:	107.0 – 107.3		165 – 175 sec	1321 – 1403 sec	3525 – 3744 sec
Any general stud size		12.8	13 – 14 cuts	103 - 110 cuts	275 - 293 cuts
Chopsaw:	106.1 – 106.4		203 – 220 sec	1629 – 1756 sec	4348 – 4688 sec
Any general studs (except 6" 97 mil; 152 mm/2.454 mm)		10.8	19-20 cuts	151 – 163 cuts	403 – 434 cuts
4" nominal (92 mm) studs		3.5	58-63 cuts	465 – 502 cuts	1242 – 1339 cuts
6" (152 mm) studs (except 97 mil; 2.454 mm)		15.7	13 – 14 cuts	104 – 112 cuts	277 - 299 cuts
6" 97 mil (152 mm/2.454 mm) studs		57.7	4 cuts	28 - 30 cuts	75 - 81 cuts
Cordless Circular Saw:	110.1 – 110.6		77 – 86 sec	618 – 689 sec	1650 – 1838 sec
Any general studs		7.2	11 – 12 cuts	86 - 96 cuts	229 - 255 cuts
4" nominal (92 mm) studs[4]		6.1	13 - 14 cuts	101 - 113 cuts	271 - 301 cuts
6" (152 mm) studs		8.0	10 - 11 cuts	77 - 86 cuts	206 - 230 cuts
Cut-off Saw:	105.5 – 106.2		213 – 252 sec	1701 - 2014 sec	4542 - 5377 sec
Any 54 mil (1.366 mm) studs		9.7	22 - 26 cuts	175 - 208 cuts	468 - 554 cuts
4" nominal (92 mm) studs[4]		4.7	45 - 54 cuts	362 - 429 cuts	1966 - 1144 cuts
Grinder:	104.4 – 105.0		281 – 328 sec	2247 – 2621 sec	6000 – 6997 sec
4" 54 mil (92 mm/1.366 mm) studs[4]		23.2	12 – 14 cuts	97 - 113 cuts	257 - 302 cuts

[1]with 9 dB of attenuation after derating 32 NRR foam earplugs per NIOSH guidelines
[2]with 13.25 dB of attenuation after derating 27 NRR hardhat-mounted earmuffs per NIOSH guidelines
[3]Time allowed calculated from Eq. 3.2
[4]Limited sampling data

Of workers who used the PAT nailer during the day, the mean number of seconds the tool was used was 40.1 sec (range 7.0 – 114.0 sec; Table 3.1). Because the operational cycle of a single-load PAT is >1 shot/sec, this equates number of seconds of tool use to number of shots fired. The L_{Cpeak} 95% confidence interval for the PAT nailer was 137.9 – 138.9 dB (Table 3.3), and 95% confidence interval L_{Cpeak} for the PAT nailer with the extension pole shooting from ~7 feet (~2.1 m) above the hearing zone was 134.0 – 135.5 dB. For PAT nailer allowances (Table

3.3) calculated for impulsive noise limits using Eq. 3.3, without hearing protectors a worker can only fire one shot with the tool before reaching 100% of impulse noise allowance. With foam earplugs derated to 9 dB, the allowance is 10 – 13 shots, 27 – 34 shots with earmuffs, and 86 – 108 shots with double hearing protectors. The PAT nailer with an extension pole allows an increase in number of allowable shots as shown in Table 3.3.

Table 3.3. Allowable number of powder-actuated tool (PAT) shots. Sound pressure levels provided with 95% confidence interval. L_{Cpeak} = C-weighted peak sound level; HPD = hearing protective device; REL = NIOSH recommended exposure limit.

PAT Shot Type	Mean L_{Cpeak} (dB)	Max # of shots to REL (No HPD)	Max # of shots (foam earplugs)[1]	Max # of shots (earmuffs)[2]	Max # of shots (double HPD)[3]
Yellow or Red Cartridges	137.9 – 138.9	1.3 – 1.6	10-13	27-34	86-108
With extension pole[4]	134.0 – 135.5	3 - 4	23 - 31	60 - 83	190 - 263

[1]with 9 dB of attenuation after derating 32 NRR foam earplugs per NIOSH guidelines
[2]with 13.25 dB of attenuation after derating 27 NRR hardhat-mounted earmuffs per NIOSH guidelines
[3]5-dB added to earmuff attenuation for double protectors per most-conservative NIOSH guidelines; as 18.25 of total attenuation
[4]Assumed shot at 7 ft (2.1 m) above hearing zone

Of workers who used an impact driver during their workday, the tool was used on average for 2.5 seconds at L_{eq} > 90 dBA per driven fastener, with an overall log-transformed mean L_{eq} of 98.5 dBA while driving screws with the impact mechanism auto-engaged (Table 3.4). Based on time allowances calculated with Eq. 3.2, the 95% confidence interval around the tool's 98.5 dBA mean equates to an allowable exposure range of 1215 – 1333 sec, or approximately 486 – 533 screws driven per worker per day into steel studs without wearing hearing protectors.

To investigate the relationship of these three commonly-used tools with REL dose, the data were fitted to a multiple regression model for independent variables of number of cuts, PAT shots, and impact driver seconds as a relationship to REL dose. The fitted equation was REL dose = 41.5156 + 9.504*(number of cuts) + 0.890*(PAT shots) + 0.581*(impact driver seconds). The overall regression was statistically significant: Adjusted $R^2 = 0.73$; $F_{(3, 13)} = 15.02$; $p < 0.001$.

It was found that PAT shots did not significantly affect REL dose ($p = 0.33$). It was found that impact driver seconds used did significantly affect REL dose ($p = 0.041$).

Table 3.4. Allowable time to use the impact driver. Sound pressure levels provided with 95% confidence interval. L_{Aeq} = A-weighted equivalent continuous sound pressure level; HPD = hearing protective device; REL = NIOSH recommended exposure limit.

			(Time Allowed)[1]	(Time Allowed)[1]
	L_{Aeq} (dB)	**Average time above 90 dBA per screw driven**	**Max # of screws to REL (No HPD)**	**Max # of screws to REL (with foam earplugs)[2]**
Impact Driver	98.3 – 98.7	2.5 sec	1215 – 1333 sec	9723 – 10664 sec
			486 – 533 screws	3889 – 4266 screws

[1]Time allowed calculated from Eq. 3.2
[2]with 9 dB of attenuation after derating 32 NRR foam earplugs per NIOSH guidelines

Discussion

Construction workers have been shown by numerous studies to be exposed to hazardous levels of noise in their job (Kerr et al., 2002; Lewkowski et al., 2018; Neitzel et al., 1999; Suter, 2002). While PPE can be and often is used to control these exposures, use of PPE is a last resort according to NIOSH's hierarchy of controls, an especially important point when workers are provided hearing protectors and either fail to insert them properly, or fail to use them at all (Casali & Park, 1990). Outside of finding alternative quiet cutting methods, such as a hydraulic cutter which can be prohibitively expensive for many framing companies, providing specific guidance in the form of administrative control recommendations can help protect workers' hearing better than relying strictly on hearing protectors alone. This paper uses data from an overall investigation into the noise exposures of steel stud framers to provide initial guidance on daily tool use to maintain noise exposures within NIOSH recommended exposure limits.

One of the loudest and most-used tools within the framer's toolbox in this study was the power saw. While there are a large variety of cutting combinations, this paper attempts to create generalized guidelines that can be easily followed to minimize hazardous noise exposure while using these saws. The generalized average cutting times take into account cuts for a variety of common studs, including dimensional size and material thicknesses.

On average, the time to cut a generalized steel stud was calculated to be 12.8 seconds (Table 3.2). While numerous factors affect cutting times, such as saw type, dimensional size of the stud, and thickness of the metal, an average cutting time can allow some overexposure while being offset by underexposure at other times. This overall generalized average therefore over-protects for studs that are faster to cut, and under-protects for studs that take longer to cut. Anecdotally, smaller, thinner-gauge studs tend to be more frequently encountered on the jobsite due to cost savings, and as such a general trend toward overprotection is therefore expected in the averaging calculations.

As Table 3.2 shows, the overall range of cuts a worker can make with any saw on any stud type varies considerably, affected by both the duration of time required to cut certain stud types, and as a function of the sound energy produced by the saw. For example, small dimensional studs such as the 4-inch nominal (92 mm) stud can be cut quickly with most saws, and with average cutting times <5 sec in some cases (the chopsaw and the cut-off saw), the allowable number of cuts before reaching 100% of the REL ranges from 45 – 63 studs per worker per day without hearing protector use. This range assumes that average cut times are maintained and, more importantly, that the worker does not have any hazardous additional noise exposure during the day. Caution must be used to ensure that the worker does not exceed the allowable 203 to 252 sec (3.4 – 4.2 min) of cutting time for these two saws. Cutting for a mere 3.5 minutes per day goes by quickly, and adding a single outlying cut, such as a 6” 97 mil (152 mm/2.454 mm) stud which averages 57 seconds alone, or a 6” 54 mil (152 mm/1.366 mm) stud which averages 29 seconds can severely affect these limitations (Chapter 1). Using the louder cordless circular saw decreases allowable cutting time substantially, allowing only 82 seconds of use without hearing protectors before exceeding the REL.

Using hearing protectors increases allowable number of cuts as expected (Table 3.2). Of note, earmuffs are easily installed on a hardhat and can be quickly and effectively deployed to provide the best protection while maintaining productivity, however earmuffs were not seen on any jobsites in this study. Foam earplugs were made available to all workers on all sites, with a most-common NRR of 32 dB. Because foam earplugs have been shown to be commonly inserted incorrectly and NRR ratings may not accurately reflect real-world attenuation (Berger et al., 1998; Franks et al., 2000; Neitzel et al., 2008), OSHA mandates derating and NIOSH recommends similar but slightly modified derating methods to compensate for likely decreased attenuation from incorrectly-worn hearing protectors. Eq. 3.4 provides derating calculations specified by the NIOSH method, where foam earplug NRRs are derated by 50% (with 7 dB subtracted from the result) and earmuffs are derated by 25% (likewise with 7 dB subtracted from the result). For earmuffs, this 13.25-dB attenuation brings the L_{Aeq} exposure to the worker for the chopsaw, cut-off saw and grinder down to 91.1 – 93.1 dBA. Calculations for this range from Eq. 3.2 allow exposure times of 4348 – 6997 sec (72 – 117 min). This is a substantial increase in exposure time and allows for a total of 277 – 1339 cuts per worker per day for common stud sizes, well within any ability of any commercial framer. For the louder cordless circular saw, this exposure time increases to 1650 – 1838 sec and allows for a total of 206 – 301 common studs to be cut with earmuff-protected ears.

In addition to power saws, two other commonly-used tools by the framers were the PAT nailer and the impact driver (Table 3.1). The PAT nailer uses a powder cartridge to drive nails into steel and concrete, and functions similar to the mechanism in which a firearm uses gunpowder to fire a bullet. The resulting sound when the tool is discharged is an impulsive noise that reaches L_{peaks} of >140 dBC (Chapter 2). Although OSHA does not have any limitations on the number of impulse/impact noises a worker can be exposed to per day other than a 140 dBA ceiling, a worker exposed to dozens of impulse events from the PAT nailer during a single work shift at ~140 dBC is concerning. Likewise, NOISH does not have any explicit limitations on the number of impulse/impact events >140 dB, however Murphy and Tubbs (2007) derived Eq. 3.3 from NIOSH's ceiling limit for impulsive noise and specifically used it for evaluating exposure to gunfire in an indoor firing range. The similarity in sound energy production of the PAT nailer allows for similar adaptations of Eq. 3.3 for construction use.

Of workers who used the PAT nailer during the day, the mean number of seconds the tool was used was 40.1 sec (range 7 – 114 shots; Table 3.1). Because the operational cycle of a single-load PAT nailer is >1 shot/sec, this equates number of seconds to number of shots. Log-transformed mean L_{Cpeak} values were 138.3 dBC for red cartridges and 139.0 for yellow cartridges (Table 3.3), a surprising finding since the red cartridge is described as a "stronger" cartridge per most manufacturers, designed for shooting nails into steel or hardened concrete. Based on calculations from Eq. 3.3 and detailed in Table 3.3, if a worker uses a PAT nailer without hearing protectors, the worker would only be able to fire <2 shots per day before exceeding the calculated impulse exposure limit.

If the worker uses the typical foam earplugs provided at the study sites, and assuming NIOSH derating (Eq. 3.4), the calculated limit increases to 10 – 13 shots for either yellow or red cartridges. This number is still at the lower end of the range of daily uses for this tool, and based on these calculations foam earplugs are not enough to prevent hazardous noise exposure in the occupational setting. Using earmuffs, workers could fire 27 – 34 shots (red or yellow cartridges), more in line with the median number of shots fired each day. Earmuffs, while more difficult to carry around, are easier and faster to use and would provide increased protection for many workers. Adding earplugs to earmuffs (double protection) provides the safest method to protect the ear during large numbers of shots, where the foam earplugs add an additional 5 dB of attenuation to the earmuffs and allow for a total of 86 – 108 shots, at the upper end of the range of use seen in the study, but still not above the upper limits. This inability to attenuate the upper limits of observed use in this study underscores the dangers of overexposure with this tool which can lead to hazardous noise exposure, even when wearing double hearing protection.

When using the ~7-foot (~2.1-m) extension pole with the PAT nailer, the mean was slightly lower at 134.8 dB. This tool provides distance from the user that allows some of the sound energy to dissipate, and increases the recommended allowable use to 3 shots per day without hearing protector use. When using foam earplugs, this separation from the tool allows for the worker to be exposed to 23 – 31 shots, a sizable increase in daily exposure. Switching to earmuffs increases the recommended limit to 60 – 83 shots, and double hearing protection increases the recommended limit to 190 – 263 shots. As can be seen with all PAT firing options from the study, double hearing protection > earmuffs > foam earplugs > no hearing protectors, as would be expected.

The L_{Aeq} of the PAT nailer is substantially lower than the L_{Cpeak} for this tool, and it is worth noting that, even though OSHA requires L_{peak} noise to be integrated into noise measurements, these instantaneous impulsive sounds are not well integrated into the L_{eq}. Although the dosimeter attempts to integrate this noise, the impulsive time interval is so brief (in milliseconds), it does not appreciably affect the L_{eq} nor the TWA. As such, even though a worker's dose may appear to be below the limit after using a PAT numerous times per day, the actual exposure will be underestimated. The calculated limits from Eq. 3.4 attempt to account for this impulsive energy better than can be done with L_{eq} calculations within the dosimeter under current calculation methods. As a particular case in point, one worker in the study had 82 PAT shots while wearing only foam earplugs, had zero saw cuts, but had a REL dose of only 87.1%. This number far exceeds the 10 –13 shots allowed by our calculations, demonstrating how a worker's dose is severely underestimated based on L_{eq} alone.

The third commonly-used tool among the framers in this study is the impact driver, a ubiquitous tool that has lower sound pressure levels than most other power tools used at the study sites. This tool is similar to an electric screwgun, but with an integrated rotational impact mechanism to increase torque while driving fasteners. The impact mechanism produces impact noise that may be greater than one impact/sec, depending on the speed at which the fastener is being driven. Based off of L_{Aeq} data taken from the dosimeter data logs, the log-transformed mean of the impact driver L_{Aeq} in the study was 98.5 dB with a 95% confidence interval of 98.3 – 98.7 dB. Using Eq. 3.2, workers are allowed 1215 – 1333 sec of impact driver use before reaching 100% of the REL. Based on these calculations with a 2.5 sec average duration of the impact mechanism engaging while driving a screw, this allows the worker to use the impact driver under load for 486 – 533 screws driven into steel studs (Table 3.4).

Using the data from all participants in the study, a predictive model was built using only the number of saw cuts as the predictor variable shown in Fig. 3.3 to analyze a relationship with REL dose ($R^2 = 0.49$). As noted in the plot, the lm y-intercept does not reach a REL dose of 100% or below. As such, although there is most likely confounding noise present in addition to saw cuts that add to the overall worker noise dose, the linear model is not strong enough to make inferences with the current data. Multiple regression was conducted with saw cuts, PAT shots, and impact driver seconds as variables, with a high p-value for PAT shots. This is not surprising for the PAT, as its impulsive noise is not well integrated in the L_{eq}. As the R^2 was the same with and without the PAT as a variable (adj. $R^2 = 0.72$), the PAT was left in the model. While the model shows some predictive ability for saw cuts and impact driver use, more data is needed to include the PAT, as well as other tools that are commonly used to add to the overall noise dose for the workday. Regardless, limiting use of loud tools during a framer's workday is an important step toward achieving safe noise exposures for this population of workers.

A major limitation of these calculations and recommendations are that they assume each tool is used in the absence of any other noise >80 dB during the workday. These calculations provide initial guidelines only on use limits per tool, but other tool use and other non-characterized noise must also be accounted for. Additional studies need to be performed which can help provide predictive models in the future for various combinations of tool use and to provide recommendations to help protect the hearing of commercial framers among all of their tasks.

Based off of these recommended allowances, additional administrative controls may need to be implemented to reduce excessive noise exposure once a worker reaches a limit. For example, a worker could be moved to a quieter task for the remainder of the day once they meet the allowed number of cuts, PAT shots, or uses of the impact driver. Additionally, as a PPE recommendation, framing companies should consider providing ear muffs in addition to foam earplugs. Earmuffs are quicker to use, especially if mounted onto a hardhat, and provide a higher and more consistent level of noise attenuation.

Conclusion

Based on the data presented in this study, commercial framers can cut 13 – 14 steel studs using any saw on any stud type, as the most basic generalization, before exceeding the REL for noise exposure. More specifically, for the most common type of saw used in this study, the chopsaw, a framer could make 58 – 63 cuts on general 4” nominal (92 mm) studs, or 13 – 14 cuts on general 6” (152 mm) steel studs (excluding 97 mil/2.454 mm thicknesses). For a PAT nailer, the limits are <2 shots per day without hearing protectors, or 10 –13 shots per day (yellow/red cartridges) with foam earplugs, the most common hearing protectors found on the study sites, or 27 – 34 shots with earmuffs. Impact driver use is limited to 486 – 533 screws driven. All recommended tool usage limits are based on isolated tool use and do not account for any additional tool use or noise exposure. Framers who cut and install steel studs as the primary part of their workday are exposed to hazardous noise from a wide variety of sources. This study provides recommendations to help limit these exposures and prevent occupational noise-induced hearing loss in this group of construction workers.

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Conclusion and Future Work

The results of this study demonstrate the hazardous noise exposures of commercial framers who cut and install steel studs as part of their primary duties. Noise exposures of framers using typical power saws during their workday had L_{eq} log-transformed means of 107.2 dBA and L_{peak} means of 120.1 dBC. While performing their daily duties of cutting and installing steel studs on construction sites, these framers had a mean PEL noise dose of 27.6%, while the same workers' mean REL dose was 340.7%, a sizeable difference due to differences in calculation criteria, however the REL dose is scientifically demonstrated to better prevent noise-induced hearing loss (NIOSH, 1998). In this study, framers had extensive use of three power tools in particular: The power saw, the PAT nailer, and the impact driver. Of these three tools, limit recommendations were made to provide initial and basic guidance on tool usage to help maintain worker exposure dose below 100% of the NIOSH REL. For cuts of generalized steel studs using a power saw, a worker could make between 13 – 14 cuts without hearing protectors to remain below the REL. Using a chopsaw on specifically 4" nominal (92 mm) studs, a worker can make 58 – 63 cuts without hearing protectors to remain below the REL. Foam earplug and earmuff hearing protectors add substantial numbers of allowable cuts to these limits, as is shown in Chapter 3. Use of the PAT nailer is much more limited, however, due to high impulse L_{peak} noise ~138 dBC. Without hearing protectors, a worker is limited to <2 shots per day. With earplugs or earmuffs, the limits are still well below what a worker normally uses the tool per day, and even with double hearing protection, some workers in the study still used the tool more than the recommended limit. As such, administrative controls are necessary to maintain workers within limits. Lastly, the impact driver, a power tool with less sound energy, but high use, is limited to 486 – 533 screws driven per day.

These results will hopefully be used within the construction industry to make changes in noise exposures of commercial framers, but ideally manufacturers will find this data concerning and make changes to the sound energy output of their tools. Although the construction industry in general has historically relied extensively on use of hearing protectors, and is slow to adopt to change, any decreases that can be found in noise exposures will ultimately improve worker safety and well-being, and allow them to enjoy their hearing longer.

This investigation has been an amazing, challenging, and extremely fun journey among both university faculty and hard-working construction workers. I am grateful for the time from all people involved, both in the university setting as well as at active construction sites. I could not have completed this project without all of their commitment. Thanks for the great times!!

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Appendix A

Table A1. Cutting times (sec) to cut steel track based on the web size and thickness of each track section, per saw type observed. Dimension = track web measurement; N = sample size of the specific track type/saw combination; SD = standard deviation; (-) = no event observed.

			Seconds to Cut One Track at a Time				Seconds to Cut Two Tracks at a Time			
Tool	**Dimension**	**Thickness**	**N**	**Mean**	**SD**	**Range**	**N**	**Mean**	**SD**	**Range**
Cordless Circular Saw	3.625 inch (92 mm)	18 mil (0.454 mm)	11	9.8	2.2	6.3-13.2	-	-	-	-
Chopsaw	3.625 inch (92 mm)	18 mil (0.454 mm)	2	5.5	1.7	4.3-6.7	-	-	-	-
Cordless Circular Saw	6 inch (152 mm)	30 mil (0.753 mm)	3	9.8	2.7	7.6-12.8	-	-	-	-
Cut-Off Saw	6 inch (152 mm)	33 mil (0.835 mm)	3	7.5	2.3	5.6-10.0	-	-	-	-
Chopsaw	6 inch (152 mm)	43 mil (1.088 mm)	10	9.2	3.6	5.5-18.7	10	19.4	4.7	13.4-28.0
Chopsaw	6 inch (152 mm)	54 mil (1.366 mm)	11	17.2	9.8	10.1-38.4	-	-	-	-
Chopsaw	6 inch (152 mm)	68 mil (1.720 mm)	6	12.2	1.4	9.5-13.6	-	-	-	-
Chopsaw	6 inch (152 mm)	97 mil (2.454 mm)	1	19.1	0	19.1-19.1	-	-	-	-
Cut-Off Saw	10 inch (254 mm)	54 mil (1.366 mm)	4	19.3	8.6	14.2-32.2	-	-	-	-