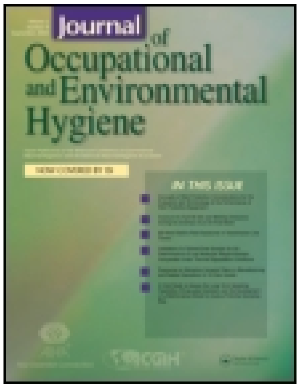

Journal of Occupational and Environmental Hygiene
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/uoeh20

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Accepted author version posted online: 27 Jun 2013.Published online: 08 Aug 2013.

Journal of Occupational and Environmental Hygiene, 10: 478–486
ISSN: 1545-9624 print / 1545-9632 online

DOI: 10.1080/15459624.2013.818230

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Noise exposure is a distinct hazard during hand-held concrete grinding activities, and its assessment is challenging because of the many variables involved. Noise dosimeters were used to examine the extent of personal noise exposure while concrete grinding was performed with a variety of grinder sizes, types, accessories, and available dust control methods. Noise monitoring was conducted in an enclosed area covering 52 task-specific grinding sessions lasting from 6 to 72 minutes. Noise levels, either in minute average noise level (Lavg, dBA) or in minute peak (dBC), during concrete grinding were significantly ($P < 0.01$) correlated with general ventilation (GV: on, off), dust control methods (uncontrolled, wet, Shop-Vac, HEPA, HEPA-Cyclone), grinding cup wheel (blade) sizes of 4-inch (100 mm), 5-inch (125 mm) and 6-inch (150 mm), and surface orientation (horizontal, inclined). Overall, minute Lavg during grinding was 97.0 ± 3.3 (mean ± SD), ranging from 87.9 to 113. The levels of minute Lavg during uncontrolled grinding (98.9 ± 5.2) or wet-grinding (98.5 ± 2.7) were significantly higher than those during local exhaust ventilation (LEV) grinding (96.2 ± 2.8). A 6-inch grinding cup wheel generated significantly higher noise levels (98.7 ± 2.8) than 5-inch (96.3 ± 3.2) or 4-inch (95.3 ± 3.5) cup wheels. The minute peak noise levels (dBC) during grinding was 113 ± 5.2 ranging from 104 to 153. The minute peak noise levels during uncontrolled grinding (119 ± 10.2) were significantly higher than those during wet-grinding (115 ± 4.5) and LEV-grinding (112 ± 3.4). A 6-inch grinding cup wheel generated significantly higher minute peak noise levels (115 ± 5.3) than 5-inch (112 ± 4.5) or 4-inch (111 ± 5.4) cup wheels. Assuming an 8-hour work shift, the results indicated that noise exposure levels during concrete grinding in enclosed areas exceeded the recommended permissible exposure limits and workers should be protected by engineering control methods, safe work practices, and/or personal protective devices.

Keywords concrete grinding, enclosed areas, hand-held grinder, noise exposure

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INTRODUCTION

Concrete grinding potentially exposes workers to noise levels that could exceed criteria set by the U.S. Occupational Safety and Health Administration[1] or recommended standard for noise exposure established by the National Institute for Occupational Safety and Health.[2] The U. S. Department of Labor[3] reported that the number of workers directly involved in concrete grinding activities such as cement masons, concrete finishers, segmental pavers, and terrazzo workers is steadily increasing from 207,800 in 2008 to a potential 234,500 in 2018. Numerous other construction trades such as general laborers as well as carpet, floor, ceiling, and tile installers are also involved in concrete grinding. An additional, fast-growing number of workers are engaged in decorative manual concrete grinding, often performed in enclosed locations.

Excessive noise exposure can lead to noise-induced hearing loss and other negative health effects.[4] Factors including site setup, worker activities, and mobile equipment and processes can influence noise generation during concrete surface grinding on construction sites. Hand-held grinding can affect the noise levels due to characteristics including the design, shape, structure, size, or speed of the concrete grinders. Attachments such as a vacuum, intermittency and duration of grinding work, and the number of workers performing grinding in an area can also contribute to increased noise levels.

Eaton[5] emphasized the difficulties of measuring noise exposure levels of construction workers mainly due to the variation in activities and work shift as well as the seasonal nature of the construction industry. However, Eaton[5] and other researchers[6,7] reported that construction workers were exposed to high levels of noise for varying hours during each day. Noise exposure studies in construction sites have focused on a variety of industrial activities. While assessing occupational noise exposures in four construction trades (carpenters, laborers, iron workers, and operating engineers), Neitzel et al.[6] reported that whereas the type of trade was a poor predictor of noise exposure, construction method, stage of construction, and the work tasks and tools used were better predictors. In their study, 40% of time-weighted average (TWA) noise levels exceeded 85 dBA and 13% exceeded 90 dBA. The highest exposure levels involved pneumatically operated tools and heavy equipment.

Elstad et al.[(7)] reported that workers operating hand-held grinders on small- to medium-size mild steel parts were exposed to more than 100 dBA. The Government of Western Australia,[(8)] in its publication titled "Noise Management Data Sheets: Angle Grinder," reported that all angle grinders tested since 1984 generated noise levels that exceeded 85 dBA while "free running." In particular, the report indicated that the noise level of 4-inch (100 mm) angle grinders when free running varied from 95 to 100 dBA, thus necessitating the use of hearing protection and other control options. According to the report, noise levels were dependent on factors such as bearing condition, gearbox wear, and the age of the grinder.[(7)]

To our knowledge, there has been no report in the literature on noise levels of hand-held concrete grinders under controlled conditions in enclosed areas. Our initial related study on silica dust exposure[(9)] indicated high noise exposure in enclosed areas. Thus, this noise study was conducted in conjunction with our second and more comprehensive monitoring of silica dust,[(10)] with the objectives of quantifying major factors of noise generation and exposure.

METHODS

Concrete Grinding Sessions

This study included concrete surface grinding sessions that covered each of the following scenarios: (1) two options of general ventilation (GV): off or on; (2) two options of concrete slab surface orientation: horizontal or inclined to simulate floor grinding or wall grinding, respectively; (3) three major dust control methods: uncontrolled (traditional with no dust control), wet-grinding, and local exhaust ventilation (LEV: Shop-Vac, HEPA-tank, HEPA-Cyclone); (4) grinding session lengths: short, medium, and long for each dust control method; and, (5) three sizes of grinding cup wheels: 4-inch (100 mm), 5-inch (125 mm), and 6-inch (150 mm). Overall, noise levels were monitored during 52 grinding sessions.

Field Lab

Concrete grinding activities were performed in an enclosed and relatively small workplace setting called the Lab (Figure 1). The Lab, measuring 24 × 15.4 × 17.3 ft (7.3 × 4.7 × 5.3 m), was a converted truck-wash bay within an industrial facility. The front/south wall, containing a large drive-through opening of 11.8 × 11.8 ft (3.6 × 3.6 m) provided an entrance to the Lab from the interior of the host facility. This large opening could be sealed off during concrete grinding sessions with a drop-down curtain. The walls, floor, and ceiling (except for the entrance) were constructed of concrete material (heavy aggregate block, medium texture, unpainted). An industrial fan provided GV for the Lab at a rate of approximately 62 room exchanges per hour. This GV system could be easily turned on or off by researchers.

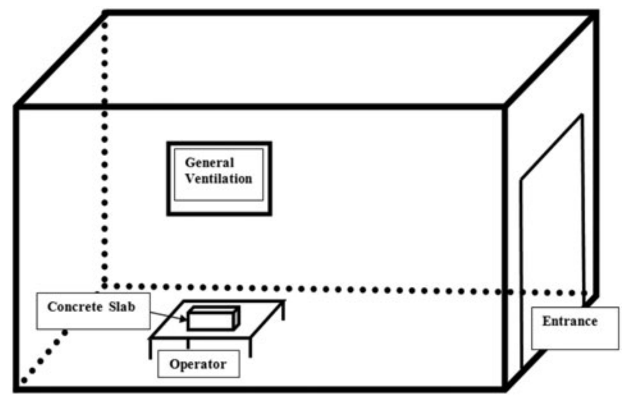

FIGURE 1. General layout of the field Lab (enclose area) for noise monitoring during concrete grinding operation.

Operator

An operator, whose background included primarily construction trade work, performed all concrete grinding. This study was reviewed and approved by the Institutional Review Board of the researchers' institution. As required by this approval, the operator's participation in the study was voluntary and he read and signed an informed consent form. The operator was provided with a powered air-purifying respirator, coveralls/rain suit/vest, gloves (common and anti-vibration), hearing protection [Honeywell, Howard Leight MAX30 Earplug Corded, Morristown, N.J.; noise reduction rating (NRR) of 33 dB], and safety shoes/rubber over-boots. To simulate actual field activities, the operator's position (sitting or standing), technique, resting times, break sessions, and number of sessions per day were chosen with the assistance of the operator.

Noise Monitoring

Noise data were collected by using 3 dosimeters concurrently for: (1) personal monitoring within the Lab; (2) area monitoring outside the Lab, immediately beyond the drive-through opening; and, (3) area monitoring within and outside the host facility.

Noise was measured using factory-calibrated personal real time noise dosimeters (Spark 705+, Larson Davis, N. Y.) and data were logged and downloaded to Blaze software provided with the noise dosimeters. Using a standard noise calibrator (Model CAL150, Larson Davis, N. Y.), the noise dosimeters were calibrated before each sampling session, and the calibration was checked after sampling. The noise levels were measured using an exchange rate (ER) of 5, threshold level of 80 dBA, and criterion level of 90 dBA.

The operator was initially trained by the research team on the instrumentation and noise monitoring. A research team member attached a calibrated noise dosimeter to the operator's right lapel, outside his powered air-purifying respirator and as close to his ear as possible (Figure 2). The operator and

FIGURE 2. The operator is grinding concrete while standing (left) or sitting (right); the noise dosimeter's microphone is on the top of his shoulder (a dust sampling device is seen below the microphone); a LEV-HEPA-Cyclone (with its attachments) is also shown (right) (color figure available online).

his activities were under continuous observation during grinding and noise measurement sessions; any deviation from the research's standard procedures was immediately remediated. The grinding was performed by the operator either in a sitting or standing position. At the end of each session, the dosimeter was removed from the operator (and fixed locations), its calibration was checked, and the data were downloaded into a computer for statistical analysis.

Noise Monitoring Sessions

Noise monitoring periods, corresponding to the concrete grinding session lengths, were set for each of the dust control methods based on anticipated level of dust generation and the cup wheel size as follows: uncontrolled-grinding sessions from 6 to 26 minutes; wet-grinding sessions from 16 to 58 minutes; and, LEV-grinding sessions from 21 to 72 minutes. During each session, the operator divided his time between the task-specific concrete grinding activity inside the Lab (about 10 minutes on average) and resting outside the Lab (usually 2 or more minutes), at his discretion, without changing the end time or affecting the total length of each session. Noise monitoring was conducted for the entire length of each session. Task-specific grinding and break times were recorded to the minute. Generally, the operator took an additional break (up to 45 minutes depending on the length of the session) between any two consecutive sessions.

Break Times

Session lengths (task-specific noise monitoring times) ranged from 6 to 72 minutes. The frequency and duration of breaks within each session were at the operator's discretion, simulating common practices in actual concrete grinding activities. On average, each noise sampling session included approximately 76% actual concrete grinding time inside the Lab and 24% rest time in non-contaminated areas. During each data collection day, the operator worked for an approximate 7–9 hour work shift. On average, each shift included approximately 57% time on grinding activities and 43% time on other related duties such as cleaning and organizing the Lab, maintaining tools, and taking major breaks.

Concrete Grinding Equipment

Angle Grinders

Three sizes of hand-held electric angle grinders, of similar type from the same manufacturer (Metabo, Meabowerke, GmbH, Nurtigen, Germany), were selected and used. A 4.5-inch (115 cm) angle grinder (Model W7-115 Quick, 11,000 rpm, 8 amps) was selected as the smallest commonly available grinder. A 6-inch (150 mm) angle grinder (Model WE14-150 Quick, 9000 rpm, 8.5 amps) was selected as representative of manual concrete grinders used in northwest Ohio where this study was conducted. A 7-inch (175 mm) grinder (Model W23-180, 8500 rpm, 15 amps) was selected as the largest hand-held angle grinder feasible for concrete grinding use. Although angle grinders are manufactured and marketed for metal grinding, they are the preferred and most commonly used equipment for manual concrete grinding. The Eibenstock Concrete Grinder (Model EBS 1801, 150 mm, 10,000 rpm, 16 amp; Elektrowerkseuge GmbH, Eibenstock, Germany), with a dust collection shroud and ventilation port as an integral part of its design, was used for a few extra LEV-grinding sessions. This concrete grinder was only available in one size, and it accommodated a grinding cup wheel of 5-inch (125 mm). This grinder represented one of a limited number of hand-held grinders manufactured specifically for manual concrete grinding.

Grinding Cup Wheels

Three different sizes of diamond grinding cup wheels: 4-inch, 5-inch, and 6-inch (100, 125, 150 mm), each from two different manufacturers (Diamond Products Inc. Helena, Mont.; Joe Due Blades & Equipment Inc. Mauston, Wisc.) were used in this study. All of the grinding cup wheels were of a similar double-row, segmented style. The 4-inch (100 mm) grinding cup wheels were used in the 4.5-inch (115 mm) angle grinder. The 5-inch (125 mm) grinding cup wheels were used in the 6-inch (150 mm) angle grinder. The 6-inch (150 mm) grinding cup wheels were used in either the 6-inch (150 mm) or the 7-inch (180 mm) angle grinder. These pairings were consistent with industry practice.

Dust Control Methods

Uncontrolled-Grinding (no dust control)

Each of the three sizes of angle grinders was used with the corresponding size of diamond grinding cup wheel and the standard metal wheel guard attached.

Wet-Grinding

Each of the three sizes of angle grinders was retrofitted for wet-grinding by soldering a metal nipple into a small hole drilled into the metal blade guard. The nipple was connected to a rubber hosing. The in-line valve (attached to the hosing) regulated the flow of water into the wheel guard and subsequently wetted the concrete. Water flow rate for the wet-grinding was adjusted by the operator as practiced in the field.

Local Exhaust Ventilation (LEV)

Three different options for LEV dust control were used in this study: (1) Shop-Vac: a common shop vacuum (Shop-Vac Model 85L575; Shop-Vac Corporation, Williamsport, Pa.) equipped with a common dust filter; (2) LEV-HEPA-Tank: High-quality, portable tank-type vacuum (Eibenstock 1500: Elektrowerkzeuge GmbH, Eibenstock, Germany), with a high-efficiency particulate air (HEPA) filter in place; and, (3) LEV-HEPA-Cyclone: high-quality, portable cyclone-type vacuum (Model DC2800c: Dustcontrol Inc., Wilmington, N.C.) used with a HEPA filter. All grinders were retrofitted with a heavy-duty urethane dust shroud and attached to each type of vacuum being used for the noise monitoring period.

Statistical Data Analysis

The data were compiled and analyzed using SPSS Statistical Version 19 Package (SPSS Inc., Chicago, Ill.). Descriptive statistics were used to summarize and tabulate data. T-test (or Mann-Whitney U test in nonparametric cases) was used to compare two variables. Analysis of variance, ANOVA (or Kruskal-Wallis test in nonparametric cases), was used to examine differences among three or more variables; the analysis was followed by Post-Hoc tests. Regression analysis was used to examine the relations between variables. Multivariate Analysis of Variance was performed to examine the relationships of outcomes and the existing factors.

RESULTS AND DISCUSSION

Influence of Major Factors of Concrete Grinding on Noise Exposure Levels

The main effects and significant interaction of factors (e.g., GV) versus outcomes (e.g., peak noise) were determined by using four-way analysis of variance (Table I). The minute TWA noise level (dBA) and the minute peak noise level (dBC) were significantly ($p < 0.05$) influenced by GV, grinding cup wheel size, concrete surface orientation, dust control method, and their interactions. The results of noise monitoring broken down by major factors of concrete grinding are summarized in Table II and Figures 3 and 4. The more detailed relationships between factors and outcomes are further discussed in the upcoming sections.

TABLE I. Effect of Major Factors of Concrete Grinding on Noise Exposure Levels Using Four-Way Analysis of Variance

Outcome	Factors	F	p
Minute Average Noise Level (Lavg, dBA)	General Ventilation	21.4	<0.01
	Grinding cup wheel size	119	<0.01
	Control method	60.3	<0.01
	Grinding position	8.34	<0.01
Minute Peak Noise Level (dBC)	General Ventilation	21.7	<0.01
	Grinder cup wheel size	58.3	<0.01
	Control method	83.8	<0.01
	Grinding position	4.30	<0.05

General ventilation: on, off; Grinding cup wheel size: 4- (100), 5- (125) or 6- (150) inch (mm); Grinding (surface) position: horizontal, inclined; Control methods: uncontrolled-grinding, wet-grinding, Shop-Vac, HEPA-tank, HEPA-Cyclone.

Comparing Noise Levels for Dust Control Methods

The Eibenstock Concrete Grinder

This type of grinder was used for a few extra LEV-grinding sessions. The noise levels generated by using this grinder were similar to those of LEV methods equipped with HEPA vacuum; therefore, the related data were combined with those of LEV-HEPA-tank.

Average Noise Levels

Analysis of variance with post-hoc LSD showed no difference among the means of minute TWA noise levels for uncontrolled grinding, wet-grinding, and grinding with LEV-Shop-Vac. Grinding with LEV-HEPA-Cyclone produced significantly ($p < 0.05$) lower noise levels than did grinding with LEV-HEPA-tank. Noise levels generated by LEV-HEPA-Cyclone and LEV-HEPA-tank were significantly ($p < 0.01$) lower than those generated by the uncontrolled grinding, wet-grinding, and grinding with LEV-Shop-Vac.

Peak Noise Levels

Analysis of variance showed significant ($p < 0.01$) differences among the mean noise levels of the control methods.

TABLE II. Task-Specific Noise Exposure During 52 Surface Concrete Grinding Sessions by General Ventilation, Dust Control Method, and Grinding Cup Wheel Size

GV	Dust Control Method	Grinding Cup Wheel Size, Inch (mm)	N	Minute Peak Noise Level (dBC) Mean ± SD (Min-Max)	Minute Average Noise Level (Lavg, dBA) Mean ± SD (Min-Max)
Off					
	Uncontrolled-grinding	6 (150)	48	121 ± 8 (110–149)	102 ± 4.1 (94.3–110)
		5 (125)	20	112 ± 8 (105–139)	93.6 ± 2.4 (90.5–99.3)
		4 (100)	29	111 ± 4 (107–129)	92.9 ± 1.1 (90.2–94.9)
	Wet-grinding	6 (150)	158	117 ± 5 (110–140)	100 ± 2.2 (87.9–105)
		5 (125)	54	110 ± 4 (105–122)	95.4 ± 2.5 (88.9–101)
		4 (100)	23	110 ± 4 (107–124)	94.3 ± 1.4 (90.3–97.7)
	LEV-Shop-Vac	6 (150)	56	113 ± 3 (110–124)	98.2 ± 1.2 (95.6–104)
		5 (125)	25	110 ± 5 (104–119)	95.6 ± 3.7 (91.5–102)
	LEV-HEPA-tank	6 (150)	149	112 ± 2 (107–122)	97.5 ± 1.4 (94.8–101)
		5 (125)	226	111 ± 3 (105–117)	95.2 ± 2.3 (86.9–101)
		4 (100)	154	110 ± 4 (105–124)	95.1 ± 3.6 (84.3–100)
On					
	Uncontrolled-grinding	6 (150)	22	124 ± 9 (118–149)	103 ± 3.7 (93.5–113)
		5 (125)	22	120 ± 9 (110–150)	101 ± 3.9 (89.7–110)
		4 (100)	23	118 ± 13 (111–153)	98.9 ± 4.7 (94.9–112)
	Wet-grinding	6 (150)	82	114 ± 3 (110–120)	98.1 ± 1.9 (91.0–101)
		5 (125)	96	116 ± 3 (109–123)	98.5 ± 2.5 (87.8–105)
	LEV-Shop-Vac	6 (150)	58	115 ± 4 (110–129)	99.6 ± 2.1 (92.3–109)
		5 (125)	31	115 ± 2 (111–120)	99.4 ± 11 (97.0–102)
	LEV-HEPA-tank	6 (150)	77	113 ± 2 (108–124)	96.4 ± 1.0 (93.3–98.5)
		5 (125)	218	112 ± 3 (105–127)	96.3 ± 2.2 (89.5–103)
		4 (100)	123	112 ± 3 (105–117)	96.5 ± 2.7 (90.0–101)
	LEV-HEPA-Cyclone	6 (150)	21	109 ± 6 (104–126)	92.9 ± 0.8 (91.3–94.3)

GV = general ventilation; N = number of minute-samples; LEV = local exhaust ventilation; HEPA = high-efficiency particulate air filter.

The post-hoc LSD test indicated that the peak noise levels were significantly ($p < 0.01$) reduced in the following order: uncontrolled-grinding, wet-grinding, LEV-Shop-Vac, LEV-HEPA-tank, and LEV-HEPA-Cyclone.

Effects of General Ventilation and Concrete Slab Position on Noise Levels

The task-specific noise levels generated using different dust control methods and grinding cup wheel sizes, while the GV is off or on, can be examined in Table II. Overall, the minute Lavg was approximately 1 dB higher when the GV was on ($n = 773$) than when the GV was off ($n = 942$), a significant difference ($p < 0.01$). This was the case for both the minute Lavg (97.2 ± 3.1 vs. 96.5 ± 3.5 dBA) and the minute peak noise level (113.6 ± 5.0 vs. 112.4 ± 5.0 dBC).

The task-specific mean noise levels were approximately 0.5 dB, higher ($p < 0.05$) when grinding was performed in an inclined position rather than horizontal position. This was the case for both the minute TWA (97.3 ± 3.9 vs. 96.9 ± 2.6 dBA) and the minute peak noise (113.4 ± 6.5 vs. 112.7 ± 3.8 dBC).

Climatic Conditions

The ambient temperature within the Lab averaged approximately 14°C (57°F), with relative humidity of approximately 47% with little variation during each day.

Exposure Assessment

The findings of this study (Table III) revealed that hand-held concrete surface grinding in an enclosed area could expose an operator to higher noise levels than the OSHA permissible exposure limit (PEL).[1] The operator would be overexposed almost 100% of the time to continuous noise of 90 dBA during any task-specific grinding types that would last for an 8-hour period. The operator would also be overexposed up to 13% of the time to peak noise of 140 dBC during uncontrolled task-specific grinding activities.

According to OSHA,[11] the estimated exposure while using a single hearing protector is calculated using "protected dBA = unprotected dBA − [(NRR – 7) × 50%]." Assuming an 8-hour exposure at the overall mean Lavg of 96.8 dBA during grinding, and knowing that the earplug used in this study had a noise reduction rating (NRR) of 33 dB, the "protected dBA" in our study would be "96.8 – [(33 – 7) × 50%] = 83.8

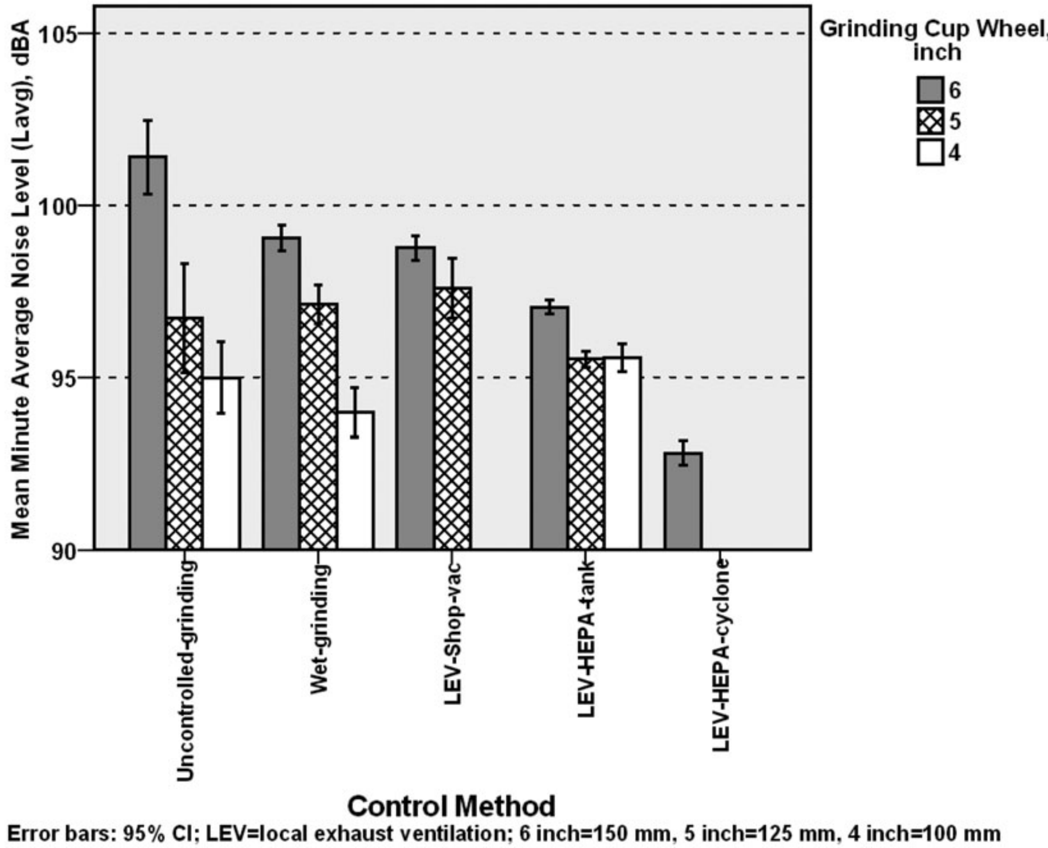

FIGURE 3. Minute average noise levels (Lavg) by dust control methods, grinding cup wheel size, and general ventilation system during concrete grinding in an enclosed area.

dBA," which is below OSHA limits.[1] The helmet-powered air-purifying respirator also provided additional noise protection to the operator. Peak noise levels should also be controlled by using these personal protective equipment (PPE).

Related Studies and Available Noise Control Options

Our literature search revealed that studies addressing noise exposure during hand-held concrete grinding in enclosed areas were scarce. It seemed, however, that awareness of the noise problems of hand and power tools dates back to the early 1980s.[12] Heisel and Gärtner,[13] while reporting on noise reduction of hand-held metal grinders, indicated high noise emissions well over 90 dBA; the levels even reached 115 dBA inside enclosed areas such as tanks. Elstad et al.[7] conducted a study to identify, design, and evaluate various noise control approaches in reducing employee noise exposure to hand-held metal grinding tools. Prior to the implementation of any noise reduction methods, employee noise exposures were typically in excess of 100 dBA. After the application of various control and evaluation approaches on different models and manufacturers of grinders, the average exposure of workers was reduced to less than 90 dBA. The major control techniques in their study included grinder booth noise enclosure by providing attenuation panels, on the sides and rear, with extended heights and sides; new grinder tools equipped with noise control devices such as mufflers to attenuate noise levels; and matting on grinder table surfaces. Attenuation panels and matting, however, seem more specific to metal grinding rather than to most concrete grinding situations.

Controlling vibration appears to be one major engineering method in reducing the noise of hand-held grinding tools. Greenslade and Larsson[14] reported that better tool design reduced vibration during hand-held grinding. Specifically, the availability of grinders with an automatic balancing device, the advances in anti-vibration grinders, and less vibration-prone grinding wheels reduced vibration and consequently decreased noise levels. The results of a case study of the noise generated by a hand-held angle grinder while running idle[15] showed that the overall free field noise level of the fully assembled grinder was 87 dBA with an overall noise generation level of 98 dB. The diffuse field measurements resulted in sound pressure and sound power levels of 92 dBA and 95 dB, respectively. The main contributors to the overall noise level were identified by applying multiple scenarios, which consisted of a step-by-step removal of components of the grinder such as the grinding wheel, guard, handle, rear housing, and gear housing. The results indicated that the main sources of noise were the motor and motor cooling system.

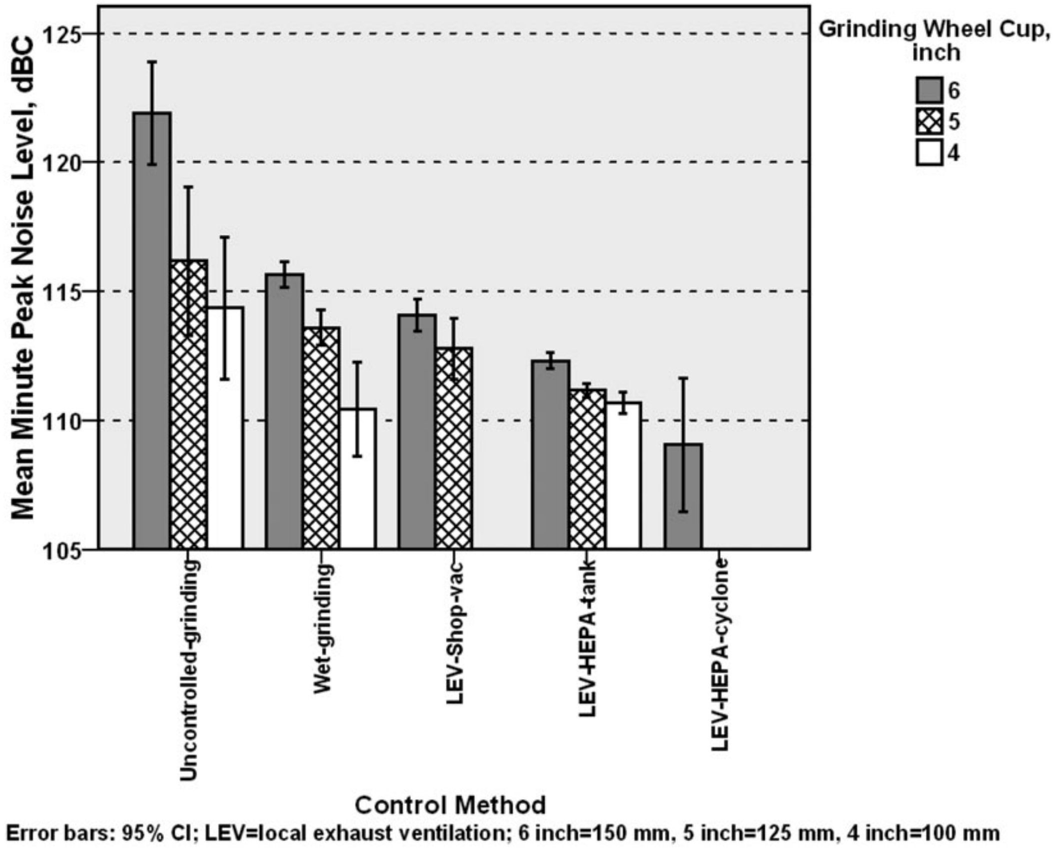

FIGURE 4. Minute peak noise levels by dust control methods, grinding cup wheel size, and general ventilation system during concrete grinding in an enclosed area.

In a noise management data sheet for angle grinders, the Government of Western Australia[8] reported that all free-running angle grinders tested since 1984 generated noise levels in excess of 85 dBA and therefore required the use of hearing protectors. The data sheet recommended various noise control options such as dampening the vibration of the material being ground or cut (e.g., clamping as close as possible to the work area); where possible, using the tool outside any confined areas (being aware of noise annoyance to adjacent areas); lining surfaces adjacent to the grinding bay with acoustic absorption materials for decreasing reflected noise; and using mobile screens around the work area for decreasing the transmission of noise. Extensive supervision may also be necessary with these tools.

Eaton[5] investigated major construction noise sources and the noise exposure of construction workers as well as the practical engineering control methods for reducing the noise at the source. The results confirmed that construction tools (including hand-held grinders) and machinery were relatively noisy, but (in general) noise control possibilities on construction sites were limited. Eaton's[5] investigation also confirmed that little action seemed to be implemented by manufacturers to reduce noise at the source except by a few or where required by law. The researcher emphasized that construction companies usually rent some tools from equipment suppliers with no liberty to enhance the tools.[5]

Noise generated by hand-held grinders could also be controlled by ensuring that bearings and brushes are in good operational order and the grinding cup wheel (blade) guard is securely fitted and not rattling. The correct disc for the task should be chosen: worn or out-of-round discs are not only unsafe, they also produce more noise than those in good condition.[8]

The surrounding structure and surfaces of a workplace can significantly influence the levels of noise exposure. In our study, the walls (except for the front entrance), floor, and ceiling of the enclosed Lab were all constructed of concrete material with low sound-absorbing properties. Therefore, the results of our study may have slightly overestimated the noise level since a concrete structure with low sound-absorbing properties has an increased level of noise compared to the conditions when internal surfaces are made of high-absorbing material. This slight overestimation can be quantified, but it is beyond the scope of this report.

There seem to be limited reports on the influence of sound properties of enclosed areas on overall noise levels during concrete grinding. However, Gorai et al.[16] offered a design of enclosure of a grinding machine for the noise attenuation

TABLE III. Percentage of Noise Exposure Exceeding the Occupational Safety and Health Administration (OSHA) Criteria, Assuming That a Particular Task-Specific Grinding Activity Lasted for the Time Period Specified

GV	Dust Control Method	Grinding Cup Wheel Size, Inch (mm)	N	% Minute Peak Noise ≥ 140 dBC	% Minute Lavg (dBA), ≥ 90 8-hr	95 4-hr	100 2-hr	105 1-hr
Off	Uncontrolled-grinding	6 (150)	48	6.3	100	98	60	33
		5 (125)	20	0	100	25	0	0
		4 (100)	29	0	100	0	0	0
	Wet-grinding	6 (150)	158	0	99	97	44	0
		5 (125)	54	0	96	52	1.9	0
		4 (100)	23	0	100	22	0	0
	LEV-Shop-Vac	6 (150)	56	0	100	100	1.8	0
		5 (125)	25	0	100	32	28	0
	LEV-	6 (150)	149	0	100	97	2.0	0
	HEPA-tank	5 (125)	226	0	100	51	2.2	0
		4 (100)	154	0	99	42	1.9	0
On								
	Uncontrolled-grinding	6 (150)	22	9.1	100	95	91	9.1
		5 (125)	22	9.2	95	95	73	9.1
		4 (100)	23	13	100	96	1.3	1.3
	Wet-grinding	6 (150)	82	0	100	96	1.8	0
		5 (125)	96	0	97	97	21	0
	LEV-Shop-Vac	6 (150)	58	0	100	98	40	1.7
		5 (125)	31	0	100	100	29	0
	LEV-	6 (150)	77	0	100	94	0	0
	HEPA-tank	5 (125)	218	0	100	67	3.7	0
		4 (100)	123	0	100	63	4.9	0
	LEV-HEPA-Cyclone	6 (150)	21	0	100	0	0	0

GV = general ventilation; N = number of minute-samples; Lavg = average noise level; hr = hour; LEV = local exhaust ventilation; HEPA = high-efficiency particulate air filter.

during stone grinding. These authors discussed different noise-absorbing materials and found that the sound-absorbing capacity (in all octave bands) was maximum for rubber, followed by thermocol and then by wood. The sound level attenuated more when the pieces of material were laid in a circular pattern (compared to other patterns) on the inside of the enclosure. The authors concluded that the data collected were quite small and the experiment provided only an outline to some materials and methods for a need-based enclosure. The enclosed areas, where most of the concrete grinding activities are performed, are not chosen and the surfaces cannot be modified by the operator, as was the case in our study.

Personal protective equipment recommended during concrete grinding activities may include total face coverage, a respirator, fire resistance clothing, (anti-vibration) gloves, and hearing protection.[12] Fine concrete dust can produce an explosion hazard; therefore all work areas should be kept organized and clean and vacuumed accordingly to reduce dust accumulation. Insulated machinery housing also helps to reduce noise. Hand-held tools with shock-resistant handles prevent vibration and hand fatigue for better ergonomics.[14] Tools with ground fault circuit interrupters (GFCI) prevent electric shock.

CONCLUSION

Noise levels, either in minute average noise (Lavg, dBA) or in minute peak (dBC), during concrete grinding were significantly ($P < 0.01$) correlated with general ventilation (on, off); dust control methods (uncontrolled, wet, shop-Vac, HEPA, HEPA-Cyclone); grinding cup wheel (blade) sizes of 4-inch (100 mm), 5-inch (125 mm), and 6-inch (150 mm); and surface orientation (horizontal, inclined). Overall, minute Lavg (dBA) during grinding was 96.8 ± 3.4 (mean ± SD) ranging from 81.0 to 111. The levels of minute Lavg during uncontrolled grinding or wet-grinding were significantly higher than those during local exhaust ventilation (LEV) grinding. A 6-inch grinding cup wheel generated significantly higher Lavg than did 5-inch or 4-inch cup wheels. The minute peak noise levels (dBC) during grinding were 113 ± 5.2 ranging from 104 to 153. The levels of minute peak noise levels during uncontrolled grinding were significantly higher than those during wet-grinding and LEV-grinding. A 6-inch grinding cup wheel generated significantly higher minute peak noise levels than 5-inch or 4-inch cup wheels. Assuming an 8-hour work shift, the results suggested that noise exposure levels during concrete grinding in enclosed areas could exceed PELs and workers should be protected by engineering control methods, safe work practices, and/or personal protective devices[(17)]

ACKNOWLEDGMENTS

This research project was partially funded by the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention (Grant # 1 R01OH009271-01). However, the findings in this report do not necessarily reflect the views of these agencies and no official endorsement should be inferred. Cynthia D. Wagner, Joshua Otiso, Robert Funa, and Amie Anschutz assisted with field data collection and data entry and verification. Duffey Concrete Cutting Inc. (Toledo, Ohio) provided the field lab space, concrete grinding operator, and field technical assistance.

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