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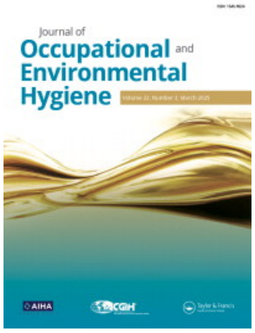

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REPORT

Hazardous exposures and engineering controls in the landscaping services industry

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ABSTRACT

Landscapers are exposed to noise, carbon monoxide (CO), respirable dust, and respirable crystalline silica (RCS) generated from the tools they use. Although engineering controls are available to reduce these exposures, no previous study has evaluated chronic exposures to landscapers in different work settings and compared exposures from landscaping tools with and without engineering controls. This field study of workers in the landscaping services industry documented the occupational exposures of 80 participants at 11 varied worksites to noise, CO, respirable dust, and RCS using personal breathing zone sampling. Results were analyzed using SAS/STAT 14.1. Analysis of variance was used for normally distributed data; otherwise, nonparametric methods were used. Most workers were overexposed to noise, with 94 of the 119 8-hr time-weighted average (TWA) noise exposures at or above the National Institute for Occupational Safety and Health (NIOSH) recommended exposure limit (REL) of 85 dBA. There were no statistically significant differences among different locations or occupations. No 8-hr TWA exposures to CO above the NIOSH REL were measured. Overexposures to RCS were measured at all locations where hardscaping (installing or maintaining non-living aspects of the landscape) was taking place. This is the first known field study of this type to include hardscapers. The use of engineering controls such as dust capture or wet methods would reduce RCS exposures, but respiratory protection may still be needed. Task-based analysis of noise and CO exposure revealed that the loudest landscaping tools used in this study were hardscaping table saws, gas chainsaws, gas leaf blowers, chipper/shredders, gas string trimmers, and fuel mowers. Workers were exposed to significantly more noise and CO when using fuel-powered versions compared to battery-powered versions of leaf blowers, string trimmers, and chainsaws.

KEYWORDS
Carbon monoxide; hardscaping; landscaping; noise; respirable crystalline silica; respirable dust

Introduction

Landscaping is one of the more hazardous industries in the United States. The U.S. Bureau of Labor Statistics (BLS) reported a rate of occupational injuries and illnesses of 3.2 per hundred full-time equivalent employees (FTEs) in 2021, 18.5% higher than the rate for all private industries of 2.7 (BLS 2022). A study (Kearney and Imai 2023) of grounds maintenance worker deaths from 2016 through 2020 revealed that the average fatality rate was 16.6 per 100,000 FTEs, compared to 3.5 for all workers. Over 80% of fatally injured Hispanic grounds maintenance workers were foreign-born. The landscaping services industry (North American Industry Classification System, NAICS, code 56173) is a large and diverse industry. Job descriptions in the landscaping services industry include landscape construction and maintenance, grounds maintenance, tree care services, lawn and cemetery care, right of way maintenance, seasonal property maintenance (such as snow removal), weed control (except crop), and design and installation of walkways, retaining walls, ponds, and similar features (NAICS 2024).

Occupations in the landscaping services industry may have many different names, but some of the major designations are landscapers, groundskeepers, arborists, and hardscapers (BLS 2023; ICPI 2024). Landscapers service many different residential and commercial properties for a variety of customers, often traveling long distances between sites during a

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working day. Although they perform similar tasks, groundskeepers are attached to one institution. The grounds of that institution may be spread across several sites, but they are often nearby (BLS 2023).

Landscapers and groundskeepers may perform some limited tree care, but this task is the main focus for arborists. Arborists trim and fell trees and may diagnose and treat tree diseases (BLS 2023). Hardscaping is a specialty of landscaping that focuses on the non-living aspects of a landscape, including driveways, walkways, steps, patios, and retaining walls (ICPI 2024).

By its nature, nearly all landscaping work takes place outdoors, where workers experience heat, cold, and other adverse weather conditions. Other hazards include the risk of injury from the use of hand and power tools, lifting heavy objects, falls, electrocution, animal and insect bites and stings, and motor vehicle incidents (OSHA 2020). Although the risks of physical hazards such as falls, injuries from power equipment, and electrocution have been well-recognized in this industry (Alexander et al. 2021, 2022), some risks due to chronic exposures have been overlooked or poorly characterized. These include exposure to loud noise and hazardous substances such as carbon monoxide (CO), respirable dust, and respirable crystalline silica (RCS). Such exposures can lead to chronic illnesses including hearing loss, hypertension, cardiovascular disease, and respiratory illness (Brook et al. 2010; Claeys et al. 2017; Münzel et al. 2017; Kerns et al. 2018; Lee et al. 2020). The results of a few landscaping industry studies give strong indications that a heavy burden of exposure is present.

Occupational noise exposure is one of the most common hazards in the United States workplace (Kerns et al. 2018). A 2016 study (Masterson et al.) showed that the industry sector, Administrative and Support and Waste Management and Remediation Services (NAICS 56), which includes landscaping services, reported a higher prevalence of hearing difficulty and tinnitus than for all industries (Masterson et al. 2016).

In a 2010 study (Meinke and LaBere), researchers measured noise exposures for 20 urban tree service workers. Although 95% of the workers were exposed above the National Institute for Occupational Safety and Health (NIOSH) recommended exposure limit (REL) and OSHA action level of 85 decibels, A-weighted (dBA), 20% of the workers never wore hearing protection. Only 15% were covered by an employer hearing conservation program. According to the authors, some of the issues complicating the implementation of a hearing conservation program in this worker population include changing work environments, variable noise exposures, unsupervised personnel, and self-employment.

Two studies (Balanay et al. 2016a, 2016b) of the noise exposure of university groundskeepers showed that many of the 8-hr time-weighted average (TWA) exposures exceeded the NIOSH REL. Measured 8-hr TWA noise exposures of groundskeepers ranged from 67.2 to 102.9 dBA (Balanay et al. 2016b). In a 2020 study (Cavallari et al. 2020), the noise exposures of 17 transportation road maintenance and repair workers were monitored for 3 days during brush-cutting activities. Eight-hour TWA exposures measured according to ISO criteria (similar parameters to the NIOSH REL) averaged 90.8 dBA, exceeding the limit of 85 dBA. Tools used included fuel-burning chainsaws, leaf blowers, and a wood chipper. Average 1-min noise exposures for the tools during use ranged from 90.3 to 92.1 dBA. These tools are often used by landscapers in other settings as well, and their exposures are almost certainly comparable.

Two-stroke engines are used in most chainsaws, string trimmers, leaf blowers, and some lawnmowers. CO emissions from these engines accounted for 4.8% of total U.S. CO emissions in 2005 (Volckens et al. 2007). Their emissions of fine particulate matter are also high (Volckens et al. 2007). This suggests that CO exposure to landscapers, who often work with two-stroke engines, may also be high.

Three studies of the exposure of loggers to CO were located (Bünger et al. 1997; Leszczynski 2014; Hooper et al. 2017). Bünger et al. measured (Bünger et al. 1997) carboxyhemoglobin levels of 14 loggers using two-stroke chainsaws. Many times during their shifts, the carboxyhemoglobin levels of the loggers exceeded the American Conference of Governmental Industrial Hygienists (ACGIH) Biological Exposure Limit (BEI) of 3.5% (ACGIH 2023). Short-term exposures well above the NIOSH ceiling limit of 200 parts per million (ppm) for CO (NIOSH 2010) were recorded. Two additional studies (Leszczynski 2014; Hooper et al. 2017) measured elevated carbon monoxide levels in the breathing zones of loggers during the use of chainsaws. An EPA study (Baldauf et al. 2006) of exposures during the use of lawn and garden equipment under controlled conditions documented elevated and fluctuating exposures to CO during the use of fuel-burning lawnmowers, chainsaws, and string trimmers. Landscapers may also be exposed to carbon monoxide when using similar tools.

The National Association of Landscape Professionals (NALP 2016) recognized that the 2016 reduction in the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) for RCS would impact “landscape companies that drill, cut, crush, or grind silica-containing materials such as concrete and stone." Hardscapers may be at particular risk for exposure to RCS, as hardscapers often cut silica-bearing materials during the construction of walkways, retaining walls, and patios. These materials are frequently cut dry, without engineering controls, releasing hazardous quantities of respirable dust and RCS into the air (Alexander et al. 2022). Exposure to RCS can cause serious illness, including silicosis, lung cancer, and an increased risk of contracting tuberculosis (NIOSH 2002).

NIOSH research into RCS exposure in the construction industry revealed high exposure during certain tasks (Alexander et al. 2022). Many of the tasks performed by hardscapers, such as cutting brick, block, and stone, are similar to some tasks in construction. RCS exposures can be reduced greatly by the implementation of engineering controls (Alexander et al. 2022).

Starting in 2024, the state of California is requiring new small off-road engines sold in the state, such as the engines used in landscaping tools and equipment, to have zero emissions (CARB 2024). Several cities across the country, including Washington, DC, Evanston, Illinois, and Miami Beach, Florida, have banned the use of gasoline-powered leaf blowers (Chiu 2023). As a result, landscapers are increasingly converting to the use of battery-powered tools and equipment. It is essential to know what impact this conversion will have on exposure to landscapers.

Objective

The purpose of this field study was to assess occupational exposures of landscaping services industry employees to noise, CO, respirable dust, and RCS under actual working conditions, in many different types of worksites and different regions of the United States. Personal breathing zone sampling was performed to measure worker exposures during a normal working day, using direct reading instruments to measure CO and noise exposures. A single dust sample was collected daily to evaluate exposures to respirable dust and respirable crystalline silica. This is the first study to evaluate chronic exposures to landscaping services industry employees across a wide range of different work settings and to compare exposures from landscaping tools with and without engineering controls, such as battery power.

Methods

According to the hierarchy of controls, (NIOSH 2023) where a hazard cannot be eliminated or a lesser hazard substituted, the use of engineering controls is preferred to administrative controls or personal protective equipment (PPE). For example, substituting battery-powered tools for tools with combustion engines can eliminate CO exposure and reduce noise exposure. Adding dust capture or using wet methods when grinding or sawing brick, block, and stone can reduce exposure to respirable dust and RCS (Alexander et al. 2022).

Instrumentation

Personal breathing zone sampling was used to characterize worker exposure to noise, CO, respirable dust, and RCS. Up to 10 participating workers at each worksite wore three small sampling devices on their clothing during one to three normal working days. Whenever possible, sampling was conducted for the entire working day.

Instrumentation-noise

Personal noise dosimetry was conducted with Larson Davis Spartan (Larson Davis, Depew, NY) model 730 datalogging noise dosimeters, which conform to the American National Standards Institute (ANSI) S1.25-1991 Specification for Personal Noise Dosimeters (R2017). Spartan noise dosimeters have a range of 52–140 dBA. Dosimeter parameters were set to measure according to the OSHA PEL and hearing conservation limits, ACGIH Threshold Limit Value (TLV), and the NIOSH REL. Dosimeters were calibrated daily at 1,000 Hz using a Larson Davis CAL150 (Larson Davis, Depew, NY) calibrator. The noise was logged once per second. Noise data were downloaded using G4 LD Utility software (PCB Piezotronics Inc., Depew, NY).

Instrumentation-carbon monoxide

CO concentrations were measured using the GasAlert Extreme (Honeywell International, Lincolnshire, IL) single gas monitor, operating in stealth mode, with alarms silenced. These detectors use an electrochemical cell to measure CO and were calibrated according to the manufacturer's instructions and bump tested daily using a MicroDock II (Honeywell International, Lincolnshire, IL) connected to a cylinder of 100 ppm CO in nitrogen. The detectors are capable of measuring CO levels of 0–1,000 ppm. CO was logged once every 5 s. CO data were downloaded using Safety Suite Device Configurator software (Honeywell International, Lincolnshire, IL).

Instrumentation-dust

Personal breathing zone respirable dust and RCS (50% cut point at 4 microns diameter) air samples were collected using a Gilian GilAir Plus (Sensidyne, St. Petersburg, FL) sampling pump connected via flexible tubing to a pre-weighed 37-mm-diameter polyvinyl chloride filter supported by a backup pad in a three-piece filter cassette sealed with a cellulose shrink band (Bureau Veritas, Ft. Lauderdale, FL) and a BGI GK2.69 respirable dust cyclone (Sensidyne, St. Petersburg, FL), in accordance with NIOSH Manual of Analytical Methods #0600 and #7500 (NIOSH 2018). Filters were pre-weighed and prepared at Bureau Veritas.

One sample for both respirable dust and RCS was collected during a working day on a single filter, using an airflow rate of 4.2 liters per minute. Pumps were calibrated daily using a Bios Defender II dry calibrator (Mesa Laboratories, Inc., Lakewood, CO). Samples and unused filters as field blanks were analyzed for respirable dust and RCS by Bureau Veritas (Novi, MI).

Where bulk samples of dust were available, these were collected in a clear glass scintillation vial or a zipper-seal plastic bag and analyzed for their percent silica by Bureau Veritas (Novi, MI) according to NIOSH Manual of Analytical Method #7500 (NIOSH 2018). The particle size distribution of a bulk sample of dust produced during hardscaping was analyzed by Scanning Electron Microscopy.

Worksites

Worksites for this study were chosen to represent a wide variety of different types of landscaping work. The worksites comprised small and large, public and private employers, in 6 different states, in urban, suburban, and rural areas. They included a zoo, residential landscaping locations, a golf course, hotel grounds, athletic fields, a military base, a cemetery, a county park, a university campus, and two U.S. national parks, one urban and one rural. Data were collected in 8 different months of the year. Characteristics of participating employers are summarized in Table 1.

Participants

This study was reviewed and approved by the NIOSH Institutional Review Board (IRB - protocol #18-DART-11). See Title 45 Code of Federal Regulations (CFR) part 46; Title 21 CFR part 56. On the first day of the study at each site, the study was described to potential participants and volunteers were requested. Volunteers were eligible to participate if they were performing landscaping activities on that day. All participants signed an informed consent document.

To the extent possible, the research team observed participants during the working day to note the tasks being performed and the time at the task. These times were later matched to the levels of noise and CO that were recorded during the tasks, making it possible to attribute part of their daily noise and CO exposures to the tools and equipment being used. Because noise and CO were measured using data-logging direct-reading instruments, multiple task-based measurements of these exposures were recorded each day for the specific tool in use at the time. Although these task measurements cannot be compared to occupational exposure limits, they are useful for comparing tools and equipment. As engineering controls for CO and noise exposures, multiple different brands of battery-powered leaf blowers and string trimmers were purchased by NIOSH researchers and offered to study participants to use at several different locations. At some locations, battery-powered tools were already in use.

Data analysis

One 8-hr TWA exposure for noise, CO, respirable dust, and RCS was obtained for each participant each day, often for the performance of many different tasks. These exposures can be compared to OSHA

Table 1. Characteristics of participating employers.

Participating Employer	Size*	Public/Private	Season	Type of Work	Part of the U.S.	Location Type
A	Large	Public	Summer	Groundskeeping	West	Rural
B	Large	Public	Fall	Groundskeeping	Midwest	Urban
C	Small	Private	Winter	Hardscaping	Midwest	Urban
D	Large	Private	Spring	Arborist/Groundskeeping	Southeast	Suburban
E	Small	Private	Summer	Groundskeeping	Southeast	Suburban
F	Large	Public	Summer	Arborist	Midwest	Suburban
G	Large	Public	Spring	Groundskeeping	Northeast	Urban
H	Large	Public	Summer	Arborist/ Groundskeeping	Southeast	Urban
I	Small	Private	Spring	Groundskeeping	Midwest	Suburban
J	Small	Private	Fall	Landscaping	Midwest	Suburban
K	Large	Public	Summer	Hardscaping/ Groundskeeping	West	Rural

*For the purposes of this table, an employer is considered small if they have less than 100 employees.

PELs and NIOSH RELs. Noise exposure was compared to the NIOSH REL for noise of 85 dBA, which has the same parameters as the ACGIH TLV, as it is more protective than the OSHA PEL of 90 dBA. Similarly, CO exposure was compared to the NIOSH REL of 35 ppm, which is more protective than the OSHA PEL of 50 ppm. NIOSH has no REL for respirable dust, so exposures were compared to the OSHA PEL of 5 milligrams per cubic meter (mg/m^3). The NIOSH REL and OSHA PEL for RCS are both set at 0.05 mg/m^3.

Data were analyzed using SAS/STAT 14.1 (SAS Institute, Cary, NC). This analysis focused on assessing variations in four response variables: average noise, average CO, respirable dust, and RCS, across different occupations, settings, and tasks. The normality of the data was checked using the Shapiro-Wilk test. Data that were not normally distributed were log-transformed for analysis. For cases where the average CO concentration had zero values, a constant of 0.0001 was added before applying the log transformation (Limpert et al. 2001). Nondetectable values were treated by substituting the limit of detection divided by the square root of two.

Pairwise comparisons were made using SAS PROC GLM for analysis of variance (ANOVA), along with Tukey's multiple comparison procedure, if the data were normally distributed; if the data were not normally distributed, even after log transformation, the nonparametric method, SAS PROC NPAR1WAY (Kruskal-Wallis Test), was used to make pairwise comparisons, along with the Dwass, Steel, Critchlow-Fligner multiple comparison method. The statistical significance was set at 5%.

Results

A total of 83 landscaping services industry employees participated in this study. The data for three of these participants were excluded from the study because these three participants did not perform landscaping tasks during the working day. Of the remaining 80 participants, 59 were groundskeepers, 10 were hardscapers, 9 were arborists, and 2 were landscapers. Demographic information was not collected from the participants. They contributed 123 full days and 5 partial days of data collection.

Noise and CO exposures were documented for 919 individual tasks during the working day, with a range of task durations from 1 to 251 min. Each of these tasks was categorized into one of 66 categories, as given in Table S1 in the Supplemental Material. Due to instrument issues, the number of noise or CO measurements does not always match the number of observed tasks shown in Table S1 (Supplemental Material). The largest number of task observations were recorded for the use of gas string trimmers and gas leaf blowers, with 159 and 158 observations, respectively.

Eight-hour TWA data for comparison to exposure limits

Eight-hour TWA exposures for the 123 full days of data are summarized in Table 2. Due to instrument issues, there are less than 123 data points for each exposure. Statistical comparisons of 8-hr TWA data by occupation are summarized in Table S2 in the Supplemental Materials.

Noise

Eight-hour TWA noise data had a range of 68.90 to 104.10 dBA, and a median of 90.2 dBA, based on NIOSH REL measurement criteria. Of the 119 values collected for 8-hr TWA noise exposures for participants in this study, 94 (79%) met or exceeded the NIOSH REL of 85 dBA. Workers exposed to over 100 dBA included three hardscapers who were using electric table saws with a dust-capturing control (saw with control) to cut paving blocks, a groundskeeper who was using a gas leaf blower, and a groundskeeper who was using both gas and battery leaf blowers. Exposures to noise that were higher than the NIOSH REL were measured at every worksite where sampling was conducted.

There were no significant differences in noise exposure among landscapers, groundskeepers, hardscapers, and arborists ($p = 0.09$) (Supplemental Material, Table S2).

Carbon monoxide

Eight-hour TWA exposures to CO ($n = 111$) did not exceed the NIOSH REL of 35 ppm. The exposures ranged from 0 to 11.37 ppm. Average CO exposures greater than 10 ppm were measured for two landscapers using gas leaf blowers, a groundskeeper using a gas leaf blower, and a groundskeeper using a riding mower and gas leaf blower. The CO exposures of landscapers were found to be marginally higher than other occupations ($p = 0.054$) (Supplemental Material, Table S2). One worksite had CO exposure that was higher than two other worksites ($p < 0.0001$).

Table 2. Full-day 8-hr time-weighted average exposures for 80 landscaping services industry participants.

Exposure	N	Geometric Mean	Geometric Standard Deviation	Arithmetic Mean	Arithmetic Standard Deviation	Minimum	Maximum
Noise* (dBA)	119	89.1	1.1	89.3	6.1	68.9	104.1
Carbon Monoxide (ppm)	111	0.9	9.8	2.7	2.9	0	11.4
Respirable Dust (mg/m^3)	122	0.05	3.00	0.11	0.25	ND	2.40
Respirable crystalline silica (mg/m^3)	122	0.01	3.61	0.03	0.15	ND	1.58

*Noise was calculated according to the NIOSH REL, using a criterion level of 85 dBA, and an exchange rate of 3 dBA.
ND – not detectable, below the limit of detection for the analytical method.

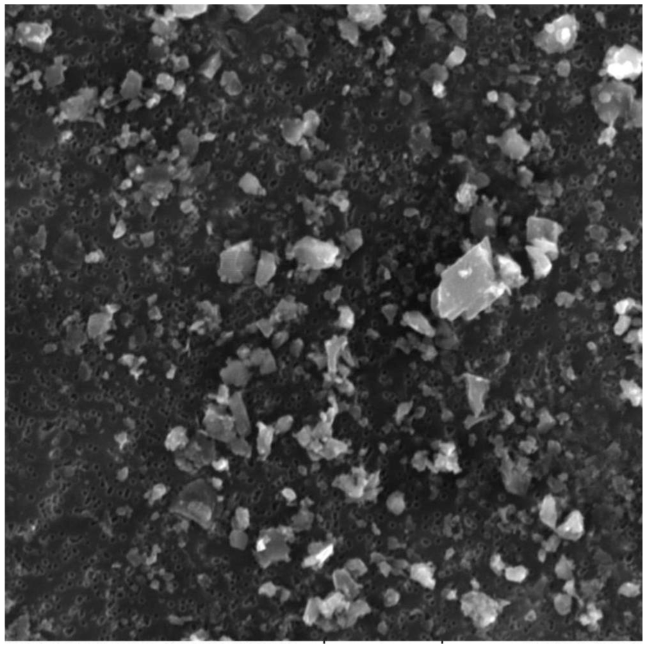

Figure 1. Scanning electron micrograph of bulk dust from dust-collecting table saw used for cutting paving blocks, magnification of 5,260×, produced by a Tescan scanning electron microscope.

Respirable dust and respirable crystalline silica (RCS)

One particulate sample was collected for each full working day and analyzed both for respirable dust and RCS. None of the 122 values for respirable dust exceeded the OSHA PEL of 5 mg/m^3. Seven of the 122 samples were below the limit of detection for respirable dust. The range of respirable dust exposures was from non-detectable to 2.40 mg/m^3. Respirable dust exposures above 0.9 mg/m^3 were measured for two hardscapers. Hardscaper exposures to respirable dust, which ranged from 0.064 to 2.40 mg/m^3, were higher ($p < 0.0001$) than those for the other three occupations (Supplemental Material, Table S2).

Ten of the 122 samples for RCS exceeded the OSHA PEL of 0.05 mg/m^3. Forty-eight of the 122 samples were below the limit of detection for RCS. The range of RCS exposures was from non-detectable to 1.58 mg/m^3.

Every hardscaper who was saw-cutting or grinding paving blocks or stone for part of the working day was exposed above the OSHA PEL for RCS ($n = 6$). Four hardscapers who were using dust-capturing table saws had a geometric mean 8-hr TWA exposure of 0.088 mg/m^3. Two hardscapers cutting and grinding materials without controls had exposures of 0.29 mg/m^3 and 1.58 mg/m^3. The other overexposures were recorded for one worker who was using a gas leaf blower, one worker using a battery string trimmer, battery leaf blower, and shoveling debris, one worker using a gas leaf blower and spreading mulch, and one worker who was using a riding mower and gas leaf blower.

A bulk sample of the dust collected in the dust-capturing table saw during paving block cutting was analyzed for particle size by scanning electron microscopy and found to consist primarily of particles between 1 and 10 microns in size. A photomicrograph of the bulk dust is shown in Figure 1.

Task data for evaluation of engineering controls

Noise and CO exposures were measured for individual tasks using direct-reading instruments, making it

Table 3. Summary of task-based noise exposures (dBA) by task category for the 30 task categories with five or more observations.

Task category	N	Geometric mean	Geometric standard deviation	Arithmetic mean	Arithmetic standard deviation	Minimum	Maximum
Battery chainsaw	11	81.1	1.04	81.1	3.31	77.0	87.8
Battery hedge trimmer	9	87.1	1.02	87.1	1.34	85.1	88.8
Battery leaf blower	39	86.2	1.06	86.4	5.02	79.7	96.7
Battery mower	10	81.9	1.06	82.0	5.18	75.3	92.5
Battery pole saw	6	81.3	1.05	81.4	4.16	76.1	88.2
Battery string trimmer	24	87.9	1.03	87.9	2.86	81.8	93.3
Carrying paving blocks	11	82.5	1.08	82.7	6.15	73.1	94.0
Chipper/shredder	27	95.9	1.09	96.2	7.22	68.6	105.0
Cleaning up	8	81.7	1.08	81.9	6.49	73.0	91.5
Driving truck	13	80.1	1.07	80.3	5.48	69.3	86.4
Fuel mower	69	91.2	1.06	91.4	5.29	78.2	102.4
Gas chainsaw	30	98.1	1.09	98.5	8.13	71.9	109.0
Gas leaf blower	157	96.8	1.06	96.9	5.39	71.8	105.9
Gas string trimmer	152	92.9	1.06	93.0	4.89	74.7	103.8
Gas string trimmer and gas leaf blower	5	94.3	1.04	94.4	3.91	89.6	99.2
Hand chisel	18	87.9	1.04	87.9	3.22	79.7	92.6
Moving stump grinder	6	90.9	1.03	91.0	3.11	86.9	95.0
Mulching	14	79.3	1.06	79.4	4.36	71.9	89.5
Near battery or manual tools	38	68.2	1.13	68.7	8.96	57.9	87.7
Near fuel tools	66	81.5	1.10	81.9	7.59	61.6	98.2
Picking up debris	26	80.0	1.08	80.2	5.83	68.9	92.1
Raking	9	82.0	1.07	82.2	5.45	72.0	89.3
Saw with control	11	107.7	1.01	107.7	1.41	105.7	111.0
Setting up	7	79.3	1.05	79.4	3.92	74.6	84.1
Shoveling	7	84.6	1.05	84.7	3.68	77.2	87.7
Smoothing sand	8	82.7	1.08	82.9	6.69	75.5	91.6
Sweeping	7	81.0	1.07	81.2	5.69	75.1	90.6
Tow-behind blower	8	85.1	1.03	85.2	2.93	82.8	90.2
Tractor	21	86.0	1.06	86.2	5.14	77.1	94.7
Utility vehicle	17	81.8	1.05	81.9	4.36	75.8	92.2

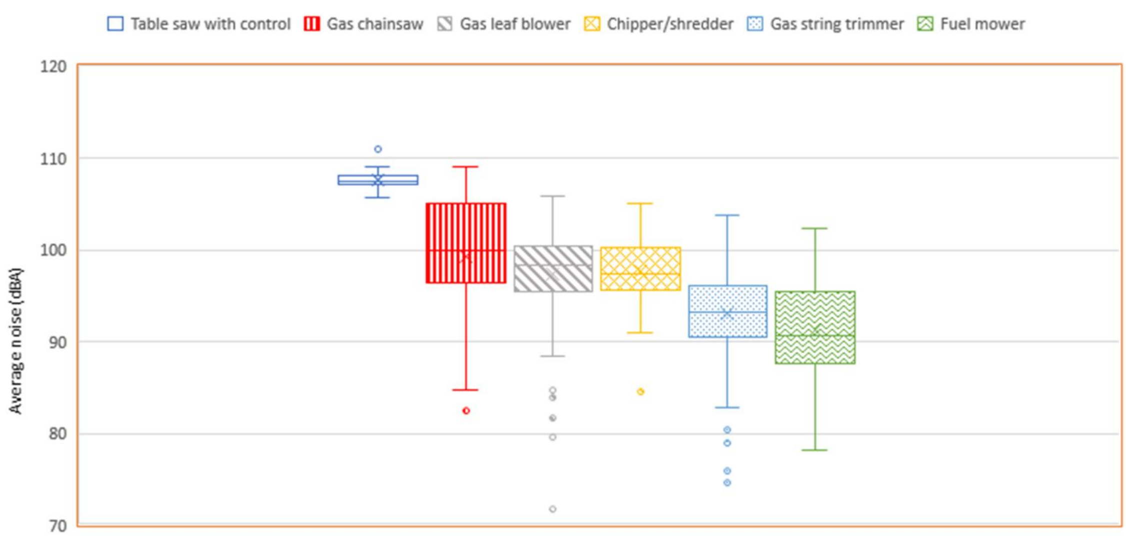

Figure 2. Box plot of noise exposures from the six tasks with the highest exposure. The height between the top and bottom "whisker" on each box indicates the range of the four quartiles of observed data; any data points outside the whiskers are outliers. The box encloses the middle two quartiles of data, while the horizontal line inside the box shows the median, and the "x" shows the mean.

possible to evaluate the performance of engineering controls such as battery power for several landscaping tools. Statistical comparisons of task-based noise and CO exposures when using different types of tools are summarized in Table S3 in the Supplemental Material.

Noise

Noise exposures for the 30 task categories having five or more observations are summarized in Table 3. One task, the use of an electric table saw with dust capture control ($n = 11$), had a geometric mean noise

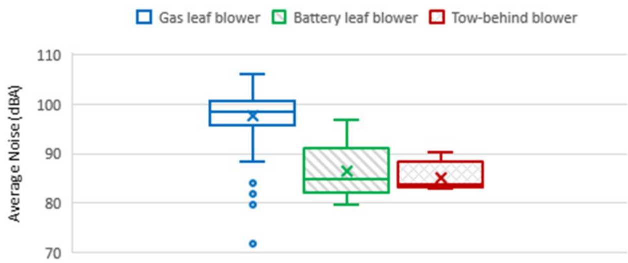

Figure 3. Box plot of noise exposures from three different types of blowers. The height between the top and bottom "whisker" on each box indicates the range of the four quartiles of observed data; any data points outside the whiskers are outliers. The box encloses the middle two quartiles of data, while the horizontal line inside the box shows the median, and the "x" shows the mean.

exposure above 100 dBA. Mean noise exposures above 95 dBA were recorded for three other tasks: use of a chipper/shredder ($n = 27$), gas chainsaw ($n = 30$), and gas leaf blower ($n = 157$). A box plot of the six tasks with the highest noise exposures is given in Figure 2. All of the tools with the highest noise exposures were fuel-powered.

Noise-leaf blowers. Gas leaf blowers were in use at 10 of the 11 sites where data were collected; battery leaf blowers were in use at four of the sites. At two additional sites, participants used battery leaf blowers provided by NIOSH for at least part of their working day. Two of the participating sites also utilized large gas-powered blowers on wheels, which were towed behind a tractor (tow-behind blower). A box plot of noise exposures for the three types of leaf blowers is given in Figure 3. The mean noise exposure of 96.9 dBA for gas leaf blowers ($n = 157$) was higher ($p < 0.001$) than those for both the battery leaf blower (86.4 dBA, $n = 39$) and the tow-behind blower (85.2 dBA, $n = 8$) (Supplemental Material, Table S3).

Noise-string trimmers. Gas string trimmers were in use at 8 of the 11 sites where data were collected; battery string trimmers were in use at three of the sites. At three additional sites, participants used battery string trimmers provided by NIOSH for part of their working day.

The mean noise exposure of 93.0 dBA for the use of gas string trimmers ($n = 152$) was higher ($p < 0.001$) than that for a battery string trimmer (87.9 dBA, $n = 24$). A box plot of string trimmer noise exposure is given in Figure 4.

Noise-chainsaws. Gas chainsaws were in use at 3 of the 11 participating worksites; battery chainsaws were used at one location. The mean noise exposure of 98.5 dBA from a gas chainsaw ($n = 30$) was higher

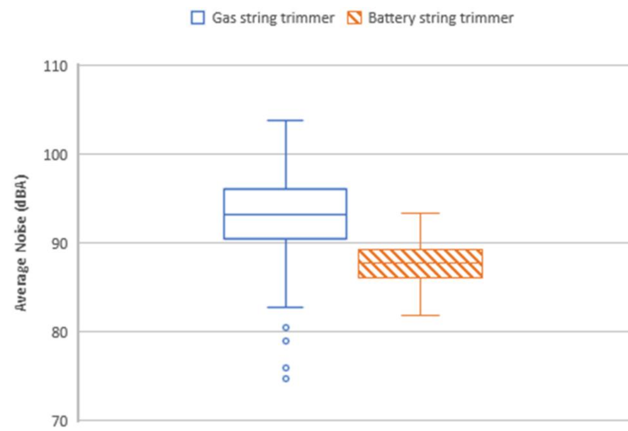

Figure 4. Box plot of noise exposures from two different types of string trimmers. The height between the top and bottom "whisker" on each box indicates the range of the four quartiles of observed data; any data points outside the whiskers are outliers. The box encloses the middle two quartiles of data, while the horizontal line inside the box shows the median, and the "x" shows the mean.

($p < 0.003$) than that from a battery chainsaw (81.1 dBA, $n = 11$).

Noise-worksites. An ANOVA found no difference in the noise exposures specifically for the use of gas leaf blowers and the use of gas string trimmers among all worksites using gas leaf blowers ($p = 0.0181$) or using gas string trimmers ($p = 0.157$). Statistical comparisons of worksite exposures when using gas leaf blowers and gas string trimmers are summarized in Table S4 (Supplemental Material).

Noise-other. The loudest task in this study was the use of an electric table saw with dust capture (saw with control) for hardscaping ($n = 11$). At this level of exposure (107.7 dBA), a worker would reach 100% 8-hr TWA dose according to the NIOSH REL in less than 3 min.

Another task resulting in high noise exposure was the use of a chipper/shredder by arborists ($n = 27$). These noise exposures, measured at three different sites, ranged from 68.6 to 105.0 dBA.

Fuel-powered mowers (gas or diesel), in use at 7 of the 11 worksites, had a mean noise exposure of over 91 dBA ($n = 69$). Most of these mowers were riding mowers. In contrast, a battery-powered push mower, used at one site, had a mean noise exposure of approximately 82 dBA ($n = 10$). It is problematic to compare the two types because of the large difference in size and power.

Many landscaping tasks are accomplished without the use of power tools. These manual tasks include mulching, raking, shoveling, sweeping, and picking up

Table 4. Summary of task-based average carbon monoxide exposures (ppm) by task category for the 28 task categories with five or more observations*.

Task category	N	Geometric mean*	Geometric standard deviation	Arithmetic mean	Arithmetic standard deviation	Minimum	Maximum
Battery chainsaw	12	0.0	1.00	0.0	0.00	0.0	0.0
Battery leaf blower	31	0.0	128.51	1.4	2.39	0.0	9.2
Battery mower	10	0.0	59.85	0.1	0.19	0.0	0.5
Battery pole saw	6	0.0	110.91	0.6	1.20	0.0	3.0
Battery string trimmer	24	0.0	55.82	0.3	0.75	0.0	3.7
Carrying paving blocks	11	0.0	115.60	0.6	1.10	0.0	3.2
Chipper/shredder	26	0.0	130.83	1.8	3.17	0.0	15.3
Cleaning up	8	0.0	121.87	1.1	2.64	0.0	7.6
Driving truck	11	0.0	226.35	2.7	4.64	0.0	14.9
Fuel mower	60	0.3	87.621	6.0	7.87	0.0	35.0
Gas chainsaw	33	0.0	362.31	10.0	20.23	0.0	103.2
Gas leaf blower	152	6.7	26.80	25.1	23.77	0.0	109.3
Gas string trimmer	142	0.2	44.19	1.8	2.40	0.0	10.7
Gas string trimmer and gas leaf blower	5	2.3	2.04	2.9	2.26	1.2	6.7
Hand chisel	18	0.0	5.17	0.0	0.03	0.0	0.1
Mulching	14	0.0	4.03	0.0	0.01	0.0	0.0
Near battery or manual tools	34	1.0	30.33	3.0	1.23	0.0	5.2
Near fuel tools	64	0.1	152.33	2.5	3.87	0.0	20.8
Picking up debris	23	0.0	86.03	1.4	3.81	0.0	13.8
Raking	7	0.0	63.77	0.5	0.59	0.0	1.5
Saw with control	13	0.7	4.10	1.6	1.69	0.1	5.0
Setting up	7	0.0	114.96	0.6	1.11	0.0	3.1
Shoveling	7	0.0	98.18	0.7	1.28	0.0	3.0
Smoothing sand	8	0.2	37.43	1.3	1.58	0.0	3.9
Sweeping	7	0.1	30.52	0.6	0.69	0.0	2.0
Tow-behind blower	6	0.2	38.97	0.7	0.66	0.0	1.8
Tractor	21	0.1	73.82	1.8	2.18	0.0	7.2
Utility vehicle	16	0.0	122.88	1.1	2.54	0.0	9.7

*Zero values had a factor of 0.0001 added to make it possible to calculate a natural logarithm of the number.

debris including trash, twigs, and branches, as well as hardscaper tasks such as carrying paving blocks and smoothing sand. During parts of a working day in this study when no specific task was recorded, it was sometimes noted that the worker was near other noisy work occurring nearby. During manual tasks or in the vicinity of noisy work, noise exposures varied over a wide range, but reached as high as 98.2 dBA.

Carbon monoxide

Average CO exposures for the 28 task categories having five or more observations are listed in Table 4. In many cases, there were large differences between the mean CO exposures and the geometric mean CO exposures, but the highest mean CO exposures were recorded for the use of gas leaf blowers ($n = 152$), gas chainsaws ($n = 33$), and fuel mowers ($n = 60$). Average CO exposures during individual tasks using a gas leaf blower reached as high as 109.3 ppm; during gas chainsaw tasks as high as 103.2 ppm; and during fuel mower tasks as high as 35.0 ppm.

While many manual tasks and/or the use of battery-powered tools did not produce any CO, nearby activities had an impact on exposures. Task-based CO exposures when not using fuel-powered tools reached as high as 20.8 ppm when working near others using fuel-powered tools.

Multiple brief, high spikes of carbon monoxide exposure (greater than 200 ppm) were recorded during various tasks using fuel-powered tools; in two cases, the CO meter reached its instrument maximum reading of 1,000 ppm. The highest spikes of CO were recorded during the use of gas chainsaws and gas backpack leaf blowers, although there were many tasks using the same tools that did not generate high spikes of CO.

Carbon monoxide-leaf blowers. Mean task-based CO exposures of gas leaf blowers (25.1 ppm, $n = 152$) were higher ($p < 0.001$) than those from battery leaf blowers (1.4 ppm, $n = 31$) and tow-behind blowers (0.7 ppm, $n = 6$) (Supplemental Material, Table S3). There was no difference between battery leaf blowers and tow-behind blowers.

Carbon monoxide-string trimmers. Mean task-based CO exposures of workers using gas string trimmers (1.8 ppm, $n = 142$) were higher ($p < 0.0001$) than battery string trimmers (0.3 ppm, $n = 24$) (Supplemental Material, Table S3).

Carbon monoxide-chainsaws. A comparison of task-based CO exposures for gas- and battery-powered chainsaws showed that mean CO exposures for gas-

Table 5. Task-based carbon monoxide exposures when using gas leaf blowers or gas string trimmers by worksite for worksites with five or more observations.

Task category	Participating Employer	N	Geometric mean	Geometric standard deviation	Arithmetic mean	Arithmetic standard deviation	Minimum	Maximum
Gas leaf blower	A	95	12.6	24.08	34.5	25.06	0.0	109.3
Gas leaf blower	B	21	14.6	1.43	15.5	5.44	8.2	28.3
Gas leaf blower	G	10	0.5	86.39	3.3	2.30	0.0	6.8
Gas leaf blower	H	13	0.2	40.65	1.5	1.70	0.0	5.1
Gas leaf blower	J	7	18.5	1.37	19.2	5.72	10.4	28.1
Gas string trimmer	A	61	0.1	57.80	1.0	1.22	0.0	4.5
Gas string trimmer	E	27	3.3	2.88	4.7	3.04	0.3	10.7
Gas string trimmer	G	38	0.1	43.15	0.7	1.31	0.0	5.6
Gas string trimmer	I	5	1.4	1.49	1.5	0.69	0.9	2.7

powered chainsaws (10.0 ppm, $n = 33$) were higher ($p < 0.003$) than those for battery chainsaws (0.0 ppm, $n = 12$) (Supplemental Material, Table S3).

Carbon monoxide-worksites. Task-based CO exposures specifically while using gas leaf blowers and gas string trimmers (Table 5) were compared among the different worksites in the study. Three of the worksites had higher CO exposures ($p < 0.0001$) compared to other sites (Supplemental Material, Table S4). At these three worksites, up to ten workers were using gas leaf blowers side-by-side for some or all of their gas leaf blower tasks. The mean CO exposure when using leaf blowers at these three sites ranged from 15.5 to 34.5 ppm, while the range at other sites was from 0.5 to 7.8 ppm.

A comparison of CO exposures during the use of gas string trimmers found that one worksite had higher mean CO exposures (4.7 ppm, $p < 0.0001$) than two other worksites (1.0 ppm, 0.7 ppm) (Supplemental Material, Table S4). At the worksite with higher exposure, some workers used string trimmers nearly continuously during the working day.

Discussion

This is the first field study to evaluate the exposures of landscaping industry workers to noise, carbon monoxide, respirable dust, and RCS under a wide range of actual working conditions, and to include tools and equipment incorporating engineering controls. The engineering controls in this study were battery-operated tools to eliminate carbon monoxide exposure and reduce noise exposure, as well as saws for brick, block, and stone that incorporate dust capture.

This study demonstrates that the use of engineering controls can lead to reduced exposure to noise, CO, and RCS for workers.

Noise

There is a heavy burden of noise exposure across the landscaping services industry as evidenced by the results of this study. Even those workers who were not using power tools were sometimes exposed to noise above the REL during the working day as a result of activities taking place nearby. One hardscaping worker who performed only manual tasks such as moving paving blocks while the electric table saw was in use nearby had an 8-hr TWA noise exposure of 90.0 dBA.

The results of this study agree well with earlier research into landscaping industry noise exposure, which also found high exposures (Meinke and LaBere 2010; Balanay et al. 2016a, 2016b). In addition, the results of this study show that the engineering control of using battery-powered tools in place of fuel-powered tools is effective in reducing worker exposure to noise, with a difference in geometric mean exposure of 17.0 dBA for chainsaws, 10.6 dBA for leaf blowers, and 5.0 dBA for string trimmers.

Although battery-powered tools reduced worker exposure to noise, mean noise exposures in this study still exceeded the NIOSH REL when using battery-powered leaf blowers, string trimmers, and hedge trimmers, indicating the need for hearing protection.

While large companies participating in this study had OSHA-mandated hearing conservation programs in place for their employees, there is a great need for increased awareness and implementation of hearing conservation programs in small landscaping services companies. None of the small companies participating in this study had hearing conservation programs in place, and in fact, most of them were unaware of such programs.

Carbon monoxide

Although 8-hr TWA exposures to CO did not exceed the NIOSH REL, elevated mean exposures to CO

($>$5 ppm) were measured during the use of gas-powered chainsaws, leaf blowers, and fuel-powered mowers. A 2020 meta-analysis of studies on the relationship between ambient carbon monoxide levels and the risk of myocardial infarction found a pooled risk ratio for myocardial infarction of 1.052 per 1 mg/m^3 (0.87 ppm) increase in CO concentration (Lee et al. 2020). Conversion to the use of battery-powered chainsaws and leaf blowers could reduce this health risk for landscaping services workers.

Some high spikes of CO were measured, especially during the use of gas chainsaws and gas backpack leaf blowers, although these spikes were not always observed when these tools were in use. Varying wind direction and speed can be a factor in whether spikes are observed. The age of the tools, preventive maintenance done on the tools, and whether they were warmed up or not may also affect their production of CO when in use. These spikes of CO exposure could be eliminated by switching to battery-powered tools.

Respirable dust and respirable crystalline silica (RCS)

The highest exposures to respirable dust and RCS were measured for hardscapers who were saw-cutting or grinding stone or block. Engineering controls such as local exhaust ventilation for dust capture or wet methods are often not utilized in this landscaping specialty. Although workers using a dust-capturing table saw during this study expressed the opinion that it had greatly reduced their dust exposure, exposure to RCS still exceeded the OSHA PEL, indicating the need for respiratory protection until improved engineering controls further reduced exposures. This is consistent with the findings of previous NIOSH research in the construction industry, for saw-cutting concrete blocks with local exhaust ventilation (Echt et al. 2007). All of the hardscaping workers with high RCS exposure were wearing respiratory protection, but the implementation of both engineering controls and respiratory protection for these workers could likely be improved.

Four workers who were not hardscapers were also overexposed to RCS. Two of these workers were performing groundskeeping tasks at different sites in parts of the country where soil levels of crystalline silica are high, which may explain their exposures. Two other workers were working at the same site in an area of the country not known to have high crystalline silica in the soil. If construction debris was present in the area where they were working, that could potentially explain the overexposure. Otherwise, the source of the exposures remains unknown.

Worksites

ANOVA comparison of noise exposures when using gas-powered leaf blowers at different worksites showed no differences in noise exposure between worksites where multiple workers used leaf blowers side by side and those where leaf blowers were not used in this fashion. In contrast, when log CO exposures for the use of leaf blowers were compared among worksites, the three sites where large numbers of workers were using leaf blowers side-by-side had higher CO exposures than other sites. Multiple leaf blowers are often used in this fashion when clearing an area of fallen leaves or other debris. No increased CO exposure would result if battery-powered leaf blowers were used.

ANOVA comparison of noise exposures when using gas-powered string trimmers at different worksites showed no differences in noise or CO exposure between sites where string trimmers were used for edging and sites where they were not used for edging. When used for edging, string trimmers may be rotated and held with the engine next to the worker's head instead of under the arm. Exposures to noise and CO might be expected to be higher when gas-powered string trimmers are being used in this fashion, but the brief durations of edging tasks may have prevented such an observation in this study.

In most settings, string trimmers were used for a few minutes at a time when it was necessary to trim vegetation near a fence, building, or tree. However, some workers used string trimmers all day long, and these were the only workers observed to use a shoulder strap and handlebar-style handles for their string trimmers, which likely improved the ergonomics and comfort of long-duration use of the tool.

Some landscaping services workers may work more than 40 hr per week, which would increase their exposure. Golf courses, for instance, may be mowed 7 days a week. Golf courses and athletic fields also spread sand during topdressing. No overexposures to RCS were measured at the golf course and the athletic fields that were part of this study, but depending on the source and percent of quartz in the sand used, there could be the potential for RCS exposures at certain locations that use topdressing.

Limitations

NIOSH research is dependent on the voluntary cooperation of employers and participants. It was not possible to recruit large numbers of workers in each occupation of interest. This may limit the ability to detect differences in exposure between occupations.

Brands and models of landscaping tools used during this study (not named here) were those currently being used at the participating companies or purchased by NIOSH for participant use and may not be representative of all brands and models of landscaping tools available. The exposures of participants using borrowed battery-powered tools may not be the same as for those experienced in the use of such tools.

Although the work settings included in this study covered a good range of sites where landscaping work takes place, some settings, such as right-of-way maintenance, were not included in this study.

Conclusion

Workers in the landscaping services industry are highly likely to be overexposed to noise, even when not personally using power tools. Engineering controls such as battery-powered tools can be effective, but where engineering controls do not sufficiently reduce noise exposure, hearing protection is needed.

In addition to noise, overexposures to RCS were frequent among hardscapers in this study. The use of engineering controls such as dust capture or wet methods reduces RCS exposures, but respiratory protection may likely still be needed, in conjunction with an OSHA-compliant respiratory protection program. To the authors' knowledge, this is the first field study of this type to include hardscapers. The limited evidence of this study shows that more research into the exposures of hardscapers is needed due to their high exposure to noise and RCS.

Small firms in this study lacked hearing conservation programs, indicating a need for increased awareness and implementation of these programs. Workers did not always use hearing protection effectively. Hearing protection can be unpopular and/or poorly implemented in the workforce for several reasons (Green et al. 2021). Research is needed to improve compliance and effectiveness of hearing protection without compromising other aspects of health and safety.

Workers in this study were not exposed to CO over the NIOSH REL. However, elevated exposures to CO were measured for workers using fuel-powered tools or near others using those tools. Switching from fuel-powered tools to battery-powered tools could reduce worker noise exposure and eliminate exposure to CO.

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Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health (NIOSH) and Centers for Disease Control and Prevention (CDC). Mention of any company or product does not constitute endorsement by NIOSH or CDC. In addition, citations to websites external to NIOSH do not constitute NIOSH or CDC endorsement of the sponsoring organizations or their programs or products. Furthermore, NIOSH and CDC are not responsible for the content of these websites. All web addresses referenced in this document were accessible as of the publication date.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Ethics approval

This study was reviewed and approved by the NIOSH Institutional Review Board (IRB—protocol #18-DART-11). See Title 45 Code of Federal Regulations (CFR) part 46; Title 21 CFR part 56. All participants signed an informed consent document.

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Data availability statement

The participants of this study did not give written consent for their data to be shared publicly, so due to the sensitive nature of the research supporting data are not available.

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