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To cite this article: Ashley M. Stumpf, Grant Erlandson, Jennifer Ruths, Deanna K. Meinke, Lee S. Newman, Lyndsay Krisher, Daniel Pilloni, Alex Cruz & Claudia Asensio (2020) Noise exposures of sugar cane mill workers in Guatemala, *International Journal of Audiology*, 59:sup1, S48-S53, DOI: [10.1080/14992027.2019.1690171](https://doi.org/10.1080/14992027.2019.1690171)

To link to this article: <https://doi.org/10.1080/14992027.2019.1690171>



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Published online: 18 Nov 2019.



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## Noise exposures of sugar cane mill workers in Guatemala

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### ABSTRACT

**Objective:** To describe personal noise exposure measurements obtained on Guatemala sugar cane mill workers as a function of job category.

**Design:** This is a descriptive evaluation of existing data.

**Sample:** The data set included 51 representative noise dosimetry surveys utilising NIOSH sampling protocol, completed on workers performing 21 jobs in a Guatemalan sugar cane mill.

**Results:** Noise doses ranged from a low of 50.9% to an extreme of 25174%. The highest observed mean noise doses were for evaporator cleaners (15761%) and juice extractors (2047%). Ninety percent of noise dosimetry samples were between 50% to 1200% dose. Annual noise exposures are also reported after considering the 7-month seasonal work schedule.

**Conclusions:** The majority of sugar cane mill workers were exposed to hazardous occupational noise exceeding the Guatemalan permissible exposure limit (GMLSW), which is consistent with U.S. NIOSH recommended exposure limit of 100% noise dose (85 dBA time-weighted average). Consequently, the majority of workers should be enrolled in a hearing conservation programme including engineering noise control in order to prevent long-term adverse effects on workers' hearing.

### ARTICLE HISTORY

Received 28 May 2019  
Revised 4 November 2019  
Accepted 4 November 2019

### KEYWORDS

Noise; noise dosimetry;  
hearing conservation/  
hearing loss prevention;  
occupational hearing loss

**This article was based on a presentation at the 2019 Annual Conference of the National Hearing Conservation Association, and is part of the 10th dedicated supplement to hearing loss prevention**

### Introduction

The promotion of occupational health and safety is essential in any workplace. For this reason, laws and regulations exist to protect workers from occupational hazards. However, global approaches to regulatory requirements are inconsistent, and countries vary in their occupational health profile and emphasis. In Guatemala, significant advances in the health and safety of workers have been made in recent years. While the first occupational health and safety regulation for the country, entitled “General Regulation on Hygiene and Safety at the Workplace,” was enacted in 1958 and certain International Labour Organisation (ILO) conventions have been subsequently ratified, it was not until 2014 that the country published guidelines independently from the ILO (González Alvarez and Guzmán-Quilo 2018). This progression of public policy towards healthier work environments is promising for the future of Guatemalan employees.

Guatemalan noise regulations are an example of this progress. Initially, one of the only mentions of “noise” in Guatemala regulations was found in Convention 148 of the ILO, ratified in 1996 (Arenas and Suter 2014). Convention 148 stated, “the term noise covers all sound which can result in hearing impairment or be harmful to health or otherwise dangerous” (International Labour Organization C148, 1977). While the document acknowledges that certain noises may damage the auditory system, the level of noise that puts a worker at risk was never quantified. Conversely, in the most updated version of this legislation published in 2014, it is directly stated that hearing protection (earplugs or earmuffs) are mandatory in areas of the workplace where sound levels exceed 85 dBA (GMLSW 2014). In areas where noise levels reach 100 dBA, workers are required to wear earmuffs. Furthermore, it is stated that the employer must make an effort to control the source of noise, offer hearing protection free of charge, and provide routine inspection of hearing protection (GMLSW 2014).

The current Guatemalan regulation provides greater detail and aligns closely with the U.S. National Institute of Occupational Safety and Health (NIOSH) best practices document entitled “Criteria for a recommended standard: occupational noise exposure” published in 1998 (NIOSH 1998). NIOSH recommends that a worker's noise exposure during a standard 8-

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h shift is limited to a time-weighted-average (TWA) of 85 dBA (100% noise dose) and exposure measurements are integrated using a 3-dB exchange rate. Documented noise exposures above this level justify the need for a hierarchical approach to controls: (1) engineering noise control, (2) administrative control, and (3) personal protective equipment wear, e.g. use of hearing protection, as a last resort (NIOSH 1998). With this in mind, advancements have been made in recent years to ensure that Guatemalan workers are protected from occupational hearing loss under the law. However, the country is still lacking in resources, education and professional expertise to ensure worker safety and health (González Alvarez and Guzmán-Quilo 2018).

Regulations and best practice guidelines are important to consider in occupational settings where high level noise is a risk, as 16% of hearing loss in adults worldwide is thought to be due to hazardous noise exposure in the workplace (Nelson et al. 2005). One sector in which noise induced hearing loss is of concern in Guatemala is within the sugar industry. This industry is responsible for a large portion of economic growth, as sugar is one of the country's leading agricultural exports. Guatemala exported 1.98 million metric tons (MMT) in raw and refined sugar in 2017 and is the highest source of foreign exchange for the Guatemalan agricultural sector, followed by bananas and then coffee (Tay and Drennan 2018). It is estimated that Guatemalan sugar production accounts for approximately 80,000 direct and 400,000 indirect jobs (Furlong 2018). Noise exposure in the sugar industry is encountered at numerous levels of the manufacturing process. Mechanical noise is a concern during harvesting, as well as during milling/production.

As sugar cane has been a long-standing part of Guatemala's economic history, most mills were designed many years ago, when noise reduction was not a recognised concern (Phoolchund 1991). The negative impacts of noise exposure are numerous and include noise-induced hearing loss, increased risk of cardiovascular disease, sleep disruptions, decreased alertness, poorer cognitive performance, and decreased overall quality of life (Basner et al. 2014). Both these auditory and non-auditory effects of noise merit attention and previous research has quantified the risks and impacts related to occupational noise in the sugar industry. Rao, Avvaru, and Krishna (2015) estimated the ratio of noise induced hearing loss among workers with at least 5 years of noise exposure in the sugar industry of India. Measured area noise levels generated by factory machines ranged from 85 to 96 dB SPL [meter weighting unspecified]. The researchers found that 30% of the study group had hearing loss [not quantified] compared to 8.33% of the control group of local residents. Further health problems self-reported in excess by the noise-exposed group included hypertension, headache, and sleep disturbance (Rao, Avvaru, and Krishna 2015). Rocha, Marziale, and Hong (2010) conducted structured interviews of Brazilian sugar industry workers (39 manual sugar cane operators and 16 mechanical harvester operators). Outcomes revealed that harvester operators often work in "high-noise conditions" [not quantified] for 10-h shifts for 11 days straight. In addition to these workers being identified as at risk for occupational hearing loss, analysis of the interviews also identified mental fatigue, resulting in a higher likelihood of job-related accidents. That study may be of limited generalizability to other countries where work shifts are shorter, such as the sites described here in Guatemala. Neither the Rao, Avvaru, and Krishna 2015 or the Rocha, Marziale, and Hong 2010 studies directly measure the relationship between the non-auditory effects and noise exposures or control for other factors that may promote the same health problems

## Industrial process

The sugar cane harvesting season in Guatemala lasts approximately seven months, from mid-November through early May. Figure 1 is a graphical illustration of the industrial process of refining sugar.

The milling process begins when raw sugar cane is delivered to the mill by truck and trailer. Crane operators then dump the trailer of cane into a system of conveyors where processing begins. The cane is then transported into the milling station. There are employees whose job is to ensure that rocks are not integrated in the cane as it enters the milling stage. At the milling stage, the cane first is chopped up in small pieces before it is completely crushed to begin the juice extraction process. The juice is then pumped through a clarification process to remove impurities such as plant fibre and soil. The tuning of the clarification process is made depending on the type of sugar being produced (white, brown, refined). Next, the clarified juice is pumped through a quintuple effect evaporation system. An evaporator is a large tank filled with hundreds of smaller metal tubes that is heated to high temperatures to evaporate water from the juice. Due to scaling, the evaporators need to be cleaned. To clean evaporators, employees enter into the evaporator through a manhole, and use a high-pressure power washer to remove scale from the piping under relatively confined conditions. After the evaporation stage, concentrated syrup is pumped into a crystallization station, where crystal formation is obtained by very low-pressure evaporation and controlled temperatures in equipment called vacuum pans. The resulting sugar product (massecuite) is then passed through a centrifuge. The centrifuges rotate at high speeds to separate substances with different densities by means of centrifugal force. Centrifuge workers ensure that each centrifuge is working correctly and monitor the production. A seeder then begins the crystallization process which is monitored by a crystallization inspector. The final stage is packaging the sugar into sacks and loading for distribution. There exist other support functions inside the mill that maintain the process. These support processes include plant maintenance (e.g. welding and equipment maintenance and mechanics) and computer operation of the manufacturing processes. Bagasse, a cane-fibre by-product of the milling process, is burned in ovens (calderas) which fuel boilers in order to generate steam energy for the plant. Heavy equipment operators drive graders outside the mill and keep the roads and yard clear of debris. Molasses, another by-product of the milling process, is either sold separately or distilled into ethanol.

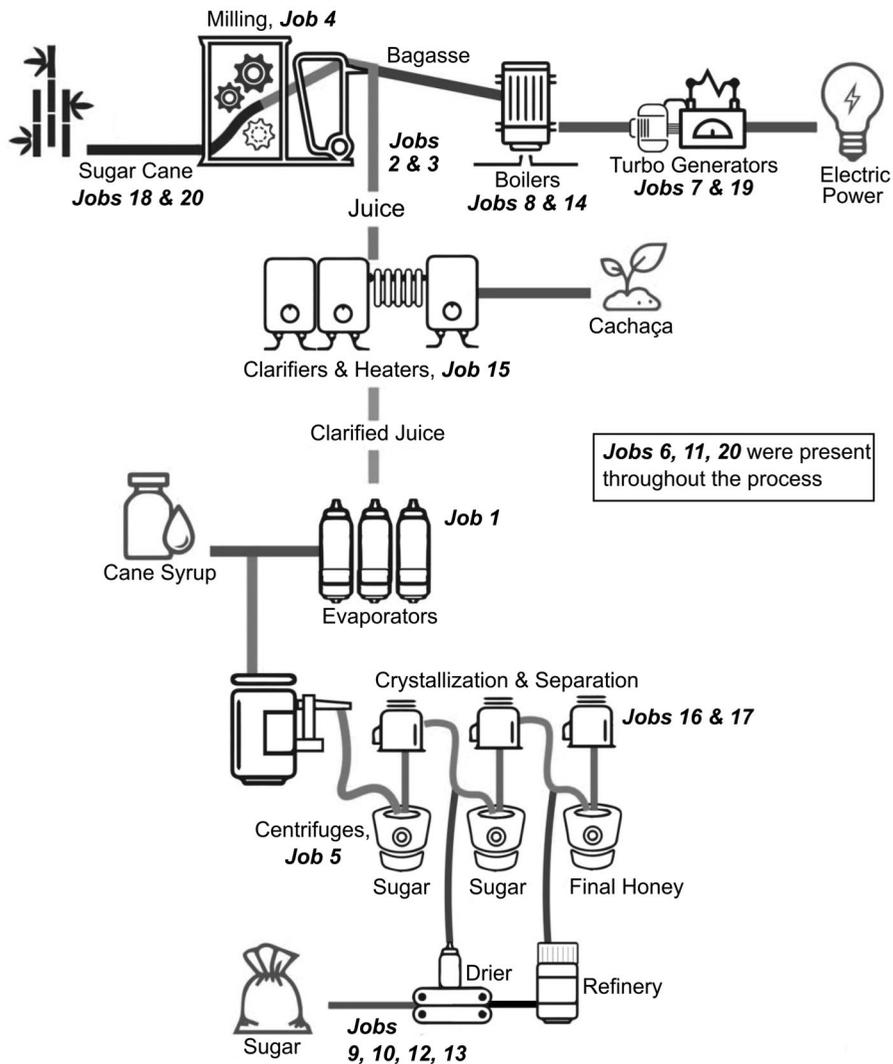
Sugar cane mill workers are exposed to noise from a variety of mill processes as well as the steam power generation system. With these noise risks in mind, the purpose of this analysis is to quantify occupational noise exposures of workers employed in various manufacturing jobs within a sugar cane mill located in Guatemala.

## Methods

### Noise exposure database description

Following approval by the University of Northern Colorado Institutional Review Board (IRB), a de-identified dataset of noise exposure measurements was accessed; all data were tracked under unique subject numbers and no personally identifiable information was available (IRB #1309896-2). The database was comprised of 51 noise dosimetry samples from a sugar cane mill in Guatemala.

The mill operates on three work shifts during the harvest season, typically from November to May. Certain operations such as repairs and refurbishing occur during the off-season. The noise dosimetry samples were collected during first and second



Jobs 6, 11, 20 were present throughout the process

Figure 1. Diagram of sugar refining process annotated with job numbers referenced in results section. Adapted from Pantaleon Diagram of the Industrial Process at <https://www.pantaleon.com/procesos/industrial-process/>.

shifts as part of the company’s noise exposure assessment and did not contain samples for third shift workers who performed the same jobs. The noise exposure measurements in the dataset were obtained over a 2-day period in December 2017, during a period of peak sugar cane processing. The workers wore the noise dosimeter microphones clipped to the upper shoulder and the microphones were placed to keep them unobstructed by clothing and minimise any interference with physical work duties. Production activity was reported by supervisors to be typical and consistent across all work shifts. Noise exposures in the dataset were measured with Type 2 dosimeters; either a Spark<sup>®</sup> 703+ (Larson Davis, Depew NY), or an Edge 5 (3M<sup>™</sup>, Minneapolis MN) dosimeter. Larson Davis dosimeters were calibrated pre and post survey using a 1000 Hz calibration tone at both 94 dB SPL and 114 dB SPL. 3M dosimeters were also calibrated pre and post survey using a 3M QC-10 calibrator producing a 1000 Hz calibration tone at 114 dB SPL. All dosimeters utilised a sampling protocol with a threshold of 80 dBA, a criterion level of 85 dBA, and an exchange rate of 3 dB. At the end of each work shift, the data was downloaded from Larson Davis dosimeters using Blaze<sup>®</sup> software and 3M data was downloaded using Detection Management Software (DMS). All data was then organised and summarised in an Excel spreadsheet. The de-identified data in the spreadsheet was accessed for this analysis.

**Data analysis**

A descriptive analysis was completed using the dosimetry measurements. 8 h equivalent continuous A-weighted sound pressure levels (L<sub>Aeq8</sub>) for each sample are reported in the dataset. When multiple samples for the same job were obtained, the individual L<sub>Aeq8</sub>’s from each sample were logarithmically combined in order to provide a representative total A-weighted L<sub>Aeq8</sub> for each job classification. The equation for combining the L<sub>Aeq8</sub>’s used the following formula;

$$\text{Total LAeq} = 10 \log \left( \frac{10^{\frac{\text{LeqA}^1}{10}} + 10^{\frac{\text{LeqA}^2}{10}} + \dots + 10^{\frac{\text{LeqA}^n}{10}}}{n} \right)$$

- LAeq is the equivalent A-weighted continuous linear weighted sound pressure level re 20µPa, determined over the measured time interval (secs) reported for each sample.

The NIOSH (1998) recommended exposure level (REL) criteria was used to determine overexposure (≥85 dBA) according to U.S. best practices and are consistent with Guatemalan noise regulations (GMLSW 2014). NIOSH (1998) assessed the excess risk of material hearing impairment as a function of noise level and duration based upon a 40-year working lifetime. In the US, annual work exposures assume 2000 hours of work annually (8 h a day,

5 days a week for 50 weeks). Therefore, the estimated annual noise exposure ( $L_{Aeq8}$ ) was calculated using seasonal November through May timeframe where sugar mill workers typically work 8+ hour shifts 6 days a week. Annual exposures were adjusted for job classifications that did not work the typical eight-hour shift (e.g. 9-h workdays). It was assumed that there was no occupational noise exposure for the remaining 5 months since there were no records of employment during the off-season available to the researchers. The REL of 85 dBA TWA for 8 h a day is equivalent to an allowable noise dose of 100%. This analysis references the NIOSH (1998) formula for calculating noise dose:

$$D = \left[ \frac{C1}{T1} + \frac{C2}{T2} + \frac{Cn}{Tn} \right] \times 100$$

where

$Cn$  = total time of exposure at a specified noise level.

$Tn$  = exposure time at which noise for this level becomes hazardous.

## Results

### Noise exposures and sound levels in the data set

Noise dosimetry samples ( $n = 51$ ) for 21 job classifications were available for two of three shifts (first and second shifts). All job classifications worked eight hour shifts apart from welding, which worked an extended shift of nine hours during the first shift only. A range of 1–5 samples were collected per job classification depending upon worker availability. All of the job duties were consistent throughout the work shift and workers did not change job tasks during a work-day. Table 1 provides a summary of noise exposure measurements for each job classification rank ordered from highest to lowest exposure levels ( $L_{Aeq8}$ ) in the refinery process. Additionally, annual exposure levels were calculated based on a 2000-hour work year since the workers work an atypical schedule of 6 days a week seasonally as compared to full-time US workers.

Forty-eight of 51 individual samples exceeded 85 dB  $L_{Aeq8}$ , which exceeds the recommended exposure limit for the majority of workers. The majority (66.6%) of daily exposures exceed 90 dB  $L_{Aeq8}$ . Figure 2 provides a comparison of the mean daily noise dose per job classification referenced to the permissible

100% dose. The evaporator job classification had the highest noise exposure of 108.1 dBA  $L_{Aeq8}$  (dose of 15,761%). Computer operators and heavy equipment operators were the only job classifications with a  $L_{Aeq8}$  below 85 dBA, and had corresponding noise doses of 52% and 51%, respectively. Estimated annual exposures were slightly lower (0.2 dB) than seasonal exposures due to the fewer work hours (1241.3–1396.4) for the Guatemalan seasonal workers as compared to a US work year (2000 hours).

## Discussion

The majority of workers in our data evaluation of Guatemalan sugar cane mill workers demonstrated levels of exposure to hazardous occupational noise exceeding the NIOSH recommended exposure limit of 100% noise dose (85 dBA TWA) and the Guatemalan permissible exposure limit (GMLSW 2014). The current noise dosimetry analysis demonstrated levels that are comparable, but in some job classifications even higher than those previously published by Rao, Avvaru, and Krishna (2015). In addition, certain job duties, such as cleaning for short periods of time, such as inside an Evaporator, may produce extreme exposures that are underestimated by our sampling procedure. In spite of working seasonally, these workers are over-exposed in an annual (2000 hour) work year. Working 6 days a week shortens the potential auditory recovery time compared to traditional 8-h, 5 day-a-week scheduling.

In light of the magnitude of the observed exposures, and the size of the sugar industry, our results indicate a need to address sampling, mitigation, and hearing conservation programme practices internationally. Our findings also demonstrate the need to perform personal noise dosimetry approaches to more precisely quantify specific job/worker exposures due to the integration of time with sound level.

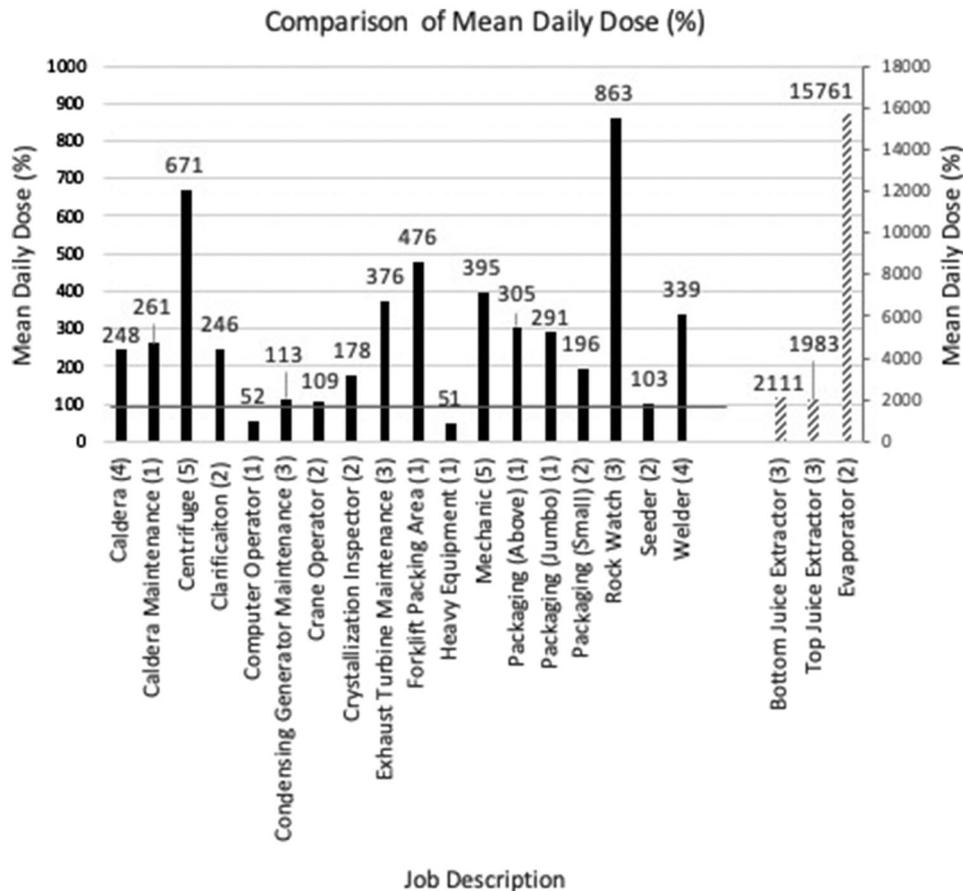
### Hearing conservation strategies

#### Noise control

The hierarchy of noise control recommends elimination of the hazardous noise source or reduction of the noise levels as a first order approach to the prevention of noise-induced hearing loss. Subsequent to the noise dosimetry sampling in 2017, a noise

**Table 1.** Summary of seasonal noise exposure per job description.

Job #	Job description	Samples (n)	Daily noise exposure (8 h)	
			$L_{Aeq8}$ (dB SPL)	Annual noise exposure (2000 hours) $L_{Aeq8}$ (dB SPL)
1	Evaporator	2	108.1	107.9
2	Bottom juice extraction	3	98.8	98.6
3	Top juice extraction	3	98.5	98.3
4	Rock watch	3	94.8	94.6
5	Centrifuge	5	94.5	94.4
6	Welding	4	92.9	92.0
7	Exhaust turbine maintenance	3	92.6	92.4
8	Caldera maintenance	1	91.2	91.0
9	Small packaging	2	91.0	90.8
10	Jumbo packaging	1	90.9	90.7
11	Mechanic	5	90.9	90.8
12	Above packaging	1	90.8	90.6
13	Forklift operator (packaging)	1	90.7	90.5
14	Caldera operator	4	90.3	90.1
15	Clarification	2	89.8	89.6
16	Crystallization inspector	2	88.3	88.1
17	Seeder	2	88.2	88.0
18	Crane operator	2	85.8	85.6
19	Condensing generator maintenance	3	85.6	85.4
20	Heavy equipment operator	1	83.6	83.4
21	Computer operator	1	83.0	82.8



**Figure 2.** Mean daily noise dose reported by job category. Dose is the amount of actual noise exposure relative to the amount of allowable exposure, and for which 100% and above represents exposures that are hazardous. Right y-axis provides an extended scale for the Juice Extractor and Evaporator job classifications.

control survey (Leq sound levels, octave-band analysis and machine specific measurements) was conducted during seasonal production in 2019 (G. Erlandson, personal communication, 26 May 2019). Five major noise sources were identified across the mill: steam venting, steam leaks, shredders, evaporator washing, and power generation. Of those five, steam vents and leaks were by and large the dominant noise source in the mill and corresponded with the highest noise exposures. Steam vents were highly prevalent in the evaporator work space and leaks were regularly found above and inside the juice extraction work space. However, steam related noise was present in a large majority of job locations. Recommendations for prioritisation of noise controls and options within those recommendations were then provided to the company by an external contractor. The company has implemented a series of noise control measures inside the mill since the noise dosimetry was completed. These include the purchasing of a silencer for one of the boilers. The “rock watch” job position was substituted for video-camera controls. However, further engineering noise controls are warranted, and the company is in the process of evaluation and implementation of those recommendations [C. Asensio, personal communication, 23 May 2019]. Double hearing protection policy was implemented for the evaporator cleaner job position and administrative noise control is planned to reduce individual exposure time. The company has also established an alliance with 3M to standardise the use and fit of hearing protection devices.

#### Hearing conservation program

In order to be compliant with the Guatemalan noise regulation (GMLSW 2014), the majority of workers (96%) would be

required to be enrolled in a hearing conservation programme. These workers are required to wear mandatory hearing protection (earplugs or earmuffs) due to mean noise exposure levels exceeding 85 dBA TWA. The job description of ‘evaporator’ would be required to wear earmuffs due to the mean  $L_{Aeq8}$  exceeding 100 dBA according to GMLSW 2014. In this similar high-noise exposure scenario, NIOSH (1998) would recommend the use of dual hearing protection (simultaneous wearing of earplugs and earmuffs). It was noted in the noise exposure data set that the majority of workers were observed to be wearing hearing protection when noise dosimetry measurements were taken. The remaining 2 workers (computer operator and heavy equipment operator) had approximately 50% noise doses. Both of these jobs are highly variable in terms of how much time of each work shift is spent in high level noise and a single noise dosimetry sample may not fully represent the auditory risk for these workers. Subsequently, the employer has evaluated all exposed workers for hearing loss and has begun the implementation of a hearingloss prevention programme consisting of audiometric monitoring, employee training and future evaluation of programme effectiveness.

#### Limitations

Due to the mill only operating in full capacity approximately 7 months of the year, noise exposures cannot be directly generalised to annual exposure levels based on year-long work schedules. Therefore, seasonal exposure levels were normalised to a 2000-hour yearly exposure which assumes no other occupational noise exposure for the remaining five months of the year. After

the seasonal to annual transformation, 19 of the 21 job classifications still exceeded 85 mean  $L_{Aeq8}$ . It may be necessary to consider a worker's additional occupational noise exposures during the off-season when making hearing conservation recommendations for individual sugar cane refinery workers. It is possible that the annual noise exposure based upon 7 months of seasonal work underestimates the true annual exposure for these workers from occupational sources. In addition, these estimates do not account for off-the job or recreational noise exposures.

The current evaluation was conducted with data from one sugar cane mill and cannot be widely generalised to all other sugar cane mills within Guatemala or in other parts of the world. Some job descriptions (3 of 21) only had one dosimetry sample, which may not be representative of all workers performing the same task. In addition, the records do not indicate that the workers were observed throughout the entirety of their shift to ensure proper dosimeter wear. The dosimeter screens were inaccessible to prevent tampering. Future efforts should include noise exposure measurements at other sugar cane mills, and should be expanded to include the harvesting, truck loading and transportation jobs. The current outcomes are reflective of noise exposure within a sugar mill which processes sugar cane. The refining process for sugar beets differ from sugar cane, and additional study is warranted for these workers.

## Summary

Guatemalan sugar cane mill workers are at risk of noise-induced hearing loss. Mean noise doses ranged from a low of 50.9% to an extreme of 25,174%. Ninety percent of noise dosimetry samples were between 50% to 1200% dose. Sugar refining is a seasonal production process running six days a week and extending over a 7-month period. Seasonal noise exposures were normalised to a 2000-hour annual exposure and ranged from 82.8 to 107.9 dBA. The majority of sugar cane mill workers were exposed to hazardous occupational noise exceeding the NIOSH recommended exposure limit of 100% noise dose (85 dBA time-weighted average) which is also consistent with the Guatemalan permissible exposure limit (GMLSW 2014). Consequently, these workers should be enrolled in a hearing conservation programme including engineering noise control in order to prevent long-term adverse effects on workers' hearing. The process of sugar refining employs workers in over 130 countries (ISO 2016). Public health and prevention efforts are needed worldwide to further quantify and control the risk of noise-induced hearing loss for sugar mill workers in order to prevent noise-induced hearing loss.

## Disclosure statement

The University of Colorado, University of Northern Colorado and Pantaleon are separate, independent organisations. University of Colorado employed appropriate research methods in keeping with academic freedom, based conclusions on critical analysis of the evidence and reported findings fully and objectively. The terms of this arrangement have been reviewed and approved by the University of Colorado in accordance with its conflict of interest policies.

## Funding

This work was supported in part by Pantaleon; the Chancellor, CU Anschutz; Centres for Disease Control and Prevention (CDC) [U19OH01127], and the Mountain and Plains Education and Research Centre [T42 OH009229]. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the CDC or the Department of Health and Human Services.

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