Chicago Transit Authority Train Noise Exposure

Linh T. Phan[1]
Rachael M. Jones

Division of Environmental and Occupational Health Sciences, School of Public Health, University of Illinois at Chicago

ABSTRACT

To characterize noise exposure of riders on Chicago Transit Authority (CTA) trains, we measured noise levels twice on each segment of seven of the eight CTA train lines, which are named after colors, yielding 48 time-series measurements. We found the Blue Line has the highest noise levels compared to other train lines, with mean 76.9 dBA; and that the maximum noise level, 88.9 dBA occurred in the tunnel between the Chicago and Grand stations. Train segments involving travel through a tunnel had significantly higher noise levels than segments with travel on elevated and ground level tracks. While 8-hour doses inside the passenger cars were not estimated to exceed occupational exposure limits, train operators ride in a separate cab with operational windows and may therefore have higher noise exposures than riders. Despite the low risk of hearing loss for riders on CTA trains, in part because transit noise accounts for a small part of total daily noise exposure, 1-minute average noise levels exceeded 85 dBA at times. This confirms anecdotal observations of discomfort due to noise levels, and indicates a need for noise management, particularly in tunnels.

KEYWORDS

[1] Phan and Jones are with the Division of Environmental and Occupational Health Sciences, School of Public Health, University of Illinois at Chicago. Correspondence: Linh T. Phan, School of Public Health, University of Illinois at Chicago, 2121 W Taylor St., Chicago, IL 60612, USA. (E-mail: lphan6@uic.edu)

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INTRODUCTION

Ridership of public transportation systems is increasing in the United States, but many train systems, anecdotally, have potentially hazardous levels of noise. In recent years, noise levels on two public transit systems in the United States have been reported in the peer-reviewed literature. In New York City, Neitzel et al. found the average noise level, L_{eq}, inside subway train cars to be 79.3 dBA, with noise levels in excess of 85 dBA, the Occupational Safety and Health Administration (OSHA) Action Level, occurring almost 20% of the time.[1] In the San Francisco Bay Area, Dinno et al. found that 22% of the measured Bay Area Rapid Transit (BART) train segments (length of track between two stations) were above 85 dBA, and in consideration of ride duration, BART riders are exposed to noise levels ≥ 70 dBA and ≥ 85 dBA for at least 60 minutes and 20 minutes per day, respectively, while trains are in motion. [2] These levels are not expected to cause hearing loss among riders, due to the relatively short duration of ride, but they do contribute to a daily noise exposure also comprised of exposures in occupational and recreational settings. However, they may cause discomfort for riders and indicate the potential for hearing loss among train operators.

The objective of this study was to characterize noise exposure of riders on Chicago Transit Authority (CTA) trains. The CTA is the second largest public transport system in the United States, and serves the Chicago metropolitan area and 35 suburbs. The CTA trains first operated in 1892 making it the second oldest train system in the United States. There are eight train lines operated by CTA, named (in order of ridership): Red, Blue, Brown, Green, Orange, Purple, Pink and Yellow Lines. According to the CTA boarding data, more than 241 million train rides were recorded in 2015 and about 1.6 million rides are taken on the CTA system daily. [3] The Red Line has the highest daily ridership, 29%, followed closely by the Blue Line, 25%. Chang et al. [14] conducted a noise assessment in CTA subways in 1974 but the measurement methodology and noise standards have changed over time, therefore, our study on public transit will contribute new understanding of the magnitude and determinants of urban and transit noise exposures.

The specific objectives of this study were to: 1) summarize measured noise levels on CTA trains; 2) quantify differences in mean noise levels among CTA train lines, if any; 3) identify factors that influence noise levels on CTA trains, if any; 4) summarize noise levels among segments of each train line; and 5) assess the risk of noise-induced hearing loss associated with riding CTA trains. Noise-induced hearing loss is a significant burden to occupational health, including among transportation workers.[4] Noise exposure has also been associated with a wide variety of other adverse health impacts, including increased risk of estrogen receptor negative breast cancer among women aged 50-64 years [5] and cardiovascular effects.[6,7]

MATERIALS AND METHODS

Noise exposure standards

The OSHA permissible exposure limit (PEL) for noise is 90 dBA as an 8-hour time-weighted average (TWA). In addition, OSHA requires employers to administer a hearing conservation program when employees are exposed to noise levels at or above an 8-hour TWA of 85 dBA, the action level. The OSHA action level uses a criterion level of 90 dBA, a threshold level of 80 dBA, and an exchange rate of 5 dBA. The OSHA PEL has the same criteria as the action level except for the threshold of 90 dBA.[8]

The National Institute for Occupational Safety and Health (NIOSH) recommends an exposure limit (REL) of 85 dBA, as an 8-hour TWA. NIOSH uses a criterion level of 85 dBA, a threshold level of 80 dBA, and an exchange rate of 3 dBA. [9] The American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV) is identical to the NIOSH REL. [12] The U.S. Environmental Protection Agency (EPA) has recommended a 24-hour equivalent continuous average noise exposure limit of 70 dBA. [13]

Train-related Definitions

The phrase "train line" refers to one of the eight train lines of the CTA train system, each named a color. All CTA trains pass through the Loop area of downtown Chicago, so "train branch" refers to the length of a train line extending from the Loop to a terminus. For example, the Blue Line has two branches extending from the Loop to O'Hare International Airport and from the Loop to Forest Park. Each train branch has two tracks (inbound to the Loop and outbound from the Loop). The train branches are: Blue to O'Hare, Blue to Forest Park, Brown to Kimball, Green to Ashland, Green to Harlem, Orange to Midway, Pink to Cermak, Purple to Linden, Red to Howard and Red to 95th Street. The phrase "train segment" refers to the track length between two stations. Each train segment was classified as being primarily underground, at ground level or elevated.

Noise Exposure Assessment

The general approach was to ask participants to ride one track of one branch of a CTA train line while wearing a noise dosimeter, and to record observations about the train ride.

Measurements were collected on seven of eight CTA lines: the Yellow Line was excluded due to low ridership and short track. Each piece of track was ridden at least twice, for a total of 48 measurements. This study was reviewed and approved by the University of Illinois at Chicago Institutional Review Board (research protocol #2014-0602).

Participants were asked to sit or stand in the middle of the car, consistent with previous studies.[1-2] Participants were asked to ride in the first car of the train, to best approximate the experience of the train driver and to eliminate the potential effect of train car position on noise levels.

The noise level meter used was the dBadge CEL 350 (Casella CEL, Inc, Buffalo, NY). The dosimeter was configured with a 65 dBA threshold, 85 dBA/8 hour criterion, and a 3 dB exchange rate. These meters measure average and peak sound pressure levels over 1-minute intervals. Dosimeters were calibrated before being given to participants. Dosimeters were clipped onto participants' clothing while riding the train. Data were downloaded using the manufacturer's software.

The 1-min L_{eq} values (dBA) calculated by the dosimeter were used to calculate the segment (between two stations) noise level, $S.L_{eq}$.

$$(1) \quad S.L_{eq,T_s} = 10 \times \log\left[\left(\sum_0^i 10^{L_{eq(i)}/10}\right)/T_s\right]$$

where $L_{eq\,(i)}$ is the 1-min noise level measured at minute i in the train segment and T_s (minutes) is the travel time on the segment.[10] Time of station arrival and/or departure (recorded by participants) was used to match the noise level data to each line segment.

The noise dose for each train ride, D, was calculated as:

(2) $D = (\sum_{i=1}^{n} C_i/T_i) \times 100$

Where n is the number of unique noise levels measured and indexed by i, i={1, 2,…, n}, C_i is the total time of exposure at noise level i, and T_i is the allowable exposure time at noise level i based on the policies of ACGIH/NIOSH or OSHA.

Using noise dose, the single TWA sound level (dBA) was calculated using the OSHA method[8]:

(3) $$TWA = 16.61 \log_{10}(D/100) + 90$$

and the ACGIH/NIOSH methods [9]:

(4) $$TWA = 10 \log_{10}(D/100) + 85$$

Equations 3 and 4 differ because of differences in the exposure standards. From the single ride dose (Eq. 2), we estimated the 8-hour projected dose of the train drivers by assuming the noise level measured during the train ride is continuous for 8 hours.

Participants' Observations

Participants were asked to record the time of station arrival and departure, time of passing trains (the time that the participant observes any other trains on the ride), train occupancy, and rider activity. Time of station arrival and departure was used to match noise level data to each line segment. In the New York City study, Neitzel et al. found that the noise levels on station platforms increased when vehicles passed. [1] Therefore, we hypothesized that the number of passing trains was associated with the noise level within the monitored train ride. Additionally, we hypothesized that train occupancy (low, medium, or high), and occupant unusual activity (yes, no) were positively associated with segment noise level, $S.L_{eq.}$ Rider activities observed included: singing, crying, talking loudly or shouting.

Data Analysis

We used exploratory data analysis and mixed-effect regression models to compare differences in 1-minute mean noise levels, L_{eq}, and segment noise levels, $S.L_{eq}$, among CTA train lines and identify factors that influence noise levels on CTA trains. Mixed-effect regression models were used to account for clustering owing to the time-series of measurements. We used $\alpha = 0.05$ to define statistical significance of the hypothesis testing.

RESULTS

The 1-min average noise level measurements, L_{eq}, are summarized in Table I by train branch and direction (inbound to or outbound from the Loop). All the L_{eq} values were greater than the dosimeter threshold of 65 dBA. Segment noise levels between two train stations, $S.L_{eq}$, have a similar pattern to the L_{eq} levels (see Supplementary Materials). By both measures, the Blue Line to O'Hare is the noisiest train branch, with highest mean L_{eq} of 78 dBA and mean $S.L_{eq}$ of 78.9 dBA. The lowest mean L_{eq} was measured on the Purple Line (71.2 dBA). The highest $S.L_{eq}$ value was 88.9 dBA, and was measured in a tunnel on the Blue Line to O'Hare (between the Grand and Chicago Stations).

We hypothesized that the number of passing trains, train occupancy (low, medium, or high), occupant unusual activity (yes, no) and track location (underground tunnel, at ground, or elevated) may be positively associated with segment noise level, $S.L_{eq}$. No trends, however, were apparent in graphical analyses (see Supplemental Materials). $S.L_{eq}$ varied with track location, and $S.L_{eq}$ was 1.9 dBA and 1.7 dBA higher for train segments in underground tunnels than for elevated and ground level segments, respectively (Table II).

Mixed-effect regression models identified that the mean of L_{eq} of the Blue Line was statistically significantly higher than all train lines except Orange (Table III). Given the high noise levels and number of tunnels on the Blue Line, we tested whether the number of tunnels through which the Blue Line travels explained the high noise level using a mixed-effect regression model and that both tunnel and Blue Line had significant effects (p-value <0.05). This means that the number of tunnels does not fully explain the noise level on the Blue Line.

Noise dose estimates were calculated for the train ride with highest noise exposures using the OSHA Action Level and ACIGH TLV criteria.Doses were calculated as 8-hour TWA based on exposure during a single ride and on an 8-hour duration exposure to the noise level measured in a single ride (Table IV). The 8-hour projected dose estimates the dose for a work shift. Noise doses arising from a single ride were < 3%, and 8-hour projected noise doses were ≤ 25%.

DISCUSSION

In this study, we measured noise levels of riders on CTA trains, and found average noise levels to be slightly lower than has been measured in other studies in the United States. The mean L_{eq} measured inside New York MTA and PATH trains was 79.3 dBA and 79.2 dBA, respectively, which are a little higher than the highest mean L_{eq} of Blue Line of 78 dBA. [1] The mean L_{eq} measured in the BART study was about 1.5 dBA higher than the mean L_{eq} on the Blue Line. [2] The TWA 8-hour levels on the Blue Line calculated by the ACGIH TLV equation (76 dBA to 79 dBA) are similar with the mean 8-hour noise exposure of bus drivers in Curitiba City Brazil, which are from 74 dBA to 79 dBA. [11]

We found that track travel through tunnels was associated with elevated noise levels, which makes physical sense and is consistent with previous work. Dinno et al. [2] found that the

L_{eq} increased by 5.1 dBA in segments involving through the tunnels, which is comparable to our findings that noise level in the underground tunnel train segments was 1.9 dBA and 1.7 dBA higher than elevated and ground level segments, respectively . We did not find passing trains to be associated with elevated noise levels inside of trains, though Neitzel et al. observed this on platforms. [1] It is likely that the train car shields riders from external noise sources.

We did find variation in noise levels among train lines, which may be due to variables that we were unable to measure, such as wheel and brake conditions, train speed, and the quality of the track. The lack of information about train speed is a particular limitation in this study as noise levels have been found to be positively linearly associated with average velocity. [2] CTA did not provide information about track length upon request, and tunnels limited our ability to obtain GIS data of CTA train lines from which to determine segment length. This is an area for future work.

Noise exposures in this study are not suggestive of noise-induced hearing loss among riders or among drivers, as 8-hour projected noise doses were ≤ 25% (Table IV), though average measured noise levels were in the range of 71-78 dBA (Table I). The experience of riders, however, may not be the same as that of drivers who are in an isolated cab with an operable window: The windows allow train conductors to observe riders getting on and off the train at each stop. A hearing conservation program, required by OSHA when noise doses exceed 50% of the criteria, may be necessary. Since decibels are logarithms, a small increase in noise level could substantially increase the risk of hearing loss. Therefore, further exploration of noise exposure among CTA train operators is warranted.

Given the alternations in the noise measurement method and noise standards over time, it is somewhat difficult to compare our measured noise levels with those measured by Chang et al. [14] in 1974. However, as in this study, the authors found that train cars operating on subway segments were noisier than on elevated and ground segments; and data indicated a risk of noise-induced hearing loss among train operators and frequent train riders.

Transit is only one component of daily noise exposure.Diaz et al. [15]found that transportation accounts for about 13% of daily noise exposure, while leisure activities and occupation contribute 65% and 10% to the daily noise exposure, respectively. [15] The U.S. EPA recommends a 24-hour equivalent continuous average noise exposure of 70 dBA.[13] Our study only collected transportation time on CTA trains, se we cannot calculate the continuous average noise exposure, but train riders are exposed to noise levels of 70 dBA and above while riding the CTA (Table I).

We did not measure noise levels on station platforms, and thus did not fully characterize the exposures of CTA train riders. In New York, L_{eq} measured on underground platforms was significantly higher than the L_{eq} measured inside train cars, and was found to increase with passing trains. [1]

CONCLUSION

Our results indicate that noise exposure on CTA train lines not trivial, though single rides as 8-hour exposure and 8-hour TWA on each train line did not exceed the OSHA and TLV standards. Occupational risk may be a concern, as train drivers may have unique exposures because they are in separate cab from riders and have longer exposure durations than riders. We noted significant differences between the mean noise levels on some train lines. The mean average noise level on the Blue Line is significantly higher than the other train lines, and this cannot be solely attributed to tunnels. In addition, the mean 1-min average noise level of train segments involving travel through tunnels was significantly higher than that of ground and elevated segments. We recommend that the CTA examine the track quality on segments enclosed by tunnels, such as on the Blue Line between the Grand and Chicago stations. While revised train speed limits may also reduce noise, this control option must be balanced with riders' value of speedy commutes.

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Tables

Table I: Mean and standard deviation (SD) of 1-minute noise levels (L_{eq}, dBA) by train branch.

		Inbound			Outbound		
		Mean (SD)			Mean (SD)		
Line	**Branch**	**N**	**Mean (SD) L_{eq} (dBA)**	**Duration (minutes)**	**N**	**L_{eq} (dBA)**	**Duration (minutes)**
Blue	O'Hare	2	77.2 (4.1)	45.4 (0.9)	2	78.3 (3.7)	30.0 (2.8)
	Forest Park	2	74.9 (3.0)	31.1 (1.5)	2	77.4 (3.5)	46.5 (6.4)
Brown	Kimball	2	73.9 (1.6)	46.5 (2.3)	4	72.7 (2.3)	50.0 (5.3)
Green	Ashland	2	73.3 (1.9)	43.7 (3.3)	2	72.8 (2.5)	22.0 (4.2)
	Harlem	2	74.1 (3.3)	32.9 (0.9)	2	72.3 (4.2)	31.5 (3.5)
Orange	Midway	2	78.4 (2.6)	37.8 (0.0)	4	73.4 (3.2)	37.0 (1.6)
Pink	Cermak	2	71.9 (3.0)	39.8 (0.4)	4	73.5 (3.6)	39.3 (3.9)
Purple	Linden	2	72.5 (2.3)	62.0 (0.2)	4	71.2 (2.6)	63.8 (4.4)
Red	Howard	2	74.6 (2.7)	38.9 (1.0)	2	72.3 (2.7)	40.0 (1.4)
	95th Street	2	77.7 (3.3)	28.1 (0.7)	2	72.9 (1.9)	29 (4.2)

Table II: Mean and standard error (SE) segment noise level ($S.L_{eq}$, dBA) and mean differences among track locations by mixed-effects regression model. Statistically significant differences indicated in bold.

		Contrast in Mean $S.L_{eq}$ (dBA)		
	Mean (SE)	**Track Location**		
Track Location	**$S.L_{eq}$ (dBA)**	**Tunnel**	**On Ground**	**Elevated**
Tunnel	77.4 (4.1)	-	-	-
On Ground	75.0 (3.4)	**1.7**	-	-
Elevated	73.5 (2.9)	**1.9**	0.2	-

Table III: Mean and standard error (SE) noise level (L_{eq}, dBA) and mean difference between train lines by mixed-effects regression model. Statistically significant differences indicated in bold.

		Contrast in Mean L_{eq} (dBA)						
	Mean (SE)	Train Line						
Train Line	**L_{eq} (dBA)**	**Blue**	**Red**	**Green**	**Purple**	**Orange**	**Brown**	**Pink**
Blue	76.9 (1.1)	-	-	-	-	-	-	-
Red	74.4 (1.1)	**2.6**	-	-	-	-	-	-
Green	73.2 (1.1)	**3.8**	1.2	-	-	-	-	-
Purple	71.4 (1.2)	**5.5**	**3.0**	1.8	-	-	-	-
Orange	75.1 (1.2)	1.9	- 0.7	-1.9	**-3.4**	-	-	-
Brown	73.1 (1.2)	**3.8**	1.2	0.0	-1.8	1.9	-	-
Pink	73.1 (0.8)	**3.9**	1.3	0.1	-1.7	2.0	0.1	-

Table IV: Maximum noise dose (%) measured on each train line, based on OSHA Action Level and NIOSH/ACGIH standards for the duration of a single ride, and continuous 8-hour exposure.

		OSHA Action Level Dose		NIOSH Dose	
Train line	**Branch**	**Per ride**	**Per 8 hours**	**Per ride**	**Per 8 hours**
Blue	Outbound to O'Hare	1.4	13.0	2.7	25.2
Green	Outbound	0.3	4.1	0.4	6.3
Orange	Inbound	0.9	11.9	1.6	20.1
Pink	Outbound	0.3	3.9	0.5	6.7
Purple	Inbound	0.1	1.0	0.2	1.4
Red	Inbound from 95th Street	0.9	14.1	1.5	24.7