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Pilot Survey of Subway and Bus Stop Noise Levels

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ABSTRACT *Excessive noise exposure is a serious global urban health problem, adversely affecting millions of people. One often cited source of urban noise is mass transit, particularly subway systems. As a first step in determining risk within this context, we recently conducted an environmental survey of noise levels of the New York City transit system. Over 90 noise measurements were made using a sound level meter. Average and maximum noise levels were measured on subway platforms, and maximum levels were measured inside subway cars and at several bus stops for comparison purposes. The average noise level measured on the subway platforms was 86 ± 4 dBA (decibel-A weighting). Maximum levels of 106, 112, and 89 dBA were measured on subway platforms, inside subway cars, and at bus stops, respectively. These results indicate that noise levels in subway and bus stop environments have the potential to exceed recommended exposure guidelines from the World Health Organization (WHO) and U.S. Environmental Protection Agency (EPA), given sufficient exposure duration. Risk reduction strategies following the standard hierarchy of control measures should be applied, where feasible, to reduce subway noise exposure.*

KEYWORDS *Excessive noise exposure, Hearing protection devices, Mass transit, Noise-induced hearing loss, Sound level meter, Subway noise, Subway riders.*

INTRODUCTION

Increasingly, noise control measures are being considered as part of an overall strategy to help improve the quality of life of urban dwellers. One important source of urban noise is related to mass transit networks, which include buses, subways, light rail, commuter rail and other transportation systems. The U.S. has the largest mass transit infrastructure in the world, and this network provides affordable and efficient transportation for roughly *33 million riders each weekday*, with over 7 million riders in New York City (NYC) alone.[1] This reliance, coupled with the numerous and varied benefits of mass transit, may have, to some extent, muted our interest and concern regarding the potential health hazards, including excessive noise exposure, associated with mass transit.[2–4] Subways, in particular, are a focus of attention, not only because of their vast ridership, which is far greater than all

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other forms of mass transit combined, but also because of the wide range of potential health and safety hazards associated with them.[5] Even though a number of these hazards, such as excessive vibration, airborne heavy metal particulates, and electromagnetic radiation, have been considered,[5–13] risk assessment data on these and other potential subway-related health hazards remain extremely sparse. Numerous barriers to conducting subway research may explain this information gap, with the lack of interest from the agencies that operate subway systems perhaps the most important barrier. Other research challenges include the inherent complexity of conducting field studies in a fluid, mixed hazard setting, which makes measurement and the determination of exposure dose and exposure rates difficult.

One potential subway-related health hazard for which published data are especially limited is excessive noise. This is important because noise exposure and noise-induced hearing loss (NIHL) is a global problem of significant magnitude, especially in urban settings in industrialized nations.[14–16] In the U.S., over 20–30 million Americans are believed to be exposed to excessively high levels of noise, with about 10 million estimated to have NIHL.[17,18] Worldwide, over 200 million people are believed to be affected.[16,19] While most NIHL is believed to be primarily due to occupational exposure,[17] determining the impact of risk factors for sociocusis (non-work related hearing loss resulting from exposure to high levels of noise associated with recreational activities and transit use) on overall hearing levels is complex.[20–23] The contribution of chronic exposure to short periods of high noise, as might be encountered on subways, especially older subway systems, to hearing loss is not entirely clear.[24] Because NIHL is incremental, involving a gradual and often unnoticeable diminution in hearing acuity, those at risk may not wear hearing protection or limit exposure through avoidance. In addition to hearing loss, excessive exposure to noise may be associated with adverse effects on mental health (believed to be related to the physiological arousal of cortisol and catecholamine) and the cardiovascular system.[25–28] More recent research has focused on the impact of excessive noise on performance, short and long-term memory, and sleep patterns.[29–31] There is also a body of research documenting the negative effect of hearing loss on interpersonal communication and quality of life and work-life issues.[25,29,31] Interesting studies exploring the impact of noise at the community-level are under way; in particular, the concept of "soundscapes"[32] is being used to measure community-wide acoustic environments, and research is focused on the impact of these environments on community level outcomes.

Unfortunately no surgical or medical treatment has been shown to be especially effective for NIHL. Management of mild through moderately severe hearing loss consists primarily of personal amplification in the form of hearing aids. Exposure prevention is therefore the best approach. Not surprisingly given the serious medical and public health implications of NIHL, it is one of the top ten priorities for targeted intervention by the U.S. Public Health Service and one of the Key Healthy People objectives of the U.S.[33]

There are several exposure limits to which subway noise levels can be compared. Limits for occupational exposure to noise have been established by the U.S. Occupational Safety and Health Administration (OSHA) and U.S. National Institute for Occupational Safety and Health (NIOSH). OSHA has established an 8-h average Permissible Exposure Limit (PEL) of 90 A-weighted decibels (dBA),[34] while NIOSH has a more health-protective 8-h average Recommended Exposure Limit (REL) of 85 dBA.[35] These limits are designed to prevent NIHL in most exposed workers. However, approximately one in four workers will suffer a compensable hearing loss after a 40-year working lifetime of daily exposure at the OSHA PEL, and roughly one in 12 workers will suffer a loss after daily exposure even at the lower NIOSH REL.[34,35] This level of risk is considered acceptable in occupational settings, but is unacceptably high for community exposure. To protect nearly all individuals from any hearing loss, the Environmental Protection Agency (EPA)[36] and World Health Organization (WHO)[37] have established guidelines for community noise exposure. Both agencies recommend that individuals not exceed an 8-h daily average level of 75 dBA or a 24-h daily average of 70 dBA over a 40-year exposure period. Table 1 shows the allowable daily exposure duration for several exposure levels according to the above limits. Noise levels below 70 dBA are generally considered to present negligible risk of NIHL, regardless of exposure duration.[35] Material impairment of hearing acuity can occur in 20–30% of workers with consistent exposure to occupational noise levels of 90 dBA or greater over a working lifetime.[35] At 85 dBA, this risk is reduced to 5–15%. It is important to note that very loud single impulse exposures in the range of 125–150 dBA can also result in permanent hearing loss through the mechanical dislocation of cochlea sensory cells.[39] In practical application, approximate levels for familiar sounds are about 30 dBA for a whisper, 45–60 dBA for normal conversation, 100 dBA for a chainsaw, and 140 dBA for a gun blast.[39] The logarithmic nature of decibels means that an increase of 10 dB equals a 10-fold increase in intensity; therefore, a 90 dB sound is ten times as intense as an 80 dB sound, 100 times as intense as a 70 dB sound, and 1,000 times as intense as a 60 dB sound.

To help address some of the knowledge gaps with respect to noise exposure associated with mass transit use, we recently conducted an environmental noise survey of the NYC subway system. This system, which began in 1904, is the largest and one of the oldest in the U.S., with over 450 subway stations, 500 subway trains, and over 2,000 miles of track. Operating 24 h a day throughout the boroughs of NYC, it has the fifth largest ridership in the world.[1]

MATERIALS AND METHODS

A protocol was developed to measure environmental noise on the subway platforms and inside subway cars. Several measurements were also made at bus stops for comparison purposes. A list of potentially high noise sites with ridership access was compiled based upon previous monitoring data[40,41] and accessibility to the research team. Specific subway stations and train lines were then chosen based on the available data and in consultation with long-term subway employees.

Measurements were made on subway platforms located in the four New York boroughs with underground subways (Manhattan, Brooklyn, the Bronx and Queens). To determine if noise levels varied by location on the subway platforms, measure-

TABLE 1. Allowable daily exposure durations for various exposure levels[34–37]

	Exposure duration (min)					
	75 dBA	85 dBA	90 dBA	100 dBA	105 dBA	115 dBA
OSHA PEL	>24 h*	960	480	120	60	15
NIOSH REL	>24 h*	480	151	15	4.5	0.5
EPA/WHO	480	47.5	15	1.5	0.5	0

*Indicates an unlimited allowable exposure duration.

ments were made at three different locations on each platform. These locations were the front end (i.e., the end at which the lead car came to rest when stopped at the platform), the middle section of the platform, and the rear section of the platform (i.e., the end at which the rearmost car came to rest when stopped at the platform). For all samples, other conditions that could affect noise levels were noted (e.g., passing trains, air brake release, police sirens, etc.). The subway stations in which platform measurements were made were classified as major transfer points if three or more subway lines intersected there; stations with fewer or no line intersections were classified as smaller stations (i.e., local stops).

Noise levels were measured using a Quest 2700 (Type II) non-integrating sound level meter (SLM) (Quest Technologies, Inc., Oconomowoc, WI) set to the A-weighting network and SLOW meter response. The SLM was calibrated according to the manufacturer's instructions at the beginning and at the end of each data collection day. A windscreen was used during all measurements. All measurements were made between 10 A.M. and 4 P.M. For convenience, the SLM was placed in a backpack held in front of the researcher's body during measurements, with the microphone protruding from the backpack and pointing towards the subway train or bus stop or, in the case of measurements inside subway cars, towards the centerline of the car. Since the SLM did not have the capability of measuring an average noise level over time, sound pressure levels (SPLs, in dBA) were read off the SLM display at 5-s intervals during the duration of each measurement.

Subway Platform Measurements

For platform noise measurements, the SLM was approximately 3 feet from the ground (the height of the backpack when the researcher was standing) and 1.5 feet from the edge of the platform. Platform measurements began when the operating motor of the first car of an inbound train was flush with the rear edge of the platform. Measurements continued until the train came to a complete stop, usually after 30 to 40 s. An average SPL was computed for each platform measurement by taking the arithmetic mean of the 5-s interval readings within each measurement. SPLs are typically averaged logarithmically to compute an equivalent continuous exposure level (L_{eq}), a measure used to summarize periods of exposure to time-varying noise levels. However, in the current study SPLs were arithmetically averaged because noise levels were not sampled continuously for each measurement, but rather at regular 5-sec intervals. For comparison purposes, calculations were repeated on the data using logarithmic averaging (results not shown); the resulting mean L_{eq} level was 3.4 dBA higher than the arithmetically averaged level. The highest 5-s interval SPL within each measurement was recorded as the maximum level.

Subway Car and Bus Stop Measurements

Subway car noise measurements were made in the middle car of the monitored trains at a height of 2 feet from the floor of the car (the height of the backpack when the researcher was sitting). Measurements began when the train starting pulling out of the station, and stopped when the train came to a complete stop at the next station; only the maximum SPL during each subway car measurement was recorded. As another mass transit comparison, measurements were made at bus stops. For these measurements, the SLM was held 3 feet from the ground and 1 foot away from the curb. Bus stop noise levels were measured as buses pulled into or away from the stop, and, as with the subway car measurements, only the maximum SPL was recorded.

The height of the SLM during all measurements makes the measured SPLs most relevant to children and shorter adults; however, in the highly reverberant environment of subway platforms (all of which were constructed completely of brick, tile, steel, and/or concrete) and subway cars, the difference between levels measured at a height of 2 or 3 feet vs. measurements made at ear height should be minimal.

Statistical Analysis

All statistical analysis was performed using Intercooled Stata 9.0 (Stata Corporation, College Station, TX). Histograms and quantile–quantile plots of the measured average and maximum noise levels were examined for potential outliers. One measured subway car maximum level of 140.3 dBA was identified, which was more than six standard deviations away from the mean maximum level. This level was determined to be an outlier and was removed from the dataset. Descriptive statistics were calculated on the remaining measurements, and mean values were statistically compared using Student *t*-tests. Exceedance fractions (the fraction of measurements over certain threshold levels) were compared using the χ^2 test. Differences were considered statistically significant if $p < 0.05$.

RESULTS

Subway Platform Measurements

Fifty-seven average SPL measurements (encompassing 377 5-s interval SPLs) were made on underground subway platforms in 17 different subway stations. Forty of the 57 measurements had durations of 30 s or less; the longest lasted 90 s. All 57 average levels were over 75 dBA, the threshold level above which there is a duration-dependent risk of NIHL.

Table 2 presents measurement durations and mean and maximum 5-s interval noise levels for all platform measurements and stratified by platform measurement location and station type. The fraction of measurements exceeding 85 and 90 dBA

TABLE 2. Noise levels and exceedance fractions in subway stations

	Measurement duration (s)			Noise level (dBA)				
Location/ station type	*n*	Mean	Standard deviation	Mean	Standard deviation	Highest 5-s interval	Percent (%) >85 dBA	Percent (%) >90 dBA
Overall	57	34.0	10.8	85.7	3.9	106.0	58.0	12.2
Location								
Back of platform	19	38.9	14.2	86.1	4.8	106.0	63.2	21.1
Middle of platform	19	33.2	8.0	85.1	3.9	105.0	63.2	5.3
Front of platform	19	30.0	7.1	86.0	3.0	105.0	47.4	10.5
Station type								
Major transfer point	24	32.3	7.1	87.5	3.1	106.0	79.2	16.7
Local station	33	35.3	12.7	84.5	4.0	105.0	42.4	9.1

is also shown. The mean level across all measurements was 85.7 dBA, and the highest 5-s interval SPL within these measurements was 106 dBA. More than half of all measurements were over 85 dBA, and more than one in ten were over 90 dBA. Measurements made at the back of the platform had the highest mean level and fraction of average exposures over 85 and 90 dBA; however, neither mean noise levels nor exceedance fractions differed significantly by platform location. Stations that are major transfer points had statistically significantly higher mean noise levels (mean difference 3 dBA, $p = 0.002$) than smaller local stations and had a statistically higher fraction of measurements over 85 dBA ($p = 0.006$). Measurement conditions associated with average platform noise levels over 85 and/or 90 dBA included track curvature, presence of two trains at a platform simultaneously, excessive brake squealing, debris on the subway tracks, presence of loud musicians on the platform, and release of compressed air from air brakes on the trains. Major transfer point stations consistently had the highest noise levels.

Maximum Levels for Subway Platforms, Subway Cars, and Bus Stops

Table 3 presents the maximum 5-s interval levels measured on subway platforms, subway cars, and at outdoor bus stops. More than one in ten of the maximum 5-s interval SPLs associated with the 57 subway platform measurements exceeded 100 dBA, and three out of four exceeded 90 dBA. The mean maximum noise level on subway platforms was 93.5 dBA, with a range of 83 to 106 dBA. Maximum SPLs on the platforms were significantly ($p < 0.05$) higher than average in instances when express trains passed the station during measurements.

Twenty-five maximum SPL measurements were collected on subway cars from five different train lines. Inside the subway cars, the mean maximum noise level was 94.9 dBA, with a range of 84 to 112 dBA. Seventeen (68%) of the maximum SPLs exceeded 90 dBA, and 5 (20%) exceeded 100 dBA. The highest maximum subway car levels were associated with passing trains. Maximum SPLs inside the cars were significantly higher ($p < 0.05$) than average when other trains were passing.

Maximum SPLs were measured at ten different outdoor bus stops. At the bus stops, the mean maximum SPL was 84.1 dBA, with a range of 76 to 89 dBA. Maximum bus stop noise levels were significantly increased ($p < 0.05$) when vehicular traffic on the street was heavy, when emergency vehicle sirens were sounding, and when garbage trucks were idling in the vicinity of the sampling.

Mean maximum noise levels on subway platforms were not statistically significantly different than those in the subway cars. However, the mean maximum

TABLE 3. Maximum 5-s interval noise levels for subway platforms, subway cars, and bus stops

	Maximum 5-s interval noise level					
	n	Mean (dBA)	Standard deviation (dBA)	Highest (dBA)	Percentage of maximum levels >90 dBA	Percentage of maximum levels >100 dBA
Subway platform	57	93.5	5.3	106.0	76.0	12.3
Subway car	25	94.9	7.1	112.0	68.0	20.0
Bus stop	10	84.1	4.5	89.0	0.0	0.0

levels on both the subway platforms and the subway cars (9.4 dBA difference, $p < 0.0001$, and 10.8 dBA difference, $p < 0.0001$, respectively) were both statistically significantly higher than those of the bus stops.

DISCUSSION

The findings from this study indicate that subway riders have the potential for exposure to levels that exceed the EPA/WHO community noise limits. The mean noise level (about 85 dBA) from the subway platforms measurements in this study has an allowable exposure duration of about 45 min under the EPA/WHO limits. Nearly 60% of the platform measurements exceeded this level. The maximum level measured on the platforms (106 dBA) has an EPA/WHO allowable exposure duration of less than 30 s, and 12% of platform measurements exceeded the level of 100 dBA, which has a 1.5 min allowable exposure duration. The maximum noise levels inside the subway cars were even higher than those on the platforms, with one in five exceeding 100 dBA (1.5 min allowable EPA/WHO exposure duration) and more than two-thirds exceeding 90 dBA (15 min allowable exposure duration). Bus stop maximum noise levels were significantly lower than those on subway platforms and inside subway cars. The mean maximum bus stop level was about 85 dBA, suggesting that bus stops may present additional, though lower, risk of exposure to excessive noise.

The implications of these findings are clear. NIHL generally results from chronic exposure to noise levels in excess of 85 dBA.[35,42] OSHA and NIOSH workplace noise exposure limits restrict 8-h work shift exposure to 90 and 85 dBA, respectively, in order to protect most workers from compensable hearing loss after a 40-year working lifetime.[34,35] EPA and WHO recommend lower daily exposures (75 dBA for 8 h, or 70 dBA for 24 h) to prevent any hearing loss among exposed individuals.[36,37] Loss of hearing is determined by audiometric measurements of hearing threshold levels, which represent hearing sensitivity at various frequencies. A 30 min daily exposure to 90 dBA of subway noise (equivalent to a daily 8-h exposure of 78 dBA) for 5 days per week over a 40 year period would be expected to produce a 4 dB loss of hearing at 4 kiloHertz (kHz) in the median individual and an 11 dB loss in the 90th percentile individual.[36] Exposure to 100 dBA for 30 min per day (equivalent to an 8-h exposure level of 88 dBA) would be expected to produce a 4 kHz hearing loss of 16 dB in the median individual and 24 dB in the 90th percentile individual. A loss of as little as 10 dB averaged across 2 and 4 kHz over both ears may affect speech comprehension.[37,43] Note that these estimates assume no other exposure to noise during the day, which is clearly not the case for many subway riders exposed to other sources of occupational and non-occupational noise. Individuals living in urban areas have been demonstrated to have greater hearing loss than those with similar occupational exposures to noise but living in rural areas.[44]

With respect to subway operators (who were not monitored for this study but are presumably exposed to levels similar to those measured here), these data indicate a potential for 8-h average exposure levels that exceed the OSHA and NIOSH limits. Additional monitoring is needed to quantify the risk of overexposure among this occupational group.

The noise levels measured in this study generally agree with the limited data available in the literature. A 1975 EPA study[45] noted that interior noise levels from various measurements in commuter railroad and subway cars in New York, Boston, and other major U.S. cities ranged from 69 to 91 dBA and concluded that riders exposed to subway and commuter railroad car noise for 1 h per day, five days per week, would exceed the EPA's recommended 24-h exposure limit of 70 dBA even in the absence of any occupational noise exposure. Cohen et al.[46] noted in 1970 that subway platform and car levels were in the range of 90 to 97 dBA (though data collection protocols were not described) and that some segment of subway riders is therefore likely at risk of NIHL from riding subways daily. Johanning et al.[47] cited New York City Transit Authority subway operator exposure levels of 80 to 85 dBA in 1991 and found that more than two-thirds of 600 operators surveyed by questionnaire complained of excessive noise exposure. As with Cohen, Johanning et al. did not describe how they derived their noise subway exposure estimates. Finally, Chang and Hermann[48] conducted an extensive assessment of noise in Chicago Transit Authority subways in 1974 and concluded that there was some risk of development of NIHL among subway operators and regular subway riders, though they stated that the risk was low. The methods and results of the Chang et al. study are somewhat difficult to compare to current exposure limits, given the changes in noise standards and measurement methodology in subsequent years and alterations over time in subway structures and maintenance. Also, the authors' assumptions regarding recovery from temporary hearing loss resulting from subway ridership are not completely consistent with current theories in noise exposure assessment.

While transportation-related noise exposure over time can be estimated, as can occupational exposure, all other sources and durations of noise exposure must be accounted for in order to assess the contribution of transit-related noise to total NIHL risk. The next step in evaluating exposure to subway-related noise among riders would be personal dosimetry measurements, which would provide time-integrated estimates of exposure to noise on subway platforms and aboard subway cars. This dosimetry would be followed by extensive assessments of noise exposure histories among subway riders and audiometric testing or self-reported hearing status. Statistical models are available to estimate the contributions of past noise exposure history, including occupational exposure, other sources of noise (e.g., recreational sources of noise such as gun use, loud music, power-tool use, etc.) and the relative contributions of aging and other risk factors for hearing loss. Estimates of transportation-related NIHL would involve some degree of imprecision and exposure misclassification but would nevertheless provide a useful indication of the risk of NIHL presented by transit use.

In the absence of definitive risk assessment data and given our findings, it would seem prudent to apply risk reduction strategies where feasible. A number of engineering controls may be implemented by subway system agencies to reduce noise levels in the subway environment.[49–52] These include sound dampening acoustical materials placed in particularly noisy sections of a subway line and repair and improved maintenance of tracks, braking mechanisms, and equipment in general. Newer subway systems can be and are designed and engineered to reduce noise through the use of rubberized rails, acoustical tiles, and other effective techniques.

At the individual level, another risk management approach is the use of personal hearing protection devices (HPDs), such as earplugs and earmuffs, which serve to attenuate the intensity of the sound that reaches the eardrum. Properly fitted ear plugs and ear muffs can reduce noise exposure by up to 33 dB; simultaneous use of both devices can add an additional 5 dB of attenuation.[53] Blocking the ear canal with cotton or other materials not specifically designed to protect hearing only reduces noise levels slightly. The use of personal listening devices by subway riders, which may be perceived as protective against noise exposure, is not protective and will, in fact, contribute to noise exposure and risk of NIHL if music is played at high volumes.[53] Public education is needed to increase awareness of the risk of NIHL from noise and appropriate use of HPDs. Persons concerned about hearing loss can complete a simple risk assessment questionnaire, available at: http://www.nidcd.nigh.gov/health/hearing/10ways.asp. Finally, avoidance may be an option for some riders, but for most urban dwellers and commuters, this is probably not practical.

CONCLUSION

With approximately 30 million mass transit subway riders in the U.S., the population at potential risk of exposure to subway-related noise is large, and the seriousness of the outcomes is well documented. Additional study of this potential public health problem is warranted in order to fully characterize the risk and to guide the development of effective risk management strategies.

REFERENCES

1. The MTA Network. Metropolitan Transit Authority. Available at: http://www.mta.nyc.ny.us/mta/network.htm. Accessed April 4, 2006.
2. A World of Trams and Urban Transit. LRTA. Available at: http://www.lrta.org/world/worldind.html. Accessed April 4, 2006.
3. U.S. Department of Transportation, Bureau of Transportation Statistics. National Transportation Statistics 2003. Fuel Consumption by Mode of Transportation, Washington, District of Columbia. Available at: http://www.bts.gov/publications/national_transportation_statistics/2003/html/table_04_05.html. Accessed April 4, 2006.
4. Seshagiri B. Exposure to noise on board locomotives. *AIHAJ*. 2003;64:699–707.
5. Gershon RRM, Qureshi KA, Barrera MA, et al. Health and safety hazards associated with subways: a review. *J Urban Health*. 2005;82(1):10–20.
6. Johanning F, Fischer S, Christ E, Gores B, Landsbergis P. Whole-body vibration exposure study in U.S. railroad locomotives: an ergonomic risk assessment. *AIHAJ*. 2002;63:439–446.
7. Guidotti TL, Cottle MKW. Occupational health problems among transit workers. *Public Health Rev*. 1987;15:29–44.
8. Chillrud SN, Epstein D, Ross JM, et al. Elevated airborne exposures of teenagers to manganese, chromium, and iron from steel dust and New York City's subway system. *Environ Sci Technol*. 2004;38:732–737.
9. Yu IJ, Yoo CY, Chung YH, et al. Asbestos exposure among Seoul metropolitan subway workers during renovation of subway air-conditioning systems. *Environ Int*. 2004;29:931–934.
10. Krause N, Ragland DR, Fisher JM, Shyme SL. Volvo award winner in clinical studies: psychosocial job factors, physical workload, and incidence of work-related spinal injury: a 5-year prospective study of urban transit workers. *Spine*. 1998;23:2507–2517.
11. Boudia N, Halley R, Kennedy G, Gareau L, Zayed J. Manganese concentrations in the air of the Montreal (Canada) subway in relation to surface automobile traffic density. *Toxicologist*. 2004;78(S-1):80.
12. Dietrich FM, Jacobs WL. *Survey and assessment of Electric Magnetic Field (EMF) Public Exposure in the Transportation Environment*. U.S. Department of Transportation, Federal Railroad Administration; 1999. Report No. PB99-130908.
13. Muc AM. Electromagnetic fields associated with transportation systems. Available at: http://www.rhsc.ca/TransEMF.pdf. Accessed April 4, 2006.

14. Nelson DI, Nelson RY, Concha-Barrientos M, et al. The global burden of occupational noise-induced hearing loss. *Am J Ind Med*. 2005;48:446–458.
15. Garcia A. Introduction. In: Garcia A, ed. *Environmental Urban Noise*. Southampton, UK: WIT; 2001:1–13.
16. Smith A. The fifteenth most serious health problem in the WHO perspective. Presentation to IFHOH World Congress, Helsinki, July 2004. Available at: http://www.kuulonhuoltoliitto.fi/tiedoston_katsominen.php?dok_id=150. Accessed April 4, 2006.
17. Simpson M, Bruce R. Noise in America: The extent of the noise problem. U.S. Environmental Protection Agency, EPA Report No. 550/9-81-101, 1981.
18. U.S. Department of Labor, Occupational Safety and Health Administration (OSHA). 2002. Noise and Hearing Conservation. Available at: http://www.osha-slc.gov/SLTC/noisehearingconservation/index.html. Accessed on April 4, 2006.
19. World Health Organization (WHO). 2004. Occupational noise: assessing the burden of disease from work-related hearing impairment at national and local levels. Environmental Burden of Disease Series, Number 9. Geneva.
20. Axelson, A. Recreational exposure to noise and its effects. *Noise Control Eng J*. 1996;44:127–134.
21. Neitzel R, Seixas N, Goldman B, Daniell W. Contributions of non-occupational activities to total noise exposure of construction workers. *Ann Occup Hyg*. 2004;48(5):463–473.
22. Davis AC, Fortnum HM, Coles RRA, Haggard MP, Lutman ME. et al. *Damage to Hearing arising from Leisure Noise: A Review of the Literature*. MRC Institute of Hearing Research. Nottingham, England: University of Nottingham, 1985.
23. Kryter KD. Hearing loss from gun and railroad noise—relations with ISO standard 1999. *J Acoust Soc Am*. 1991;90(6):180–195.
24. Starck J, Toppila E, Pyykko I. Impulse noise and risk criteria. *Noise Health*. 2003;5(20):63–73.
25. Vallet M. Effects of noise on health. In: Garcia A, ed. *Environmental Urban Noise*. Southampton, UK: WIT; 2001:63–109.
26. Davis R, Hamernik R. Noise and hearing impairment. In: Levy BS, Wegman DH, eds. *Occupational Health: Recognizing and Preventing Work-Related Disease*. 3rd ed. Boston: Little Brown; 1995:321–336.
27. Talbott EO, Gibson LB, Burks A, Engberg A, McHugh KP. Evidence for a dose-response relationship between occupational noise and blood pressure. *Arch Environ Health*. 1999;54(2):7178.
28. Lusk SL, Hagerty BM, Gillespie B, Caruso CC. Chronic effects of workplace noise on blood pressure and heart rate. *Arch Environ Health*. 2002;57:273–281.
29. Hetu R, Getty L, Quoc HT. Impact of occupational hearing loss on the lives of workers. *Occup Med State Art Rev*. 1995;10:495–512.
30. Melamed S, Luz J, Green MS. Noise exposure, noise annoyance and their relation to psychological distress, accident and sickness among blue collar workers–the Cordis Study. *Israel J Med Sci*. 1992;28:629–635.
31. Miller JD. Effects of noise on people. *J Acoust Soc Am*. 1974;53(3):729–764.
32. Barrett D. Urban Soundscapes: What should a public space sound like? Available at: http://www.hmmh.com/presentations/urban_soundscape-deb.pdf. Accessed April 4, 2006.
33. U.S. Department of Health and Human Services. *Healthy People 2010: Understanding and Improving Health*. 2nd ed. Washington, District of Columbia: U.S. Government Printing Office; 2000.
34. U.S. Occupational Safety and Health Administration (OSHA). Occupational Noise Exposure: Hearing Conservation Amendment; Final Rule. Fed Reg Washington, District of Columbia: U.S. Department of Labor, Occupational Safety and Health Administration. 1983:9738–9785.
35. U.S. National Institute for Occupational Safety and Health (NIOSH). *Criteria for a recommended standard: Occupational noise exposure revised criteria 1998*. Cincinnati, OH: Department of Health and Human Services, Public Health Service, Centers for

Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 98–126; 1998.
36. U.S. Environmental Protection Agency (EPA). *Protective noise levels: condensed version of EPA levels document*. EPA Report No. 550/9-79-100. Washington, District of Columbia, U.S., 1979.
37. World Health Organization (WHO). In: Berglund B, Lindvall T, Schwela D, eds. *Guidelines for Community Noise*. Geneva: World Health Organization; 1999.
38. Passchier-Vermeer W, Passchier WF. Noise exposure and public health. *Environ Health Perspect*. 2000;108 (Suppl 1):123–31.
39. Gassaway D. Noise-induced hearing loss. In: McCunney R, ed. cc*A Practical Approach to Occupational and Environmental Medicine*. 7th ed. Boston: Little Brown; 1994:230–247.
40. Harris CM, Aitken BH. Noise in subway cars. *Sound Vibration*. 1971; February issue:21–24.
41. Stanton GT. Noise survey of rapid transit lines for the Board of Transportation of the City of New York, NYC. June 20, 1931.
42. May J. Occupational hearing loss. *Am J Indust Med*. 2000;37:112–120.
43. U.S. Environmental Protection Agency (EPA). *Information on levels of environmental noise requisite to protect public health and welfare with an adequate margin of safety.* EPA Report 550/9-74-004, Washington, District of Columbia, U.S.; 1974.
44. Abbate C, Concetto G, Fortunato M, et al. Influence of environmental factors on the evolution of industrial noise-induced hearing loss. *Environ Monitoring Assess*. 2005;107:351-361.
45. U.S. Environmental Protection Agency (EPA). *Passenger noise environments of enclosed transportation systems*. EPA Report Number 550/9-75-205. Environmental Protection Agency, Office of Noise Abatement and Control. Washington, District of Columbia; 1975.
46. Cohen A, Anticaglia J, Jones H. Sociocusis: hearing loss from non-occupational noise exposure. *Sound Vibration*. 1970;4:12–20.
47. Johanning E, Wilder DG, Landrigan PJ, Pope MH. Whole-body vibration exposure in subway cars and review of adverse health effects. *J Occup Med*. 1991;33:605–612.
48. Chang HC, Hermann ER. Acoustical study of a rapid transit system. *Amer Ind Hyg Assoc J*. 1974;35:640–653.
49. Manning CJ, Harris GJ. Noise control in transportation. *Noise Health*. 2003;5(18):43–45.
50. Garcia A. Urban noise control. In: Garcia A, ed. *Environmental Urban Noise*. Southampton, UK; WIT; 2001:183–225.
51. Wolfe SL. Introduction to train noise. In: Nelson P, ed. *Transportation Noise Reference Book*. Butterworths, London; 1986:13/1–13/6.
52. Remington PJ, Kurzweil LG, Towers DA. Practical examples of train noise and vibration control. In: Nelson P, ed. *Transportation Noise Reference Book*. Butterworths, London; 1986:17/1–17/23.
53. Berger EH. Chapter 10: Hearing protection devices. In: Berger EH, Royster LH, Royster JD, Driscoll DP, Layne ML, eds. *The Noise Manual*. 5th ed. U.S.: American Industrial Hygiene Association. Fairfax, VA; 2000:379–454.