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Noise in a Laboratory Animal Facility from the Human and Mouse Perspectives

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The current study was performed to understand the level of sound produced by ventilated racks, animal transfer stations, and construction equipment that mice in ventilated cages hear relative to what humans would hear in the same environment. Although the ventilated rack and animal transfer station both produced sound pressure levels above the ambient level within the human hearing range, the sound pressure levels within the mouse hearing range did not increase above ambient noise from either noise source. When various types of construction equipment were used 3 ft from the ventilated rack, the sound pressure level within the mouse hearing range was increased but to a lesser degree for each implement than were the sound pressure levels within the human hearing range. At more distant locations within the animal facility, sound pressure levels from the large jackhammer within the mouse hearing range decreased much more rapidly than did those in the human hearing range, indicating that less of the sound is perceived by mice than by humans. The relatively high proportion of low-frequency sound produced by the shot blaster, used without the metal shot that it normally uses to clean concrete, increased the sound pressure level above the ambient level for humans but did not increase sound pressure levels above ambient noise for mice at locations greater than 3 ft from inside of the cage, where sound was measured. This study demonstrates that sound clearly audible to humans in the animal facility may be perceived to a lesser degree or not at all by mice, because of the frequency content of the sound.

Abbreviation: dB(A), A-weighted sound pressure level; FFT, fast Fourier transform.

Noise and vibration affect many behavioral and physiologic parameters in animals and can be confounding variables in research studies.[1,2,15,16,19,20] Studies have shown that husbandry practices and equipment typically found in animal facilities produce sound at frequencies exceeding those humans can hear but within the hearing range of animals.[10,16] In controlled studies where mice are exposed to prolonged high-decibel sound at frequencies well within their hearing range, noise has caused teratogenic and reproductive effects.[11,12,21] One source of noise in the laboratory animal environment that is poorly controlled stems from construction, demolition, or repair of the physical plant structure within or close to an occupied laboratory animal-holding facility. Studies have shown that these activities cause adverse effects on laboratory mice by causing reproductive problems, alteration in stress hormones, and potentially decreasing growth rates in mice or rats.[4,5,14] Construction noise perceived by humans to be 70 and 90 decibels caused decreased live birth rates and increased the number of stillborn pups in mice.[14] The question remains as to how much of this construction noise are mice actually hearing. In the current study we determined the approximate sound levels originating from common types of construction equipment that are audible to mice compared with humans and the effect that distance from the sound source has on the noise perceived in the animal's microenvironment relative to that perceived by humans.

Mouse hearing extends into the ultrasonic frequencies and ranges from 1 to about 100 kHz[7,9] whereas the human hearing range is between 20 Hz and 20 kHz.[6,17] Graphs of human and mouse audiograms are both roughly U-shaped when decibels are plotted against increasing frequencies.[7,9] The audiograms show less-sensitive hearing at low frequencies within the hearing range, while hearing becomes more sensitive as the frequencies increase to a point (the bottom of the U), when hearing again becomes less sensitive as the frequencies increase. Hearing is most sensitive for humans at frequencies of approximately 1 to 4 kHz[6] and approximately 16 kHz for mice.[9] Misunderstanding of the differences in sensitivity to sound of different frequencies across species could lead to the incorrect assumption that if humans can hear a sound, mice can hear it as well.

In humans, the total decibel value of sound pressure levels within the hearing range can be presented as 'A-weighted' data, and this weighting process roughly normalizes data to the decibel levels that humans actually would hear. In A-weighting of sound data, sound pressure levels at frequencies within but above or below the most sensitive part of the hearing range contribute relatively less to the total decibel level of the sound than do the pressure levels in the most sensitive part of the audiogram. Such a weighting scheme is not available for mice, but the total unweighted (linear) sound pressure level within the audiogram for mice can be compared with that of humans to ascertain the approximate level of the mouse's auditory perception to the same sound. This comparison is possible due to the similar shapes of the human and mouse audiograms and of the sound pressure curves within each audiogram. Because variables such as age, disease, noise exposure, and strain (for mice) can affect the hearing in individual humans or mice, audiograms represent an approximation of what each species may perceive.

Due to the need for extensive floor repair in a vivarium at our facility, the issues of how much noise would be generated during this repair and the potential effect on the animals located within the vivarium had to be addressed. The options

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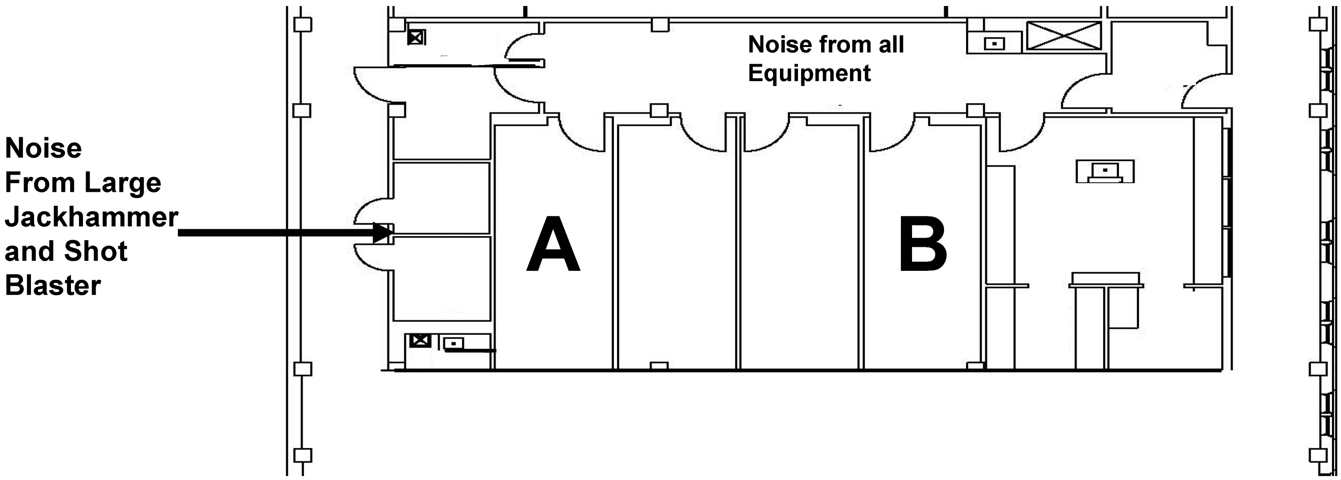

Figure 1. Physical plant configuration of vivarium module where noise testing occurred.

for the floor repair ranged from extensive repair with a large amount of noise generated to a more limited repair that affected a smaller area of the facility and was predicted to cause only minimal noise. Although the more extensive repair option was preferable, we were unable to move the majority of the rodents out of the facility because of space constraints. To ascertain the sound levels that mice might perceive, a study was designed to maximize the noise from construction equipment in and around an unoccupied module in this facility. Airborne sound levels originating from several types of construction equipment were measured inside of a ventilated rack cage to assess the level of sound that mice inside similar caging would perceive. In addition, airborne sound originating from the normal operation of a ventilated rack and an animal transfer station was analyzed in this manner.

Materials and Methods

Sound measurements. All sound measurements were taken from inside of a bedded, 75 in.^{2} polysulfone cage on a fully stocked 140-cage, positive-pressure, mouse ventilated cage rack (model PNC75JU70SPSH-R, Allentown Caging, Allentown, NJ) at 60 air changes per hour per cage. To minimize exposure of rodents in the building to noise, no mice were present in the module where the testing was conducted or in an adjacent module. Although no animals were used in this study, the IACUC was made aware of the intent to perform this work before it was initiated.

After an 8-mm, circular hole was drilled into the front of a ventilated cage, the microphone was placed inside of the cage, and plummer's putty was used to seal the hole around the microphone's cable to prevent leakage of air around the cable. The end of the microphone where sound is detected was placed in the middle of the cage at the head height (approximately 1.5 in.) of mice. Consistent with operation of the rack in this vivarium, the cage contained our standard amount of approximately 200 mL 1/4-in. corncob bedding. The cage was placed on the middle of the bottom row of the ventilated cage rack. Remaining equipment for the study was located on a portable cart adjacent to the ventilated rack during the measurements.

Sound measurements were made by using a Pulse System Acoustic Analyzer (with 7536 and 3110 modules, Brüel Kjaer, Nærum, Denmark) and microphone (4939-A-011, Brüel Kjaer). Sound was measured unfiltered at frequencies from 0 to 102.4 kHz. The sampling rate was 3.815 µs, 800 lines were used for fast Fourier transform (FFT), and the delta F was 128 Hz. The recordings were made with a sampling rate of approximately 262 kHz. A linear FFT average was obtained, where the analyzer was set up with 800 lines at 102.4 kHz bandwidth. By using 66.67% overlap and a fixed averaging time of 15 s, this process yielded 5758 time buffers captured, with each transformed by FFT and then averaged together. The levels in each FFT line are the root mean square value. The total energy was calculated by summing the energy in each of the FFT lines of the spectrum. The microphone used for measurements was omnidirectional, so it received sound effectively equally from all directions.

Sound initially was generated by the construction equipment inside of an empty module 3 ft from the ventilated rack. The sound was generated by a large jackhammer (Brute11304, Bosch, Farmington Hills, MI), small jackhammer (11316EVS, Bosch), vacuum (6.5-hp 2-in-1 [blower and vacuum], Ridgid, Organe, VA), grinder and vacuum (1873-6 15-A angle grinder, Bosch), terrazzo grinder (501S, Terrco, Watertown, SD) and shot blaster (without shot; 1-10D blaster with 5-54 dust collector, Blastrac, Oklahoma City, OK), an animal transfer station (model NU612-400, Mobile Animal Transfer Station, NuAire, Plymouth, MN) with the ventilated rack, and the ventilated rack alone. For all of the construction equipment, sound was generated 3 ft from the cage and measurements taken from within the corridor immediately outside of the animal rooms (Figure 1). In addition, the large jackhammer and shot blaster (without shot) were chosen to generate sound that would be measured at greater distances, in light of the high decibel level of sound they produced and their different modes of creating sound (striking the floor and without striking the floor, respectively). Sound from the large jackhammer and shot blaster was generated immediately outside of the module, and the sound measurements were measured in rooms A and B (Figure 1) as well as on the second and third floors directly above the site where the noise was generated. Sound that was generated by an animal transfer station and the ventilated racks was measured in rooms A and B as well as in the corridor outside of the animal rooms. Due to technical difficulties, only sound measurements of the ventilated rack with the animal transfer station in rooms A and B could be used for analysis.

Physical plant construction. The outer walls of the module are constructed of concrete masonry units coated with epoxy paint,

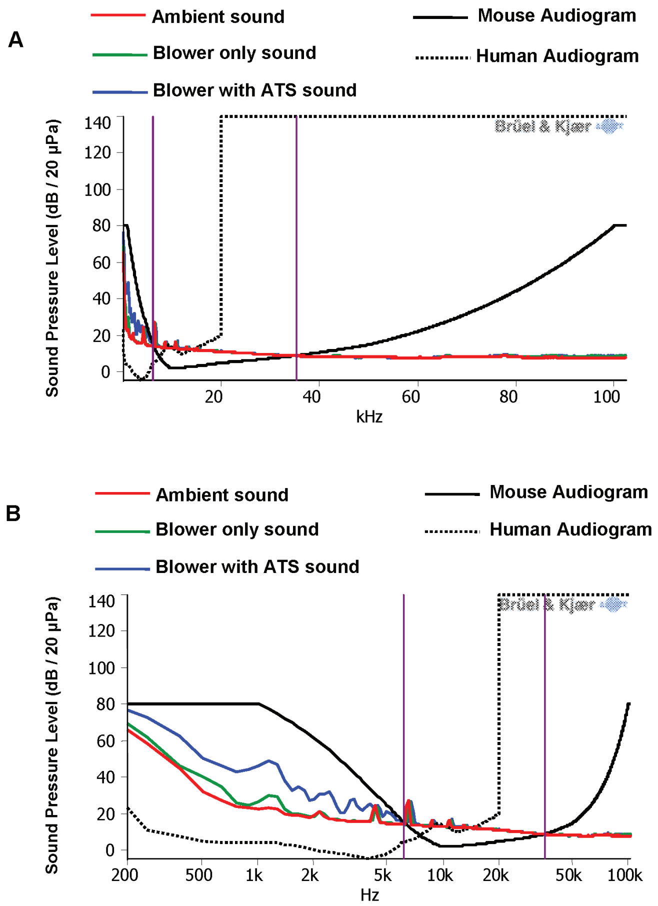

Figure 2. Sound pressure levels produced from ambient noise, the ventilated rack blower, and ventilated rack blower with the animal transfer station (ATS), as measured from inside of the cage. The human and mouse audiograms are superimposed on the graph. Measurement of the sound pressure levels that existed within each audiogram were made by determining the decibel level of sound pressure within the δ zone (area between the violet vertical lines). For example, the sound pressure level within the mouse audiogram is demarcated. Data are presented on (A) a linear scale to show the trend of data at all frequencies, as well as on (B) a log scale so that more detail can be seen at the lower frequencies.

whereas the inner walls and ceiling are made of dry wall. Floors consist of epoxy coating over a concrete slab, and the floor-to-ceiling height is approximately 8 ft. The distances from the site where noise was generated immediately outside of the module to rooms A and B (Figure 1) are 15 and 50 ft, respectively.

Data analysis. All data was analyzed by using Pulse LabShop software (version 13.1, Brüel and Kjaer). Both the human[8] and mouse audiograms[9] were superimposed onto the sound pressure levels of each measurement, and the sound pressure within each audiogram was determined. The sound pressure levels within the human audiogram were analyzed with A-weighting to more closely approximate what humans hear; however, no weighting algorithm exists to approximate the perceived decibel level of a sound for mice. Linear measurements of sound within the mouse and human hearing ranges were compared to investigate the decibel level of a sound that mice would hear as compared with that for humans. The mouse audiogram used to calculate sound pressure levels ranged from 1 to 90 kHz, and the human audiogram ranged from 20 Hz to 20 kHz. In rare cases, peaks of lower frequency sound originated from outside of the mouse audiogram but extended into the audiogram. For consistency, measurements were made including these entire peaks; however, including the data outside of the audiogram added only a negligible number of decibels to the total decibel level. Because humans hear lower frequency sound than do mice, these extraneous data did not complicate determining the linear sound pressure level within the human audiogram for these measurements, because the entire peak was within the audiogram.

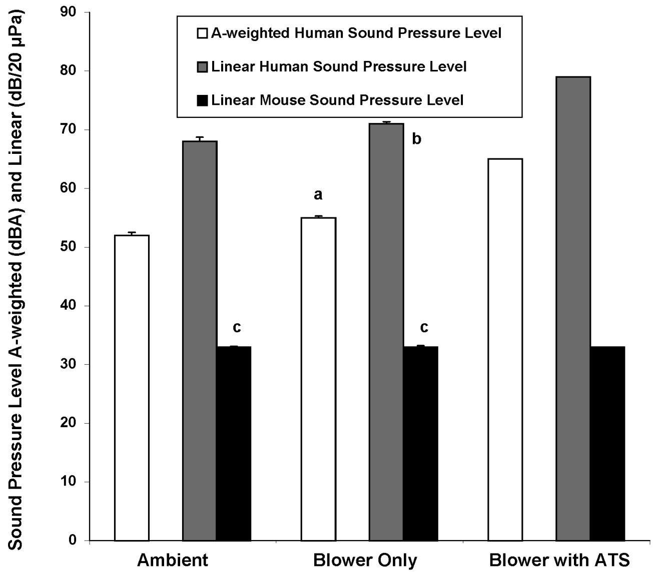

Figure 3. Sound from the ventilated rack blower only and with the animal transfer station (ATS) measured from inside of the cage and compared with ambient noise. Both the A-weighted (a, $P \leq 0.05$) and linear (b, $P = 0.05$) levels of sound pressure for humans increased due to the ventilated rack blower as compared with ambient noise. The linear sound pressure level for mice was lower (c, $P \leq 0.001$) relative to the human linear level of sound pressure for both ambient noise and the ventilated rack blower only. Although sound pressure increased in the human hearing range as a result of the ATS, the linear sound pressure level in the mouse hearing range was not increased above ambient noise or blower-only levels. Each bar represents the mean ± SEM with 2 degrees of freedom. Due to technical issues, data from the ventilated rack blower with ATS could be used from only 2 locations and therefore were not included in the statistical analysis.

Sound that the ventilated racks produced over the ambient noise was analyzed for significance by using one-tailed, paired *t* tests (Excel, Microsoft, Redmond, WA). Statistical analysis of data taken from the ventilated rack with the animal transfer station was not possible because only 2 viable measurements were available. To minimize the damage to the floor from the construction equipment, one measurement was taken from each piece of construction equipment at each location described.

Results

Within-cage sound due to ventilated racks and animal transfer stations. The sound that was measured from inside of a cage as a result of ambient noise and the ventilated rack blower alone and in combination with the blower of the animal transfer station in room A is shown in Figure 2. The human sound level in dB(A) corresponds to the level that humans would experience if inside the cage on a ventilated rack. According to 3 independent measurements (rooms A and B and the corridor outside of the animal rooms), the blower significantly ($P \leq 0.05$) increased the noise level (mean ± SE) from ambient noise at 52 ± 0.5 dB(A) to 55 ± 0.3 dB(A). The addition of the animal transfer station to

Table 1. A-weighted and linear sound generated by various items of construction equipment 3 ft from the cage

	Human A-weighted (dB[A])	Human linear (dB/20 µPa)	Mouse linear (dB/20 µPa)	Total linear sound pressure below 1 kHz (%)
Ambient noise	53	70	33	99.9
Shot blaster (without shot)	84	93	72	99.3
Large jackhammer	90	92	90	60.6
Small jackhammer	88	91	88	73.3
Terrazzo grinder	79	89	67	99.6
Grinder with vacuum	78	83	74	90.4
Vacuum only	67	75	61	96.3

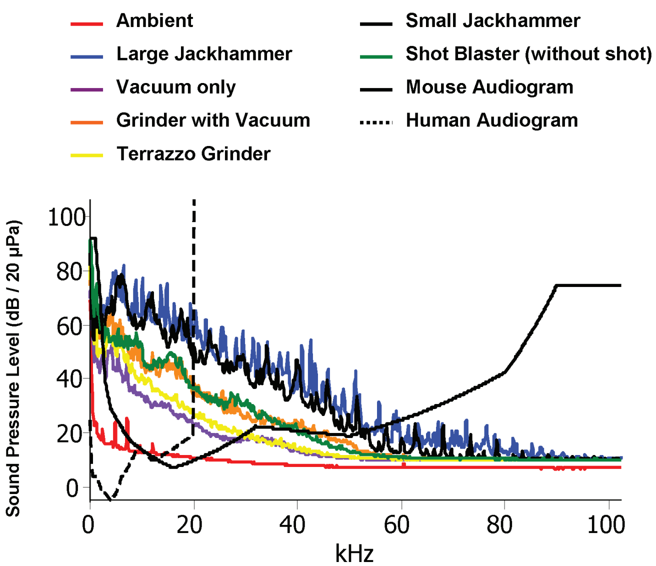

Figure 4. Intracage sound pressure levels from various types of construction equipment as measured 3 ft from the equipment. The human and mouse audiograms are superimposed.

the sound of the blower increased the noise level inside of the cage to an average of 65 dB(A) ($n = 2$; Figure 3).

To determine the approximate sound level that mice would perceive, the unweighted (linear) sound pressure levels within the human and mouse audiograms were calculated (Figure 2). The area between the violet vertical lines in Figure 2 delineates the sound pressure level within the mouse audiogram, as an example. The linear ambient noise that humans would experience inside the cage would be 68 ± 0.7 dB/20 µPa, whereas the linear sound pressure level within the human hearing range with the ventilated rack blower running was significantly ($P \leq 0.05$) increased to 71 ± 0.3 dB/20 µPa (Figure 3). The total linear ambient sound pressure level in the mouse audiogram was significantly ($P \leq 0.001$) less (33 ± 0.1 dB/20 µPa) as compared with the total linear sound pressure level of ambient noise in the human hearing range. In contrast to that for humans, the linear sound pressure level in the mouse hearing range did not increase as a result of the ventilated rack blower (Figure 3), nor did it increase above ambient noise in a room with 4 blowers running simultaneously (data not shown). The linear sound pressure level with the addition of the animal transfer station increased to 79 dB/20 µPa in the human hearing range as compared with 71 ± 0.3 dB/20 µPa for the blower only, but no increase above ambient noise was noted in the hearing range for mice (Figure 3).

Within-cage sound due to various types of construction equipment. The data regarding sound generated by various types of construction equipment 3 ft from the cage are summarized in Table 1 and graphically depicted in Figure 4. The corresponding sound that humans would hear if inside the cage ranged from 67 dB(A) for the vacuum only to 90 dB(A) for the large jackhammer. Although only one highly precise measurement (see Materials and Methods) was taken for each item of equipment to limit damage to the floor, sound levels appeared to be higher than ambient noise for each item that was assessed. A relatively high proportion of the total linear sound pressure produced by the various items of equipment, as well as ambient noise, was below 1 kHz and beyond the hearing range of mice.

To determine the intracage sound levels in various locations within the animal facility, the large jackhammer and shot blaster (used without shot) were used to generate noise. Although the shot blaster produced the highest level of linear sound pressure in the human hearing range, 99.3% of the total linear sound pressure was at frequencies below 1 kHz (below the mouse hearing range) as compared with the large jackhammer, for which only 60.6% of the total linear sound pressure was below 1 kHz (Table 1). This difference contributed to a lower linear sound pressure level in the mouse hearing range.

Noise levels at various locations within the animal facility from the large jackhammer and shot blaster. The sound levels caused by the large jackhammer at various locations within the animal facility are shown in Figure 5. The blower-only data were collected from room A, although these data were consistent (data not shown) between rooms and floors. The A-weighted data for humans demonstrate that sound inside the ventilated rack cage from the large jackhammer reached 77 dB(A) in the closest room (Room A) and

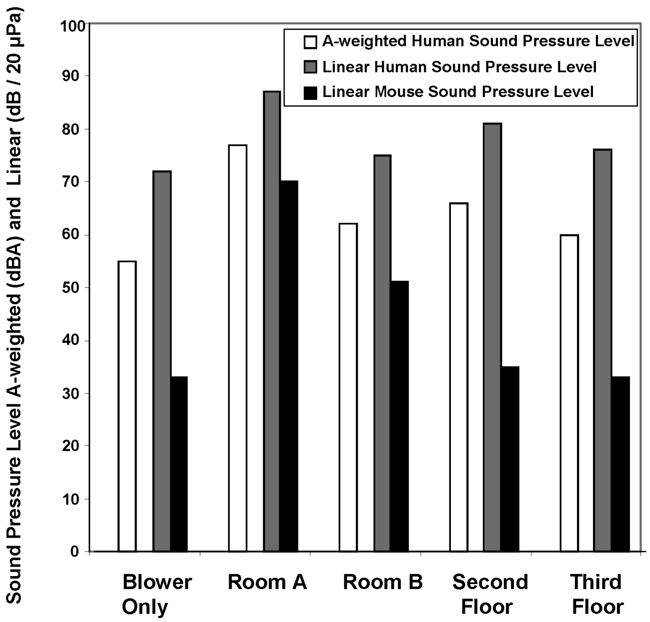

Figure 5. Sound pressure levels from the large jackhammer as measured at various locations.

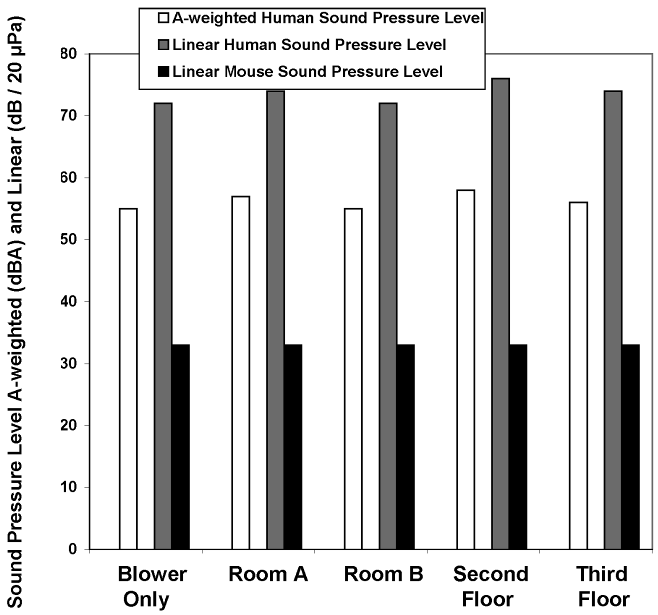

Figure 6. Sound pressure levels from the shot blaster as measured at various locations.

would be audible, albeit at a lower sound level, in the remaining locations. The linear sound pressure level within the hearing range of humans increased above blower-only levels and stayed above blower-only levels at all locations. The weighted and linear sound pressure levels for humans did not show an appreciable decrease from Room B to the second and third floors. The linear sound pressure level for mice increased to more than 2 times the blower-only levels in Room A, but in contrast to the human levels, sound pressure levels decreased to approach or reach blower-only levels on the second and third floors, respectively (Figure 5). Therefore, the data show that humans can hear the sound caused by the large jackhammer in all locations, whereas mice would hear little or no sound above blower-only levels on the second and third floors.

The sound generated by the shot blaster at the same locations delineated in Figure 1 is shown in Figure 6. The data with regard to humans show that sound, although limited, from the shot blaster can be perceived at most of the locations. However, the shot blaster did not generate sound pressure levels for mice above blower-only levels at any of the locations.

Discussion

A-weighted sound pressure levels de-emphasize the decibel levels of the sound pressure that are within the human hearing range but beyond the most sensitive frequencies for humans. A-weighted measures therefore provide an approximation of the decibel level of sound that humans would hear. In contrast, unweighted or linear determinations of sound in decibels are determined without de-emphasizing the decibel level at any frequencies within the hearing range.[13] In the current study, we obtained linear measurements of sound within the mouse and human hearing ranges to determine the decibel level of a sound that mice would hear relative to what humans would. The assessment of the airborne sound levels that animals are actually able to hear is important when examining the effects of noise on the wellbeing of laboratory animals and on interference of research efforts. Because the level of sound that animals hear can be higher or lower than the level that humans hear, erroneous conclusions in regard to the effects of sound on animals or research can be made if sound is analyzed by weighting the data to fit the human hearing range only.

A-weighted sound pressure levels for human hearing are about 30 dB(A) for a soft whisper and 60 dB(A) for normal conversation, whereas sound from shouting into the ear equates to about 110 dB(A).[3] The ambient sound measured inside of a cage on a ventilated rack was an average of 52 dB(A), but this value increased to an average of 55 dB(A) with the rack blower running. These data demonstrate that the sound from the ventilated rack blower and air movement in the cage would be clearly audible to humans at a level between a soft whisper and normal conversation. This, of course, estimates the human auditory experience from outside of the cage as we can perceive the sound of the ventilated rack blower. However, this scenario is not likely for mice, because the resulting sound pressure levels did not rise above the ambient noise level when the ventilated rack was running. The finding that mice cannot hear noise from a ventilated rack blower is supported in the literature.[18] The animal transfer station can be clearly heard by humans, and this assertion is supported by the data as the sound inside of the cage increased by 10 dB(A) to 65 dB(A) over the sound of the ventilated rack alone, equating to a sound level exceeding that of normal conversation. However, similar to the sound from the ventilated rack, the sound from the animal transfer station did not increase above ambient for mice. Therefore, because much of the sound generated by the ventilated rack and animal transfer station was at frequencies too low for mice to hear, the airborne sound of this common equipment within a vivarium likely will not introduce stress or create research variables in mice.

The operation of construction equipment 3 ft from the cage produced sound that could easily be perceived by humans and, as the data show, by mice as well. Because the decibel level of the sound produced by the construction equipment was proportionately higher at low frequencies, the sound would be louder to humans than mice even at 3 ft from the cage. The shot blaster (without shot) and large jackhammer produced the highest linear sound in the human hearing range, but the sound that was produced by the shot blaster contained a higher percentage of low-frequency sound (below the mouse hearing range) relative to that of the large jackhammer. Due to the difference in frequency content of the sound produced, the use of the shot blaster and jackhammer showed how sound at different frequencies generated by construction equipment can affect noise perception by mice at various locations within the animal facility.

The sound produced by the large jackhammer immediately outside of the module could easily be heard by those involved in the study within the rooms located inside the module as well as on the second and third floors of the facility. This finding is supported by the data as the sound pressure levels in the human hearing range remained relatively high at the various locations. The study shows, however, that although mice should easily hear sound from the large jackhammer in rooms A and B, the sound for mice approached or was the same as ventilated rack blower-only sound on the second and third floors, respectively. The reason that the sound level that mice would hear declined more rapidly than that for humans in rooms and floors distant from the noise source is likely due to both the lower decibel level sound that occurred at higher frequencies and the fact that high-frequency sound is attenuated more readily than is low-frequency.[3] Even though the shot blaster produced a high decibel level of sound at 3 ft from the cage, a high percentage of this sound was at very low frequencies. As the data demonstrate, humans can perceive some sound above that of the ventilated rack blower in room A and on the second and third floors, because this low-frequency sound was of a higher decibel level and more likely would penetrate the physical plant structure. However, the high-frequency sound from the shot blaster that can be perceived by mice was not able to reach the rooms in the module or other floors in a manner that would increase the decibel level of the sound above that of the ventilated rack blower.

Noise and vibration within a vivarium can induce animal distress and ultimately interfere with research outcomes in animal models. However, this study demonstrates that it cannot be assumed that a sound that is clearly audible to humans would be perceived as loudly or at all by mice. In some cases vibration actually could be causing the adverse effect on research animals that has been attributed to noise. Future studies in regard to how sound affects research animals should include not only the decibel level of the sound but also analysis of the frequency content of the sound in relation to the mouse audiogram and the vibration inherent in the sound-producing activity.

References

1. **Anthony A, Harclerode JE.** 1959. Noise stress in laboratory rodents. II. Effects of chronic noise exposures on sexual performance and reproductive function of guinea pigs. J Acoust Soc Am **31:**1437–1440.
2. **Buckley JP, Smooker HH.** 1970. Cardiovascular and biochemical effects of chronic intermittent neurogenic stimulation, p 85–74. In: Welch BL, Welch AS, editors. Physiological effects of noise. New York (NY): Plenum Press.
3. **Center for Hearing and Communication.** [Internet]. Facts on noise. [Cited 17 Sep 2009]. Available at: www.lhh.org/noise/facts/evironment.html.
4. **Dallman MF, Akana SF, Bell ME, Bhatnagar S, Choi S, Chu A, Gomez F, Laugero K, Soriano L, Viau V.** 1999. Warning! Nearby construction can profoundly affect your experiments. Endocrine **11:**111–113.
5. **Dallman MF, Akana SF, Bradbury MJ, Strack AM, Hanson ES, Scribner KA.** 1994. Regulation of the hypothalamo-pituitary-adrenal axis during stress: feedback, facilitation, and feeding. Seminars in Neuroscience **6:**205–213.
6. **Geisler CD.** 1998. Sound waves, p 11–20. In: Geisler CD, editor. From sound to synapse: physiology of the mammalian ear. New York (NY): Oxford University Press.
7. **Heffner HE, Heffner RS.** 2007. Hearing ranges of laboratory animals. J Am Assoc Lab Anim Sci **46:**20–22.
8. **International Organization for Standardization.** [Internet]. ISO 226 standard. [Cited 23 Oct 2009]. Available at: http://www.iso.org/iso/home.htm.
9. **Koay G, Harrington IA, Heffner RS, Heffner HE.** 2002. Audiograms of mice lacking Scn8a sodium channels and their heterozygous littermates. Hear Res **171:**111–118.
10. **Milligan SR, Sales GD, Khirynkh K.** 1993. Sound levels in room housing laboratory animals: an uncontrolled daily variable. Physiol Behav **53:**1067–1076.
11. **Murata M, Takigawa H.** 1989. Teratogenic effects of noise in mice. J Sound Vib **132:**11–18.
12. **Nawrot PS, Cook RO, Hamm CW.** 1981. Embryotoxicity of broadband high-frequency noise in the CD1 mouse. J Toxicol Environ Health **8:**151–157.
13. **Norton MP, Karczub DG.** 2003. Noise and vibration measurement units—levels, decibels, and spectra, p 256–341. In: Fundamentals of noise and vibration analysis for engineers. Melbourne (Australia): Cambridge University Press.
14. **Rasmussen S, Glickman G, Norinsky R, Quimby FW, Tolwani RJ.** 2009. Construction noise decreases reproductive efficiency in mice. J Am Assoc Lab Anim Sci **48:**363–370.
15. **Sales GD, Wilson KJ, Spencer KE, Milligan SR.** 1988. Environmental ultrasound in laboratories and animal houses: a possible cause for concern in the welfare and use of laboratory animals. Lab Anim **22:**369–375.
16. **Small JD, Dietrich T.** 2007. Environmental and equipment monitoring, p 409–436. In: Fox J, Barthold SW, Davisson MT, Newcomer CE, Quimby FW, Smith AL, editors. The mouse in biomedical research, vol 3. San Diego (CA): Academic Press.
17. **Smith SW.** 1997. Audio processing, p 351–372. In: Smith SW, editor. The scientist and engineer's guide to digital signal processing. San Diego (CA): California Technical Publishing.
18. **Thomas S.** 2005. The ABCs of IVCs. ALN Mag. **Nov/Dec 2005:**11–15.
19. **Turner JG, Bauer CA, Rybak LP.** 2007. Noise in animal facilities and why it matters. J Am Assoc Lab Anim Sci **46:**10–13.
20. **Turner JG, Parrish JL, Hughes LF, Toth LA, Caspary DM.** 2005. Hearing in laboratory animals: strain differences and nonauditory effects of noise. Comp Med **55:**12–23.
21. **Zakem HB, Alliston CW.** 1974. The effects of noise level and elevated ambient temperatures upon selected reproductive traits in female Swiss–Webster mice. Lab Anim Sci **24:**469–475.