SOURCES OF SOUND IN THE LABORATORY ANIMAL ENVIRONMENT: A SURVEY OF THE SOUNDS PRODUCED BY PROCEDURES AND EQUIPMENT

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Sounds in the laboratory and animal house environment were monitored for sound pressure levels over both low frequency (10Hz–12.5kHz) and high frequency (12.5–70 kHz) ranges and were recorded for frequency analysis over the range 10Hz–100kHz. Forty sources of sound were investigated at 10 different sites. Sources included environmental control systems, maintenance and husbandry procedures, cleaning equipment and other equipment used near animals. Many of the sounds covered a wide frequency band and extended into the ultrasonic (> 20kHz) range. Sound levels produced by environmental control systems were generally at a low level. High sound pressure levels (SPLs) up to and exceeding 85dB SPL were recorded during cleaning and particularly high levels were recorded from the transport systems studied. Equipment such as a tattoo gun, a condensation extractor system, a high-speed centrifuge, and an ultrasonic disintegrator produced high levels of sound over a broad spectrum.

As many laboratory animals are much more sensitive to a wider range of sound frequency than humans, it seems likely that the levels of sound reported here could adversely affect animals through physiological or behavioural changes, or may even cause sensory damage in extreme cases. There appear to have been no studies on the minimal threshold levels for such adverse responses, or on the long-term effects of exposure to the types of sounds recorded here. It is not yet possible to set realistic exposure limits for laboratory animals.

Keywords: *acoustic environment, animal welfare, laboratory animals, noise, sound levels*

Introduction

Most aspects of the physical environment of laboratory animals are controlled and only vary either within relatively narrow limits over time (eg temperature and humidity), or with regular, predetermined changes (eg light levels). By contrast, the acoustic environment of laboratory animals is largely uncontrolled and appears to fluctuate widely. A recent study of sound levels in a variety of animal facilities (Milligan *et al* 1993) showed that in many cases levels were low overnight, and then increased with the activity of personnel during the day.

This occurred in rooms on normal lighting and in rooms on reversed lighting. In other cases, for example in a room housing marmosets, sound levels followed those of the light levels. In further cases, sound levels fluctuated erratically over 24h, both on weekdays and at weekends. Other, prior studies have also shown markedly varying sound levels in animal facilities. Pfaff and Stecker (1976) reported that in a room housing rats the number of sound impulses exceeding 90dB (see, *Methods* for explanation of sound level measurements) increased between 0700h and 1600h with the highest rates (60 such impulses in 30min) between 0800h–1000h and 1400h–1600h. Sounds exceeding 100dB occurred at low rates (10 per 30min) between 0800h and 1500h. The sources of such sounds were not identified.

Sound is caused by vibrating objects, biological and non-biological, which in turn cause changes in air pressure above and below atmospheric pressure. Sounds can vary in duration, in the frequency of vibration and so of the pressure changes per second (perceived as pitch and measured in Hz), and in the magnitude of the pressure changes which is an indication of intensity (perceived as loudness and measured in decibels, dB, as described below). Many different sources could contribute to the overall sound levels recorded in animal facilities. These will include: more or less continuous sources such as environmental control systems (eg ventilation and lighting); common maintenance procedures which may be regular but are discontinuous (eg cleaning, feeding and associated human activity); as well as sources, procedures and equipment that are employed or carried out near the animals on an irregular basis (eg experimental protocols). The animals themselves are also important sources of sound – through both their activities and their vocalizations. In a study by Pfaff and Stecker (1976) the loudest sounds were correlated with short-lasting staff activity in the room. Peterson (1980) also reported high sound levels, over 90dB and associated with the presence of personnel, in rooms housing dogs or rhesus monkeys, *Macaca mulatta*. In both cases, feeding was often the stimulus that triggered the high levels of sound which were caused by barking of the dogs and through banging and rattling of the cages by the monkeys.

High sound levels can cause a variety of adverse responses in man and in laboratory animals, with both auditory and non-auditory effects documented. The responses of laboratory animals to sound within the human auditory sensitivity range include decreased activity, audiogenic seizures, reduced fertility and changes in blood glucose and corticosteroid levels (Milligan *et al* 1993). High sound levels can also damage the auditory system (Peterson 1980). For humans, and apparently for laboratory animals, impulsive sounds (ie sudden, brief sounds which rise above background levels by substantial amounts) can be more damaging than more continuous sounds at moderately high levels (Peterson 1980); and higher frequency sounds are more damaging than lower frequency ones (Knight 1967).

Many laboratory animals are very sensitive to sound and have minimum auditory thresholds below those of humans (Fay 1988). It is therefore not surprising that cats, chinchillas, monkeys and guinea pigs are all reported to be more sensitive to trauma from acoustic overstimulation than humans (Peterson 1980). Many laboratory animals including rats, mice, hamsters, cats, dogs and small primates, are also sensitive to sounds above the 20kHz upper limit of the human hearing range (ie to ultrasounds) – and rodents use these sounds for communication (see Sales & Milligan 1992). It is becoming apparent that such high frequency sounds may be a regular feature of the laboratory animal environment. Milligan *et al* (1993) reported that levels of 50–75 dB commonly occurred over the frequency range 12.5–70 kHz and some purely ultrasonic sources were reported by Sales *et al* (1988). The responses of laboratory animals to high frequencies have received less attention than those to lower frequency 'audible' sounds, but they also include similar physiological and behavioural effects and, by analogy with the lower frequency sounds, they too are potentially stressful and may be damaging. A detailed knowledge of the acoustic environment of laboratory animals is therefore important for ensuring good welfare.

A proper evaluation of the physical environment of laboratory animals requires knowledge not only of the 'loudness level', ie the sound pressure level (see below) of the noise the animals are exposed to, but also its frequency content (Pfaff & Stecker 1976). Such measurements are necessary to evaluate the potential significance and danger of uncontrolled noise to animals. They are also necessary to define the physical properties of any artificial background noise which may be used to try to mask impulsive sounds. Any such masking sound must be related both to the animals' auditory sensitivity and to the frequency content of the offending noise (Pfaff 1974).

Despite the importance of sound in the physical environment, there have been very few studies of the precise frequency characteristics of the various sounds produced in animal facilities – and these have mainly been limited to frequencies up to 16kHz. Pfaff and Stecker (1976) recorded 'a great number of high frequency impulses' (high frequency was defined as 4–8 kHz in their study) during husbandry work in the room. Most of these were at sound pressure levels between 80 and 90dB. Impulses exceeding 90dB were more common at lower frequencies of 250Hz–1kHz. A frequency analysis of the sounds between 31.5Hz and 16kHz produced by dogs barking and by rhesus monkeys during banging and rattling of the cages showed that peak levels of 95dB (A) (see pp 100 for description of weighting scales and terminology) occurred at 1kHz during barking and at 250Hz–8kHz during cage rattling (Peterson 1980). In a more recent study of the laboratory animal environment, 24 out of 39 sources of sound studied contained frequencies of up to 60–120 kHz (Sales *et al* 1988).

The purpose of the present study was to extend the studies of Sales *et al* (1988) and Milligan *et al* (1993), to identify the sources of sound that contribute to the overall and changing sound levels in the laboratory animal environment and, in particular, to categorize these sounds as precisely as possible in terms of both frequency and sound pressure level. Particular attention was paid to high frequency sounds (above 10kHz) which have so far received even less attention than sound within the human hearing range. In this study, recordings were made in a wide range of animal facilities and over 40 different sound sources were investigated.

Materials and methods

Sounds were monitored and recorded at 10 different facilities and a wide range of procedures and equipment were investigated. To prevent undue repetition, the details of the sources investigated are given together with the results. Four major categories of sound sources were monitored:

i) *Environmental control systems* – for both whole rooms and individual cages. These included ventilation, lighting and condensation control.

ii) *Maintenance and husbandry procedures* – carried out by personnel, for example cleaning, feeding, watering and transport of animals.

iii) *Cleaning equipment* – such as cage and bottle washers, vacuum and floor cleaners.

iv) *Other equipment* – used in the vicinity of the animals such as a tattoo gun, centrifuge and computer equipment.

As indicated earlier, sound can vary across three 'dimensions': time, frequency and intensity. Thus, sounds may be of short or of long duration and may be composed of a narrow band of frequency or of a broad band in which the different frequencies may be present at different magnitudes. In practice, it is difficult to measure all three aspects of sound simultaneously and it is not feasible to measure the magnitude of each frequency component over long periods. It is possible, however, to measure the changes in sound pressure of the total sound (which give an indication of intensity) over long periods. In this study, sound pressures were monitored for up to 24h over a broad range of frequencies to give 'overall' levels. At present, equipment is not available to measure sound pressure over the whole frequency range of interest, 10Hz –100kHz. Sound pressure levels were therefore generally monitored over two frequency ranges, called 'overall ranges': i) 10Hz–12.5kHz (low frequency [LF] range), or ii) 12.5–70 kHz (high frequency [HF] range). Less commonly, the range 0.01–20 kHz was monitored. In addition to the overall levels, short samples of sound were analysed for frequency content by measuring the sound pressure over a number of very narrow bands of frequency to give a 'frequency-' or 'sound-spectrum' – a 'picture' of the distribution of the sound energy over each of these narrow bands.

Sound pressure is measured on a logarithmic scale, the decibel (dB) scale. Decibels are not actual units of measurement, but logarithmic ratios between a certain measured value of sound pressure, measured in Pascals (1Pa = $1Nm^{-2}$) and a reference level, which is usually but not always, set at the threshold of human hearing – 20μPa. Sound pressure levels (SPLs) are conventionally expressed relative to this standard, as dB SPL. In this study all levels were measured with reference to 20μPa and so are referred to as dB SPL. However, sound pressure varies above (positive) and below (negative) atmospheric pressure and it can be measured in a number of different ways. In this survey three different measures were taken:

i) The 'Peak' value – the maximum positive or negative value reached over a set sample period.

ii) The 'Root Mean Square' (RMS) value – an 'average' value determined from readings of SPL taken at infinitesimally small intervals of time over a fixed period (here, generally 30s or 3min). The readings are squared (to make all values positive), the mean value calculated and then the square root of this mean obtained.

iii)The 'L_{eq}' (Equivalent, Continuous Sound Level) value – used in studies of industrial or other noise to assess the potential for damage to human hearing. Sound levels are sampled many times over a fixed period and a single value is calculated. This is the sound level of a continuous constant sound that has the same energy content (and so the same damage potential) as the varying sound. The relation between noise exposure and damage is far less well understood for animals than for humans, but the L_{eq} value was taken as an indication of the noise exposure of the animals (see Milligan *et al* [1993] for further discussion of noise level measurements).

Studies of noise in the human environment generally measure SPL using a weighting scale, the A weighting, which takes into account the varying sensitivity of the human ear to different frequencies and, in particular, the reduced sensitivity to low frequencies. Weighted values are expressed as dB(A). This is clearly inappropriate for laboratory animals. In the current study, a linear weighting was used which weights all frequencies equally.

Overall sound pressure levels of all types were measured with a Bruel and Kjaer Sound Level Meter, Type 2231 (Bruel and Kjaer, DK 2850 Naerum, Denmark). This was used with a 0.5-inch microphone (Type 4155) for the low frequency ranges (up to 20kHz) and with a 0.25-inch microphone (Type 4135) and ultrasonic filter set for the high frequency range (12.5–70 kHz). SPLs were measured over sample periods of either 3s, 3min or 15min and levels were recorded and stored over short periods of 12min or 24min or downloaded to a computer for periods of 24h. The equipment was calibrated before all measurements, using a Bruel and Kjaer pistonphone (Type 4220) in an anechoic chamber.

Sound spectra were obtained from samples of sound which had been recorded on site for later analysis. Recordings were made onto 0.25-inch Ampex tape on a Racal Store 4DS tape recorder (Racal, Southampton, UK) at a tape speed of 30inches s^{-1} (30 ips). A 0.25-inch Bruel and Kjaer microphone (Type 4135) was used with a high-quality Bruel and Kjaer amplifier (Type 2606). The recordings were analysed with a Bruel and Kjaer 1/24th-octave band frequency analyser (Type 2143). This produced frequency spectra and plots of the SPL of each of 84 narrow bands of frequency (each 1/8th of an octave) generally spanning the range 10–100 kHz, although the range 0.05–22 kHz was also used. The analyser had an upper frequency limit of 22kHz. To analyse the higher frequencies, the tape recordings were replayed at 1/8th speed (3.75 ips) to give a corresponding eight-fold reduction in frequency; the original frequencies were restored on the displays. Note that the high frequency range of the overall SPL measurements (12.5–70 kHz) differs somewhat from that of the frequency spectra (10–100 kHz).

Results

Details of overall SPLs and of maximum values of RMS and L_{eq} measurements together with the frequency ranges of the sounds studied are given in Table 1. The frequency spectra showed that all of the sounds for which they were obtained were broadband and generally covered the whole frequency range studied. However, the precise characteristics of the spectra varied and to simplify the descriptions below they have been arbitrarily divided into five categories, although intermediate and combined categories did occur: i) no pronounced peaks (NPP) in the spectrum; ii) few, slight and smooth peaks (SSP); iii) irregular non-pronounced peaks (INP), where marked peaks occurred at irregular frequency intervals; iv) irregular pronounced peaks (IPP), where the peaks were often of at least 20dB; and v) regular pronounced peaks (RPP), where pronounced peaks occurred at regular frequency intervals in the spectrum and so were probably harmonically related.

Environmental control systems

A variety of systems were monitored in this survey (Table 1). The three ventilation systems studied produced only low levels of high frequency sound, just above the background noise and with NPP (Figure 1). No high frequency sound could be detected near air ventilation exits or from various lighting systems including strip lights. A similar spectrum to that shown in Figure 1 was obtained from a rodent isolation unit for both maximum and minimum settings of the air pump. Somewhat higher levels were recorded near another rodent isolation unit. Measurements taken near the unit every 15min over 24h showed a marked rhythm with maximum RMS levels around 35dB overnight and increasing at about 0800h to fluctuate between 60 and 85dB throughout the working day before decreasing again at about 1700h; but L_{eq} levels did not exceed 50dB. Low sounds levels and a NPP spectrum were also recorded from a controlled environment behaviour monitoring unit and a metabolic chamber with sample freezer, although the latter showed a single small peak at about 16kHz.

A condensation extractor system using compressed air produced high noise levels with L_{eq} values of 110dB at 1m and 102dB at 5m away in an adjacent room with the intervening door open; and even when the intervening door was closed, levels of 85dB L_{eq} were recorded (Table 1).

Table 1 Acoustic analyses of sounds associated with environmental control.

Situation	Acoustic analysis	Frequency range recorded (kHz)	Distance of micro-phone (cm)[1]	Sound Pressure Levels recorded (dB)			Total frequency range of sound (kHz)	Comments
				Overall RMS	From spectrum			Spectrum type[2] and Peaks (kHz)
					Max RMS	Max L_{eq}		
Ventilation								
a) different distances from inlet in rabbit room	spectrum	10-100	20 &30 40 & 50 80 &150		35 & 35 35 & 31 29 & 29		10-100	NPP
b) different distances from ventilation in rodent room	spectrum	10-100	50 2.5m		26 26		10-25 10-25	NPP
c) near ventilation in rat room	spectrum	10-100	1.0m		25		14	NPP
Lighting	spectrum overall	10-100	1.0m					No significant sound
Inside isolator								
max air press	spectrum	10-100		42	25			NPP
min air press				42				
Near rodent isolation unit	SPL every 15min for 24h	12.5-70	30		up to 85	up to 50		
Controlled environment behaviour monitor	spectrum overall	10-100	50	43	28		10-20	NPP, but one peak at 17
Inside metabolic chamber	spectrum overall	10-100		52	43-47		10-100	NPP, but one peak at 16
Condensation extractor system using compressed air	SPL L_{eq}	12.5-70	1.0m 5.0m DO[3] 5.0m DC[4]			110 102 85	} 12.5-70	NPP

[1] Distances given in cm unless otherwise stated.
[2] See text for explanations and abbreviations.
[3] DO intervening door open.
[4] DC intervening door closed.

Maintenance and husbandry procedures

These were accompanied by a wide range of sounds in terms of both frequency and SPL (Table 2). Most sounds were broadband and extended to at least 50kHz and often up to 100kHz. High levels between 80 and 90dB SPL (maximum RMS) were recorded in both the low (10Hz–12.5kHz) and the high frequency (12.5–70 kHz) ranges during general cleaning and cage changing when sound levels were monitored every 3min, over 24min and 12min, on two separate occasions.

The various components of the cleaning regime such as brushing the floor, wiping a glass cage front, changing metal cage bases, adding food to cages and running water into a sink when filling water bottles all produced considerable energy in the high frequency range (Table 2). The activity of brushing the floor with a stiff brush gave sounds with INP and contained high energy levels in the range 5–40 kHz, with an overall level of 77dB for the

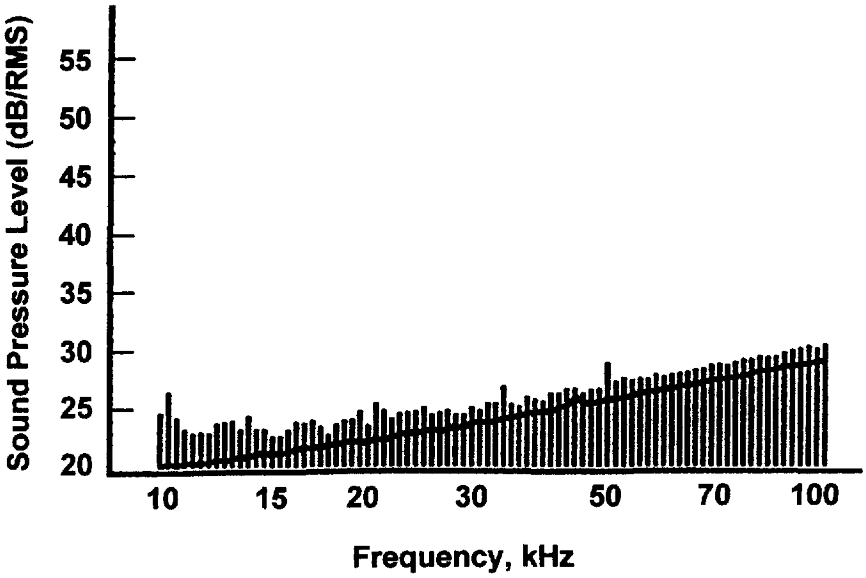


Figure 1 **Ventilation inlet. High frequency (10–100 kHz) spectrum of sound with no pronounced peaks (NPP) produced during operation, recorded at 25cm. The solid line represents the sensitivity of the system.**

high frequency range (Figure 2). Similar overall levels in the high frequency range were recorded during wiping and scraping the glass front of a marmoset cage. Here, the sound spectrum showed IPP, with SPLs decreasing with frequency. A similar spectrum was obtained from the sound produced by dropping an object on the floor, as when a broom is dropped (although a ruler was used in this instance).

Maintenance activities such as changing metal base grids, adding food to a cage and shutting a metal door between adjacent marmoset cages resulted in sounds with a series of IPP reaching over the whole high frequency range (Figure 3). These reached 70–80 dB in the lower part of this range (10–20 kHz) and then decreased with frequency. Water running into a sink resulted in broadband noise with a decease in SPLs above 50kHz, although the spectrum differed on different occasions from NPP to IPP.

Two different types of animal transport system were investigated. One involved mice or rats being placed in a metal cabinet on a metal trolley. The SPLs experienced by animals in transit were recorded by placing the sound level meter, set to record high frequencies, in the cabinet and recording the SPLs every 3s over a typical journey. Peak SPLs (ie the highest level reached every 3s) were recorded, as well as the maximum RMS and L_{eq} values. The RMS values for high frequency sounds were between 70 and 85dB for much of the transport period. Peak readings were between 88 and 110dB for the initial, continuous part of the journey and then varied between 50 and 106dB during the second part when the trolley moved intermittently as it passed through a series of doors (Figure 4a). When a rubber mat was placed between the cabinet and the trolley in an attempt to reduce the noise inside the cabinet, the acoustic profile of the journey was similar but values for all measurements fell by about 10dB (Figure 4b).

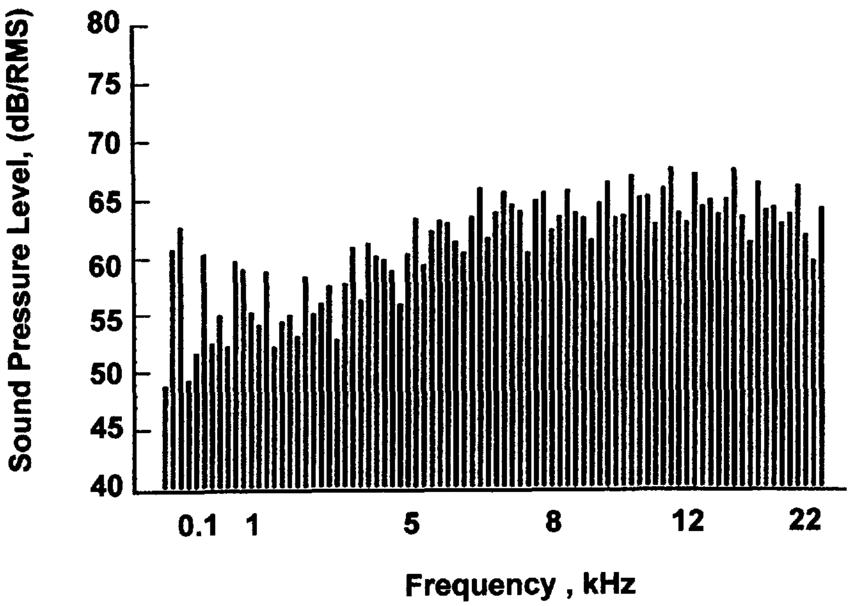
Table 2 **Acoustic analyses of sounds associated with maintenance and husbandry procedures.**

Situation	Acoustic analysis	Frequency range recorded (kHz)	Distance of micro-phone (cm)[1]	Sound Pressure Levels recorded (dB): Over-all RMS	From spectrum: Max RMS	From spectrum: Max L_{eq}	Total frequency range of sound (kHz)	Comments: Spectrum type[2] and Peaks (kHz)
Cleaning in empty room	spectrum	10-100	1.0m		50		10-85	IPP, variable SPL decreases over range
Cleaning in rat room	SPL every 3min		centre of room					
a) over 12min		12.5-70			62-85	45-60		
b) over 24min	SPL every 3min	0.01-20	centre of room		77-90	67-70		
Brushing								
a) floor of empty marmoset enclosure	spectrum overall	10-100	1.5m	77	64		10-100	INP over 10-40, decrease in SPL above 40
b) floor of empty rat room	spectrum	0.05-22	1m		67		0.05-22	INP, high SPL 5-22
	spectrum	10-100			69		10-100	INP, high SPL10-45
Wiping/ scraping glass cage front								
a) in cage	spectrum overall	10-100	1.0m	77	74		10-100	IPP, variable over range 10-40
b) in adjacent cage	spectrum overall	10-100	1.0m	65	57		10-100	IPP
Object (ruler) dropped on floor	spectrum	10-100	30		77		10-100	IPP, peaks at 12,14,17,40
Changing metal cage bases	spectrum overall	10-100	1.5m	82	78		10-100	IPP, with gradual decrease in SPL with frequency
Food added to wire hoppers	spectrum	10-100	50		80		10-100	IPP, peaks over whole range
Moving door in marmoset cages	spectrum overall	10-100	50	60	51		10-75	IPP over whole range
Water running into sink								
a)	spectrum	10-100	1.0m		53		10-80	IPP over whole range
b)	spectrum	10-100	2.5m		43		10-50	NPP, decrease in SPL over range
c)	spectrum overall	10-100	3.0m	63	50	10-100		NPP
Transport system, metal								
a) no rubber matting	overall	12.5-70	inside cabinet			85-88	64-80	Peak values over 110 dB (see text)
b) with rubber matting	overall	12.5-70	inside cabinet			70-87	50-70	Peak values over 100 dB (see text)
Plastic bag for transport	spectrum overall	10-100	in bag	80	50-70		10-100	IPP over whole range

[1] Distances given in cm unless otherwise stated.

[2] See text for explanations and abbreviations.

(a)



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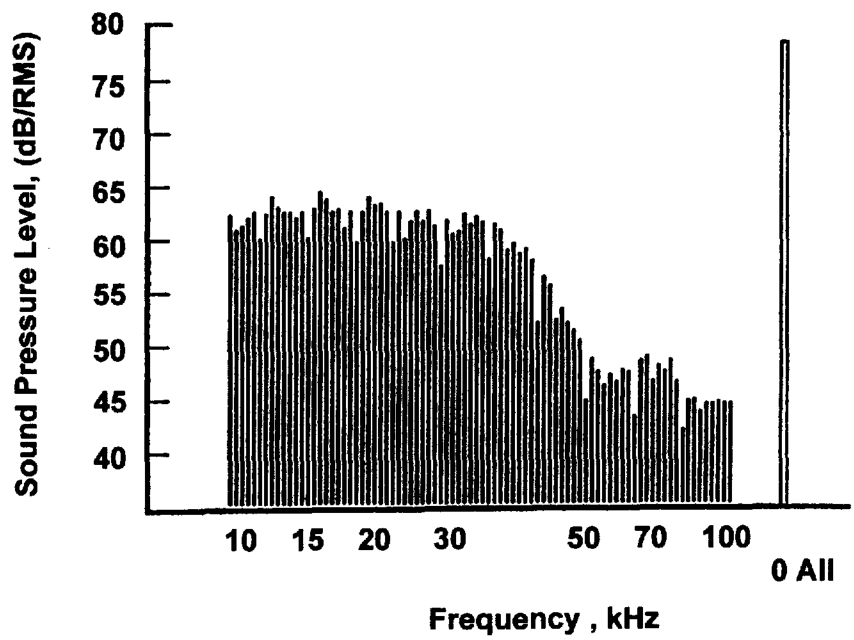


Figure 2 **Brushing. Frequency spectra showing irregular non-pronounced peaks (INP) recorded at 1.5m during brushing the floor with a stiff brush: (a) low frequency (50Hz–22kHz) sample; (b) high frequency (10–100 kHz) sample. The overall SPL in the high frequency range (12.5–70 kHz) is indicated by the vertical bar above 'O All'.**

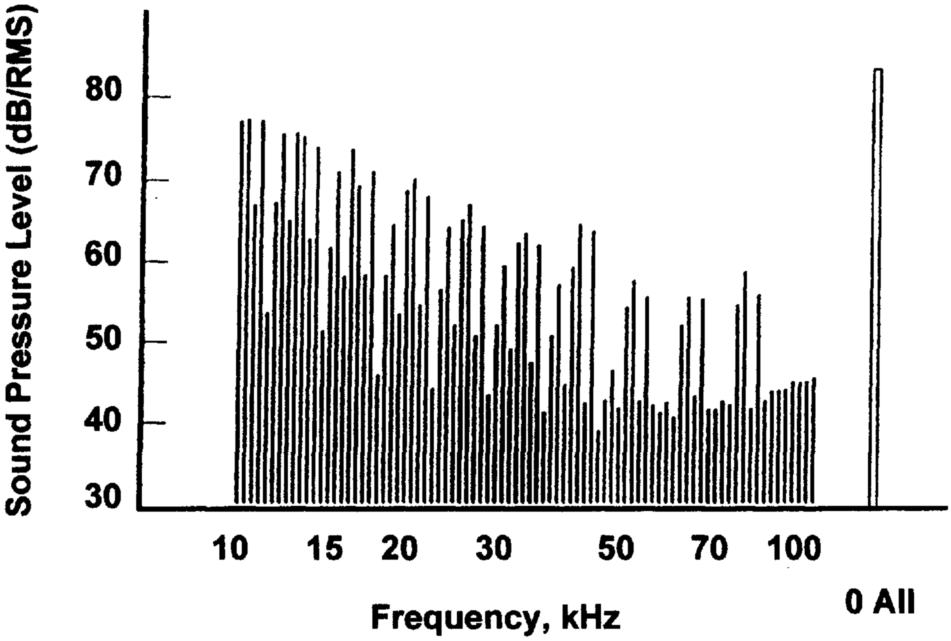


Figure 3 **Cage maintenance. High frequency (10–100 kHz) spectrum of sound showing irregular pronounced peaks (IPP) recorded at 1.5m during changing of wire grids beneath cage. The overall SPL in the high frequency range (12.5–70 kHz) is indicated by the vertical bar above 'O All'.**

In another facility, mice were occasionally transported in stiff plastic bags to minimize handling by humans. Recordings made from inside the bags during typical 'handling' showed IPPs in the high frequency range and an overall SPL of 80dB.

Maintenance and cleaning equipment

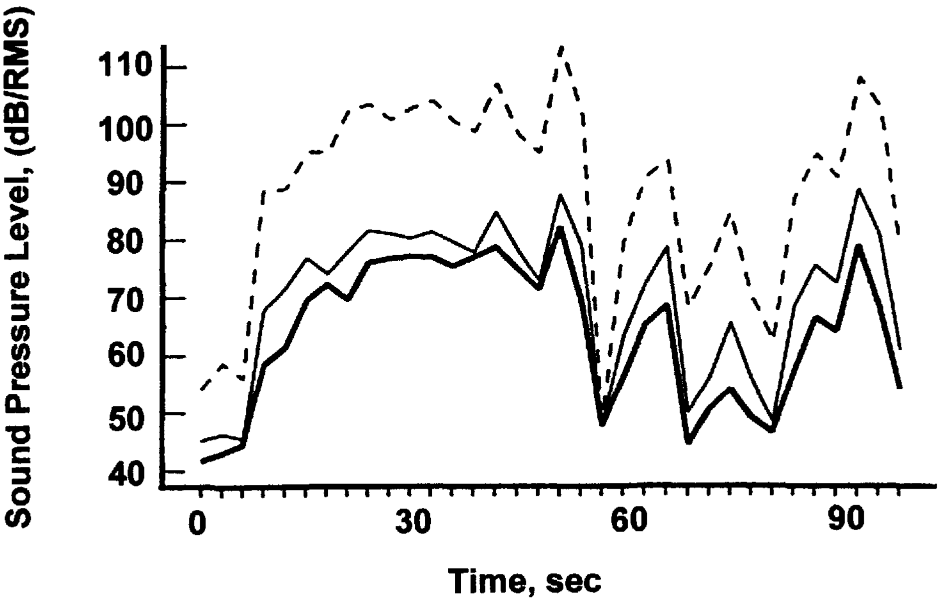
A wide variety of sounds were monitored from such equipment (Table 3). Both cage and bottle washers produced broadband sounds extending well into the high frequency range and with NPP spectra, but levels were generally low. For the cage washer, IPPs occurred above 40kHz and for the bottle washer the spectrum showed a slight decrease in SPL with increasing frequency up to 70kHz. An automatic flushing tray cleaning system used beneath rabbit cages produced an IPP spectrum during operation but with relatively low sound levels.

Equipment used for cleaning near the animals, a vacuum cleaner and floor cleaner, both produced sounds with frequency spectra showing SSP (Figure 5) as did a water pump used to provide pressure during cleaning operations and a mist making machine used for disinfecting animal facilities. These sounds were generally between 50 and 80dB with overall values of between 70 and 85dB.

Additional equipment

Other equipment which would occasionally be used near laboratory animals, either in the animal room or in experimental rooms or laboratories, was examined. This included: equipment used for sampling and data acquisition, eg centrifuges, an ultrasonic disintegrator,

(a)



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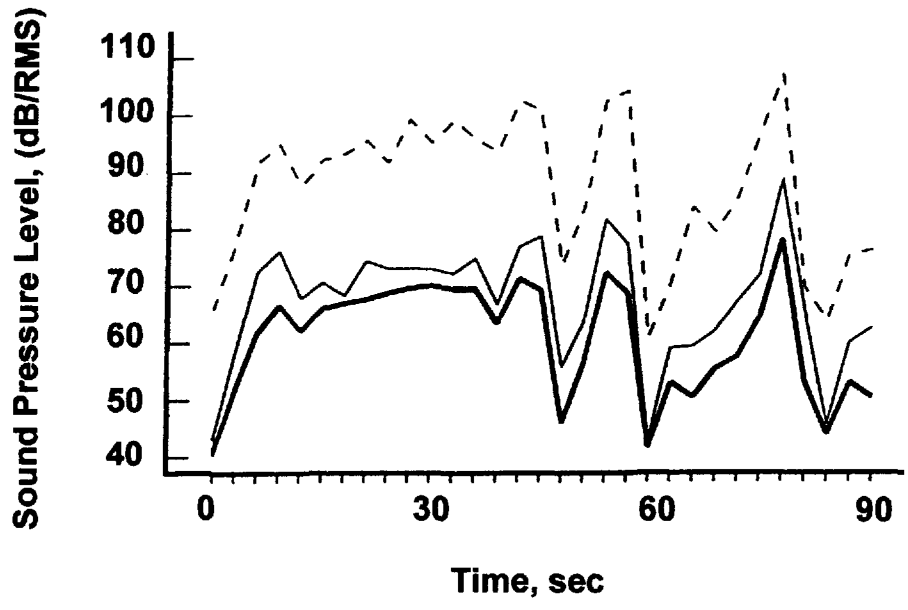

Figure 4 **Animal transport systems. High frequency (12.5–70 kHz) overall sound levels recorded during transit from inside a metal cabinet placed on a metal trolley: (a) cabinet in direct contact with trolley; (b) rubber mat placed between cabinet and trolley.**

Table 3 Acoustic analyses of sounds associated with cleaning equipment.

Situation	Acoustic analysis	Frequency range recorded (kHz)	Distance of micro-phone (cm)[1]	Sound Pressure Levels recorded (dB) Over-all RMS	From spectrum Max RMS	Max L_{eq}	Total frequency range of sound (kHz)	Comments: Spectrum type[2] and Peaks (kHz)
Cage washer a) in adjacent corridor	spectrum	10-100	1.5m		47		10-100	NPP,10-40 and IPP, 40-100
b) in adjacent room	spectrum	10-100	2.0m					very low levels
Bottle washer	spectrum	10-100	20		42		10-100	NPP, decrease in SPL over range
Automatic flushing system for rabbit cages	spectrum overall	10-100	50	 55	43-53		10-52	IPP, decrease over range
Vacuum cleaner a)	spectrum overall	10-100	1.0m 3.0m 3.0m+	70 65 56	60 58 50		}10-45	SSP, decrease in SPL over range
b)	spectrum overall	10-100	1.0m	85	65-70		10-100	SSP
Floor cleaner	spectrum overall	10-100	30 1.0m	82 72	68 58		10-100	SSP, peaks at 35-45
Water pump	spectrum overall	10-100	1.5m	77	63		10-100	SSP, peaks at 10-50
Mist machine for disinfecting	spectrum overall	10-100	10	68	54		10-100	SSP, peaks at 10-50

[1] Distances given in cm unless otherwise stated.
[2] See text for explanations and abbreviations.

and computer equipment; equipment used in husbandry such as clippers, a tattoo gun and an air filter helmet; as well as other sundry equipment such as power supplies, an extension lead and air pump (Table 4).

Very low levels of sound (< 45dB at 1m) in the high frequency range were recorded from a centrifuge, but a microcentrifuge monitored from a similar distance generated a broad, flat, spectrum of high frequency sound with a plateau level of 80dB across the whole high frequency range. Sound spectra with slight NPP were recorded in the ultrasonic range from an homogenizer while the spectrum of an ultrasonic disintegrator showed a series of peaks at regular frequency intervals (ie RPPs), which reached values of 60–97 dB with an overall SPL in the high frequency range of 98dB at up to 0.5m. Similar high frequency RPP spectra were obtained from computer systems. Overall SPLs were 56dB at 1m and 70dB at 0.1m for the two systems studied in detail, but a maximum of 84dB was recorded from another installation. The source of most of the sound appeared to be the computer monitor (Figure 6).

A RPP spectrum of sound with high levels of sound in the high frequency range and harmonically related peaks was also produced by the ultrasonic cleaning bath At 40kHz maximum levels were over 124dB at 0.3m and this reduced only to 112dB at 1m and 106dB at 2m. There was a more rapid reduction of the highest frequency peaks with increasing distance when compared with the lower frequency peaks.

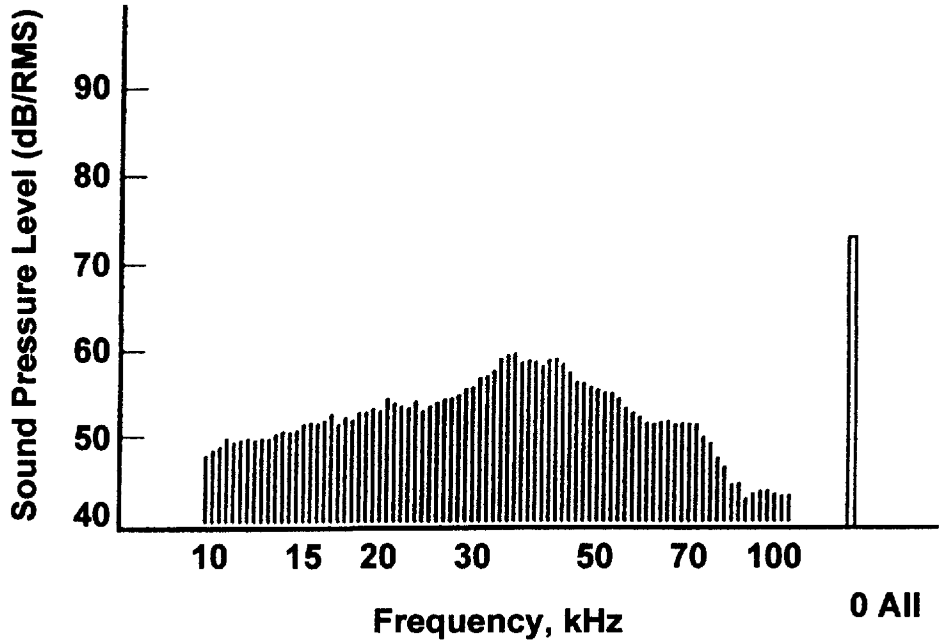

Figure 5 **Floor cleaner. High frequency (10–100 kHz) spectrum of sound showing slight smooth peaks (SSP) recorded at 1.0m during operation. The overall SPL in the high frequency range (12.5–70 kHz) is indicated by the vertical bar above 'O All'.**

A tattoo gun and electric clippers both generated broad INP spectra with considerable energy between 10 and 45kHz. Overall levels were 75dB at 0.1m for the clippers and 90 dB at 0.3m for the gun. Broadband sound extending up to 50kHz was generated by an electronic insect killer when in operation. Similar sound was produced by an air pump and a lawn mower which had an overall level of 60dB at 5.0m and energy extending over the whole range of 10–100 kHz with a slight decrease in sound level with increasing frequency. A stabilized power supply and a retractable extension lead being rewound both gave IPP spectra, with the energy spread over a broad range.

A portable radio was recorded in an animal unit and a hi-fi unit in a domestic room with similar tiled construction (a kitchen). The frequency ranges produced by radios will be limited by the speakers, but no appreciable high frequencies were recorded from either system. The SPLs will clearly depend on the volume set by the listener, but on 'average listening' settings, the overall sound levels in the LF range were around 70dB at 1.5m and the frequency spectra showed NPP in the LF range (Figure 7).

Recordings were made both inside and outside an air filter helmet used by personnel to prevent them inhaling allergens. LF recordings made inside the helmet during operation showed a broad IPP spectrum of sound, with peak energy at around 0.12kHz where the level reached 80dB. High frequency recordings made outside the helmet also gave a broad IPP spectrum but levels were only 43–45 dB and the overall level did not exceed 55dB.

Table 4 Acoustic analyses of sounds associated with additional equipment.

Situation	Acoustic analysis	Frequency range recorded (kHz)	Distance of Micro-phone (cm)[1]	Sound Pressure Levels recorded (dB) Over-all RMS	From spectrum Max RMS	Max L_{eq}	Total frequency range of sound (kHz)	Comments: Spectrum type[2] and Peaks (kHz)
Centrifuge	spectrum overall	10-100	10	48	34		10-100	NPP
			50	45	31			
			1.0m	45	30			
High speed micro-centrifuge	spectrum	10-100	10		80		10-100	NPP, spectrum flat across whole range
			50		78			
			1.0m		82			
			2.0m		60			
Homogenizer	spectrum	10-100	50		80		10-100	NPP
			1.0m		72			
			1.5m		58			
Ultrasonic disintegrator	spectrum overall	10-100	20	97	97		10-100	RPP, peaks 12, 24,36,48 (values of 64-97 dB)
			50	98	98			
Computer system and monitor								
a)	spectrum	10-100	20		68	65	10-70	RPP, peaks at 16,24,32,48,74
			1.0m		54	54		
b)	Max LMS and L_{eq}	12.5-70	20		84	57		
c) monitor alone	spectrum overall	10-100	10	70	67			RPP, peaks at 16,32,48,64,78
Ultrasonic cleaning bath	spectrum	10-100	10		130			RPP for all distances, peaks at 19,38,57,76 (values of 130 at 19kHz decreasing to 85 dB at 76kHz)
			30		122		10-100	
			50		118			
			70		115			
			1.0m		112			
			2.0m		105			
Tattoo gun	spectrum overall	10-100	30	92	82		10-100	INP, peaks at 10-14 and c 45
Electric clippers	spectrum overall	10-100	10	76	64		10-100	INP, variable over10-50
Electronic insect killer in operation	spectrum overall	10-100	20	60	52		10-50	NPP
Air pump	spectrum overall	10-100	10	78			10-100	NPP, plateau with few peaks 12-35
			20	78				
			40	50				
			1.0m	47				
			2.0m	45				
Lawn mower	spectrum overall	10-100	5.0m	60	50			NPP, 40-50dB over range
Stabilized power supply	spectrum overall	10-100	10	54	52		10-65	IPP, peaks at 16,32,48,64
Extension lead holder	spectrum overall	10-100	40	80	80		10-100	IPP, peaks at 14,20,30,40
Radios	spectrum overall	1-20	1.5	62-72				NPP, no high frequencies detected
Air filter helmet	spectrum	0.03-10	inside	82	80		0.06-10	IPP, peak at 0.12
	overall	10-100	5	55	45		10-100	IPP, peaks at 12,20

[1] Distances given in cm unless otherwise stated.

[2] See text for explanations.

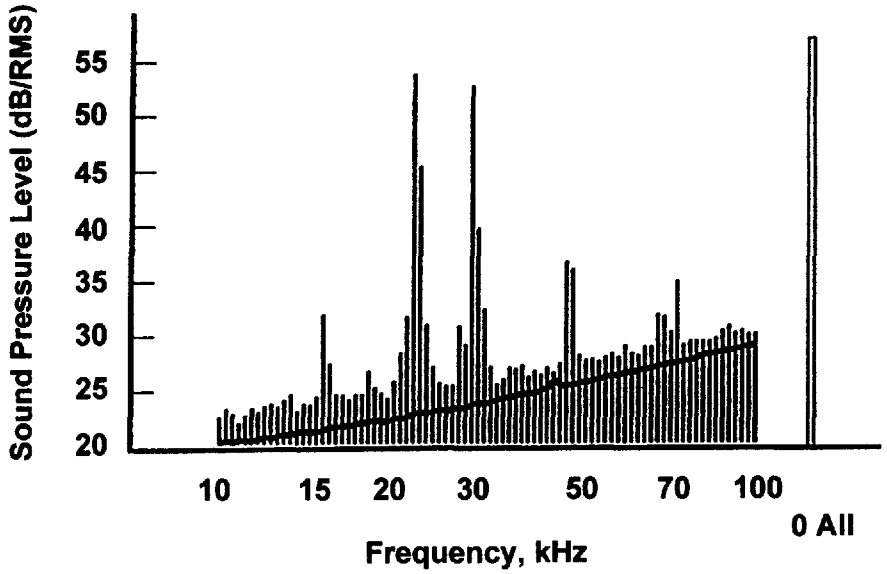

Figure 6 Computer monitor. High frequency (10–100 kHz) spectrum of sound showing regular pronounced peaks (RPP) recorded at 1.0m. The overall SPL in the high frequency range (12.5–70 kHz) is indicated by the vertical bar above 'O All'. The solid line represents the sensitivity of the system.

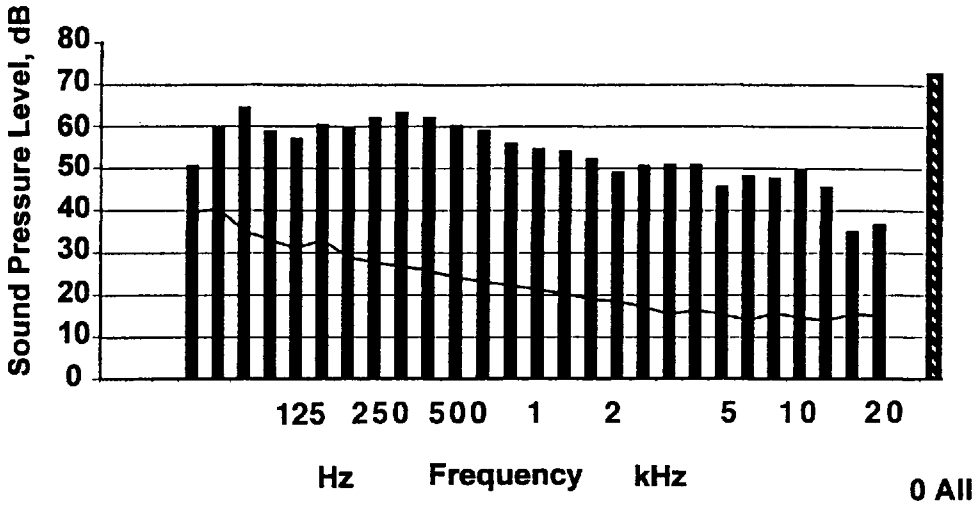

Figure 7 Radio. Low frequency (50Hz–20kHz) spectrum showing no pronounced peaks (NPP) recorded at 1.5m from a domestic radio playing pop music. The overall SPL in the low frequency range (10Hz–12.5kHz) is indicated by the vertical bar above 'O All'.

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Discussion

The exact nature of the acoustic environment of laboratory animals will obviously vary between institutions as the acoustics of animal facilities will be affected by room dimensions, the materials used, the nature of the fixtures, fittings and 'furniture' as well as by the types of equipment and the maintenance practices employed. Even the manner in which personnel work can have an effect on the sounds produced. It is therefore not possible to translate measurements made in one situation directly to another, but it is possible to demonstrate the types of sound produced in different situations and to indicate the various sources of sound. This study has indeed shown that laboratory animals are exposed to a wide variety of sounds that vary in frequency content, SPL and in duration – and it has indicated some of the major sources of these sounds which are probably common to many animal units. Many of the sources studied produced sounds up to 100kHz in frequency and levels of 80dB and over were common. These sounds are, therefore, well within the audible range of laboratory animals.

The effects of noise on humans have been studied extensively (see Kruyter 1985) and criteria set for human noise exposure are based on these studies. For humans, exposure to noise of 85dB(A) for 8h per week is considered an upper limit beyond which risk of auditory damage is such that measures must be taken to reduce exposure to these levels in the workplace. However, even exposure to 75dB(A) is considered undesirable. Where workers would be exposed to 90bdB(A) for 8h per day, proposed EC Directives stipulate that access must be limited and ear protectors must be provided (Tyler 1993). The higher the level of the noise, the shorter the exposure which can lead to damage. Thus, the damage potential of 8h of exposure at 90dB(A) is experienced in 1h at 99dB(A) and in only 30min at 110dB(A). It seems likely that similar relationships will hold for laboratory animals.

The effects of sound on laboratory animals, as on humans, depend on the nature of the sound, in particular on its frequency content, the SPL and on the duration of exposure. Peterson (1983) has suggested that for noise of moderate to high intensity (80–100 dB SPL) as well as that of high intensity (> 100dB) exposure to sound of a uniform energy spectrum and unchanging intensity may lead more readily to hearing loss due to mechanical or metabolic failure within the ear; while exposure to sound of equal energy but characterized by rapidly changing intensity, impulsiveness and unpredictability may lead more readily to various disorders associated with the 'General Adaptation Syndrome', through activation of neuroendocrine mechanisms. Even sounds of very short duration (2–10 s) at high intensity, or lower level sounds which are more prolonged, can affect animals – for example by increasing sensitivity to sound-induced convulsions as in laboratory mice (see Clough 1982; Gamble 1982), or by increasing diuresis and sodium excretion as in rats (Lockett 1970).

Despite the knowledge of the various effects of sound on laboratory animals, there appear to have been few systematic studies on the tolerance of animals to various types of sound and especially on threshold levels for the different responses reported. It is, therefore, difficult to predict the effects that the sounds present in animal units may have on the animals themselves. Over 30 years ago, Anthony (1963) considered the then known sensitivity of rodents to sound and their responses to it. He suggested that background noise levels should not exceed 85dB and that a desirable goal would be to achieve noise levels of 55–60 dB over a wide range of frequencies (then set at 1.2–9.6 kHz). Such levels, he suggested, would cause minimum disturbance to the animals.

Based on these criteria, it would appear from the present work that environmental control systems generally pose no serious risk of disturbance or damage to the animals – even for those inside isolation units. This survey, however, and the brief one of Pfaff and Stecker (1976) have shown that maintenance procedures such as feeding and cleaning can result in some high sound levels over wide frequency ranges, albeit for short periods. Overall levels during floor brushing did not exceed 80dB in this study, and while such levels in themselves may affect activity in the short term, they probably do not have lasting effects. However, the presence of personnel in the room can stimulate behaviours such as the banging of cages by monkeys and barking by dogs (Peterson 1980) which result in high sound levels. In the present survey, procedures involving metal cages, cage tops or base plates did result in high sound levels of 80dB and more. There is no doubt that the cleaning procedure does affect the behaviour of laboratory animals at least in the short term (Saibaba *et al* 1996) and it seems likely that the sounds produced during the procedure would contribute to this.

High sound levels were also reported for some equipment commonly used near animals including an ultrasonic disintegrator and a tattoo gun. Of particular cause for concern were the sound levels produced by the metal transport system, where peak values exceeded 110dB in the high frequency range for brief periods during transport. Also of potential significance were the mainly ultrasonic sounds recorded from computer systems, especially monitors. It is known that relatively low intensity sounds in the ultrasonic range can affect activity both during and for a short time after exposure (Sales 1991); and the presence of a video monitor has been shown to affect the activity of rats in the open field (Sales *et al* in preparation). The presence of such equipment could, therefore, affect the outcome of experiments, especially those involving behavioural measurements.

It seems clear that the acoustic environment of laboratory animals could adversely affect these animals and should be more rigorously controlled, or at least more carefully monitored, than appears to be the case at present. Over 20 years ago, Pfaff (1974) concluded that the standards then set for noise levels in the human environment were insufficient both to protect laboratory animals from the hazards of sound (and especially from ultrasound) and also to protect many experiments from the physiological disturbances caused by sound. Despite the calls of Pfaff (1974) and earlier ones of Anthony (1963), there is still not enough information on the responses of animals to sound, particularly of threshold levels, to be able to draw up noise exposure criteria as for humans. Since Anthony suggested minimum levels of 85dB in 1963, studies on the auditory sensitivities of many laboratory animals have indicated that some animals, such as mice and dogs, are up to 20dB more sensitive than humans (Fay 1988). In addition, the human noise tolerance criteria have been reduced over this time to take into account the increasing body of research in the area. It seems possible that 85dB should be considered as an upper limit for background noise and that, as Anthony suggested, lower levels should be the overall aim.

The value of masking noises to reduce the adverse effects of impulsive noise has been debated for animals. Some advocate the use of 'white noise' or music (Pfaff 1974) or of radios (Morton *et al* 1993), but the loudspeakers of most domestic radios or public communication systems would limit the sound output to below 16 kHz and probably to below 12 kHz. As the present study has shown, this would not cover the full frequency range of environmental noise which is within the hearing range of most laboratory animals. While radios may, therefore, be of benefit to animal house staff (and so indirectly to animals) a direct effect on the animals themselves seems unlikely, although this area together with more detailed studies of the effects of environmental noise on laboratory animals would benefit from rigorous study.

Animal welfare implications

Many of the sounds monitored in this study lay well within the hearing ranges of most laboratory mammals – and some were of a level which, by comparison with humans, could cause stress or even damage to the animals. Therefore, it seems likely that in at least some situations the welfare of laboratory animals is compromised by their acoustic environment. It is hoped that awareness of this possibility will lead to measures to reduce the exposure of laboratory animals to sound levels that could have adverse effects and will promote further research in this area so that realistic tolerance levels can be set.

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