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1. INTRODUCTION

The Federal Railroad Administration (FRA) has sponsored preparation of this report to support a rulemaking process about the use of locomotive horns and the accompanying environmental impact statement. This document reviews select current and past research on the effect of transportation noise on the physiological and psychological health for both people and wildlife. This review includes research from national and international sources.

1.1 Background

Noise is often defined as any unpleasant or unwanted sound. The earliest record of a government taking action to reduce transportation noise dates back to the Roman Empire just before Julius Caesar. Complaints of the noise caused by the wheels of chariots led to the passage of a law which banned the use of chariots at night.

Two thousand years later - while chariots are no longer a noise concern in the US, we can still relate to too much noise in our communities. In addition to interference with speech, sleep, and thought, noise can lead to annoyance and indirect effects on human health and well-being.

Protection of the public against the possible harmful effects of noise are the goals of organizations including the U.S. Environmental Protection Agency (EPA), the World Health Organization (WHO), the Institute of Noise Control Engineering (INCE), the International Committee on Biological Effects of Noise (ICBEN), and the Occupational Safety and Health Administration (OSHA). These organizations, working with government agencies, as well as other noise- and health-interest researchers, continually monitor transportation and technology trends in order to better understand and mitigate the effects of its by-product, noise, on all living beings.

1.2 Scope and Objectives

The objective of this document is to provide a brief summary of the health effects of environmental noise on people and wildlife. The scope of this document includes all environmental noise with a primary focus on transportation noise, such as aircraft, highway, and rail noise. This document includes a review of select current and past national and international research.

2. TERMINOLOGY

This section presents pertinent terminology used throughout the document. Note: Definitions are generally consistent with those of the American National Standards Institute, Taber's Cyclopedic Medical Dictionary, and Dorland's Illustrated Medical Dictionary.

A-WEIGHTING - A frequency weighting network used to account for changes in human auditory sensitivity as a function of frequency.

ACTIGRAPH - Wrist-watch-sized devices that record human movement and can provide an indication of sleep.

ANNOYANCE - Any bothersome or irritating occurrence.

ANXIETY - A feeling of apprehension, uncertainty, and fear without apparent stimulus. It is associated with physiological changes (tachycardia, sweating, tremor, etc.) - the source of which is often nonspecific or unknown to the individual.

ARRHYTHMIA - Any irregularity in the rhythm of the heart's beating.

AUDIOMETRY - Measurement/testing of the hearing, including aspects other than hearing sensitivity.

AUDITORY THRESHOLD - Minimum audible perceived sound.

CARDIOVASCULAR - Pertaining to the heart and blood vessels.

DAY-NIGHT AVERAGE SOUND LEVEL (abbreviation DNL, denoted by the symbol L_{dn}) - Twenty-four hour average sound level for a given day, after addition of 10 decibels to levels from midnight to 0700 hours and from 2200 hours to midnight. L_{dn} is computed as follows:

$$L_{dn} = L_{AE} + 10*\log_{10}(N_{day} + 10*N_{night}) - 49.4 \qquad \text{(dB)}$$

where:

L_{AE}	=	Sound exposure level in dB (see definition on Page 5);
N_{day}	=	Number of vehicle pass-bys between 0700 and 2200 hours, local time;
N_{night}	=	Number of vehicle pass-bys between 2200 and 0700 hours, local time; and
49.4	=	A normalization constant which spreads the acoustic energy associated with highway vehicle pass-bys over a 24-hour period, i.e., $10*\log_{10}$(86,400 seconds per day) = 49.4 dB.

DECIBEL (unit dB) - Unit of level when the base of the logarithm is the tenth root of ten, and the quantities are proportional to power.

EPINEPHRINE - A hormone secreted by the adrenal medulla (inner or central portion of an organ) in response to stimulation of the sympathetic nervous system.

EQUIVALENT SOUND LEVEL (abbreviation TEQ, denoted by the symbol L_{AeqT}) - Ten times the logarithm to the base ten of the ratio of time-mean-squared instantaneous A-weighted sound pressure, during a stated time interval T, to the square of the standard reference sound pressure. L_{AeqT} is related to L_{AE} by the following equation:

$$L_{AeqT} = L_{AE} - 10*\log_{10}(t_2 - t_1) \qquad \text{(dB)}$$

where L_{AE} = Sound exposure level in dB (see definition on Page 5).

HEARING IMPAIRMENT - A decreased ability to perceive sounds as compared with what the individual or examiner would regard as normal. The result is an increase in the threshold of hearing.

HEARING THRESHOLD - For a given listener and specified signal, the minimum: (a) sound pressure level; or (b) force level that is capable of evoking an auditory sensation in a specified function of trials.

HERTZ - (abbreviation Hz) Unit of frequency, the number of times a phenomenon repeats itself in a unit of time.

L_{AE} (see Sound Exposure Level)

L_{dn} (see Day-Night Average Sound Level)

L_{Aeq} (see Equivalent Sound Level)

NOISE - Any unwanted sound.

NOISE INDUCED TEMPORARY THRESHOLD SHIFT - Temporary hearing impairment occurring as a result of noise exposure, often phrased temporary threshold shift.

NOISE INDUCED PERMANENT THRESHOLD SHIFT - Permanent hearing impairment occurring as a result of noise exposure, often phrased permanent threshold shift.

NOREPINEPHRINE - A hormone produced by the adrenal medulla similar in chemical and pharmacological properties to epinephrine, but chiefly a vasoconstrictor with little effect on cardiac output.

PARACUSIS - Any abnormality or disorder of the sense of hearing.

PEAK SOUND PRESSURE LEVEL - Level of the peak sound pressure with stated frequency weighting, within a stated time interval.

PATHOLOGICAL - Any condition that is a deviation from the normal.

PHYSIOLOGICAL - Of the branch of biology dealing with the functions and vital processes of living organisms or their parts and organs.

PRESBYACUSIA, PRESBYCUSIS - Hearing deterioration occurring after middle age.

PSYCHOPHYSIOLOGICAL - Characteristic of or promoting normal, or healthy functioning of the mind or mental processes.

RECRUITMENT - (Loudness) Abnormal loudness perception.

REVERBERATION - Sound that persists in an enclosed space, as a result of repeated reflection or scattering, after the source has stopped.

REVERBERATION TIME - Of an enclosure, for a stated frequency or frequency band, time that would be required for the level of time-mean-square sound pressure in the enclosure to decrease by 60 dB, after the sound source has stopped.

SOUND EXPOSURE LEVEL (abbreviation SEL, denoted by the symbol L_{AE}) - Over a stated time interval, T (where $T=t_2-t_1$), ten times the base-10 logarithm of the ratio of a given time integral of squared instantaneous A-weighted sound pressure, and the product of the reference sound pressure of 20 micropascals, the threshold of human hearing, and the reference duration of 1 sec. The time interval, T, must be long enough to include a majority of the sound source's acoustic energy. As a minimum, this interval should encompass the 10 dB down points (see Figure 1). In addition, L_{AE} is related to L_{AeqT} by the following equation:

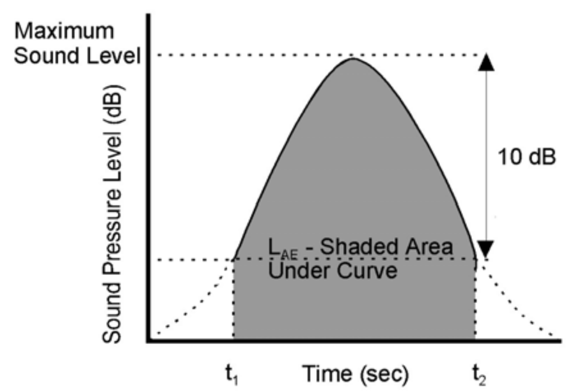

Figure 1. Graphical representation of L_{AE}.

$$L_{AE} = L_{AeqT} + 10*\log_{10}(t_2-t_1) \qquad \text{(dB)}$$

where L_{AeqT} = Equivalent sound level in dB (see definition above).

SOUND PRESSURE LEVEL (abbreviation SPL) - Ten times the base-10 logarithm of the ratio of the time-mean-square pressure of a sound, in a stated frequency band, to the square of the reference sound pressure in gases of 20 micropascals.

STRESS - The sum of the biological reactions to any adverse stimulus, physical, mental, or emotional, internal or external, that tends to disturb the organism's state of stability.

THRESHOLD OF HEARING - (see Hearing Threshold)

TINNITUS - A sound of ringing or whistling in the ears, excluding hallucinations of voices. Otological condition in which sound is perceived by a person without an external auditory stimulation.

VASOCONSTRICTION - Tightening or compressing of the blood vessels.

3. GENERAL EFFECTS

The effects of environmental noise on people are generally undesirable. These effects include psychological effects (see Section 4), such as annoyance, and physiological effects (see Section 5), such as hearing impairment and sleep disturbance. In 1972, the Noise Control Act was established to address the concerns of noise as a growing danger to the health and welfare of the Nation's population, particularly in urban areas. In response to the Noise Control Act, the Environmental Protection Agency (EPA) published, " Information of Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety" (EPA 1974). The objective of the EPA's "Levels Document" was to identify levels of environmental noise required to protect the public from adverse health and welfare effects (Beranek 1992).

Table 1 summarizes the yearly average equivalent sound level and/or day-night average sound level (L_{eq} or L_{dn}, respectively) recommended as protective of the public health and welfare. Twenty-four-hour exposure levels of 70 decibels or less are identified as necessary to prevent measurable hearing loss over a lifetime. Levels of 55 decibels outdoors and 45 decibels indoors are identified as requisite for preventing activity interference and annoyance. It should be noted that the levels presented in the table below are not to be considered standards, criteria, or regulatory goals. The levels also include a margin of safety and should be viewed as levels below which there is no reason to suspect that the general population will be at risk from any of the identified effects of noise (EPA 1974, FICAN 1992, WHO 2000).

Table 1. Yearly average equivalent sound levels in decibels identified as requisite to protect the public health & welfare with an adequate margin of safety (EPA 1974).*

	Measure	Indoor			Outdoor		
		Activity Interference	Hearing Loss Consideration	To Protect Against Both Effects (b)	Activity Interference	Hearing Loss Consideration	To Protect Against Both Effects (b)
Residential with Outside Space and Farm Residences	Ldn	45			55		55
	Leq(24)		70	45		70	
Residential with No Outside Space	Ldn	45		45			
	Leq(24)		70				
Commercial	Leq(24)	(a)	70	70(c)	(a)	70	70(c)
Inside Transportation	Leq(24)	(a)	70	(a)			
Industrial	Leq(24)(d)	(a)	70	70(c)	(a)	70	70(c)
Hospitals	Ldn	45		45	55		55
	Leq(24)		70			70	
Educational	Ldn	45		45	55		55
	Leq(24)		70			70	
Recreational Areas	Leq(24)	(a)	70	70(c)	(a)	70	70(c)

	Measure	Indoor			Outdoor		
		Activity Interference	Hearing Loss Consideration	To Protect Against Both Effects (b)	Activity Interference	Hearing Loss Consideration	To Protect Against Both Effects (b)
Farm Land and General Unpopulated Land	Leq(24)			(a)	70	70(c)	

Note: * The exposure period which results in hearing loss at the identified level is a period of forty years.
(a) Since different types of activities appear to be associated with different levels, identification of a maximum level for activity interference may be difficult except in those circumstances where speech communication is a critical activity.
(b) Based on lowest level.
(c) Based only on hearing loss.
(d) An Leq(8) of 70 dB may be identified in these situations so long as the exposure over the remaining sixteen hours is low enough to result in a negligible contribution to the 24-hour average, i.e., no greater than an Leq(24) of 60 dB.

In addition to noise exposure guidelines, the EPA and other agencies have established noise exposure limits (see Table 2), above which feasible administrative or engineering controls must be utilized. The permissible equivalent A-weighted sound level for an eight-hour exposure period ranges from 75 dBA for the EPA to 90 dBA for the Occupational Safety and Health Administration (OSHA 1998).

Table 2. Permissible Equivalent Sound Exposure Levels (Beranek 1992).

Duration of Exposure (Hours)	OSHA	U.S. Army	U.S. Air Force	EPA
8	90	85	84	75 *
4	95	89	88	
2	100	93	92	-
1	105	97	96	-
0.5	110	101	100	-
0.25 or less	115 **	105	104	-

Note: * The threshold for detectable noise-induced permanent threshold shift (NIPTS) at 4,000 Hz; exposures exceeding 75 dB may cause NIPTS exceeding 5 dB in 100 percent of the population after cumulative noise exposure of 10 years.
** Ceiling on exposure level and duration.

Long-term exposure to high noise levels results in interference with conversation and other normal human activities, such as sleeping, working, and recreation. To determine if long-term exposure to any specific type of environmental, primarily transportation, noise is a risk factor for cardiovascular or other disorders, would require highly sophisticated epidemiologic field studies. In addition, these field studies would need to place greater emphasis on ensuring appropriate controls to account for other known risk factors such as age, sex, smoking, caffeine, body weight, diet, and hereditary proclivity (HCN 1994, Thompson 1996). The 1982 EPA publication, Guidelines for Noise Impact Analysis, stated that research implicates noise as one of several factors producing stress-related health effects such as heart disease, high-blood pressure, stroke, ulcers, and other digestive disorders. However, the relationship between noise and these effects has not been fully quantified with most studies on these effects having only limited data available and no definitive conclusions (EPA 1982, Babisch 1993, HCN 1994, IEH 1997, Thompson 1981, Thompson 1996).

The estimated of the number of people exposed to environmental noise at various levels as published in a 1981 EPA document is shown in Table 3 (EPA 1981). As noise levels are directly related to population density (EPA 1974), the general trend is that noise in communities is increasing (Suter 1991). Although in 2000, the Federal Aviation Administration estimated that there will be about 500,000 Americans exposed to significant levels of aircraft noise - down substantially from the 4.7 million estimated in 1981 (FAA 2000). This decrease in population exposure can be attributed to the advent of quieter aircraft.

Table 3. Summary of U.S. population exposed to various day-night average sound levels (L_{dn}) from noise sources in the community (EPA 1981).

L_{dn} (dB)	Estimated Number (in Millions) of People in Each Noise Category					
	Roadway Traffic	Aircraft	Construction	Rail	Industrial	Total
> 80	0.1	0.1	-------	-------	-------	0.2
> 75	1.1	0.3	0.1	-------	-------	1.5
> 70	5.7	1.3	0.6	0.8	-------	8.1
> 65	19.3	4.7	2.1	2.5	0.3	27.8
> 60	46.6	11.5	7.7	3.5	1.9	63.6
> 55	96.8	24.3	27.5	6.0	6.9	92.4

Note: L_{dn} values are yearly averages, outdoors. In addition, there is some overlap among populations exposed to multiple noise sources.

4. PSYCHOLOGICAL EFFECTS

This section contains a discussion of the psychological effects of environmental noise. Psychological effects include annoyance, speech interference, and interference with recreational activities.

4.1 Annoyance

Annoyance with environmental transportation noise is the general adverse reaction of people resulting from speech interference and disturbance to comfort, peace of mind, and sleep. Earlier EPA publications and related reports (EPA 1974, EPA 1973, EPA 1978, Galloway 1970, von Gierke 1977) on transportation noise and human annoyance were later superceded by the 1978 Schultz synthesis (Schultz 1978). This study examined 11 major social surveys on annoyance due to transportation noise. It resulted in the so-called "Schultz curve" which related noise level to annoyance. Since its publication, the Schultz curve has been used nationally and internationally as the nominal response curve for characterizing the average community response to transportation noise.

More recent U.S. Air Force (USAF) research re-examined the Schultz curve as part of a long-term study on the effects of aircraft noise on humans (Finegold 1990, Finegold 1993a, Finegold 1993b, Finegold 1994). In this work, the Percent Highly Annoyed (%HA) relationship, the accepted measure for assessing long-term community noise exposure, was also re-examined. Based on the Schultz data and further refined by the USAF work, the following relationship has become the more widely used model for predicting community annoyance response to all types of transportation noise:

$$\%HA = \frac{100}{1 + e^{(11.13 - 0.14 L_{dn})}}$$

where: %HA is the Percent Highly Annoyed and
L_{dn} is the Day-Night Average Sound Level.

Figure 2 illustrates the Percent Highly Annoyed relationship for the 3 primary types of transportation noise: aircraft, highway/road traffic, and railway. Although the figure implies that people are more sensitive to aircraft noise as compared to noise from highway and rail, more data are required to substantiate this observation. The highway and rail data used in the figure are relatively sparse.

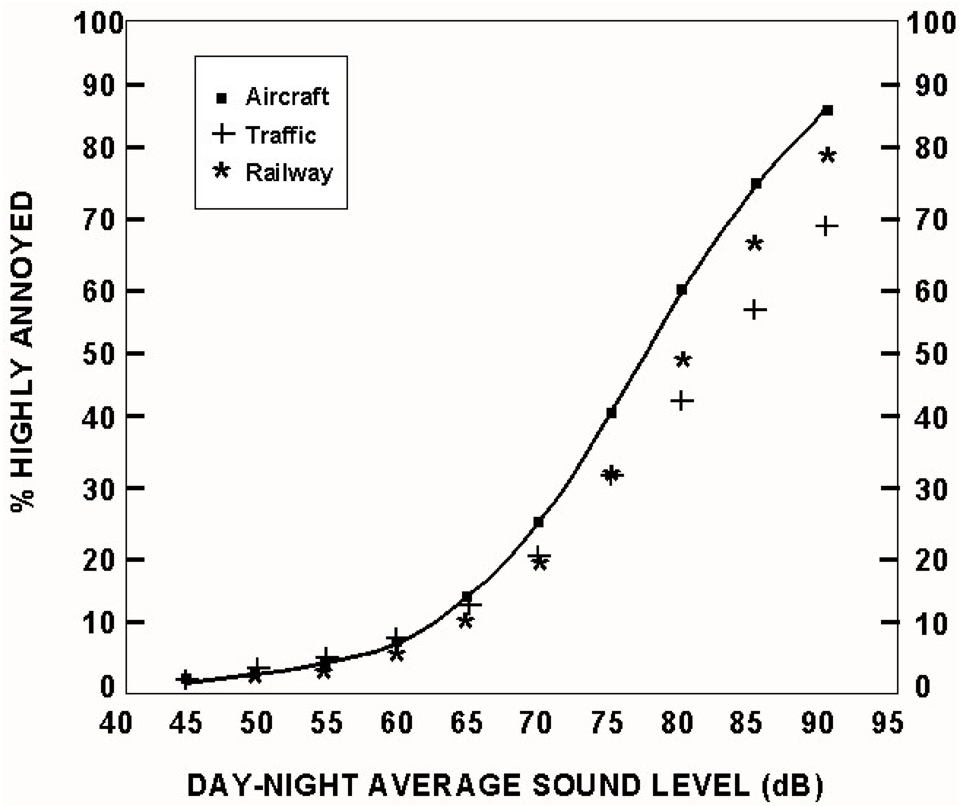

Figure 2. %HA versus L_{dn} from aircraft, road traffic, and railway noise (Finegold 1994).

Further research is required to more fully assess other factors which contribute to a person's level of annoyance in association with transportation noise. These factors may include frequency content, duration, and accompanying rattle/vibration. It is well documented that annoyance increases with sound-induced rattle/vibration (WHO 2000, HCN 1994, Stansfeld 1997). In addition, community attitudes towards noise sources can be an important influence on the degree of annoyance. Annoyance may be reduced when the noise maker maintains a good community relationship and convinces the community that everything that can be done is being done to reduce the noise (FAA 2001).

Finally, it should be mentioned that although annoyance is used to predict community response to noise, complaints are not as useful a measure of community impact (FICAN 1992). This is because annoyance can exist without complaints and, conversely, complaints may occur without high percentages of annoyance. As such, complaints cannot reliably be used to predict community response (FICAN 1992).

4.2 Speech Interference

Speech interference occurs when speech is masked by other sounds occurring simultaneously. Because most of the acoustic energy associated with speech is in the frequency range of 250-5000 Hz, speech intelligibility is often adversely affected by noise (Harris 1991, WHO 2000). The effects of noise are compounded by other factors also influencing speech intelligibility, including speech pronunciation, distance between speaker and listener, hearing acuity, level of attention, reverberation characteristics of the listening environment, and sound characteristics of the interfering noise. As the sound pressure level of an interfering noise increases, the speaker compensates by also increasing the volume of his voice. This places additional strain on the listener as well. Noise may mask not only speech but can be of even greater concern when it masks other acoustical signals important for daily life, such as door bells, telephones, alarm clocks, fire alarms, music, and other warning signals (Edworthy 1996).

The American National Standards Institute (ANSI) Standard S3.5, "Methods for Calculation of the Speech Intelligibility Index," includes a Speech Interference Level (SIL) metric which relates speech interference caused by relatively constant noise sources (ANSI 1997). However, because this standard is based on steady-state noise, its applicability to evaluation of nonsteady-state noise events, such as aircraft and railroad grade-crossing horn noise, is limited. Use of the SIL metric would require careful judgement regarding the variability of level, duration, direction, and frequency spectrum of the noise source (FICAN 1992).

Figure 3 shows the voice effort required at differing distances and sound levels and can be used as a very general guide to the effects of noise and speech interference.

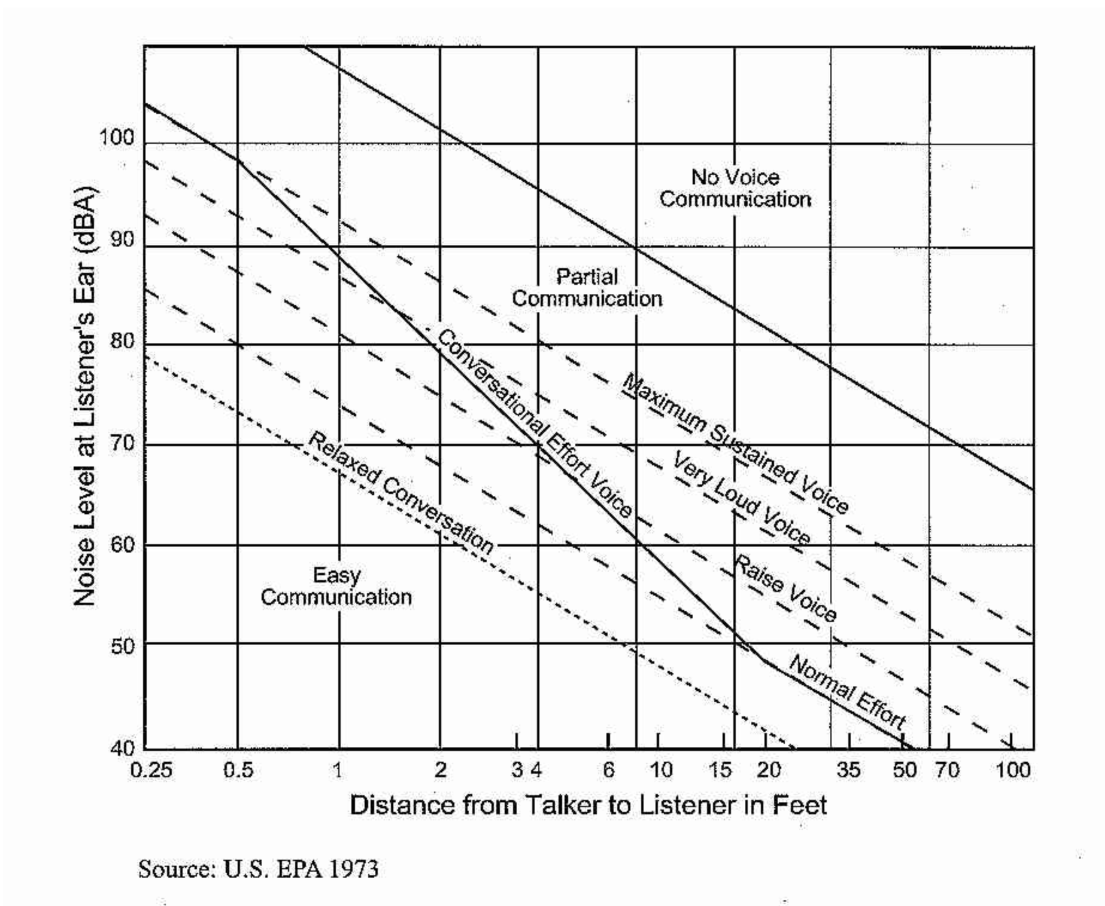

Figure 3. Noise level effects on speech interference (EPA 1973).

4.3 Effects of Noise on Performance

In both laboratory and workforce environments, noise adversely affects cognitive task performance (WHO 2000). The level of noise necessary to produce adverse effects does depend greatly on the type of task, however. For example, transportation noise may be more disruptive during reading activities as compared to recreational activities. In addition to type of activity, the frequency content and temporal characteristics may also play a part in producing adverse effects. High frequency sound is typically more disruptive than low-frequency; and intermittent sounds are generally more disruptive than continuous sounds of equivalent acoustic energy (Suter 1991).

Other studies suggest that noise slows rehearsal in memory, acting as a distraction stimulus, thus, increasing the need for focusing (Mohindra 1983). People whose performance strategies are already limited for other reasons (e.g., through high anxiety), and who are faced with multiple tasks may be more vulnerable to the masking and distracting effects of nosie (Stansfeld 1997).

Of considerable research interest are the effects of transportation noise on children. Noise has been shown to affect children's cognitive and motivational parameters (Bronzaft 1975, Bronzaft 1981, Cohen 1980, Evans 2001, Evans 1998, Evans 1995, Evans 1993, Haines 1998, Hygge 1998, Kohut 2001, Stansfeld 1997). Among the cognitive effects, reading, attention, problem solving, and memory are most affected by noise. Most of the studies reviewed have found the uncontrollability of noise, rather than the intensity of the noise, appears to be the most critical variable.

4.4 Interference with Recreational Activities

Noise affects people at home and at work, but also during leisure. It is difficult, however, to estimate the magnitude of these effects, especially when considering other noise sources present during leisure activities. High noise exposure sources/situations which people expose themselves to voluntarily, include music (e.g., concerts, clubs, and headphones), loud games, and sports (e.g., hunting, stadiums, and motor sports), and toys (e.g., cap pistols, rattles, and arcades). The trend in noise levels for these kinds of activities has been upward (Axelsson 1996, Suter 1991).

For those leisure activities where people purposely avoid noise or expect quiet, including libraries, churches, and remote areas of parks, the intrusion of transportation noise is of greater concern. Several studies document the development of relationships between noise exposure (or change in noise exposure) and human response. These relationships are being used as tools to assist the National Park Service in reducing the impacts of aircraft overflight sound levels on visitors to the National Parks (NPS 1995, Anderson 1993, Fleming 1998). Impacts caused by aircraft overflights in the National Parks are of two types: impacts on natural quiet and impacts on visitor enjoyment. The findings of a study performed in Bryce Canyon National Park indicate that approximately one-quarter of the survey respondents expressed annoyance as a result of aircraft overflight noise. It should be noted, however, that respondents also reported a number of other factors besides aircraft noise as annoyances, e.g., crowds/other people, trail conditions, weather, lack of restroom facilities (Fleming 1998).

5. PHYSIOLOGICAL EFFECTS

This section discusses the physiological effects of environmental noise. Physiological effects include hearing impairment, sleep disturbance, and startle and defense reactions leading to potential increase of blood pressure.

5.1 Hearing Impairment/Loss

A report by the Federal Interagency Committee on Aviation Noise documents some of the direct, indirect, short-term, and long-term health and welfare effects of airport noise (FICAN 1992). Hearing impairment is typically defined as an increase in the threshold of hearing. Changes in hearing threshold level, the lowest level a sound signal of a specific frequency can be detected by the ear, of less than 5 dB are not generally considered noticeable. A noise-induced permanent threshold shift of 5 dB or more is considered significant by the EPA (EPA 1974). Hearing impairment due to noise is typically detected beginning at the frequencies 4000 Hertz (Hz) or above. The impairment may also be accompanied by tinnitus (ringing in the ears).

In 1995, at the World Health Assembly, it was estimated that there are 120 million people with disabling hearing difficulties worldwide (Smith 1998). Men and women are equally at risk of noise-induced hearing impairment (ISO 1990, WHO 2000). Prolonged exposure to high levels of noise exposure can cause hearing impairment, though most cases were found to be related to occupational noise exposure. Guidance for determining noise-induced hearing impairment due to occupational noise exposure can be found in the International Organization for Standardization's (ISO), "Acoustics - Determination of Occupational Noise Exposure and Estimation of Noise-Induced Hearing Impairment" (ISO 1996).

A review of studies by the World Health Organization shows hearing impairment/loss for cases outside of occupational noise exposure. Deterioration of the hearing capability is more often shown to be caused by diseases, head trauma, hereditary links, and normal aging. Environmental noise exposures due to noisy activities, especially leisure-time activities of children and young adults, have not been as scrutinized or regulated (WHO 2000).

5.2 Sleep Disturbance.

The National Sleep Foundation reports that the most common environmental elements affecting sleep are noise, sleep surface, temperature or climate, and altitude with age and gender playing a part in determining the level of sleep disturbance caused by these factors (NSF). It is estimated that only 10 to 20 percent of the reported cases of sleep disturbance are for reasons relating to transportation noise (Reyner & Horne 1995). While most experimental research studies have been performed in controlled environments, some field studies of sleep disturbance conducted within people's homes have been performed (ANSI 2000). The majority of transportation-noise, sleep-disturbance research has focused on aircraft noise (Basner 2001) - few are conducted for highway or railway noise (Griefahn 1996, Griefahn

1998). Most studies monitor awakening by a verbal response, a button push, and/or various physiological signals, including polysomnographic measurements (EEG, EOG, EMG), the electrocardiogram, finger pulse amplitude, respiration, and actigraphy. In addition, urine samples were examined for stress indicators, including cortisol, epinephrine, and norepinephrine.

Of greater concern are the possible secondary effects, i.e., after effects, of sleep disturbance. These effects may include reduced perceived sleep quality, increased fatigue, depressed mood or well being, and decreased performance (Carter 1996, Ohrstrom 1993, Passchier-Vermeer 1993, Pearsons 1995, Pearsons 1998).

Based on the literature reviewed in a USAF-sponsored study of sleep disturbance (Pearsons 1989), no specific long-term health effects have been clearly linked with sleep disturbance (FICAN 1992). It has also been observed that habituation typically occurs over time when similar sound exposures occur across nights (Griefahn 1977, LeVere 1975, NSF, Ohrstrom 1988, Stansfeld 1997, TRB 1997). Comparison of results of laboratory and field studies shows that habituation to night-time noises occurs to a large extent with respect to awakening, but not, or to a much lesser extent, with respect to changes in sleep stage and heart rate (HCN 1994). Regardless however, sleep disturbance is indisputably undesirable and, thus, still considered a noise impact.

Scientists agree that more studies are needed to confirm or disaffirm what relatively little is known about sleep (NSF). The USAF review also included the need for additional data to satisfy the following areas of concern:

- large discrepancies between laboratory and field studies;
- highly variable and incomplete data bases;
- lack of appropriate field studies;
- the studies' methodologies; and
- lack of consideration of non-acoustic effects.

In addition, it has been found that people do intervene to a certain extent in their own living and working environment, e.g., by moving to more quiet surroundings or by changing their job. This may result in a selection in which people who are "noise-proof" will remain in noise situations and those who are not will leave the situation (HCN 1994).

The findings of several field studies over the past twenty-five years have been compiled and analyzed using meta-analytic techniques to derive a prediction model of noise-induced awakenings for transportation noise sources. The prediction model is based on a curvilinear power-function fit through the data points defining the percent of study participants awakened at given indoor single-event noise levels, or sound exposure levels (L_{AE}), of aircraft (Finegold 2001). This relationship is shown in Figure 3 below and in the following equation:

$$\% Awakening = 0.58 + (4.30 \times 10^{-8}) \times L_{AE}^{4.11}$$

In considering Figure 4, it should be noted that the time interval between two noise events also has been found to have an important influence on the probability of obtaining a response (WHO 2000, Griefahn 1977, Ohrstrom 1990).

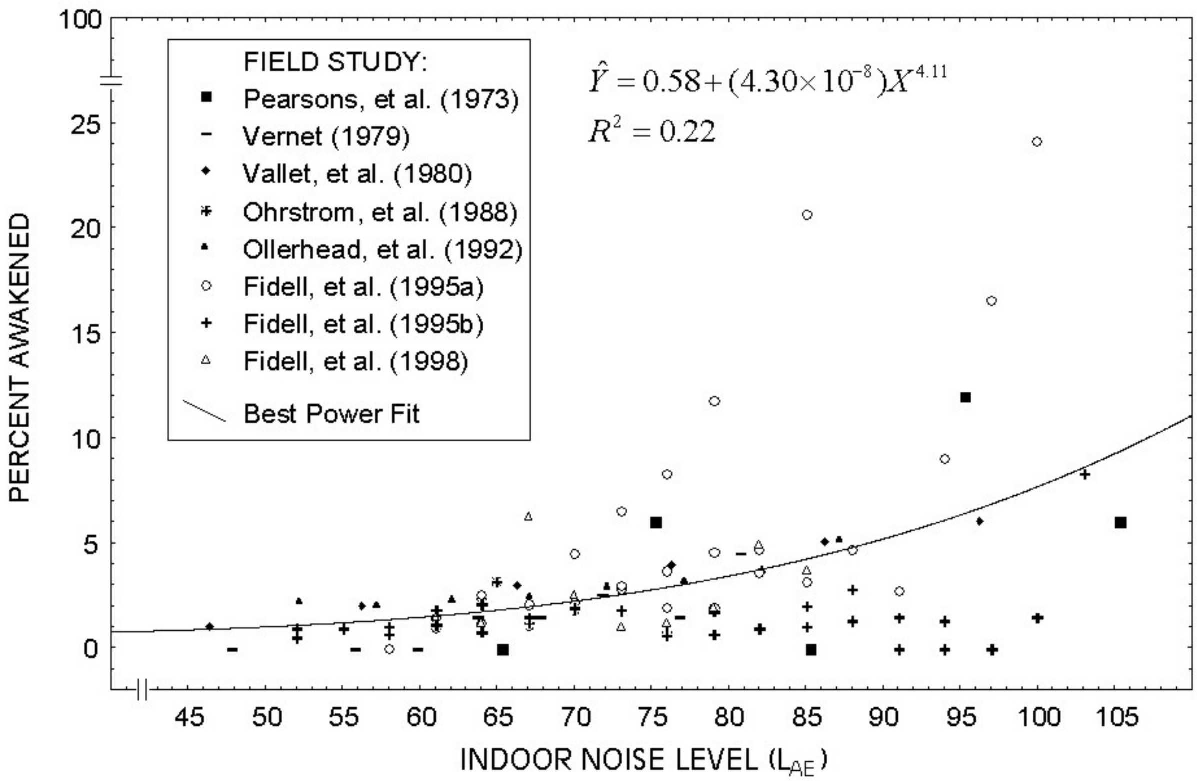

Figure 4. Sleep disturbance as a function of single-event noise exposure levels (Finegold 2001).

5.3 Muscular Effects of Noise

Muscular reflex responses to noise involves obvious movements (startle response) of voluntary muscle groups and less obvious electrical activity found in muscle tension. The magnitude of a startle response is related to the magnitude of the noise stimulus and rate of onset (May 1971, Thackray 1973). Most research concerning human reaction to impulsive noise comes from studies of the effects of gunfire with some limited occupational noise exposure data from industrial situations. While a reduction in response, or habituation, is typical with continuation or repetition of the stimulus, the sudden muscular response due to noise could potentially interfere with critical motor tasks at critical moments. In addition, short and long term muscular tension has many negative cardiovascular implications (Harris 1991, Stansfeld 1997).

A hazard exists when impulsive noises exceed a peak sound pressure level of 140 dB for more than 5 continuous milliseconds (ms). Higher maximum levels may be tolerable for durations of less than 5 ms. Peak sound pressure levels in excess of 165 dB even for minuscule durations, are likely to cause acute cochlear damage (WHO 2000).

5.4 Cardiovascular Effects of Noise

Epidemiological and laboratory studies involving workers exposed to occupational noise and general populations (including children) living in noisy areas around airports, industries, and noisy streets, indicate that noise may have both temporary and permanent impacts on physiological functions of people (WHO 2000).

Research has correlated exposure to environmental noise with physiological changes in blood pressure, sleep, digestion and other stress-related disorders (Parrot 1992, Passchier-Vermeer 1993, Petiot 1992). Low frequency noise (0 to 20 Hz) can be directly absorbed through the surface of the body and can excite sense organs other than the ears causing disturbances to the nervous system, equilibrium, and sight (Newman 1985). These changes relate chronic noise exposure and some elevated neuroendocrine and cardiovascular measures. Certain acute noise exposures can activate the autonomic and hormonal systems. Laboratory experiments and field research have shown that if noise exposure is temporary, the physiological system usually returns to normal after an appropriate recovery period (WHO 2000).

Prolonged exposure, however, may cause more serious cardiovascular and hormonal responses, including increases in heart rate and peripheral vascular resistance, changes in blood pressure, blood viscosity, and blood lipids, and shifts in electrolyte balance. Susceptible individuals may develop permanent effects, such as coronary heart disease (Bronzaft 1997, Cohen 1980, Evans 1995, Ising 1997, Schwarze 1988).

The overall conclusion is that cardiovascular effects are associated with long-term exposure to daily equivalent sound levels greater than 65 dB. These exposures have been implicated in the development and exacerbation of a variety of health problems, ranging from hypertension to psychosis. However, most of these findings have been criticized by the research community because the associations are usually weak, only the average risk is considered, and sensitive subgroups have not been sufficiently characterized (WHO 2000, Suter 1991, Thompson 1981, Thompson 1996). More research into the long-term effects of noise is required before unequivocal guideline values can be established.

5.5 Mental Health Effects of Noise

Noise, particularly transportation noise, is not believed to be a direct cause of mental illness, but it is assumed that it accelerates and intensifies the development of latent mental disorder (WHO 2000). Studies on the adverse effects of transportation noise on mental health include symptoms such as anxiety, emotional stress, nervousness, nausea, headaches, instability, argumentativeness, changes in mood, increase in social conflicts, as well as general psychiatric disorders, including neurosis, psychosis, and hysteria.

There is also only very limited evidence that relatively more admissions to psychiatric hospitals might occur from areas with very noisy conditions, primarily due to high levels of aircraft noise, than from more quiet surroundings (HCN 1994). Most studies linking transportation noise, primarily aircraft noise, to mental disorders are inconclusive and have been criticized for methodology and response bias (Halpern 1995, Schwarze 1988, Thompson 1996, WHO 2000). In many cases, it should also be noted that noise-sensitive individuals are likely to be sensitive to other non-transportation-related sounds in their environment as well (Anderson 1971, Broadbent 1979, Ohrstrom 1988, Thomas, 1982, Weinstein, 1978).

6. EFFECTS OF NOISE ON WILDLIFE

There has been extensive research into the effects of environmental noise, particularly transportation noise, on wildlife, especially since the establishment of the Endangered Species Act in 1973. There are over 200 published and unpublished reports which include many species that vary in scope from long-term research studies to government investigations to environmental agency citings (Gladwin 1987, NPS 1994). This section overviews the research on the effects of transportation noise on wildlife.

The majority of transportation-noise research, primarily tied to aircraft noise, has shown that certain noise intrusions can cause some effects on wildlife - however, less than originally expected. In general, some research indicates that extensive or repeated loud noise intrusions interfere with communication and breeding. By far, two of the largest, most comprehensive reviews of current and past research are contained in:

- The National Parks Service's Report to Congress (NPS 1994)
- The National Ecology Research Center's report for the U.S. Department of the Interior (Gladwin 1987)

Noise impacts on wildlife cover a wide range of effects. The following categories of impacts are adapted from work performed by Oak Ridge National Laboratory, the U.S. Army Construction Engineering Research Laboratory, and the U.S. Environmental Protection Agency (Efroymson 2000, NPS 1994). They represent a practical synopsis for judging potential impacts on wildlife due to transportation noise:

- Negligible Impacts
  - No species of concern are present and no or minor impacts on any species are expected.
  - Minor impacts that do occur have no secondary (long-term or population effects).
- Low/Minor Impacts
  - Non-breeding animals of concern are present in low numbers.
  - Habitat is not critical for survival and not limited to the noise intrusion area.
  - Occasional fright responses are expected, but without interference with feeding, reproduction, or other activities necessary for survival.
  - No serious concerns are expressed by State or Federal fish and wildlife officials.
- Moderate Impacts
  - Breeding animals of concern are present, and/or animals are present during particularly vulnerable life-stages, such as migration or winter.
  - Mortality or interference with activities necessary to survival is expected on an occasional basis.
  - Mortality or interference are not expected to threaten the continued existence of the species.
  - State and Federal officials express some concern.

- High/Major Impacts
  - Breeding individuals are present in relatively high numbers, and/or animals are present during particularly vulnerable life-stages.
  - Habitat (subjected to noise intrusions) has a history of use by the species during critical periods, and this habitat is somewhat limited to the noise impacted area; animals cannot go elsewhere to avoid impacts (animals can rarely relocate except temporarily).
  - Mortality or other effects (injury, physiological stress, effects on reproduction and young raising) are expected on a regular basis.
  - These effects could threaten the continued survival of the species.
  - State and Federal wildlife officials express serious concern.

While extensive research has been conducted on the effects of noise on wildlife - differences between study species and methodologies make a clear, quantitative definition of noise impact on wildlife difficult. Most studies pertain to specific species and result in primarily broad generalizations and observations of the behavioral responses (Arner 1999, Lelis 1999, Levy 1999, Parks 2000, Presley 2000, Reijnen 1995, Robertson 2000). With regard to transportation-related noise, most of these studies have been based on aircraft noise (DND 1998, Wells 2000). Responses of wildlife to aircraft noise vary from almost no reaction to virtually no tolerance of the sound with the question of the adaptability of wildlife to certain sounds remaining largely unanswered (Newman 1985). Further research is necessary to better correlate actual noise levels, critical frequency ranges, types of noise sources, and other variables to the behavioral responses of wildlife.

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