Reference: Mark S. Sanders and Ernest J. McCormick. Human Factors Engineering and Design. McGRAW-HILL, 7'TH Edition.

NOISE

NOISE: It is considered in an information-theory context, as "that auditory stimulus or stimuli bearing no informational relationship to the presence or completion of the immediate task".

- Human ear is not equally sensitive to all frequencies of sound. In general, we are less sensitive to low frequencies (below 1000 Hz) and more sensitive to higher frequencies.
- Therefore, a low-frequency tone must have more intensity than a higher frequency tone to be of equal loudness.

SOUND LEVEL MEASUREMENTS

Because of the very large range of sound intensities encountered in the normal human environment, the decibel scale has been chosen. In effect, it is the logarithmic ratio of the actual sound intensity to the sound intensity at the threshold of hearing of a young person. Thus, the sound pressure level (L) in decibels (dB) is given by:

$$L = 20 \log_{10} P_{rms}/P_{ref}$$

Where: P_{rms} = Root-mean-square sound pressure in microbars.

Pref = Sound pressure at the threshold of hearing of a young person at 1000Hz (0.0002 microbars).

Since sound pressure levels are logarithmic quantities, the effect of the coexistence of two or more sound sources in one location requires that a logarithmic addition be performed as follows:

$$L_{TOT} = 10 \log_{10}(10^{L_1/10} + 10^{L_2/10} + ..)$$

Where: L_{TOT} is the total noise.

L_1 and L_2 are the two noise sources.

Sound-pressure meters built to American National Standard Institute (ANSI) specifications contain frequency-response weighting networks (designed A, B and C).

Reference: Mark S. Sanders and Ernest J. McCormick. Human Factors Engineering and Design. McGRAW-HILL, 7'TH Edition.

Each network electronically attenuates sound of certain frequencies and produces a weighted total sound-pressure level.

- The Occupational Safety and Health Administration (OSHA) standards for daily occupational noise limits (1974) has selected the A scale (dBA). This is because the A scale is the closest to approximating the response characteristics of the human ear.

PSYCHOPHYSICAL INDICES OF LOUDNESS OF THE SOUND:

The Phon and Sone

EXPERIMENT:

(1600 Hz pure tone at different sound-pressure levels "The reference sound")

Compared with various pure tones and let the subjects adjust intensity.

e.g.: 60-dB, 1000 Hz tone – 60 phons

Note: The phon does not tell us about the relative loudness but tells us about the subjective equality of various sounds.

ONE SONE: Is the loudness of 1000-Hz tone of 40 dB.

RELATIONSHIP BETWEEN PHONS AND SONES:

40 phons = 1 sone

50 phons = 2 sones

60 phons = 4 sones

70 phons = 8 sones

30 phons = 0.5 sone

20 phons = 0.25 sone

- Every 10 phons above 40 phons double the sones.
- 40-phon sound is 4 times as loud as a 20-phon sound.

Reference: Mark S. Sanders and Ernest J. McCormick. Human Factors Engineering and Design. McGRAW-HILL, 7'TH Edition.

EQUIVALENT SOUND LEVEL:

The Environment Protection Agency (1974) concluded that the long-term average sound level (L_{eq}) was the best measure for the magnitude of environmental noise.

Note: L_{eq} is constant and depends on the time interval and acoustic events occurring during that period.

NOISE AND LOSS OF HEARING: (Nerve Deafness and Conduction Deafness)

1. NERVE DEAFNESS: Usually results from damage or degeneration of the hair cells of the organ of Corti in the cochela of the ear. The nerve Deafness is typically uneven, being greater in the higher frequencies than in lower ones.

   e.g.: Normal deterioration of hearing through aging.
   Continuous exposure to high noise may cause Nerve Deafness.

2. CONDUCTION DEAFNESS: It is caused by some condition of the outer or middle ear that affects the transmission of sound waves to the inner ear.
   Conduction Deafness is more even across frequencies and does not result in complete hearing loss. It is only a partial loss because airborne sound waves strike the skull and are transmitted to the inner ear by conduction through the bones of the skull. This type of deafness can sometimes be arrested or even improved.
   - Hearing aids are more useful in this type (i.e. Conduction Deafness) than they are when deafness is caused by nerve damage.

MEASURING HEARING:

1. SIMPLE HEARING TESTS: These include a voice test, a whisper test, a coin-click test, etc.
   This test lacks the Standardization.

Reference: Mark S. Sanders and Ernest J. McCormick. Human Factors Engineering and Design. McGRAW-HILL, 7'TH Edition.

2. AUDIOMETER TEST: They are of two types:
    a. Reproduces through earphone, pure tones of different frequencies and intensities. Determine for each frequency tested the lowest intensity that can just barely be heard (i.e. threshold).
    b. Speech audiometer (Direct speech or a recording speech is reproduced to earphones or to a loudspeaker and intensity is controlled)

HEARING LOSS:

1. NONOCCUPATIONAL HEARING LOSS:
    a. Presbycusis: hearing loss due to normal aging
    b. Sociocusis: due to an occupational noise sources.
       e.g.: television, traffic…etc.

2. OCCUPATIONAL HEARING LOSS: The hearing loss from continuous exposure, over time, to a noise that is considered occupationally related.

- After exposure to continuous noise of sufficient intensity there is some temporary hearing loss which is covered a few hours or days after exposure. However, with additional exposure the amount of recovery gradually becomes less and less and the individual is left with some permanent loss.

Note: Temporary hearing loss however can also have serious consequences if a person depends on auditory information in the performance of a job or task.

3. TEMPORARY HEARING LOSS FROM CONTINUOUS NOISE:

- The measurement of hearing loss must take place at a fixed time after exposure to be comparable. Traditionally, this has been done 2 min. after the end of exposure.

- Any shift in threshold is called the temporary threshold shift at 2 min. (TTS_2).
- Some sound levels (called effective quiet) will not produce any measurable TTS_2 regardless of the duration (60-65 dBA).
- For 80-105 dBA; TTS_2 increases in the proportion to the Log of the sound-pressure level (SPL).
- Although both the Growth and Recovery of TTS_2 are proportional to the Log of Time, recovery takes longer time.
- The maximum TTS_2 is produced not at the frequency of the exposure noise, but at frequencies well above the exposure noise.

Note: TTS_2 depends on individual differences.

4. PERMANENT HEARING LOSS FROM CONTINUOUS NOISE:

- With repeated exposure to noise of sufficient intensity, a permanent threshold shift (PTS) will gradually appear.
- With further noise exposure, the hearing loss at 4000Hz continues and spread over a wider frequency range.

Note: It is widely accepted that average TTS from an 8-h exposure to noise in young, normal ears is similar in magnitude to the average permanent threshold shift found in workers after 10 to 20 years exposure to the same levels of noise.

5. HEARING LOSS FROM NONCONTINUOUS NOISE:

(Include Intermittence, but steady Impact noise, etc.)

- Heavy doses→ Hear loss

PHYSIOLOGICAL EFFECT OF NOISE:

IN SHORT TERM → a start to response characterized by muscle contractions, blink and a head jerk movement. In addition larger and slower breathing movements, small changes in heart rate and dilation of pupils occur. Also, a reduction in the diameter of blood vessels in the peripheral regions, particularly skin.

→ All these are transient and settle back to normal or near normal very quickly.

→ Repeated measures; diminishes the magnitude of response.

IN LONG TERM → Repeated Exposure → Stress

- Over 95 dBA of noise: Adverse effects on health.
  e.g.: Hypertension, gastrointestinal problems, complaints of headache, etc.

EFFECTS OF NOISE ON PERFORMANCE:

- They are not clear.
- With the possible exception of tasks that involve short-term memory, the level of noise required to obtain reliable performance effect is quite high (generally > 95 dBA).
- Performance of simple, routine tasks may show no effect and often will even show an improvement as a result of noise.
- The detrimental effects of noise are usually associated with tasks performed continuously without rest pauses and difficult tasks that place high demands on perceptual and/or information processing capacity.
- If task-related acoustic ones are present and noise masks them, a decrement may well result.

Note: The level of noise required to exert measurable degrading effects on performance is, with the exception of short-term memory tasks, considerably higher than the highest levels that are acceptable by other criteria, such as hearing loss and effects on speech communications. Thus the noise levels are kept within reasonable bounds in terms of, say, hearing loss considerations; the probabilities of serious effects on performance would be relatively nominal.

Reference: Mark S. Sanders and Ernest J. McCormick. Human Factors Engineering and Design. McGRAW-HILL, 7'TH Edition.

Noise Exposure Limit	Permissible Noise Exposure (OSHA)	
	L: Sound level dBA	T: Permissible Time*
e.g.: 95 dBA- 3.5 h	80	32
105 dBA- 0.5 h	85	16
85 dBA- 4.0 h	90	8
	95	4
	100	2
	105	1
	110	0.5
	115	0.25
	120*	0.125*
	125*	0.063*
	130*	0.031*

* $T=8/2^{(L-90)/5}$

$$\text{TWA} = 16.61\log\frac{D}{100} + 90$$

$$\text{Noise Dose} = 100\left(\frac{3.5}{4.0} + \frac{0.5}{1.0} + \frac{4.0}{16.0}\right) = 163.5 = \text{D}$$

$\Rightarrow$ Time Weighted Average (TWA) $\cong$ 93.5 dBA > 85 dBA

- OSHA $\rightarrow$ The TWA= 85 dBA, as the action level or the point at which employer must implement a continuing effective hearing conservation program. The program must include exposure monitoring, audiometric testing, hearing protection employee training and record keeping.
- OSHA $\rightarrow$ A noise dose of 100 percent (TWA=90dBA) is designated as the permissible exposure level or the point at which the employee must use feasible engineering and administrative controls to reduce noise exposure.

Reference: Mark S. Sanders and Ernest J. McCormick. Human Factors Engineering and Design. McGRAW-HILL, 7'TH Edition.

IMPULSE NOISE: a standard is available $\rightarrow$ see table below:

Peak sound-pressure level, dB P	Maximum number of impulses per 8 hours $10^{[16-(p/10)]}$
140	100
135	316
130	1,000
125	3,162
120	8,913
115	31,623
112.4	57,600

Source: Mark S. Sanders & Ernest J. McCormick.

INFRASONIC NOISE (< 20 Hz) There are no national or international standards for permissible exposure limits to infrasonic noise. Von Gierke and Nixon (1976) present a review of the effects of infrasound and conclude that it is not subjectively perceived and has no effect on performance, comfort, or general well-being. To protect the auditory system, however, they recommend 8-hours exposure limits ranging from 136 dB at 1 Hz to 123 dB at 20 Hz. If the level is increased 3 dB, then the permissible duration must be halved.

ULTRASONIC NOISE (> 20000 Hz):
Limit 110 dBA for frequencies $\geq$ 20000 Hz

THE ANNOYANCE OF NOISE: Annoyance $\neq$ Loudness
Loud noises are usually more annoying than soft noises but there are exceptions.

- It is measured by subjects rating noises on a verbal scale.

Reference: Mark S. Sanders and Ernest J. McCormick. Human Factors Engineering and Design. McGRAW-HILL, 7'TH Edition.

Some Factors That Influence The Annoyance Quality Of Noise

Acoustic factors	Nonacoustic factors
Sound level	Past experience with the noise
Frequency	Listener's activity
Duration	Predictability of noise occurrence
Spectral complexity	Necessity of the noise
Fluctuations in sound level	Listener's personality
Fluctuations in frequency	Attitudes toward the source of the noise
Risetime of the noise	Time of year
	Time of day
	Type of locale

- The day-night level (L_{dn}) is used by the Environmental Protection Agency to rate community exposure to noise:

  L_{dn}= $L_{eq24\ hours}$ + correction of 10 dB added to noise levels occurring in the night time (10 p.m. to 7 a.m.).

  Generally, a normalized L_{dn} of 55 dBA or lower will not result in complaints.

Note: It must be remembered, however, that these predictions are not precise, but rather are only rough indications of the probable community reaction.

HANDLING NOISE PROBLEM:

a. FIRST PHASE: Measuring the noise itself.
b. SECOND PHASE: Determine what noise level would be acceptable, in terms of hearing loss, annoyance, communications, etc.

NOISE CONTROL: A noise problem can be controlled by attacking the noise at the source, along its path, from the source to the receiver and at the receiver.

CONTROL AT THE SOURCE:

- Maintenance
- Isolation
- Quieter equipment selection

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CONTROL ALONG THE PATH:

- High frequency noise is more directional than low frequency noise and is more easily contained and deflected by barriers.

  (e.g.: Full enclosures are not necessary to reduce high frequency noise. A single wall, shield or barrier placed between source and receiver will deflect much of this noise).
- Adding sound absorption materials to walls.

CONTROL AT THE RECEIVER:

- Use of hearing protection (e.g.: hearing protection devices: Insert type or muffle type)
- Audiometric testing $\rightarrow$ Reduce exposure times for those showing signs

HEARING PROTECTION & SPEECH COMMUNICATION:

They affect communications.