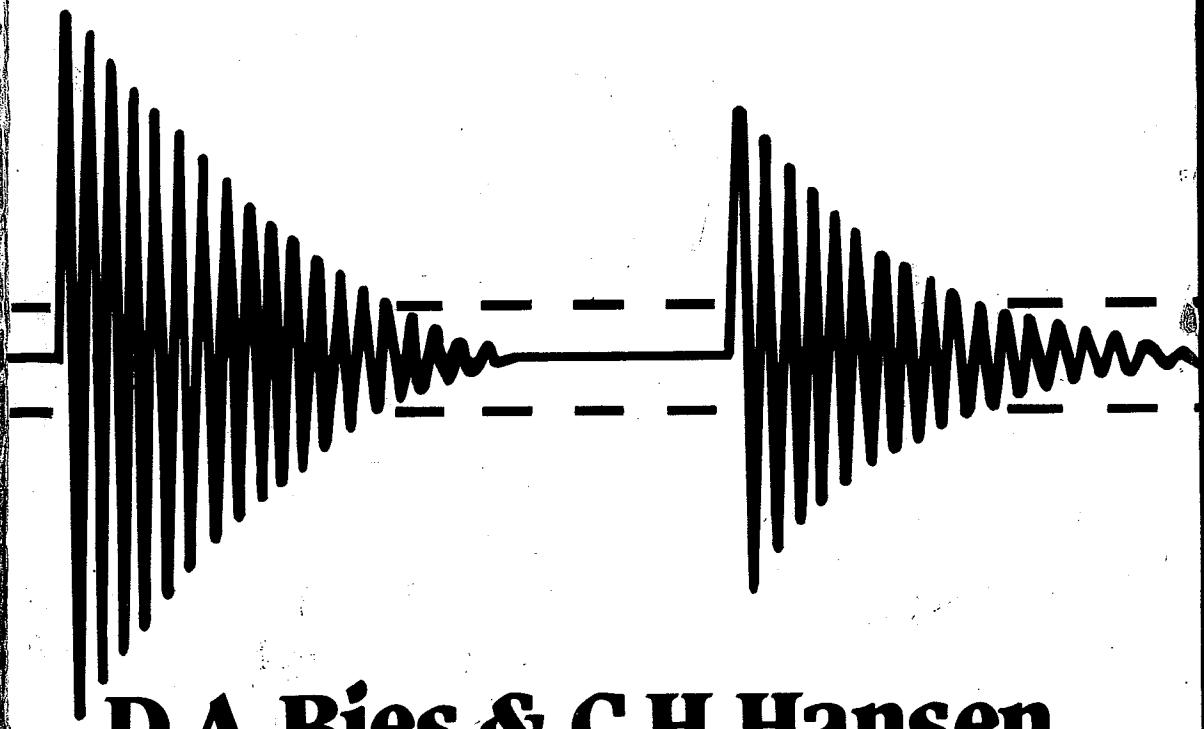
ENGINEERING NOISE CONTROL



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characteristically complains that all he can hear is noise. This, in fact, is the best that the hearing aid will ever do for such an unfortunate person.

2.2 Subjective response to sound pressure level

The foregoing description of the ear has been presented in an attempt to inspire respect on the one hand, and to provide a basis for understanding the limitations of the ear on the other, as they are manifested in the subjective response of people to noise. The former is meant to augment motivation while the latter is meant to provide a kind of mnemonic device for keeping track of the various seemingly rather arbitrary rules-of-thumb describing subjective response. It is the subjective response of people to sound, rather than direct physical damage to their hearing, which determines the standard to which any proposed noise control must be compared, and which will determine the relative success of the effort. For these reasons we now consider the subjective response of people to sound, determined as means of large samples of the human population (Moore 1982). The quantities of concern are loudness and pitch. Sound quality, which is concerned with spectral energy distribution, will not be considered.

2.2.1 *Loudness*

If we consider a single fixed frequency or a narrow band of noise containing all frequencies within some specified and fixed narrow range of frequencies within the audio-frequency range, we may investigate the subjective response of a group of normal subjects to variation in sound pressure. In the mid-frequency range at sound pressures greater than about 2×10^{-3} Pa (40 dB *re* 20 μPa *SPL*), Table 2.1 summarizes the results which have been obtained. Note that a reduction in sound power of 50% results in a reduction of 3 dB and is just perceptible to the normal ear.

The consequence for noise control of the information (Stevens 1957, 1972, Zwicker 1958, Zwicker & Scharf 1965) contained in Table 2.1 is of interest

Table 2.1 Subjective effect of changes in sound pressure level.

Change in sound level (dB)	Change in power		Change in apparent loudness
	Decrease	Increase	
3	1/2	2	just perceptible
5	1/3	3	clearly noticeable
10	1/10	10	half or twice as loud
20	1/100	100	much quieter or louder

Given a group of noise sources all producing the same amount of noise, their number would have to be reduced by a factor of ten in order to achieve a reduction in apparent loudness of one half. To decrease the apparent loudness by half again, that is to one quarter of its original subjectively judged loudness, would require a further reduction of sources by another factor of ten. Alternatively, if one started with one trombone player behind a screen and subsequently added 99 more players, all doing their best, an audience out in front of the screen would conclude that the loudness had increased by a factor of four. The advertisement claiming 90% reduction in noise is written by the uninformed for the ignorant.

An impaired ear may suffer an effect called recruitment, in which the apparent dynamic range of the sufferer is greatly compressed. While the sufferer's threshold has been raised, his tolerance for loud sounds has been sharply reduced, and tolerable audition is thus confined to a narrow range of "loud enough but not too loud". Interestingly, such a person can readily detect small changes in sound pressure; Table 2.1 does not apply to a person with recruitment. For example, an increase or decrease in sound power of about 10%, rather than 50% as in the table, could be just perceptible to such a person.

Exposure to loud noise for an extended period of time will produce effects such as recruitment as described above. The exposure impairs the function of the hair cells, which with time and rest may recover if the exposure has not been too extreme. However, with relentless exposure, the damage to the hair cells will be permanent and recruitment may be the lot of their owner. As a matter of interest, the outer hair cells are more sensitive to excessive noise than are the inner hair cells, which apparently determine one's auditory threshold. Thus outer hair cell destruction can be well under way before a significant shift in auditory threshold is noticed. A person with such damage may then have the experience of enjoying seemingly reasonable hearing and yet be unable to understand conversation in a noisy environment.

2.2.2 *Loudness levels in phons*

We have considered variation in level of a single fixed tone or narrow band of frequencies, and a person's response to that variation. We now consider the comparison of two sounds of different frequency content. The experiment has been carried out, using many young people with undamaged normal ears, in which a 1 kHz tone was used as a reference, and a second tone compared with it. The subject was placed in a free field with the sound frontally incident. After the subject had adjusted the second tone so that, subjectively, it seemed equally loud as the 1 kHz tone, the sound pressure of the variable tone was recorded. A map based on mean lines through the resulting data is shown in Figure 2.5. It is evident from the figure that the