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Reduction in the Loudness of a 250-Cycle Tone in One Ear Following the Introduction of a Thermal Noise in the Opposite Ear

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Under certain conditions, the perception of a given sound stimulus in one ear may be altered when a different sound is presented to the opposite ear. For instance, changing an observer's perception of the loudness of a sound presented by an earphone to one ear by introducing a dissimilar sound in the opposite ear has been reported in the literature. Egan (1948), using two subjects, found that the loudness of speech delivered to one ear only was nearly 7 db louder than when a 70 to 80 db sensation level thermal noise was introduced into the opposite ear. A possible explanation of the increase in loudness, according to Egan, may be that there is a sort of summation because of the similarity between the temporal and frequency characteristics of thermal noise and speech. In seeming contrast, Bekesy and Rosenblith (1951) have stated that a loud high frequency pure tone delivered to one ear will reduce the loudness of a low frequency tone in the opposite ear between five and ten db. According to these writers this reduction in loudness can be attributed to the acoustic reflex.

The acoustic reflex refers to the contraction of one or both of the two muscles in the middle ear. These muscles, the tensor tympani and the stapedius, are known to contract during the period when the ear or ears are subjected to high acoustic stimulation. Also known is the fact that this reflex mechanism is bilateral, that is, when a sound of sufficient strength to ellicit contraction of the middle ear muscles is presented to one ear only, the muscles of the opposite ear will also contract.

According to Metz (1951) the bulk of evidence now available suggests that the contraction of the middle ear muscle stiffens the transmission system of the middle ear. The result of this increased stiffness is to increase the normal acoustic impedance of the ear for low frequencies, thus attenuating the transfer of energy from the eardrum to the oval window. Frequencies above 1000 cycles seem not to be attenuated at all, or, as in the case of the guniea pig, (Wiggers, 1937) tones between 1300 and 1800 cycles are actually transmitted with greater efficiency, i.e., the threshold for these frequencies is actually reduced.

The relationships which may exist between sound intensity, sound perception, and the acoustic reflex are still rather vague. Several approaches are possible which have been used in an attempt to quantify the effectiveness of the acoustic reflex in certain individuals. For instance, if the middle ear muscles of one ear function normally but in the other ear do no function at all, then the loudness of two equally intense low frequency sounds should be different for the two ears, assuming the acoustic reflex is actually capable of attenuating low frequency tones. In line with this approach, Perlman (1938) reported a case involving a temporary unilateral facial paralysis which was accompanied by a loudness imbalance between the two ears. The patient perceived tones of 128 to 2000 cycles presented at intensities above 60 db as being louder in the ear on the affected side. Perlman attributed this increased loudness to the paralysis of the middle ear muscles of the ear on the affected side. The paralysis, according to Perlman, negated the protective function of the middle ear muscles for those frequencies. In making a loudness balance, the patient equated an 85 db tone on the affected side to a 95 db tone on the unaffected side. Cochlear function for both ears at these frequencies was believed by Perlman to be essentially equal for upon return of normal functioning of the facial and (presumably) middle ear muscles, the loudness imbalance disappeared.

If paralysis of the intra-tympanic muscles allows a tone to sound louder, contraction should reduce loudness. Some individuals are reportedly able to voluntarily contract these muscles and in this way raise their normal threshold for certain pure tones. An example of this approach has been reported by Smith (1943). He published an account of an army officer who asserted he could voluntarily contract his tensor tympani. Two threshold curves were obtained, one with and one without voluntary contraction. A maximum threshold shift of 35 db at 128 cycles was observed, with a decreasing shift as the frequency increased. At 2,000 cycles there was no difference in the threshold, but at 4,000 cycles there was again a threshold shift of 15 to 20 db resulting from a reduced loudness effect.

In contrast to the methods involving abnormally functioning muscles of the middle ear, Metz (1946) used an acoustic bridge to measure the change in impedance at the eardrum of one ear when a noise was introduced in the opposite ear. The change observed was presumably caused by the contraction of the tensor tympani in a normal acoustic reflex. Metz calculated that the change in absorption of sound under these conditions was around five db.

In the process of checking the performance of an audiometer, this writer observed that the loudness of a 250 cycle tone at an 80 db sensation level seemed markedly reduced when the masking noise available in the audiometer was suddenly introduced, also at an 80 db sensation level, in the opposite ear. The reduction in loudness was so dramatic the writer's first reaction was that a defect in the audiometer caused tone output level to drop when the masking noise circuit was turned on. A check of the tone output with and without the noise circuit turned on revealed the tone output to be constant. The apparent change in loudness of the tone definitely exceeded the five to ten db value Bekesy reported in connection with a low tone in one ear and a high tone in the opposite. On the other hand, the possibility of a greater change in loudness when noise is used might be inferred from Metz (1946) who reported that the reflexive contraction is more easily elicited by noise than by pure tones. This argument assumes, of course, that whatever the magnitude of the change in loudness under these conditions, the change is primarily the result of the acoustic reflex.

Regardless of the mechanism involved, the loudness shifts of a tone in one ear when a noise is introduced in the opposite seem not to be satisfactorily quantified in the literature. On the assumption that the shift in loudness which the writer observed could also be observed by others, the following investigation was carried out in May, 1953.

A technique similar to that used by Egan (1948) in his experiment with speech and noise was used in an attempt to quantify the observed loudness change in a pure tone for 30 observers. A 250 cycle tone at a 90 db sensation level was introduced by phone into the right ear of each observer. Two seconds following the introduction of this tone a thermal noise was introduced by phone into the left ear, this also at a 90 db sensation level. For every subject in this experiment, the introduction of the noise in one ear was followed by a reduction in the loudness of the tone in the opposite ear. Of the thirty listeners, five were experienced listeners in hearing experiments, and these five reported that the reduction in loudness was observed to require noticeably more time to manifest itself than is the case when a tone in one ear is suddenly masked by a noise in the same ear. These subjective impressions seem to lend credence to the possibility that a muscular reflex latency time is involved. The observers were given five seconds to note the reduced loudness of the tone while the noise was being delivered to the opposite ear. The noise stimulus was then terminated suddenly. Invariably the loudness of the tone would begin to increase. If no adjustments in the equipment were made, the loudness would return to the original level, not instantly, but gradually over a period of two to four seconds. The observer was instructed to attenuate the sound during this period of loudness growth by means of a continuously variable attenuator with an unmarked dial. He attenuated the tone in an attempt to maintain the loudness which seemed to him to be equal to the loudness observed during the presentation of the noise in the left ear. The investigator recorded the attenuation in db introduced by the subject as indicated on a separate calibrated dial attached to the shaft of the subject's attenuator but kept from his view. The subject was then given a 15 second silent period before the cycle was repeated.

In order to reduce the position cues for the observer, an additional attenuator operated by the investigator was adjusted so that from zero to five db attenuation was automatically introduced immediately following cessation of the noise signal. This forced the observer to turn his attenuator different amounts from one time to the next in order to obtain equal total attenuation.

The results of this experiment are shown in Table 1. The mean shifts for 30 observations ranged from 7.4 db for Subject 8 to 26.8 for Subject 10. The standard deviations of the observers ranged from 0.86 db to 4.56 db. The overall mean shift for the 900 judgments was 15.1 db with a standard deviation of 5.57 db. Although each subject seemed fairly consistent in his own judgments, considerable intersubject variability is apparent. Several reasons might be suggested for this variability:

1. Comparisons were sometimes made on the basis of pitch rather than loudness since some observers in this investigation reported that the pitch of the pure tone changed during the presentation of the noise. For some observers a different amount of attenuation is required for pitch matches than for loudness matches.

2. The loudness shift may be a function of intensity level rather than sensation level. Since the threshold of detectibility for the

Table 1

The mean shift and standard deviation in db based on thirty judgments by each subject in this study

Subject	Mean Shift	Standard Deviation
1	19.98	2.10
2	12.31	1.37
3	15.39	1.37
4	10.36	1.67
5	12.71	2.58
6	11.56	1.20
7	23.27	1.47
8	7.42	0.86
9	8.91	3.18
10	26.77	4.41
11	10.89	3.01
12	14.04	2.75
13	16.12	2.59
14	22.14	3.33
15	13.09	2.80
16	25.77	4.56
17	15.80	2.71
18	18.73	3.14
19	12.76	2.55
20	11.86	1.99
21	18.73	3.16
22	15.77	1.25
23	15.33	2.62
24	10.55	1.25
25	10.37	2.15
26	12.87	1.83
27	17.19	2.94
28	14.07	2.41
29	8.18	2.71
30	19.41	1.96

stimuli varied somewhat from subject to subject, so also did the intensity of the sound at a 90 db sensation level. These differences in intensity levels may have influenced the observed loudness shift.

3. The ability of the acoustic reflex to attenuate a 250 cycle tone may vary widely from person to person.

A question to consider is whether or not a 90 db noise in one ear is likely to mask by cross-hearing the loudness of a tone in the opposite ear. Bekesy (1948) has pointed out that there is an energy loss of about 50 db from one ear to the other when a conventional headband and rubber cushioned headphones are used. Thus with 90 db noise in one ear, a 40 db noise level may be expected in the opposite ear, assuming equally acute ears. But according to Hawkins and Stevens (1950) a 40 db sensation level noise in one ear masks a 90 db 250 cycle tone in the same ear only about 4 db. Therefore it seems likely that at least 11 db of the observed mean shift in this investigation must be due to factors other than peripheral masking. An eleven db shift seems to be in line with the loudness imbalance reported by Perlman for the patient with unilateral facial paralysis.

Perhaps the most interesting aspect of this investigation is the variability of the mean shifts among the 30 observers. Although subject differences are to be expected, the 19 db range in mean shifts seems rather large for 30 college students having essentially normal hearing. The mean shifts of 20 db or more found in this study suggest strongly that the middle ear muscles may provide for some human ears considerable protection against noise of the type used in this investigation, assuming that a reduction in loudness is a useful measure of protection. It seems possible that the procedure outlined herein may be useful in determining a person's relative resistance to loud noises of the broad band continuous type. Further investigation now under way may lead to an evaluation of this and similar techniques as possible noise susceptibility tests.

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