The Effect of Sound Intensity Level on Judgment of "Tonal Range" and "Volume Level"

STEPHEN E. STUNTZ*

A discussion of the wide variety of factors which influence the conclusions derived from listener preference tests.

For many years we have been aware that changes in the physical intensity of sounds are accompanied by changes in the subjective dimension which we call *loudness*. We also know that for the normal human listener these two quantities are not always linearly related. This becomes apparent when we stimulate the ear with pure tones at various frequencies, over a range of intensity-level. *Figure* 1 will illustrate this point. Here the data of Fletcher and Munson[1] are displayed in a form enabling us to make direct comparisons between the loudness of a given frequency at several intensity-levels, or between the loudness of several frequencies at a single intensity-level. The scaling of the psychological dimension, loudness, in this figure follows the recommendations of the American Standards Association Committee on Acoustical Measurements and Terminology[2]; the term "sone" is applied to the unit of loudness measurement according to a suggestion by Stevens.[3] Intensity-level is referred to the acoustical standard of 10^{-16} watt per cm^2.

*Research Psychologist U.S.N. Medical Research Laboratory U.S.N. Submarine Base, New London, Conn.

[1] H. Fletcher and W. A. Munson. Loudness, its definition, measurement and calculation. *J. Acous. Soc. Am. 5*, 2, 82, 1933.

Opinions and conclusions expressed in this paper are the author's own and do not reflect policies of the United States Navy.

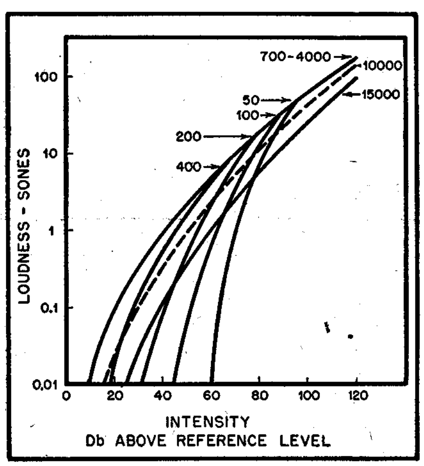

Fig. 1. The loudness function, showing how sound intensity-level (reference 10^{-16} watt/cm^2) affects the loudness of pure tones at different frequencies in the useful auditory spectrum. Frequency is shown as parameter.

The curves shown here depict the growth of sensation magnitude with signal intensity, at a variety of frequencies.

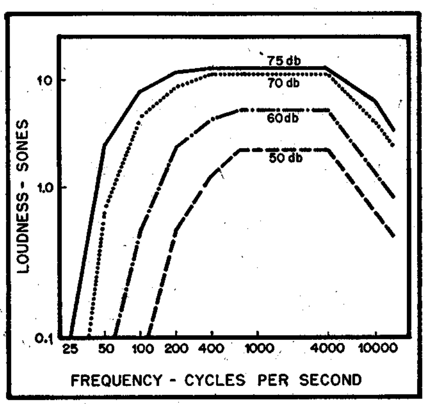

Fig. 2. An interpretation of the loudness function, showing how the over-all frequency-response of normal human hearing varies with the intensity-level of sound. Intensity-level is the parameter.

They characterize the reactions of an average listener over the greater portion of the useful auditory spectrum. Several details are worth special attention: first, that although the growth of loudness is far more rapid at low (those below 200 cps) than at high frequencies for ordinary intensity-levels, much greater intensity of sound is required at the low frequencies to initiate any sensation at all. Second, the rate of growth is not uniform for all frequencies until an intensity-level is reached approaching the threshold of feeling, that is, non-auditory sensation. Third, the loudness of frequencies in the range 700 to 4000 cps seems to be affected by intensity changes least of all. It will be recalled that the normal human ear is most sensitive to this portion of the spectrum, often called the "middle range." Fourth and last, loudness shifts at the higher frequencies (around 10,000 cps), those with which we are often concerned in "high-fidelity" sound reproduction, are not greatly different from those of the middle frequencies. In summation, these curves suggest that the ear's frequency response is to a considerable extent directly influenced by the intensity of stimulating sounds.

[2] Proposed standards for noise measurement. *J. Acous. Soc. Am. 5*, 2, 109, 1933.

[3] S. S. Stevens. A scale for the measurement of a psychological magnitude: loudness. *Psychol. Rev. 43*, 405, 1936.

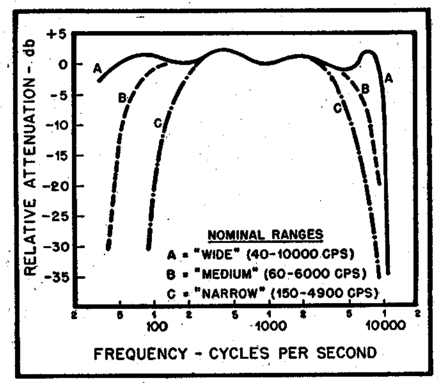

Fig. 3. Response characteristics of Eisenberg and Chinn's electrical system, exclusive of loudspeaker, used in their study of preference for "tonal range" and "volume level." (Reproduced from the Journal of Experimental Psychology, 1945, by permission of that Journal and of the American Psychological Association.)

Let us review this conclusion in more conventional terms. *Figure* 2, based on the same data as *Fig.* 1, shows directly how variations of intensity affect what might be called the normal listener's frequency response. The four intensity levels shown as parameters—50, 60, 70, and 75 db—were chosen on the basis of some experimental data which will be discussed subsequently. The implications of this figure are of considerable interest to the audio engineer. For one thing, the ear does not behave like the usual electroacoustic transducer, whose frequency response remains relatively unchanged over a range of intensities limited at the upper extreme by the onset of overloading. In this connection, it is noteworthy that the 75-db intensity level is far below the ear's overload limit. Therefore, we cannot say that the apparent broadening of the flat top of the curve is necessarily related to overexcitation of the auditory mechanism. Another point of importance is that when we raise signal intensity from 50 db to 75 db, we effectively add to the listener's range at 1 sone, or 1000 millisones, loudness, something over three octaves downward from 400 cps. Put another way, by raising the intensity-level from 50 db to 75 db, we render a 125-cps tone over 90 times louder for the average listener. By either statement, it is evident that a tremendous improvement of the ear's effective bass response follows a rise in over-all signal intensity. To a somewhat lesser extent, the same is true at the treble end of the spectrum, as these curves suggest. It is expected that the 50-db contour, if extended, would intersect the 100 millisone (0.1 sone) loudness ordinate just below 20,000 cps, or near the upper frequency limit of normal hearing.

Listener Preferences

Recently a number of experimenters have investigated the preference of listeners for various conditions of frequency range and intensity-level in the reproduction of music and speech. Of the several studies reported, the most extensively documented appear to be Eisenberg and Chinn's[4] and Olson's.[5] In both of these experiments, it will be recalled, listeners were required to compare consecutive passages of musical selections played through adjustable frequency filters. In Eisenberg and Chinn's study, electrical filters were employed restricting the range at both ends simultaneously. *Figure* 3 shows the three band-pass characteristics upon which their listeners based judgments of "tonal range" preference. The authors note that these curves apply only to the electrical portions of their apparatus; in discussing their results, they imply that these curves also represent conditions in the acoustical field surrounding their listeners. It will also be recalled that Eisenberg and Chinn studied preference for program intensity-level, choosing 50, 60, and 70 db as the three values for comparison. In one series of subexperiments, these three intensity-levels were combined with the three frequency passbands already described, and the listeners asked to state preference for the resultant condition of both "tonal range" and "volume level." As we have already seen, when a sufficient change in signal intensity occurs listeners will report an apparent change in frequency range even though no physical control of passband has been imposed. Now in the measurement of preferences, it is important that the conditions serving as bases for judgment be clearly discriminable to the average observer. If the differences between them be discernible only by chance, then the observer is plainly handicapped in stating his preference with certainty. Keeping this in mind, then, let us look at the effects of Eisenberg and Chinn's filters upon the auditory spectrum as perceived by an average observer under the three intensity-levels used. Returning to *Fig.* 2, we can estimate from the 50, 60, and 70 db curves the perceptual results of sound transmission through a system nominally flat from 40 to 10,000 cps, corresponding to the "wide tonal range" of these experiments. *Figure* 4 shows the subjective effect of the "medium-tonal-range," that is, 60 to 6,000 cps, filtering; it will be noted that only at the "high volume level" do the restrictions at both high and low ends become noticeable. At the two lower levels, the observer would be expected to report mainly a change in highs as a result of filtering, but a variation of both lows and highs would be reported as a result of the changes in level. *Figure* 5, showing the effects of "narrow-range," that is, 150 to 4,900 cps, filtering, suggests an opposite conclusion: here the greatest perceived differences occur at the low-frequency end as level is varied. Restriction at the high end is so severe that raising level from 50 to 70 db expands subjective frequency range hardly more than half an octave upward at 1 sone loudness. *Figures* 2, 4 and 5 indicate that a growth in the perceived range of frequencies probably occurred independently of the bandpass controls imposed by means of filters.

In *Figs.* 6, 7 and 8 we can see the effects of filtering at any one of the three intensity-levels. *Figure* 6 suggests that at "high-volume level" the average listener would experience little difficulty discerning the shift from "wide" to "narrow" ranges, that is, from band A to band C. Likewise, the shift from "medium" to "narrow", band B to band C, probably would be easily detected. However, in comparisons of "wide" with "medium", that is, "A" with "B", discrimination is likely to be uncertain, yielding statements of preference not acceptably reliable. *Figure* 7 shows an aggravation of this difficulty, brought about by reducing intensity-level to 60 db. Here the three bands become more easily confused, although discrimination of "wide" (A) from "narrow" (C) might still be accomplished with better than chance success. *Figure* 8 presents a pic-

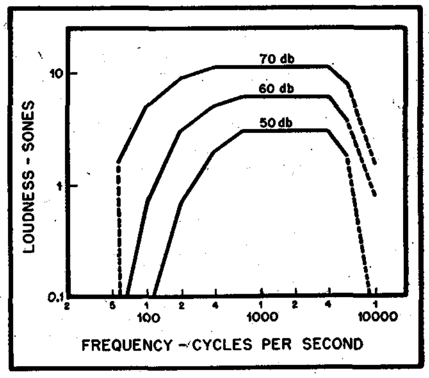

Fig. 4. Subjective effect of Eisenberg and Chinn's "medium tonal range" filters at "high" (70-db), "moderate" (60-db), and "low" (50-db) volume levels. Broken lines indicate cutoff effect of filters. Note the apparent ineffectiveness of high-pass filters at 50 and 60 db.

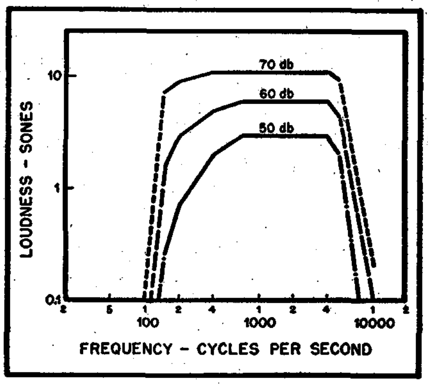

Fig. 5. Subjective effect of Eisenberg and Chinn's "narrow tonal range" filters at "high" (70-db), "moderate" (60-db) and "low" (50-db) volume levels. Broken lines indicate cutoff effect of filters. Note relative ineffectiveness of high-pass filter at 50 db, and slight effect on subjective bandwidth at high end caused by change in intensity-levels.

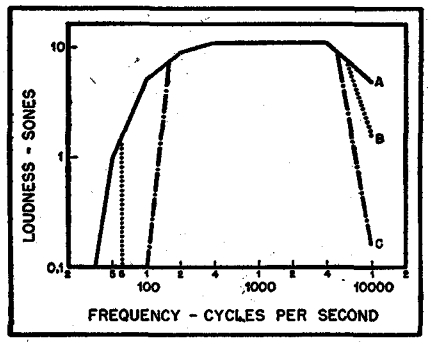

Fig. 6. Subjective effect of Eisenberg and Chinn's "wide," "medium" and "narrow tonal range" filters at 70-db intensity-level ("high volume level"). Broken lines indicate cutoff effect of filters.

[4] P. Eisenberg and H. A. Chinn. Tonal range and volume level preferences of broadcast listeners. *J. Exp. Psychol.* 35, 5, 374, October 1945.

[5] H. F. Olson. Frequency range preferences for speech and music. *J. Acous. Soc. Am.* 19, 4, 549, July 1947.

ture of potential confusion bordering on chaos. Here, at 50 db intensity-level, differential effects of high-pass filtering have almost disappeared. Any discrimination among the three bands must be made on the basis of changes at the high end alone. Since there is relatively little difference between "narrow" (C) and "medium" (B) for the listener (perhaps one-third of an octave above 5,000 cps at 1 sone loudness), we would anticipate largely unreliable judgments of preference for one or the other. However, the subjective difference between "wide" (A) and "narrow" (C) is more evident, and likely would produce more satisfactory indications of preference.

In the experiments conducted by Olson, intensity-level was maintained at 75 db throughout, and but two frequency-range conditions were compared—unrestricted bandwidth, and a nominal 5,000 cps low-pass. *Figure* 9 shows the physical effect of the frequency-range controls imposed in this experiment, while *Fig.* 10 represents the subjective effect of these controls. Observe that at the high frequency end this curve compares favorably with that for Eisenberg and Chinn's "narrow range" at 70 db (*Fig.* 6, curve C), while the curve representing the effect of Olson's unrestricted condition closely resembles Eisenberg and Chinn's "wide-range" curve at "high volume level" (*Fig.* 2, 70 db). From these observations we might infer that as far as the high-frequency end of the range is concerned, there was little difference between the discrimination task presented Olson's listeners and that confronting Eisenberg and Chinn's. Also, we may predict that Olson's two passbands should be easily discriminable on the basis of their subjective differences, and therefore give rise to highly reliable estimates of preference for one or the other.

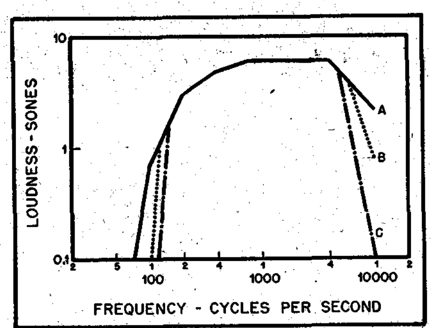

Fig. 7. Subjective effect of Eisenberg and Chinn's "wide," "medium" and "narrow tonal range" filters at 60-db intensity-level ("moderate volume level"). Broken lines indicate cutoff effect of filters.

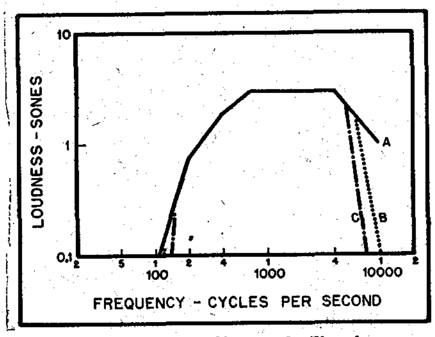

Fig. 8. Subjective effect of Eisenberg and Chinn's "wide," "medium" and "narrow tonal range" filters at 50-db intensity-level ("low volume level"). Broken lines indicate cutoff effect of filters.

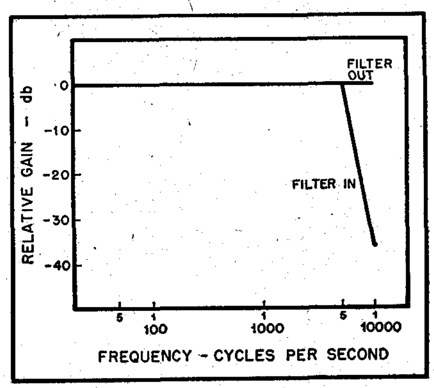

Fig. 9. Approximate response characteristic of acoustical filter system used in Olson's study of preference for frequency range, showing acoustical cutoff of "5000-cps" low-pass filter.

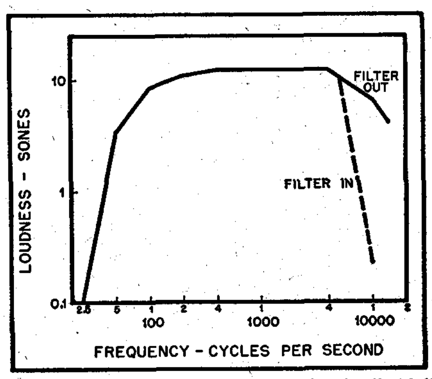

Fig. 10. Subjective effect of Olson's "wide" and "narrow frequency range" filters at 75-db intensity-level. Broken line shows cutoff effect due to filter. Note similarity between this low-pass cutoff effect and that of Eisenberg and Chinn's "narrow tonal range" at "high volume level" (70-db curve, Fig. 5).

Analysis of Tests

The published results of the two studies cited here have been analyzed for the purpose of estimating the reliability of preferences indicated by the listeners. The results of this analysis are shown in Table I. Only the preferences of the "cross-section", or unspecialized, listeners are treated, on the grounds that they are more representative of the general population than would be the judgments of, say, professional musicians, high-fidelity enthusiasts, audio engineers, or other specialists. This table summarizes only the testing in which music was used. It lists the preference-statements of whose occurrence we can be reasonably sure 99 or more times out of 100 (".01 level of confidence"). Eisenberg and Chinn's preferred combinations of "tonal range" and "volume level" appear in the left-hand columns. From their results as here interpreted, there emerge two facts of considerable importance. First, out of the twenty combinations of band-pass filtering, intensity-level, and musical content which their listeners were asked to evaluate, only the nine shown here appear to have produced adequately reliable statements of preference. This suggests that in the remaining eleven, judgment was complicated by inadequate discriminability of the conditions offered for comparison, due either to the effects of combining frequency-range and intensity-level, or to failure of the musical samples to sufficiently occupy the portions of spectrum studied.[6] The second important point is indicated by the asterisks appearing in the left-hand column of the upper table. Five out of nine of the reliably preferred combinations yield passbands which are subjectively broader than their non-preferred counterparts, although by *physical* definition they are narrower. To some extent, the authors may have been aware of this apparent anomaly, for they conclude that "the most reliable judgments were made when both tonal range and volume level were varied."[7] However, the findings reported here strongly suggest that their prime conclusion, "listeners prefer either a narrow or medium tonal range to a wide one,"[8] may deserve careful reviewing. Submitting the results of Olson to similar analysis, we do not find evidence of such contaminating factors. (Table I) Evidently the passbands and intensity-level used so unequivocally structured the judgmental situation, and were so occupied by the spectra of the musical samples chosen, that his listeners could make their choices relatively unhampered by doubt. All of the judgments rendered by his unselected listeners meet the criterion for reliability, and definitely favor wide-passband transmission over narrow.

If the preceding arguments be ac-

[*Continued on page 26*]

[6] In designing tests of this sort, one must be aware that a mere statement of the range of frequencies which his apparatus will transmit is insufficient evidence that this range was actually occupied by the sound on which the listeners had to base their preferences. Neither of the studies reviewed in this paper makes any direct mention of the frequency content of the program material used. Some sort of spectral analysis is plainly required in order to demonstrate the physical effect of the frequency-restricting controls imposed.

[7] *Ibid.*, p. 390.

[8] *Loc. cit.*

 [*from page 28*]

TABLE I

Tonal Range/Volume Level Preferences Significant at or Above .01 Level of Confidence

From data of Eisenberg and Chinn (1945): unselected listeners

PREFERRED COMBINATION

TONAL RANGE	VOLUME LEVEL	TONAL RANGE	VOLUME LEVEL	MUSIC TYPE
* Narrow	Moderate	Wide	Low	Classical
Narrow	Moderate	Wide	High	Classical
Narrow	Moderate	Wide	High	Popular
Narrow	Moderate	Wide	High	Light Classical
* Narrow	High	Wide	Moderate	Classical
* Wide	Moderate	Wide	Low	Classical
* Narrow	Moderate	Narrow	Low	Classical
* Wide	High	Wide	Moderate	Classical
Narrow	Moderate	Narrow	High	Classical

* Range-level combination which gives subjectively greater frequency passband than non-preferred combination.

From data of Olson (1947). Unselected listeners

PREFERRED FREQUENCY RANGE	TYPE OF MUSIC
Wide	Popular
Wide	Semiclassical

ceptable, then we may postulate a considerable similarity between the results of Eisenberg and Chinn and those of Olson. This similarity would be even more apparent, we might predict, had certain of the physical controls of Eisenberg and Chinn been more rigorously applied.

Addendum

It is often observed that the disagreement between Olson's and Eisenberg and Chinn's results is due to a possible inherent difference between listening to music transmitted acoustically direct from its original source and listening to the same sounds played through a reproducing system. Up to now this criticism has been offered without empirical support, indicating a gap of crucial significance in the case for wide-range sound reproduction. A research group headed by H. F. Olson at the Princeton laboratories of RCA is currently collecting data to determine whether listeners' preerences based on directly transmitted sound are comparable to those based on reproduced sound.