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# EFFECTS OF PEAKS IN HEARING AID FREQUENCY RESPONSE CURVES ON COMFORTABLE LISTENING LEVELS OF NORMAL HEARING SUBJECTS

**DENIS BYRNE, RUDI CHRISTEN AND HARVEY DILLON**

National Acoustic Laboratories
5 Hickson Road
Sydney

**ABSTRACT**

For normal hearing subjects, MCLs were measured for speech presented through an amplifying system having a smooth frequency response and for 12 conditions in which a peak was added to the base response. Low, mid, and high frequency peaks were tested for 4 bandwidths ranging from one twenty-third of an octave to over one octave. All peak conditions caused a reduction in MCL, relative to the smooth response condition. The amounts of reduction agreed closely with predictions based on Zwicker's loudness model. The presence of peaks in a hearing aid frequency response curve would result in less signal being delivered than for a smooth response, when the hearing aid volume control has been set for comfortable listening. This is consistent with research which shows that peaks adversely affect speech intelligibility and supports the view that response curves should be made as smooth as possible.

The frequency response curves of hearing aids typically show a number of distinct peaks. The existence of such peaks has always been regarded as being undesirable. This is supported by studies which show that irregularity of frequency response (i.e., the extent to which peaks and troughs are present) is negatively correlated with speech intelligibility (Jerger and Thelin, 1968; Smaldino, 1979).

One of the alleged effects of peaks concerns listening comfort, specifically the level of overall gain, as indicated by some kind of average, which will be preferred for listening with a hearing aid in everyday life. It has been held that less overall gain will be acceptable if an aid has a peaky rather than a smooth response (e.g., Villchur, 1978; Millin, 1978). Indeed, this is one of the original rationales (and probably the most justifiable one) for selecting the aid which results in the lowest speech reception threshold when several aids, all adjusted for comfortable listening, are compared (Davis, Stevens & Nicholls, 1947). Although the above mentioned effect seems generally accepted, we are aware of only one study (Martin, 1978) which has tested it directly and the conclusion of that study was that the presence of peaks did not significantly affect the preferred listening levels.

In this article we shall report a series of studies which systematically examine the effects of peaks, superimposed on a base frequency response, on most comfortable loudness level (MCL). These experiments are part of a larger series designed to investigate the effect of frequency response variations on comfortable listening levels.

## EXPERIMENTAL PROCEDURES

### General Description

Four experiments were performed using the same procedure except for the differences which are noted below. In each experiment, MCLs were measured for continuous speech presented through an amplifying system with a reference, broad band, frequency response (bandwidth approximately 0.2 to 5kHz) and for three other conditions in which a peak was added to the reference response. For the three 'peak' conditions of experiments 2, 3 and 4, the centre frequency of the peak was 0.4 kHz, 1 kHz or 2.5kHz. The latter two frequencies were selected as being typical of the position of peaks in hearing aids and 0.4 kHz was included to investigate the effects of low frequency peaks. The reference frequency response was that indicated by the National Acoustic Laboratories' (NAL) selection procedure (Byrne & Tonisson, 1976) for a flat (i.e. uniform) hearing threshold level, except that it was adjusted to allow for differences between the long term rms spectrum of the speech which was used, and the average spectrum on which the procedure is calculated.

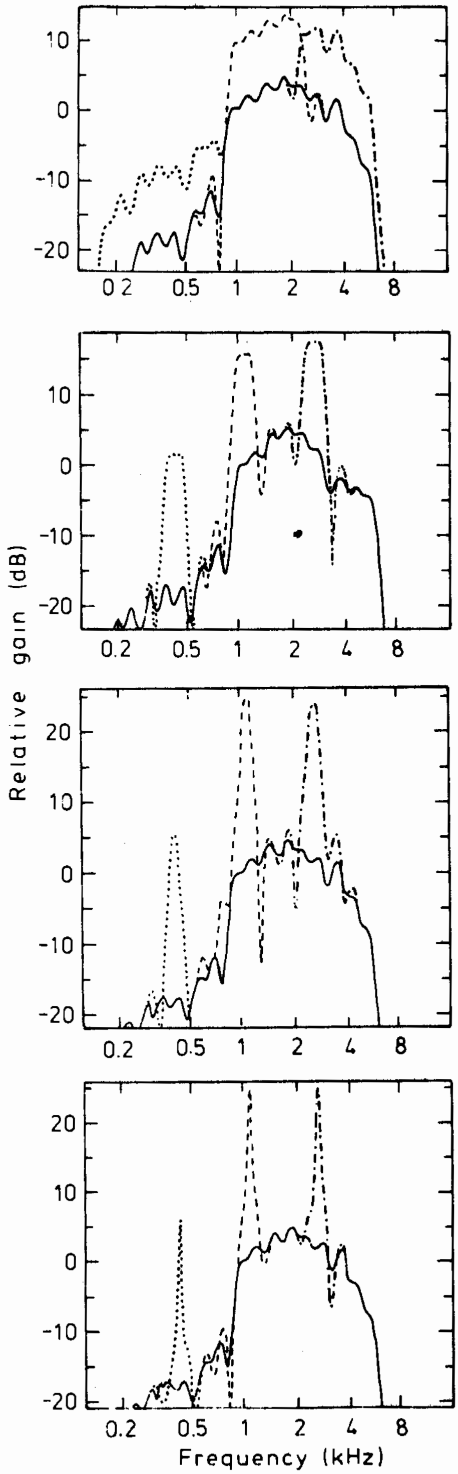


**FIG 1. Reference frequency response and peak conditions of Experiments 1 — 4. (Reference response extends slightly further [0.2 — 5 kHz] than shown in figure.)**

The height and width of the peaks varied for each experiment. This information is provided in Figure 1 which shows the frequency responses, used in the four experiments, indicated by the acoustic output of a supra-aural earphone (TDH 49) measured in an artificial ear (Bruel & Kjaer, model 4153). MCL was measured with a tracking procedure which we have previously described in detail (Christen & Byrne, 1980). The subject was instructed to press a switch as soon as the speech became louder than the level which he would prefer for long term listening and to release the switch as soon as the speech became softer than this level. An ascending approach was used in which the speech increased from an initial inaudible level. MCL was taken as the mid point of the tracking excursions after excluding an initial stabilization period.

### Subjects

12 normal hearing subjects participated in experiments 1, 2 and 3. Six subjects were used in experiment 4. Their ages ranged from 20 to 40 years and none had hearing thresholds which exceeded 20 dB HTL (ISO standard) at any of the octave frequencies from 0.25 kHz to 4 kHz, in the test ear. Some of the subjects participated in all experiments but others participated in only one, two or three of the experiments. There were approximately equal numbers of men and women in each subject groups.

### Equipment

The equipment was the same as described previously (Christen & Byrne, 1980) except for an additional filter and the use of a different tape recorder and a different amplifier for experiments 3 and 4. The major items of equipment were: a tape recorder (Nagra, model 4.2 or Ampex, model AG-4400); a multifilter (General Radio, model 1925); a filter (Bruel & Kjaer, model 2121) an amplifier (custom made or Technics model SU-7300); a recording attenuator (Grason Stadler, model E3262 A). The spectral analyses were performed with a Bruel and Kjaer model 2131 real time analyser.

### Testing Arrangements

In experiment 1 (reported in Byrne & Christen, 1979) each condition was tested once on each of three consecutive days. The MCL value for each subject, for each condition, is the mean of the three measurements. Similarly, for experiment 2, the MCL is the mean of three measurements made on consecutive days. In experiments 3 and 4, each condition was measured twice in four sessions held on consecutive days. Thus, each MCL is the mean of 8 measurements. All experiments used a counterbalanced testing order and in experiments 1 and 2 a correction for order was made (see Christen & Byrne, 1980).

**Loudness Calculations**

The differences in MCL for the various conditions were compared with the calculated differences in the loudness of the speech which would occur if the overall gain of the system were left unchanged. The speech material was played through each filter condition and the output of the test earphone (TDH 4 9) was recorded through an artificial ear (Bruel & Kjaer model 4153). These recordings were subjected to real — time analysis (integration time of 128 seconds) to obtain the earphone output levels in each one-third octave band. These levels were converted to equivalent sound field levels by subtracting the difference between monaural minimum audible pressure and binaural minimum audible field in each band. The loudness (in phons) of this output was calculated by Zwicker's method, using the figures which apply to free field conditions (ANSI, 1969, method B). These calculations were made for each condition to derive the required differences in loudness (see Byrne & Christen, 1979 for further details).

## RESULTS

The reduction in MCL for each of the peak conditions, relative to the N condition, is shown in Figure 2. This indicates the mean, median and the complete range of values for each subject group. (It should be noted that there are 12 subjects in three of the groups but only 6 subjects for the 1/23 octave condition). Predicted values, derived from the calculated differences in loudness are also shown. In general the measured values (whether we take the means or the medians) agree reasonably with the predicted values. The largest discrepancy (about 2dB) is for the 1/7 octave peak at 1 kHz. We are not aware of any explanation for this or the other discrepancies or indeed whether there is any reason other than measurement error and/or imprecision in the prediction procedure or in our calculations.

We calculated a complete set of intersubject and intrasubject standard deviations. These indicated that the intersubject variability could not be explained completely by intrasubject variability. This could also be inferred from the fact that the majority of the distributions shown in Figure 2 are positively skewed whereas none is negatively skewed. If intrasubject (i.e. test-retest) variability were the only operative factor we would expect either that all of the distributions would be normal or that any skewness which occurred (by chance) would be equally likely to occur in either direction.

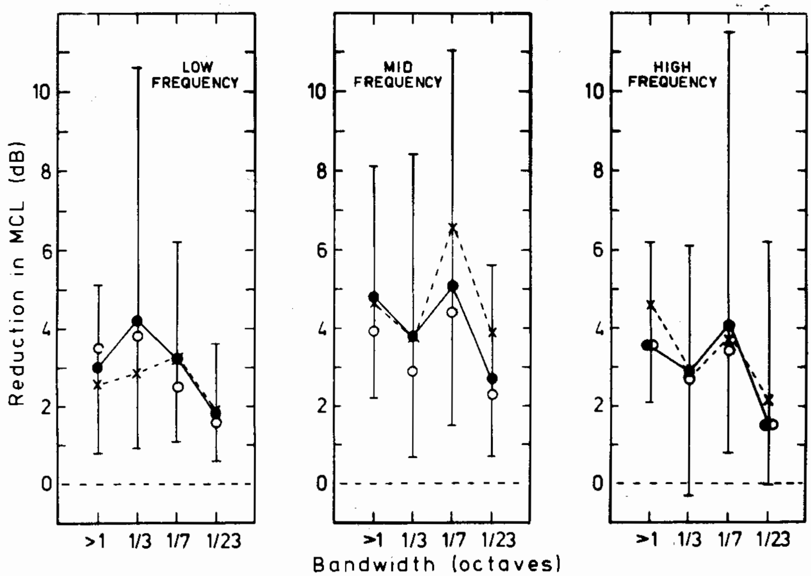


**FIG 2. Reduction in MCL for peak conditions relative to MCL for reference response. Mean reduction (●), median reduction (O) and reduction predicted from loudness model (X) are shown. Bars indicate total range of values for 6 subjects for 1/23 octave condition and for 12 subjects for other conditions. N.B. Peaks vary in height as well as bandwidth (see Figure 1).**

Because intersubject variability exceeds intrasubject variability, it seems clear that some subjects were more affected by the peaks than others, for at least some conditions.

## DISCUSSION

These experiments show that MCLs for normal hearing persons are influenced by peaks in a predictable manner. The group average values (means or medians) are generally close to those predicted by the loudness model. There were few instances where there were large differences between individual values and the predicted value. In the majority of these, the peak had a larger effect than predicted. These comments apply to all four peak bandwidths and all three peak frequencies which were tested. To some extent, our findings conflict with the report of Martin (1978) who concluded that peaks did not have a significant effect on the comfortable listening levels of either normal hearing or hearing-impaired subjects. However, Martin used smaller peaks than those of our studies and the small effects which he found agree reasonably with what would be predicted from the loudness model. His suggestion that MCL may be unaffected by peaks which are narrower than the critical bandwidth, is clearly contrary to our finding that even very narrow peaks have predictable effects on MCL. The loudness prediction method utilizes only the long term level in each 1/3 octave band (as an approximation to the level in each critical band). Thus for peaks less than a critical band in width, a halving of the peak bandwidth and a simultaneous increase in peak height of 3dB will leave the effect of the peak on MCL unchanged. Of course, this trading relationship cannot be taken too far, as extremely narrow peaks will only be excited by the speech signal on rare and irregular occasions. Under these conditions the loudness model may no longer apply, although this does not appear to have happened for the narrowest peaks (1/23 octave) used in this study.

Figure 3 illustrates the effects which hearing aid frequency response peaks should have on the amount of gain which would provide comfortable listening. Curve A is the measured frequency response of a hearing aid. Curve B is a hypothetical response with the peaks completely removed. The curves have been positioned in such a way that speech delivered through each of two amplifying systems with the frequency responses and relative gains as shown, would be equally loud for a normal hearing person (assuming that the overall level provided comfortable listening). The situation would be more complex for a hearing-impaired person having an abnormal most comfortable equal loudness contour or any other abnormalities (e.g. reduced frequency selectivity) which would affect the loudness of complex sounds (e.g. speech). Nonetheless, in the great majority of cases the general situation should be as depicted in Figure 3, namely that a smooth response would provide more gain, and hence more signal, over most of the frequency range at the expense of a little less gain in the regions of the peaks. From this, it could be expected that a smooth frequency response would tend to provide better speech discrimination than a 'peaky' response. This agrees with the findings of Jerger & Thelin (1968) and Smaldino (1979).

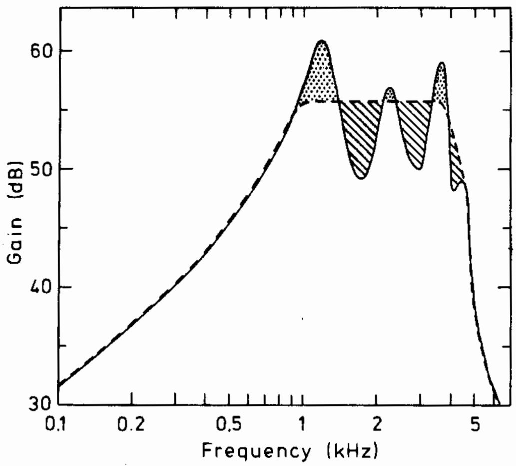


**FIG. 3. Normal (solid line) and smoothed (broken line) frequency response curves of a hearing aid. The curves are positioned so that speech amplified by the two systems would be equally loud for a normal hearing person. Hatched area indicates amount of additional signal provided by smooth response at the expense of signal losses (dotted area) in the region of peaks.**

These experiments have been concerned only with the effects of peaks on comfortable listening levels. Other effects include an increased risk of mechanical and acoustic feedback and allegedly unpleasant effects on the quality of speech. Some 'quality' effects have been investigated by Martin (1978) but with rather inconclusive results. Lawton & Cafarelli (1978), however, found that 'smoothing' the frequency response of a hearing aid resulted in a more acceptable quality for listening to speech. Specifically, two hearing aids which were modified to remove the peaks were judged, by a group of 28 hearing-impaired subjects, to be more clear, more pleasant, more smooth and more mellow than their 'peaky' counterparts. Further investigations of the effects of peaks on listening quality are warranted. However, regardless of what such studies may show, our experiments, together with the above cited studies of the effects of peaks on speech intelligibility, provide strong support for the traditional view that a smooth frequency response characteristic is highly desirable in hearing aids. Various methods have been suggested for reducing or eliminating peaks in hearing aid response curves (Carlson, 1974; Krogh, 1975; Walker, 1979; Killion, 1977, 1980) and the clinical application of some of these methods is the subject of a recent monograph (Libby, Johnson & Longwell, 1981). As these procedures are reasonably simple and quite practical, we support the view that they should be adopted for regular clinical use.

**References**


Byrne, D. and Christen, R. (1979). Preferred listening levels and loudness of filtered speech: determinants of acceptable hearing aid gain setting. *Austral. J. Audiol.* 1, 32-40.

Byrne, D. and Tonisson, W. (1976). Selecting the gain of hearing aids for persons with sensorineural hearing impairments. *Scand. Audiol.* 5, 51-59.

Carlson, E. (1974), Smoothing the hearing aid frequency response. *J. Audio. Eng.* Soc. 22, 426-429.

Christen, R. and Byrne D. (1980). Preferred listening levels for bands of speech in relation to hearing aid selection. *Scand. Audiol.* 9, 3-10.

Davis, H., Stevens, S.S. and Nicholls, R.H. (1947). *Hearing Aids. An Experimental Study of Design Objectives.* Harvard U.P. Cambridge, Mass.

Jerger, J. and Thelin, J. (1968). Effects of electroacoustic characteristics of hearing aids on speech understanding. *Bull. Prosthet. Res.* 9, 159-197.

Killion, M. (1977). *Application of improved acoustic resistance (damping) elements for smoothing the hearing aid frequency response.* Industrial Research Products Inc. Elk Grove, Illinois.

Killion, M.C. (1980) Problems in the application of broadband hearing aid earphones, in *Acoustical Factors Affecting Hearing Aid Performance.* (Ed. G.A. Studebaker and I. Hochberg) University Park Press, Baltimore.

Krogh, H. (1975) Placing the receiver in the earmould. *Scand. Audiol. Suppl.* 5, 113-122.

Lawton, B.L. and Cafarelli, D.L. (1978). *The effects of hearing aid frequency response modification upon speech reception.* ISVR memorandum No. 588, The University, Southampton.

Libby, E.R., Johnson, J.H. and Longwell, T.F. (1981), Innovative earmould coupling systems: rationale, design, clinical applications. *Zenetron Monograph No.4,* Zenetron Inc. Chicago, 30 pages.

Martin M.C. (1978), *Subjective response to frequency response peaks.* Royal National Institute for the Deaf, London. (unpublished report to D.H.S.S.)

Millin, J.P. (1978). A critical review of current hearing aids, in *The Application of Signal Processing Concepts to Hearing Aids.* (Ed. P. Yanick and S.F. Freifeld) Grune and Stratton, New York.

Smaldino, J. (1979). A multivariate strategy for prediction of psychoacoustic performance from electroacoustic characteristics of hearing aids. *J. Am. Audit. Soc.* 5, 130-137.

Villchur, E. (1978). Signal Processing . . . in *Auditory management of Hearing Impaired Children.* (Ed. M. Ross and T.G. Giolas) University Park Press, Baltimore.

Walker, G. (1979). Earphone termination and the response of behind-the-ear hearing aids. *Br. J. Audiol.* 13, 41-46.