Psychophysical two-tone suppression as a function of input level for \( f_2/f_1 > 1.0 \)

Larry E. Humes

Hearing Research Laboratory, Division of Hearing and Speech Sciences, Vanderbilt University School of Medicine, Nashville, Tennessee 37232
(Received 5 July 1979; accepted for publication 3 December 1979)

Psychophysical two-tone suppression was measured in three normal-hearing young adults using the pulsation-threshold technique. The primary objective was to study the effect of \( L_1 \) on psychophysical two-tone suppression for \( f_2/f_1 > 1.0 \). Measurements were obtained at low and mid frequencies and for input levels ranging from 40 through 85 dB SPL. For \( f_1 = 1000 \) or 2000 Hz, suppression increased initially with \( L_1 \) and then decreased for \( L_1 \geq 55 \) to 70 dB SPL. For \( f_1 = 500 \) Hz, however, suppression increased monotonically throughout the range of \( L_1 \) values examined. These findings are explained by assuming that for \( f_1 \geq 1000 \) Hz the nonlinear mechanism responsible for two-tone suppression is very susceptible to reversible dysfunction produced by the presentation of high-intensity stimuli.

PACS numbers: 43.66.De, 43.66.Fe, 43.66.Mk [DM]

INTRODUCTION

When a tone is presented to the ear, the physiological response or the underlying percept associated with this stimulus may be altered in a variety of ways by the addition of a second tone. One such effect of the addition of the second tone is known as two-tone suppression (e.g., Sachs and Kiang, 1968; Houtgast, 1974). Suppression refers to the ability of the second tone, the suppressor, to reduce the physiological response or diminish the percept associated with the presentation of the first tone, the suppressor.

Psychophysical demonstrations of two-tone suppression require the use of nonsimultaneous paradigms (Houtgast, 1972, 1974). Two nonsimultaneous paradigms have enjoyed the most popularity in the psychophysical measurement of suppression: the pulsation-threshold technique (Houtgast, 1972, 1974; Verschuren et al., 1976; Duifhuis, 1977) and the forward-masking paradigm (Houtgast, 1974; Shannon, 1976; Terry and Moore, 1977; Weber and Green, 1978, 1979). The latter technique yields a less direct measure of suppression referred to as “unmasking.” Although Weber and Green (1979) provide evidence that unmasking data can be converted readily to suppression values, a quantitative comparison between suppression measurements obtained with the pulsation-threshold and forward-masking methods cannot be made without difficulty. Nonetheless, variations in key parameters of the two-tone input affect results obtained with both paradigms in a similar manner. Thus, qualitative comparisons between suppression measurements obtained with the pulsation-threshold and unmasking methods derived with a forward-masking paradigm are permissible.

Houtgast (1974) and Shannon (1976) have recently described several of the conditions under which psychophysical two-tone suppression/unmasking occurs. Crucial parameters appear to be the ratios of the frequencies of the two tones \( f_2/f_1 > 1.0 \) and the difference in their respective levels \( (L_2 - L_1) \), where \( L_1 \) is the level of the tone at \( f_1 \) and \( L_2 \) is the level of the tone at \( f_2 \). Suppression/unmasking is greatest for \( f_2/f_1 > 1.0 \) and does not occur for \( f_2/f_1 < 1.0 \) except when the difference in level is large \( (L_2 - L_1) > 20 \) dB; Houtgast, 1974; Duifhuis, 1977]. In addition, for a given value of \( f_2/f_1 > 1.0 \), suppression/unmasking appears to grow monotonically as \( (L_2 - L_1) \) is increased from 5 to 20–25 dB (Houtgast, 1974; Shannon, 1976). In general, the most extensive psychophysical data have been obtained for \( f_1 = 1000 \) Hz and \( L_1 = 40–50 \) dB SPL (re 20 \( \mu \)Pa). Under these conditions, \( (L_2 - L_1) = 15 \) dB, the greatest amount of suppression/unmasking occurs for \( f_2/f_1 \) values from 1.1 to 1.2 (Houtgast, 1974; Shannon, 1976).

A parameter that has not been varied extensively in prior psychophysical studies of two-tone suppression/unmasking, however, has been the overall level of the two-tone input for a fixed level difference [e.g., varying \( L_1 \) for a fixed \( (L_2 - L_1) \)]. This is especially true for \( f_2/f_1 > 1.0 \). Shannon (1976, his Fig. 6), for instance, has published unmasking data obtained from three subjects for this condition and for \( f_1 = 1000 \) Hz, \( (L_2 - L_1) = 20 \) dB, and \( L_1 \) varied from 30 to 70 dB SPL. An analysis of these data indicates that as the overall level of the two-tone stimulus increases, unmasking also increases up to \( L_1 = 50–60 \) dB SPL and then decreases as intensity increases further. These findings, however, are fairly limited in that only one frequency region \( (1000 \text{ Hz}) \) was studied and \( L_1 \) never exceeded more than a moderate intensity \( (70 \text{ dB SPL}) \).

Duifhuis (1977) has also obtained psychophysical data on two-tone suppression with the pulsation-threshold method for \( L_1 \) varied from 30 to 50 dB SPL, \( f_1 = 1000 \) Hz, \( f_2/f_1 = 1.1 \) and 1.3, and \( (L_2 - L_1) = 20 \) dB. For this limited range of \( L_1 \) variation, suppression increased monotonically with increase in \( L_1 \). This trend concurs with that observed in the unmasking data of Shannon (1976) over a similar range of \( L_1 \) values. Again, however, these data are limited in that \( L_1 \) was varied only over a restricted range of intensities and only one frequency was examined. It was the purpose of this study, therefore, to investigate the dependence of psychophysical two-tone suppression on \( L_1 \) for levels up to 85 dB SPL and for frequencies other than 1000 Hz. The effect of \( L_1 \) was examined here for \( f_2/f_1 > 1.0 \).
I. METHODS

A. Subjects

Three normal-hearing young adults were subjects. Each subject had tympanograms of normal amplitude, shape, and peak-pressure point, acoustic reflexes present at 500-4000 Hz upon contralateral presentation of pure tones at a level of 100 dB HL (ANSI, 1969), and air-conduction pure-tone thresholds from 500 through 4000 Hz ≤10 dB SPL.

B. Apparatus

The pulsation-threshold paradigm (Houtgast, 1972, 1974) was used to measure the amount of two-tone suppression. The two "muskets" were pure tones fixed in frequency \((f_1, f_2)\) and level \((L_1, L_2)\) while the signal was a probe tone fixed in frequency at \(f_1\) and varied in level by the subject. The two muskets were generated by oscillators (GenRad 1310-B), gated, attenuated, mixed, and fed to an electrodynamic earphone (TDH-49 mounted in an MX-41/AR cushion). The signal was produced by an oscillator (Leader LAG-120A), gated, attenuated by a subject-controlled recording attenuator (Grason-Stadler E3262A), mixed, and fed to the same earphone as the muskets. The masker and signal at \(f_1\) were phase-locked so as to avoid the detection of audible transients during the 15 ms in which the masker and signal overlapped (Duifhuis, 1977). Signal frequency was monitored continuously with a frequency counter (Data Precision 5800). Calibration of the levels and temporal features of the two-tone input was performed periodically throughout the experiment. The linearity of the recording attenuator was confirmed over a 70-dB range (roughly 25-95 dB SPL). The gating of the stimuli was such that the maskers were alternated with the signal at a rate of 4 Hz. Signal and maskers both had a 125-ms duration with a 15-ms Gaussian-shaped rise/fall time (Houtgast, 1972; Verschuure et al., 1976). The timing sequence was controlled by Coulbourn Instruments timers and rise/fall gates.

All testing was accomplished in a sound-treated booth having an ambient noise level below that specified for audiometric test suites (ANSI S3.1-1977).

C. Procedure

Following selection of subjects, each individual was instructed for the pulsation-threshold task. The initial approach to pulsation-threshold was always an ascending one. It has been demonstrated previously that ascending and descending approaches to pulsation threshold can yield slightly different results, thereby increasing with-subject variability (Sachs, 1975). The subject was instructed to increase signal level until the continuous percept associated with this tone began to pulsate. This transition from a continuous to a pulsating percept was accentuated by omitting every fourth signal as has been recommended previously (Houtgast, 1974; Sachs, 1975).

After receiving 5–6 h of practice with the pulsation-suppression technique (3 sessions of 1.5–2.0 h each), pulsation threshold was determined for single-tone and two-tone "muskets." A Békésy tracking technique was utilized to establish pulsation threshold in which the median of ten consecutive level reversals defined a single-threshold estimate. At least four threshold estimates were obtained from each subject for each condition. In the case of single-tone maskers, the masker and signal tone frequencies were both set to \(f_1\), and the level of the single-tone masker \((L)\) was adjusted to 40, 55, 70, or 85 dB SPL. In this case, pulsation thresholds were always 1–3 dB above \(L\), which is consistent with prior observations (Houtgast, 1974; Duifhuis, 1977). In the case of two-tone maskers, a second tone of frequency \(f_2\) was added to the masker at a level 15 dB above \(L\) \([i.e., \ (L_2-L) =15 \text{ dB}]\). In other words, pulsation-thresholds were determined for the differing \(L\) values both with and without the suppressor \((L_2)\) present. The difference in these two measurements represents the amount of suppression produced by \(L_2\).

Three \(f_1\) values, 500, 1000, and 2000 Hz, were investigated in this experiment. For \(f_1=500\) and 1000 Hz, frequency ratios of 1.1, 1.2, and 1.4 were investigated. For \(f_1=500\) and 1000 Hz, frequency ratios of 1.1, 1.2, and 1.4 were investigated. For \(f_1=2000\) Hz a frequency ratio of 1.05 was also studied. Single-tone and two-tone maskers, as well as \(f_1, f_2/f_1, L_1\) values, were presented in random order.

II. RESULTS

The dependence of two-tone suppression on \(L_1\) for \(f_1=500\) Hz is illustrated in Fig. 1. Data are provided for individual subjects in the top two and lower left panels of this figure with the frequency ratio \((f_2/f_1)\) differing in each of these three panels. The data displayed in panels (a)–(c) are median suppression values for each subject. The median values for each subject represent the average of at least four independent estimates of

![FIG. 1. Each panel in this figure plots the amount of suppression as a function of \(L_1\) for \(f_1=500\) Hz. The lower right panel displays the group medians for three \(f_2/f_1\) values while the other three panels show individual data for each \(f_2/f_1\). (a) \(f_2/f_1=1.1\), (b) \(f_2/f_1=1.2\), (c) \(f_2/f_1=1.4\). Each symbol in these three panels represents the median suppression values for each subject (circles: S1; squares: S2; triangles: S3). Group medians are plotted in panel (d).](image-url)
suppression (pulsation threshold for \( f_1 \) minus that for \( f_1 \) and \( f_2 \)) for each condition. The range of individual suppression values obtained for each subject never exceeded 3 dB in any condition. The fourth panel of Fig. 1 [panel (d)] contains the group median values for the three subjects with \( f_2/f_1 \), the parameter. From this figure it is apparent that suppression remains essentially constant as \( L_1 \) is increased from 40 to 55 dB SPL, but increases monotonically as \( L_1 \) is raised further in intensity. This trend is most apparent in the group medians [panel (d)]; the individual data showing more variation.

Figures 2 and 3 illustrate comparable data for \( f_1 \) values of 1000 and 2000 Hz, respectively. The data for \( f_1 =2000 \) Hz and \( f_2/f_1 = 1.4 \) are not depicted in Fig. 3 in that essentially no suppression was observed for this condition. The trend apparent in the data obtained for \( f_1 =1000 \) or 2000 Hz differs considerably from that observed previously in Fig. 1 for \( f_1 =500 \) Hz. A general conclusion to be reached from the data for higher frequencies (Figs. 2 and 3) is that psychophysical two-tone suppression decreases for \( L_1 \) values above 55-70 dB SPL. Although this generalization holds for all three subjects, the size of the decrease in suppression and the \( L_1 \) value at which it occurs vary considerably among subjects.

Nonetheless, it would appear that the dependence of suppression on \( L_1 \) differs considerably for \( f_1 =500 \) Hz as opposed to 1000 or 2000 Hz. This point is illustrated more clearly in Fig. 4 in which the group medians for two differing values of \( f_2/f_1 \) are depicted with \( f_1 \) as the parameter. While the amount of suppression at 500 Hz increases throughout the range of \( L_1 \) values studied, such is clearly not the case for \( f_1 =1000 \) or 2000 Hz. This same trend, moreover, emerges when the data from each subject are treated separately.

III. DISCUSSION

The present results confirm the earlier findings of Shannon (1976) that psychophysical two-tone suppression/unmasking decreases at high intensities for an \( f_1 \) value of 1000 Hz. This conclusion was arrived at only following a re-analysis of the unmasking data obtained by Shannon (1976, his Fig. 6). The present data also indicate that the same applies to an \( f_1 \) value of 2000 Hz, but not to 500 Hz. Because of the different psychophysical paradigms employed in the present study and the investigation of Shannon (1976), however, only qualitative comparisons are justified.

Recent suppression measurements obtained by Duifhuis (1977) with the same technique used in this study (pulsation threshold), however, permit some quantitative comparisons to be made. Duifhuis provides data on two-tone suppression obtained for \( (L_2-L_1) =15 \) dB, \( f_1 =1000 \) Hz, \( f_2/f_1 = 1.1 \) and 1.2 and \( L_1 = 30 \) and 50 dB SPL. Thus, these parameters are very similar to some of the parameters studied here. When the necessary interpolations and extrapolations are made on Duifhuis' data so as to estimate the amount of suppression for \( L_1 = 40 \) and 55 dB SPL (two of the four values studied in this investigation), the estimated values are
within 3–4 dB of the median values observed in this study.

Two basic questions remain regarding the data obtained in the present investigation. Why does suppression decrease for higher intensities \( (L_2 > 70 \text{ dB SPL}) \) at 1000 and 2000 Hz and why isn’t this same effect evident for \( f_2 = 500 \text{ Hz} \)? The following hypothesis is offered as an answer to both questions. In this hypothesis two-tone suppression is viewed as one component of auditory nonlinearity, as has been suggested previously (e.g., Pfeiffer, 1970; Snoerenburg, 1974). Second, the distortion mechanism is hypothesized to be vulnerable even to short-term low-level exposures (1–2 min, 90 dB SPL) to pure tones at \( f_1 \) and \( f_2 \) (Siegel et al., 1977). Thus, suppression could be reduced at high intensities due to acute and reversible dysfunction to the nonlinearity produced by the intense two-tone input. To explain the present results more completely, one need only add that the nonlinearity in the region of the cochlea associated with frequencies of 1000 and 2000 Hz is more susceptible to reversible dysfunction than in the cochlear region associated with \( f_1 \) of 500 Hz. Although post hoc experimentation revealed no measurable threshold shifts in the three listeners of the present study following presentation of the various two-tone stimuli used here, this does not necessarily indicate that the distortion mechanism was unaffected.

There are also some neurophysiological data on two-tone suppression obtained by Abbas and Sachs (1976) to which qualitative comparisons can be made to present data. In particular, these investigators have observed that for \( f_1 \) values sufficient to drive auditory nerve fibers into saturation, the amount of suppression for \( f_2/f_1 > 1.0 \) (\( f_1 \approx f_2 \) Siegel et al., 1977). Thus, if one assumes that the nerve fibers located at \( f_1 \) were also saturated for \( L_2 > 55 \) dB SPL in the present study, then the decrease in suppression with increase in \( L_2 \) above 55 dB SPL observed in this study is consistent with the physiological observations of Abbas and Sachs (1976). Comparisons between physiological and psychophysical data, however, must be made with caution in view of the considerable methodological differences involved.

Finally, these data on two-tone suppression have implications for suppression measurements obtained from cochlear-impaired listeners. These findings suggest, for instance, that if suppression measurements are to be obtained from cochlear-impaired subjects it would be advisable to utilize the same sound-pressure levels \( (L_2 = L_1) \) as used with normal hearers. Use of equivalent sensation levels for both groups might lead to less suppression in the hearing-impaired subjects for \( f_2 > 1000 \) Hz by virtue of the dependence of suppression on \( L_1 \) as observed here. That is, equivalent sensation levels would probably result in the use of higher sound-pressure levels for the hearing-impaired group in which case suppression would be reduced. To data, this has not been a problem with the psychophysical data on two-tone suppression obtained from hearing-impaired listeners in that identical sound-pressure levels have been utilized for normal-hearing and hearing-impaired subjects (Leshowitz and Lindstrom, 1977; Wightman et al., 1977). These studies revealed decreased suppression in hearing-impaired listeners despite the utilization of equivalent sound-pressure levels with both groups. Thus, in these studies decreased suppression may be attributed to effects of cochlear pathology and not simply the use of high intensities.

References


