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MONAURAL LOUDNESS FUNCTIONS UNDER MASKING

by

Alan M Richards

Bureau of Medicine and Surgery Navy Department
Research Work Unit MF022 01 04 9004 05

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Gerald J Duffner CAPT MC USN
COMMANDING OFFICER
U S Naval Submarine Medical Center

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SUBMARINE MEDICAL RESEARCH LABORATORY
U. S. NAVAL SUBMARINE MEDICAL CENTER REPORT NUMBER 509

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SUMMARY PAGE

PROBLEM

To determine the psychological loudness function in the presence of external noise, using a purely monaural method.

FINDINGS

It was found that under external noise the loudness functions accelerated more rapidly than the analagous function in the presence of no-noise, and that the degree of acceleration was directly related to the level of the masking noise.

APPLICATIONS

The parameters are now available in order to design sonar equipment with facilities to equate loudness for a given signal under varying noise conditions.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Bureau of Medicine and Surgery Research Work Unit MF022.01.04-9004 — Optimizing the Special Senses in Submarine and Diving Operations. The present report is No. 5 on this Work Unit, was approved for publication on 14 February 1968, and has been designated as Submarine Medical Research Laboratory Report No. 509.

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ABSTRACT

Monaural sone functions are obtained for a no noise condition and under five levels of masking noise using the method of fractionation This method precludes the use of both ears in obtaining such functions as has been the case with dichotic loudness balance and other related procedures The obtained curves are found to parallel previously found masked functions in one case and in another to show a more rapid acceleration at low levels but identical slopes above one sone

When the power function exponent of a 1000 Hz tone is plotted against overall SPL of a masking noise a power transformation which parallels that found for speech in noise is obtained Although no numerical calculations are presented it appears that above 60 dB of noise the exponent grows as approximately the 0 16 power of the noise

MONAURAL LOUDNESS FUNCTIONS UNDER MASKING

INTRODUCTION

Several investigations (Hellman and Zwislocki 1964 Lochner and Burger 1961 Scharf and Stevens J C 1958 Steinberg and Gardner 1937 Stevens 1966 1967) have shown that the subjective loudness function as well as the power function exponent are influenced by the presence of a masking noise Lochner and Burger (1961) using a method of dichotic loudness balance established loudness functions for a 1000 Hz tone at 15 35 and 55 dB sound pressure level (SPL) Their technique was to alternate a tone in noise with a pure tone alone (both of 1 3 sec duration) subject (S) was required to balance the loudness of the two by adjusting the knob of the attenuator of the tone alone Lochner and Burger concluded Masking noise does not only produce a shift in the threshold of the pure tone but it also affects its loudness at higher levels From the present work it appears as though masking reduces the loudness of a pure tone at all levels by a constant amount (p 1707)

Although Lochner and Burger did not refer to the earlier study the conclusion that masking produces a constant reduction in loudness was an hypothesis originally advanced by Steinberg and Gardner (1937) and by many th St nb g and Ga dn were primarily interested in the differences between loudness judgments made in each ear of persons with a unilateral hearing defect They used a method of loudness balance in which S s good ear was masked by wide band thermal noise which raised threshold 40 dB S adjusted a pure tone in the unmasked ear to equal loudness with a tone of the same frequency in the masked ear Their loudness functions from normal ears in the presence of noise were similar to functions obtained from abnormal ears in quiet The loudness functions for the normal ears under masking and for the abnormal ears both show a loss of hearing at low intensities with hearing becoming normal or near normal as the stimulus intensity increased

Figure 1 is the function plotted at 1000 Hz by Steinberg and Gardner to show the loudness functions obtained for the normal ear the nerve deafened ear and the conductive deafened ear Hearing loss due to nerve deafness is most prominent at the lower intensities whereas the pattern for conductive deafness is more or less uniform throughout the intensity range

When Steinberg and Gardner plotted functions for the normal ear under masking the loss of sensitivity was greatest for the lesser intensities and the pattern resembled the function for the nerve deafened ears Steinberg and Gardner concluded Since the variable type of deafness (nerve deafness) occurs when there is a loss in the number of fibers normally active the hearing loss caused by a masking sound will be expected to be of the variable type (p 14)

Using the method of magnitude estimation Scharf and J C Stevens (1958) presented white noise at var ous levels (35 65 and 95 dB SPL) simultaneously with a 1000 Hz tone Their data indicated that near the masked threshold the loudness function resembles the function obtained near the unmasked threshold Their contention was later supported by Hellman and Zwislocki (1964) who used both the method of loudness balance and numeri al l udn balan (a m thod mpos d f aspects of both magnitude production and magnitude estimation) of a 1000 Hz tone under masking Hellman and Zwislocki concluded (p 1627) that At sound intensities near masked threshold the masked loudness curves tend to become parallel to themselves as well as to the unmasked loudness curve They also concluded (in line with the earlier work of Steinberg and Gardner (1937) and with interpretations of Stevens and Davis (1938) that The effect of masking on the loudness function is essentially the same as that of a sensorineural hearing loss (p 1627)

Thus it was assumed that a given masking noise reduced the loudness of a masked stimulus by a constant loudness since it incapacitated some of the total number of neural elements normally contributing to the loudness

of a tone. If this is the case, Stevens (1966, p. 725) has noted that a constant subjective value (ψ) subtracted from the psychophysical loudness function would be all that is necessary to account for the loudness function under masking. In symbolic form:

$$\psi = k(\emptyset - \emptyset_o)^{\beta}$$

where (ψ) is the subjective value, $\emptyset$ is the stimulus value, $\emptyset_o$ is the effective threshold, and (β) is an exponent which varies with sense modality.

However, Stevens goes on to say that this simple constant subtraction from (ψ) is not an adequate explanation of the phenomenon. Rather, the presence of a masking noise produces a "power transformation" upon the characteristic of the auditory system. A power transform simply refers to a change in the slope and intercept of the straight line obtained when using logarithmic coordinates (log-log) to represent the subjective loudness function.

The principal purpose of the present investigation was to examine the monaural loudness function under masking conditions using a purely monaural technique. This method was chosen because it precludes the operation of any irrelevant inter-aural effects. However, a second purpose has relevant clinical diagnostic applications. That is, an abnormal growth of loudness (recruitment) may be detected monaurally rather than by means of dichotic loudness matches. This is of extreme importance when one ear is not normal, for then it is of course impossible to use dichotic loudness matches.

METHOD

Subjects:

Ten adults free from hearing defects, graduate assistants and laboratory personnel, were used. No attention was paid as to whether S was naive or experienced in judging loudness, since both Stevens and Poulton (1956) and J. C. Stevens and Tulving (1957) have shown that untrained observers were able to make consistent qualitative judgments of loudness on their first attempts which differed in no significant manner from the judgments of more experienced observers.

Apparatus:

A 1000-Hz tone and a wideband white noise were used throughout. All stimuli were presented monaurally through a Permaflux PDR-8 earphone mounted in an MX-41/AR cushion and calibrated in a standard 6-cc coupler. The response characteristics of the transducer were found to be essentially flat from 200-1200 Hz. The unused ear was covered by a dummy wooden earphone also mounted in an MX-41/AR cushion.

Procedure:

The fractionation method (Reese, 1943, Hanes, 1949) was used. Ss were presented with a number of standard intensities; they adjusted a comparison stimulus to one-half the subjective magnitude of the standard. Standard intensities of 46, 51, 61, 71, 81, 91, and 101 dB SPL were used. However, since Hellman and Zwislocki (1961) pointed out that loudness is related to sensation level

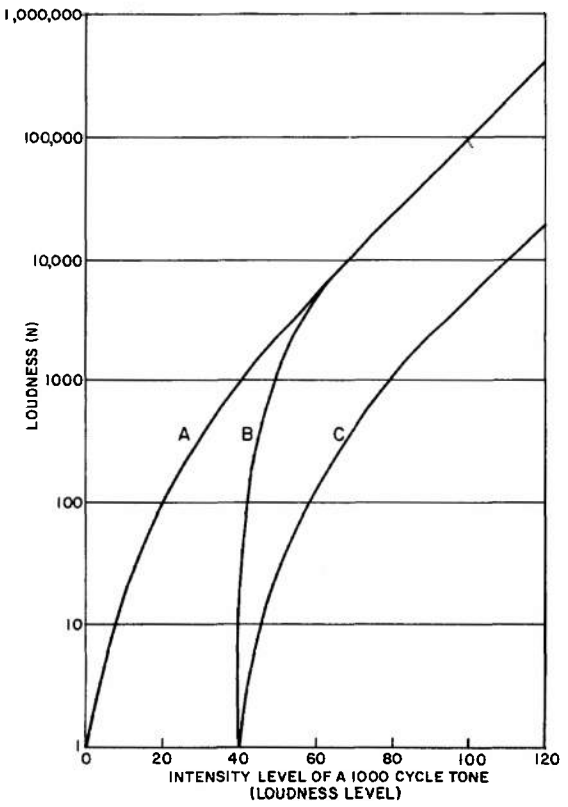

Figure 1. Loudness versus intensity level of a 1000-cycle tone for (A) normal, (B) nerve deafened, (C) conductive deafened observers (After Steinberg and Gardner, 1937, p. 13).

(SL) rather than SPL, it was necessary to determine absolute threshold for all Ss at 1 kHz. This value was found to be 6 dB SPL; reduction of 6 dB converts each standard to dB SL. Table I indicates each standard intensity in dB re: .001 V, SPL, and SL.

TABLE I

Standard Intensities in dB/RE: .001 Volt, dB/SPL, and dB/SL.

Stimulus Value	1	2	3	4	5	6	7
DB/re: .001 V	-5	0	10	20	30	40	50
DB/SPL	46	51	61	71	81	91	101
DB/SL	40	45	55	65	75	85	95

Five noise levels were used, overall SPLs of 54, 59, 69, 79, and 89 dB. A no-noise condition was also included. Spectrum levels per cycle were 26 dB down from overall.

Stimuli were presented in repetitive sequences; a standard tone-in-noise (2-sec duration) was followed by .25-sec of noise, then by another tone-in-noise (also of 2-sec duration), then by a 1-sec interval of noise before the next sequence.

No limit was placed on the number of stimulus sequences necessary for S to make a confident half-loudness judgment. (Rationale for not including a limit comes from J. C. Stevens (1958) and Jerger and Harford (1960), who showed that neither the length of time allowed for a judgment, nor the number of stimulus sequence presentations, affects the subjective loudness function significantly.) Each S made half-loudness judgments for all 42 combinations of the seven SPLs of the standard and the six overall SPLs of the noise. Four half-loudness judgments per S were required for each standard intensity/masking level combination.

Half-loudness functions relating stimuli judged one-half against their respective standards were obtained using averaged SL data. Subjective functions were directly extrapolated from these curves using the method outlined by Reese (1943). Generally, the method involved choosing an arbitrary intensity and assigning it a subjective magnitude. All other intensities were then assigned subjective magnitudes in relation to the reference point.

RESULTS AND DISCUSSION

Half-Loudness Functions:

Figures 2(a-f) are half-loudness functions relating the standard intensities of the 1000-Hz tone to their respective mean subjective half-loudness under all masking conditions. It will be noted in functions 2(d), (e), and (f) that vertical lines are drawn on the graphs to indicate masked threshold values. Although points below these lines are plotted they were not used in the plotting of the subjective functions.

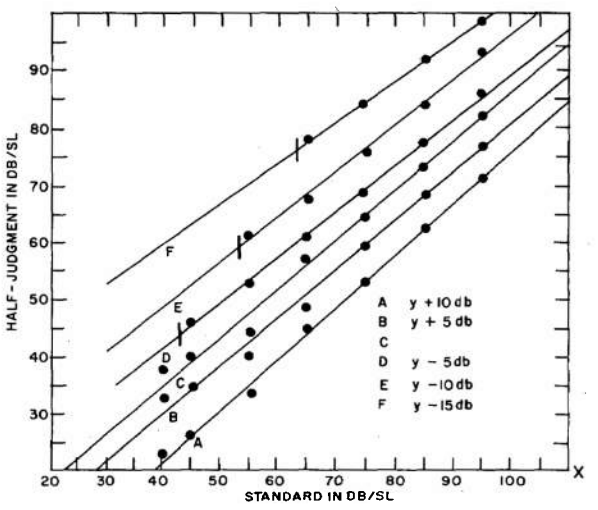

Figure 2. Half-loudness functions, relating the stimuli judged one-half (in dB/SL against their respective standards), (also in dB/SL) under (A) no noise, and for (B) 28, (C) 33, (D) 43, (E) 53, and (F) 63 dB thresholds shifts.

The success or failure of the use of fractionation data for the generation of loudness functions under masking noise was thought to be directly contingent upon how well the half-loudness data collected under a no-noise condition compared to data previously collected (Stevens, 1955; Stevens, 1957). If they compared favorably with well-known parameters then the functions under noise conditions could be obtained with little apprehension of measurement error. Stevens

(1955, 1957) has shown that for a 1000-Hz tone the change in the physical stimulus which corresponds to a 2:1 change in the judgment of subjective loudness is approximately 10 dB. Figure 2(a) indicates that a change of this order (11.05 dB) was indeed necessary for half-loudness.

The analagous relationship between standard and comparison stimuli for the five masking conditions may be seen in Figures 2(b-e). It is quite evident that under masking noise the simple 10 dB reduction in stimulus intensity does not correspond to a 2:1 relationship in loudness. Rather, it is found that the 10 dB rule does not occur until the tone is approximately 22-27 dB above the masked threshold. For example, in curve 2 (c), a difference between standard and comparison of 10 dB occurs only when a 55 dB SL tone is above a 33 dB threshold shift, or 22 dB above masked threshold. These results are in agreement with Robinson (1957), who plotted SPL against dB changes for 2:1 loudness. Robinson's data indicate that at approximately 32 dB SPL a 10 dB change is first attained. Now assuming that all of his Ss had 1000-Hz thresholds of 6 dB SPL, it can be said that at approximately 26 dB SL the 10 dB rule first holds. This point is in excellent agreement with the results obtained in this study above masking thresholds. Robinson's data also indicates that below approximately 26 dB SL there is a steady decline from 10 dB in judged half-loudness. This too is confirmed by this study above masking noise.

Construction of the Loudness Scales:

Construct subjective loudness functions under noise has generally been undertaken using the methods of magnitude balance, magnitude estimation, or magnitude production. All of these methods have used both ears in order to form the loudness scales. Monaural fractionation procedures have not been used, and presented problems heretofore not encountered. A major problem was the derivation of sone functions from the obtained half-loudness functions in figs. 2(d-f). This was so because under these more intense masking levels, the loudness of a 1-sone tone (40 dB SL in quiet) was not heard, therefore precluding the use of this point as a reference against which all other intensities could be judged. Thus, it was decided to use an intensity which could be heard above all masking levels as the reference point from which all functions could be generated. These obtained functions could, in turn, be shifted on their ordinates to form sone functions. Fig. 3 shows that the loudness of a 1-kHz tone at 100 dB SL (in quiet) was assigned the subjective value of 1000, and then all other intensities were assigned magnitudes relative to this point (see Reese, 1943).

Having once established the shape of the various functions, it was only necessary to convert to sones by finding that point along the no-noise function (fig. 3(a)) which corresponded to 40 dB SL, and to reassign that point the magnitude of one unit. Fig. 4 is

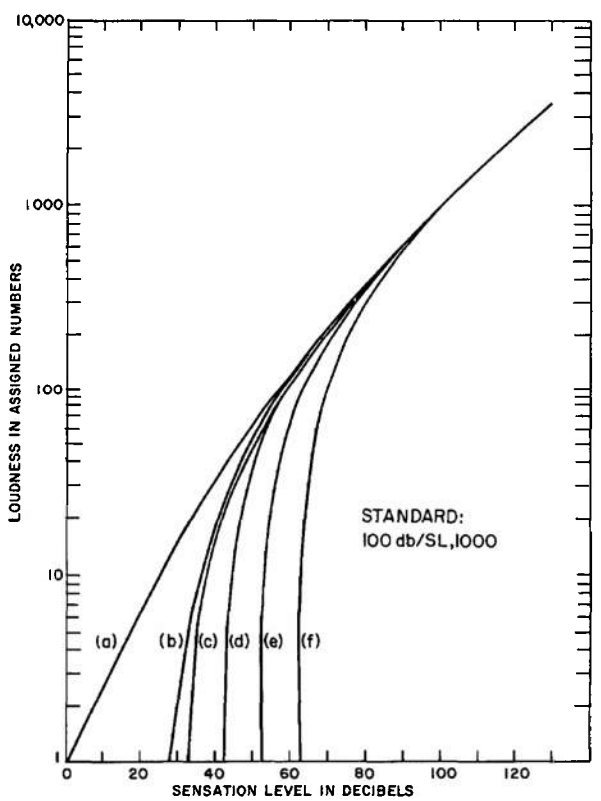

Figure 3. Monaural loudness functions under (A) No Noise, and for (B) 28, (C) 33, (D) 43, (E) 53, and (F) 63 dB threshold shifts. All functions are plotted with 100 dB/SL equivalent to 1000 subjective units.

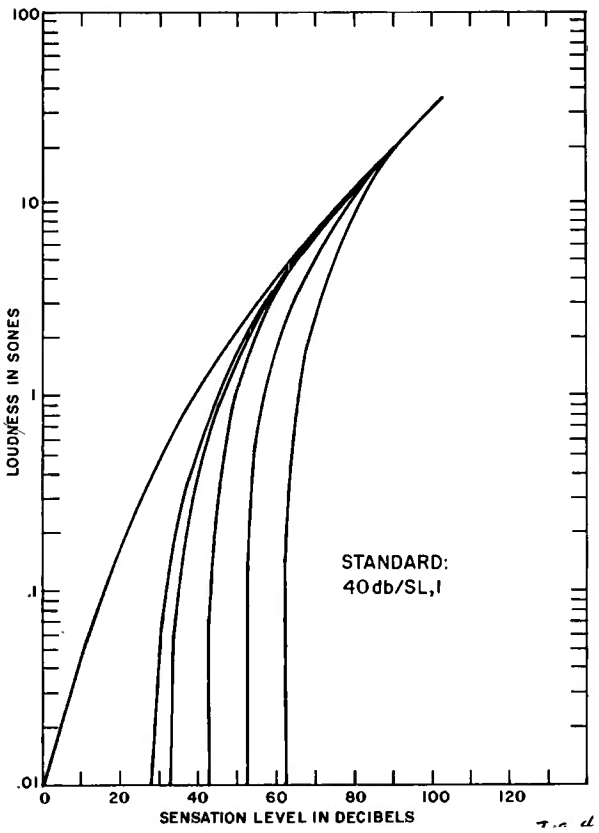

Figure 4. Monaural sone functions obtained under a no-noise condition, and for 28-dB, 33-, 43-, 53-, and 63-dB threshold shifts.

the result of this operation; it shows monaural sone functions for the no-noise condition, and for the five noise conditions.

Comparison of Loudness Functions Obtained Using Fractionation and Other Studies:

Fig. 5(a) is the monaural sone function taken from fig. 4. Curves A and C are monaural loudness functions obtained by Hellman and Zwislocki (1963) using the method of magnitude estimation with designated standards of 43- and 48-dB. Inspection of the entire figure reveals that the curve (B) (present study) accelerates more rapidly than the others, but that it exhibits the identical power exponent as curve C at intensities between 40- and 105-dB.

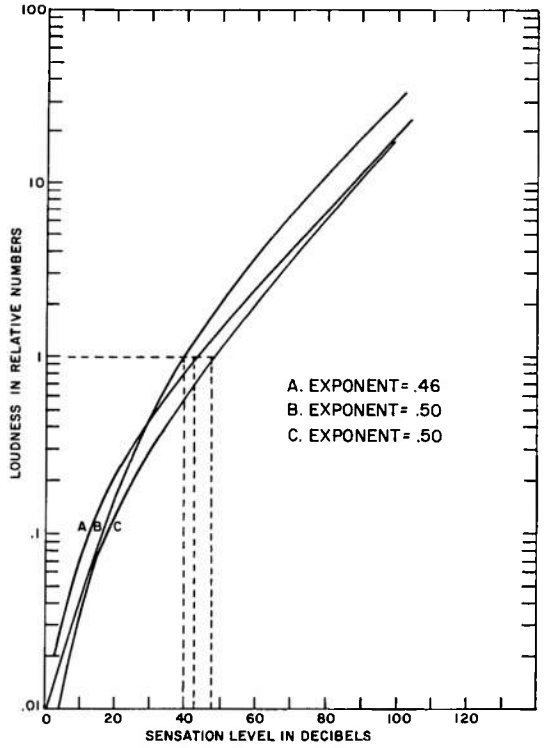

Figure 5. Comparison of monaural loudness functions obtained in the present study (B) with a reference point of 40-dB/SL; 1 unit and functions obtained by Hellman and Zwislocki (1963) with references of (A) 43-dB, and (C) 48-dB.

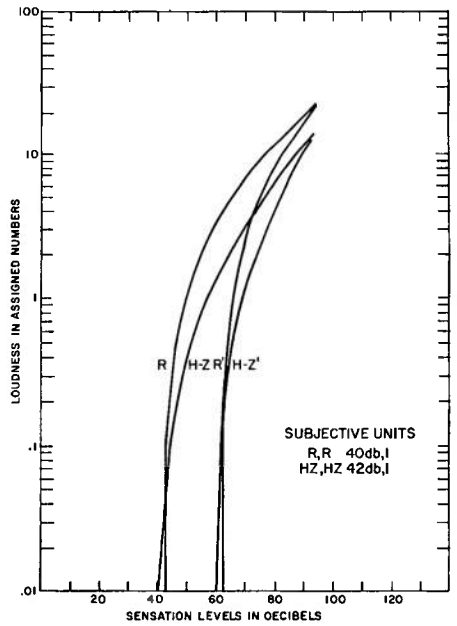

Figure 6. Comparison of loudness functions obtained by Hellman and Zwislocki (1964) for (H-Z) 40-dB, and (H-Z') 60-dB threshold shifts, and for shifts of (R) 43-dB, and (R') 63-dB in this study.

Fig. 6 compares the present data with loudness functions under noise obtained by Hellman and Zwislocki (1964) as loudness level is shifted 40 and 60 dB. Again, as in the no-noise condition (fig. 5), the loudness functions found in this study accelerate much more rapidly, but exhibit equivalent power function exponents above one sone.

The relationship between the present data and those of Hellman and Zwislocki (1963, 1964) does not prevail when comparison is made with the study of Lochner and Burger (1961), as shown in fig. 7. Threshold shifts amounting to 35 and 55 dB were used by Lochner and Burger, whereas 33 and 53 dB were used here. As can be seen, the acceleration and paralleling of the functions are fairly uniform throughout, however, at the upper ranges the curves coincide.

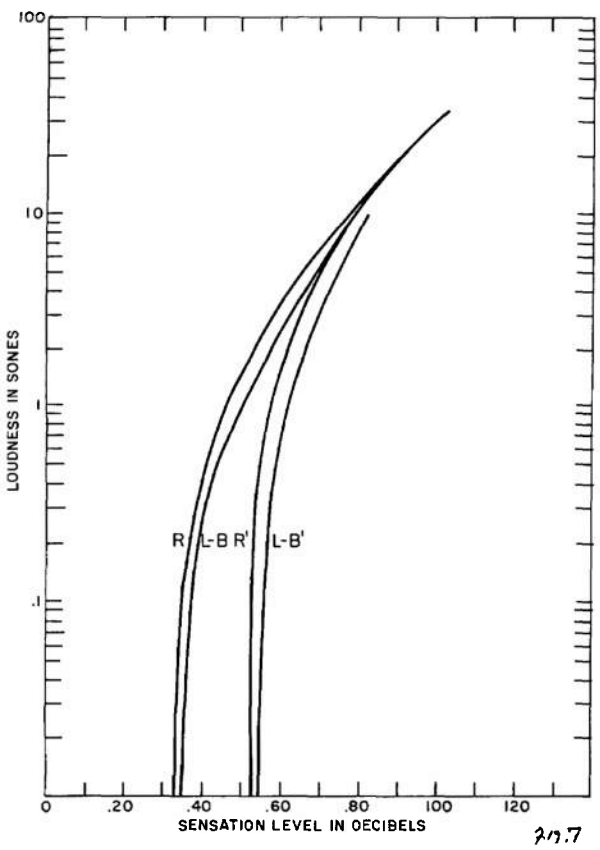

Figure 7. Comparison of sone functions obtained by Lochner and Burger (1961) for (L-B) 35-dB, and (L-B') 55-dB threshold shifts, and for shifts of (R) 33-dB, and (R') 53-dB in the present study.

In sum, it seems rather likely that the monaural functions measured in this study are functionally identical to those previously obtained. Evidence for this is contingent upon the fact that a parallel rise in the loudness function is obtained when comparison is made with Lochner and Burger's (1961) study, and that similar slopes to those found by Hellman and Zwislocki (1963, 1964) are found at levels above one sone. However, the reason for the upward displacement of the functions when comparison is made with Hellman and Zwislocki's studies is obscure; it most likely rests in differences in methodology.

The Relation Between Power Function Exponents and SPL of Noise:

In his exposition of the "power transformation" concept, Stevens (1966) reported that the exponent of the masked loudness function increases as the 0.16 power of the SPL of the masking noise above 35 dB SPL. This value was derived from a study which

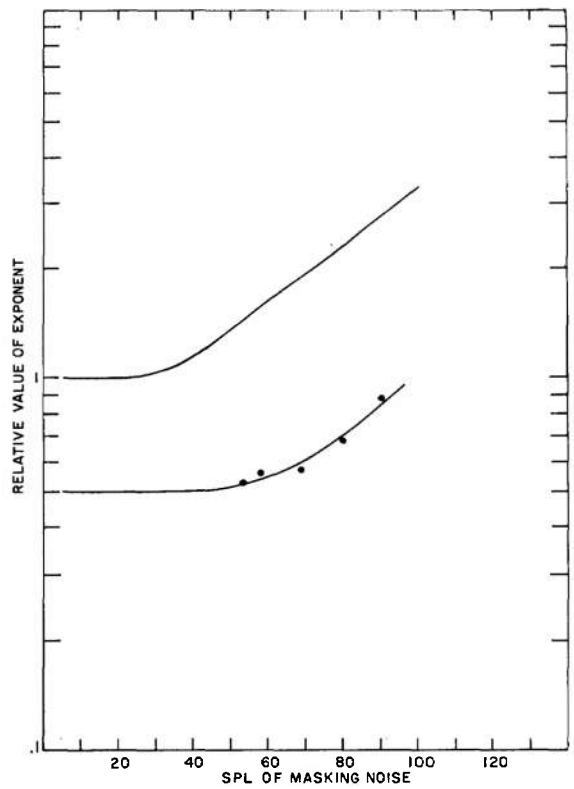

Figure 8. Relative value of the power exponent as a function of overall sound pressure level of a masking noise for speech (Stevens, 1966) and for a 1000-Hz tone.

dealt with the relationship between masking and speech intelligibility. It was assumed by Stevens that the same relationship existed as well for tones masked by noise, as for speech. However, Stevens did not at the time present any data to confirm this hypothesis. Fig. 8 shows the relative power exponent as a function of the overall SPL of masking noise. Stevens is correct in his assumption that the exponent increases as the 0.16 power of the noise, since both curves appear to become nearly parallel above noise which masks by 60 dB or more. However, it should be noted that a difference does exist at lower noise levels. A noise which raises threshold at 1 kHz by 55 dB is necessary to increase the exponent for a tone in noise, whereas the critical masking is only 35 dB (as reported by Stevens) in order to increase the exponent for speech in noise.

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13. ABSTRACT

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