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Loudness Enhancement: Monaural, Binaural and Dichotic

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SUMMARY

When one tone burst (T_c) precedes another (S_1) by 100 msec, variations in the intensity of T_c systematically influence the loudness of S_1 . When T_c is more intense than S_1 , S_1 is increased and when T_c is less intense, S_1 loudness is decreased. This occurs in monaural, binaural and dichotic paradigms of signal presentation. Where T_c and S_1 are presented to the same ear (monaural or binaural) there is more enhancement with less intersubject variability than when they are presented to different ears (dichotic paradigm). Monaural enhancements as large as 30 dB can readily be demonstrated but decrements rarely exceed 5 dB. Possible physiological mechanisms are discussed for this loudness enhancement, which apparently shares certain characteristics with time-order-error, assimilation, and temporal partial masking experiments.

INTRODUCTION

When one stimulus follows another by a brief interval of time, each influences the perception of the other. With auditory stimuli, and when subjective loudness is being judged, listeners report that a given tone may either enhance or diminish the loudness of the other. This paper examines some particular cases in which the first sound of a pair alters the subjective loudness of the second, and considers some of the mechanisms that might be involved.

An early study aimed specifically at this problem is that of Buytendijk and Meesters (1942). They presented click pairs and required their subjects to adjust the intensity of the second click so that it matched the loudness of the first click. As the interclick interval decreased from 200 to 10 msec, subjects progressively weakened the second click; at interclick intervals below 25 msec, the second click, when equated in loudness to the first, was actually 15 dB less intense. Similar results were obtained when the first click was presented to one ear and the second to the other and when both clicks entered the same ear. Buytendijk and Meesters concluded that the residual sensation from the first click added to and thereby "intensified" the sensation from the second. Gol'dburt (1964) obtained similar results using monaurally presented 1 kHz tone bursts up to 50 msec long, but interpreted the result as a failure to discriminate the second signal from the first.

Interestingly, studies of this sort have also been performed

within another conceptual context, that of the time-error, a psychophysical phenomenon known since 1860, when Fechner reported his experiments on lifted weights. Time-error (or time-order-error, Woodworth & Schlosberg 1954) refers to the fact that the judged magnitude of a given stimulus will vary with the time interval by which it follows a previous stimulus. Thus Needham (1934) and Postman (1946) required their subjects to judge the loudness of a second tone relative to that of a preceeding standard tone; their report of a "negative time-order-error" of 2 or 3 db seems to be identical to the simpler statement that, given their stimulus parameters, the second signal seemed to be a few dB stronger than the first. Unlike the signals of Buytendijk and Meesters, those used in auditory time-error experiments have generally been of relatively long duration (e.g. 200 msec or longer) with interstimulus intervals of 1 sec. or more. The Buytendijk and Meesters measurements can thus be viewed as extending the time-order experiment to brief signals presented very close together, or alternatively, the time-error studies can be considered to extend the Buytendijk and Meesters experiment to longer stimulus durations and increased interstimulus intervals.

What is common to all such studies is that only two signals are employed and relative loudness is what a subject reports upon. Hence, if he adjusts the second signal to be physically less intense than the first, one cannot decide whether the second signal seemed louder to him or the first seemed weaker. In what we call here loudness enhancement studies, by contrast, subjects are given a third stimulus

(sufficiently separated in time from the first two) and asked to adjust its amplitude for equal loudness with either of the two signals of interest. With this method, about 5 dB of loudness enhancement of the second signal has been reported when the physical intensity of paired tone bursts is equal (Irwin and Zwislocki, 1971). When the intensity of the first signal is greater than that of the second, enhancements of up to 15 dB have been reported both in the dichotic paradigm (the first stimulus to one ear, the second to the other, Galambos et al, 1972) and when all stimuli are presented monaurally (Zwislocki and Sokolich, 1974, Zwislocki et al, 1974). The experiments to be reported here directly compare the loudness enhancement which occurs under the monotic, binaural and dichotic conditions when uniform stimulus parameters and comparable subject populations are used.

METHODS

The instrumentation and methods used are essentially those described by Galambos et al (1972). Three tone bursts, all 5 kHz, 20 msec, were presented in the sequence shown in Fig. 1. The first (T_c) preceded the second (S_1) by an interval (ΔT) of 100 msec. S_2 followed S_1 by 1500 msec. Subjects seated in a sound treated chamber varied the strength of S_2 so as to make it match S_1 in loudness. They did this by pressing one of eight buttons on a control box so as to alter the intensity of S_2 on the next trial by plus or minus .5, 1.5, 3.0, or 6.0 dB. By successive increments over trials, S_2 could be varied over a range of 57 dB. When the subject was satisfied that the loudness of S_1 and S_2 were equal, he pressed a "match" button. S_2 was then adjusted to a new level by the experimenter and the procedure was repeated two additional times. The average of the three matches was considered to be one judgment. Experimental conditions were selected in random order until all conditions had been sampled. The whole procedure was repeated two additional times to yield three judgments (nine matches) of the loudness of S_1 for each subject for each experimental condition.

S_1 and S_2 were generated by a computer-controlled Wavetek model 155 signal generator. T_c was produced by a Wavetek model 116. The tone bursts were then bandpassed at 5 kHz by a Krohn Hite model 3550 filter with 24 dB/octave skirts, passed through an attenuator, and amplified by Marantz amplifiers which drove a matched pair of

TDH-39 earphones. Stimulus frequency was measured with a Systron Donner model 7014 counter, intensity with a Bruel and Kjaer type 2416 electronic voltmeter, and earphone inputs were monitored on a Tektronix type 565 oscilloscope. A PDP-9 recorded the subject's responses and controlled the signal presentations.

RESULTS

Experiments 1, 2, and 3.

Experiments 1, 2, and 3 are binaural, monaural, and dichotic analogues, respectively. In all three T_c was set at one of five intensity levels (60, 70, 80, 90 or 100 dB) and S_1 was fixed at 70 dB. In Experiment 1, the binaural paradigm, all signals were presented to both ears; in Experiment 2, the monaural paradigm, all signals were presented to one ear; in Experiment 3, the dichotic paradigm, T_c was presented to one ear while both S_1 and S_2 were applied to the other ear.

Separate groups of eight subjects were used for each experiment. In Experiment 1, the eight were unaware of the signal parameters and naive to the purpose of the experiment. In Experiments 2 and 3, seven of the eight subjects were naive and one was not. The data for the informed subject in each case fell close to the average for the other subjects.

The results of Experiments 1, 2, and 3 are shown in Figs. 2, 3 and 4 respectively, where the intensity to which each subject adjusted S_2 to match the loudness of S_1 is plotted as a function of T_c intensity. The results of all three experiments show that as T_c intensity is increased, S_2 intensity is also increased in order that it match the loudness of S_1 . In the binaural and monaural experiments S_2 is set approximately 15 dB above S_1 in order to match S_1 in loudness when T_c is at 100 dB. In the dichotic paradigm, the effect is somewhat smaller and intersubject variability is much larger.

Because of the possibility that subject gender might be relevant to loudness enhancement, four male and four female subjects were used in Experiment 1. An analysis of variance found that sex and all its interactions with subjects and/or T_c level were not significant.

Table 1 shows the results of analysis of variance performed on the data. The main effect of T_c is significant beyond the .01 level for all three experiments. The square root of the mean square error is the best estimate of the standard deviation of subjects' judgments in each experiment taken as a whole. All three ANOVAs show that subjects' judgments had a standard deviation of approximately 2 dB. This value is a typical result for this task.

Experiment 4.

To eliminate the possibility that the results of the previous experiments were unique for the loudness matching task itself, the subjects employed in Experiment 1 were restudied after its completion, being asked to rate T_c , S_1 , and S_2 in relative order for loudness. The loudest tone burst was to be scored a "3"; the next loudest a "2"; the least loud a "1". Ties were allowed. All signals were binaural and ratings were obtained with T_c set at 90, 70, and 60 dB SPL. S_1 and S_2 were fixed at 70 dB. The data are tabulated in Table 2.

Rating results clearly agree with loudness matches made by the same subjects. When T_c was set at 90 dB, the average subject rated S_1 as being greater in loudness than S_2 . It is particularly

interesting to note that when all signals were at 70 dB, S_1 was rated louder than T_c , which is qualitatively the same as the Buytendijk and Meesters' result from which they concluded that the second signal (S_1) was being increased in loudness. Note, however, that our subjects also rated S_2 , reporting it to be slightly greater than S_1 in loudness, and clearly louder than T_c . These facts suggest that for our subjects, and for those of Buytendijk and Meesters as well, the loudness of the first stimulus (T_c) was depressed, not (as they concluded) that the loudness of the second (S_1) was increased.

Before leaving this section we might note that all subjects expressed surprise when told that S_1 , the signal they had been judging for loudness throughout Experiments 1 and 4, had always been constant in intensity.

Experiment 5.

In Experiments 1 through 3, different subjects were exposed to each of the three paradigms; in Experiment 5 a given subject was exposed to all three paradigms in succession. The condition in which T_c is 90 dB and S_1 is 70 dB was selected, and 14 subjects were used. Six of these were tested as described under Methods. For the eight others the formal randomization procedure was not used, and most were asked to make only a single judgment in both the monaural and the binaural condition. Since the data from these eight were not distinguishable from those more formally obtained on the six, it was deemed proper to pool the results.

Results are shown in Fig. 5 which also replots the averaged data for Experiments 1, 2 and 3. The average loudness enhancements for the monaural, binaural, and dichotic conditions reported by the subjects in this experiment agree closely with those obtained in the previous experiments. (The 2.5 dB discrepancy between the dichotic values is largely due to the one subject in Experiment 3 who showed the most enhancement.)

Each subject experienced the least enhancement in the dichotic condition and ten of the fourteen experienced the most enhancement in the monaural paradigm. Thus, both the individual data and the averaged results of Experiments 1, 2, and 3 indicate that monaural presentation is the most effective, followed by binaural, with dichotic presentation the least effective. Using the binomial theorem to calculate the probability of obtaining such a result, one finds that dichotic presentation is significantly different from either monaural or binaural well beyond the .01 level, whereas the monaural-binaural difference obtains only at the .10 significance level.

Experiments 1 through 5 were designed to examine loudness enhancement phenomena in large numbers of naive subjects. Experiments 6 and 7 examine the phenomenon in greater depth with single subjects, highly experienced in making psychoacoustic judgments.

Experiment 6.

Experiment 6 is the same as Experiment 2 except that the influence of T_c is examined in 10 dB steps from 100 dB SPL to threshold.

S_1 is fixed at 70 dB. The data for one subject are shown in Fig. 6. The decrement in loudness noted in Experiment 2 when T_c is less intense than S_1 is more apparent here. This decrement reaches a maximum with T_c set at 50 dB and then decreases as threshold is approached. The subject adjusted S_2 in the absence of T_c close to the actual intensity of S_1 ; the difference between his judgments of S_1 loudness with T_c set at 50 dB and with T_c absent was significant beyond the .01 level. In 9 other subjects the decrement at the 50 dB T_c setting ranged from 0.5 to 5.5 dB, averaging nearly 3 dB; the U-shape of the curve in Fig. 6 was present in 8 of these cases (Elmasian et al, 1974).

Experiment 7.

Experiment 7 (monaural) fixed T_c intensity at 90 dB SPL and varied S_1 in 10 dB steps from 100 dB to 40 dB SPL. The subject's unmasked threshold for S_1 (i.e., no prior T_c) was 28 dB. Fig. 7 plots his loudness matches of S_2 to S_1 against actual S_1 intensity with and without T_c present. As S_1 intensity decreases, his S_2 setting that matches S_1 for loudness decreases at a very much slower rate with T_c present than with T_c absent. Thus, as S_1 intensity drops from 80 to 40 dB SPL, S_2 intensity drops only from 83.6 to 77.3 dB with T_c present, but from 80.75 to 41.5 dB with T_c absent. The loudness enhancement is therefore greatest near threshold and approximates 35 dB.

DISCUSSION

The data show that loudness enhancement is greater and intersubject variability less, when T_c and S_1 are presented to the same ear (monotic and binaural) as compared to when they are presented to opposite ears (dichotic). In spite of these differences the results can be summarized by a single generalization: listeners tend always to "misjudge" S_1 in the direction of the difference in physical intensity between S_1 and T_c . Thus when T_c equals S_1 in intensity, subjects report little or no change in S_1 loudness; when T_c is more intense they report S_1 loudness to be enhanced, and when T_c is weaker they report it to be reduced. The amount of this loudness enhancement or decrement increases (to a limit) 1) as the intensity difference between the two stimuli increases and 2) (from experiments already reported, Galambos et al, 1972; Zwislocki and Sokolich, 1974) as the interval between them, ΔT , decreases. While loudness decrement is rarely greater than 5 dB (e.g. Fig. 6), loudness enhancement can exceed 30 dB (e.g. Fig. 7), a significant portion of the dynamic range of the ear.

Because judgments of S_1 loudness follow T_c intensity so systematically, we must consider whether our subjects mistakenly judged T_c instead of S_1 . This hypothesis can, we believe, be rejected for several reasons that follow. It is well known (Hirsh, 1959) that subjects discriminate the order and identity of pairs of acoustic signals of this type separated by only 25 msec; this interval was a full 100 msec in the present experiments. Also, we carefully instructed our subjects before and during the experiments to avoid the

error in question; both the naive and the experienced among them produced similar data and expressed confidence they had made their judgments on the proper signal (see, for example, Exp. 4). Finally, unlimited opportunity to listen to the signals, and experience in doing so, does not eliminate the phenomenon. It appears, therefore, that the loudness enhancements and decrements reported here do not result from misinstruction of, or simple confusion by, the subjects.

The influence of mere propinquity upon the perception of stimuli has been studied in several modalities (e.g. hearing, vision, lifted weights). At the present time, different terminologies exist to deal with such data. For instance, what is called here "loudness-enhancement" is called by others a "negative time-error" (see Introduction). Similarly the "assimilation" reported by Cross (1973) is perhaps equally well described as a 4 dB loudness decrement in a 95 dB 1 sec noise burst that followed a similar 55 dB burst by 7.5 seconds in his studies. And what Stevens (1957) called "hysteresis" - the fact that subjects shift loudness bisection judgments toward the most recently presented stimulus of the pair to be bisected - could well be another word used to deal with one of this group of related phenomena whose interrelationships remain to be worked out. Loudness enhancement, we believe, is the end result of both sensory and cognitive interactions. In this connection the effort of Zwislöcki and his colleagues (Zwislöcki et al, 1974; Zwislöcki and Sokolich, 1974) to differentiate loudness enhancement from loudness summation (or "assimilation"?) is a laudable step in the direction of separating these variables.

Loudness enhancement experiments are also obviously related to

temporal and partial masking experiments. As in temporal masking studies, we have here examined the influence of a masker (T_c) on the perception of a target (S_1) presented a short time later. As in partial masking studies we had our subjects make suprathreshold judgments of target loudness. From the standpoint of the masking literature, loudness enhancement experiments are therefore also temporal partial masking studies. As in temporal masking, we have found that the masker (T_c) has more influence when presented to the same ear as the target (S_1) and less when presented to the opposite ear. However, unlike simultaneous partial masking studies (e.g. Hellman and Zwislocki, 1964), we found that increasing T_c intensity results in increased, not decreased S_1 , loudness.

The neural mechanisms by which stimulus propinquity influences perceptual judgments about them is unknown. In general descriptive terms the brain events created by T_c in our study must overlap and interact with those created by S_1 , an interaction which in some manner alters the perception of them both. In the time error literature the word trace denotes this hypothetical sequence of the brain events induced by T_c ; further, this trace is said to fade with time, and attentive set controls its fading and magnitude in important ways (Woodworth and Schlasberg, 1954).

In an effort to provide evidence for hypotheses such as "trace" and "fading", we have performed electrophysiological studies in both cats (Bauer and Galambos, 1975) and man (Bauer et al, 1975). At the level of the brainstem in both species T_c does not increase the neural response to S_1 in stimulus situations where the loudness of S_1

is significantly enhanced for human listeners: the evoked response to S_1 is, in fact, either unchanged or slightly depressed. The proposition that in man, the enhanced loudness of S_1 can be correlated with a corresponding increase in amplitude of the cortical evoked response (100-500 msec post-stimulus) must also be answered negatively; the S_1 evoked response can actually be totally suppressed in those situations where its loudness is maximally enhanced (Bauer, 1974).

Many questions regarding the perceptual and physiological mechanisms involved when two similar signals occur closely together in time obviously remain to be answered. Further study of the situation described here, where loudness bears such unusual relationships to signal intensity, will undoubtedly provide useful clues not only to the way loudness perceptions are encoded, decoded, and interpreted, but also to the general problem of how any two closely spaced stimuli interact in perception.

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TABLE 2

Experiment IV

Ratings of the relative loudness of T_c , S_1 , and S_2 with three conditions of T_c (90, 70, 60 dB SPL) and S_1 and S_2 fixed at 70 dB SPL. Subjects rated loudness 1, 2 or 3, with 3 the loudest; ties were averaged. All signals binaural.

SUBJECT	<u>$T_c = 90$ dB</u>		<u>$T_c = 70$ dB</u>		<u>$T_c = 60$ dB</u>	
	<u>T_c</u>	<u>S_1 S_2</u>	<u>T_c</u>	<u>S_1 S_2</u>	<u>T_c</u>	<u>S_1 S_2</u>
1	3	2 1	2 2	2 2	3	1.5 1.5
2	3	1 2	1 2	3 3	1	2 2
3	2	3 1	1 3	2 2	1	2 3
4	3	2 1	2 2	2 2	1.5	1.5 3
5	3	2 1	1 2	3 3	2	2 2
6	3	2 1	1.5 1.5	3 3	1	2 3
7	3	2 1	1 3	2 2	1	3 2
8	3	2 1	1 2	3 3	3	1.5 1.5
SUM	23	16 9	10.5 17.5	20 20	13.5	15.5 19
APPROX. MEAN	2.9	2.0 1.1	1.3 2.2	2.5 2.5	1.7	2.0 2.4

FIGURE LEGENDS

1. Diagrams showing signal presentation to the two ears for the binaural (a), monaural (b), and dichotic (c) paradigms.
2. Expt. 1, stimuli binaural. Separate lines: S_2 intensity selected by each of 8 subjects as matching the loudness of S_1 (70 dB SPL throughout). Right ordinate: actual setting of S_1 ; left ordinate, difference in dB between S_1 and S_2 . Squares: average of all data.
3. Expt. 2, stimuli monaural. Details as in Fig. 2.
4. Expt. 3, stimuli dichotic. Details as in Fig. 2.
5. Expt. 5, loudness enhancement in 14 subjects tested at $T_c=90$ dB and S_1 at 70 dB. M, B, D: average enhancement experienced by the subjects in the monaural, binaural and dichotic paradigms, respectively. Circles, squares, crosses; mean data obtained in Expts. 2, 1 and 3, respectively.
6. Expt. 6, loudness enhancement and decrement for one subject. Monaural paradigm, S_1 at 70 dB. Subject's unmasked threshold (T on abscissa) was 28 dB SPL. Bars indicate range of the data.
7. Expt. 7, monaural loudness matches by one subject. Squares: S_2 match to S_1 with T_c absent; circles: same with T_c set at 90 dB. The difference between the two curves is the amount of loudness enhancement.

TABLE 1 FOR EXPERIMENTS 1, 2 AND 3

ANALYSIS OF VARIANCE

Source	df	Mean Square			F*		
		Exp. 1	Exp. 2	Exp. 3	Exp. 1	Exp. 2	Exp. 3
T _c level	4	1218.39	1561.67	391.08	72.17	161.68	10.79
Subjects	7	99.53	25.42	264.08	23.19	7.07	60.62
Subjects w/ T _c	28	16.88	9.66	36.37	3.93	2.69	8.35
**Error	80	4.29	3.60	4.36			

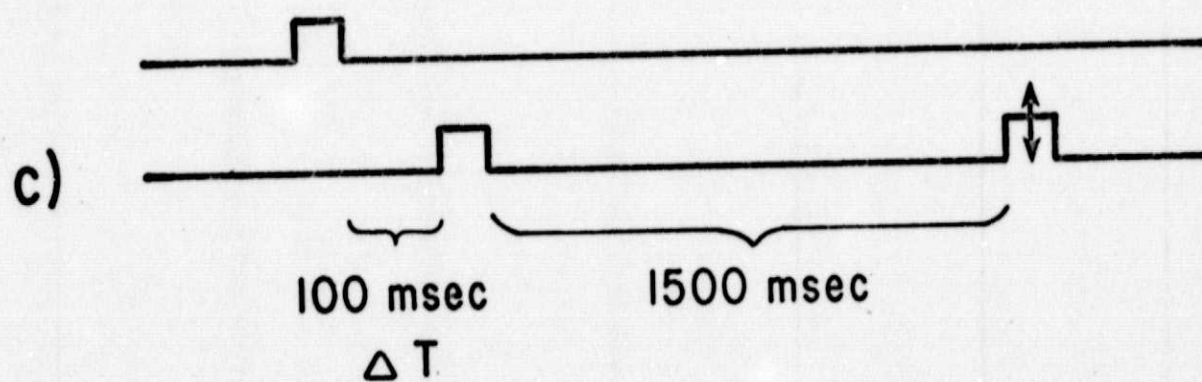
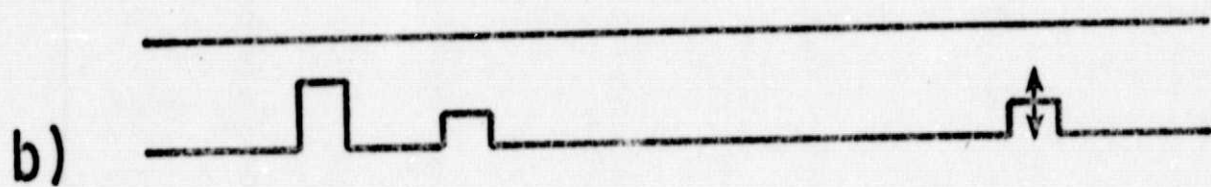
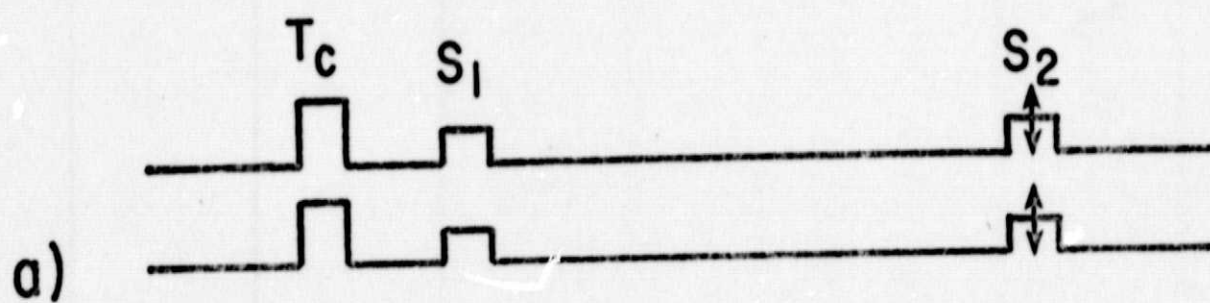
*All F's are significant beyond .01 level.

** $\sqrt{\text{Error}}$ is 2.07, 1.90 and 2.09 for Experiments 1, 2 and 3, respectively.

BIBLIOGRAPHY

- Bauer, J.W. (1974). The electrophysiological correlates of loudness enhancement. Ph.D. thesis, University of California, San Diego.
- Bauer, J.W., Elmasian, R.O. and Galambos, R. (1975). Loudness enhancement in man. I. Brainstem evoked response correlates. J. Acoust. Soc. Amer. 57:165-171.
- Bauer, J.W. and Galambos, R. (1975). Evoked potentials in cat auditory nerve: suppression by prior tonal stimulation. Percept. Psychophys. 17:43-47.
- Buytendijk, F.J.J. and Meesters, A. (1942). Duration and course of the auditory sensation. Comments Pontif. Acad. Sci. 6:557-576.
- Cross D.V. (1973). Sequential dependencies and regression in psychophysical judgments. Percept. Psychophys. 14:547-552.
- Elmasian, R.O., Bernheim, A. and Galambos, R. (1974). Loudness decrement: monaural and dichotic, forward and backwards. J. Acoust. Soc. Amer. 55: 449 (A).
- Fechner, G.T. (1860). Elemente der psychophysik (Brietkopf and Harterl, Leipzig). English transl. of Vol. 1 by H.E. Adler (D.H. Howes and E.G. Boring, Eds.). Holt, Rinehart and Winston (1966). pp. 7²-77.
- Galambos, R., Bauer, J., Picton, T., Squires, K. and Squires, N. (1972). Loudness enhancement following contralateral stimulation. J. Acoust. Soc. Amer. 52:1127-1130.

- Gol'dburt, S.N. (1964). Discrimination between the order and loudness of two short tones in relation to their duration and the interval between them. Fed. Proc. 23: T1206-T1210.
- Hellman, R.P. and Zwislocki, J.J. (1964). Loudness function of a 1000 cps tone in the presence of a masking noise. J. Acoust. Soc. Amer. 36: 1618-1627.
- Hirsh, I.J. (1959). Auditory perception of temporal order. J. Acoust. Soc. Amer. 31:759-767.
- Irwin, R.J. and Zwislocki, J.J. (1971). Loudness effects in pairs of tone bursts. Percept. Psychophys. 10:189-192.
- Needham, J.G. (1934). The time-error as a function of continued experimentation. Amer. J. Psychol. 46:558-567.
- Postman, L. (1946). The time-error in auditory perception. Amer. J. Psychol. 56:193-219.
- Stevens, S.S. (1957). On the psychophysical law. Psychol. Rev. 64:153-181.
- Woodworth, R.S. and Schlosberg, H. (1954). Experimental Psychology (Revised Ed.), Holt, Rinehart and Winston, New York.
- Zwislocki, J.J., Ketkar, I., Cannon, M.W. and Nodar, R.H. (1974). Loudness enhancement and summation in pairs of short sound bursts. Percept. Psychophys. 16:91-95.
- Zwislocki, J.J. and Sokolich, W.G. (1974). On loudness enhancement of a tone burst by a preceding tone burst. Percept. Psychophys. 16:87-90.



BINAURAL

