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OF SIGNAL INTENSITY AND MASKING NOISE
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SELECTIVE ATTENTION AND THE AUDITORY VERTEX POTENTIAL

II: EFFECTS OF SIGNAL INTENSITY AND MASKING NOISE¹

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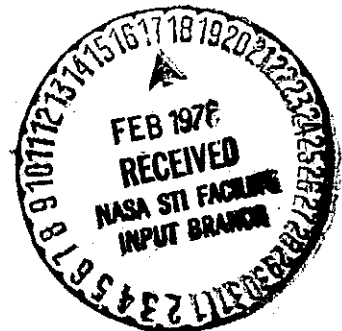
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SELECTIVE ATTENTION AND THE AEP

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Recent studies by Hillyard et al. (1973) and Schwent and Hillyard (1975) have demonstrated that the amplitude of the N_1 wave of the auditory vertex potential can reflect the distribution of selective attention among competing channels of tonal stimuli, over and above any influences of non-selective arousal or alertness factors. In the preceding report (Schwent et al. 1976a), it was shown that a rapid rate of stimulus delivery (i.e., a high information load) is essential for producing reliable alterations in the N_1 wave when attention is shifted from one auditory channel to another. The magnitude of this attention-related N_1 enhancement, however, was considerably smaller in the Schwent et al. (1976a) study, which used 60 dB SL tone pips, than in either of the aforementioned studies, which used 50 and 45 dB SL tones, respectively. This suggested that stimulus intensity might be a crucial variable in determining the lability of the auditory evoked potential (EP) to shifts of attention. Indeed, in a number of studies which failed to obtain reliable attention effects upon N_1 , relatively high stimulus intensity levels were employed (eg. Hartley 1970; Smith et al. 1970; Wilkinson and Lee 1972). The present study is accordingly designed to make a direct comparison of selective attention effects on the auditory N_1 wave under conditions of low and high tone intensities.

Several lines of evidence suggest that the addition of background white noise to the channels of tone information would

make for an even greater attentional enhancement of the auditory N_1 wave. First, in studies where subjects detected 1000 Hz tone pips that were just barely discernable against a noise background (Hillyard et al. 1971; Squires et al. 1973), marked enlargement of N_1 occurred when attention was shifted from a reading task to the tones; these studies were not controlled for shifts in non-selective alertness or arousal, however, since EPs were recorded only to the one channel of tones (Näätänen 1967). Secondly, addition of a background noise which makes the stimuli more difficult to discriminate should result in greater processing efforts and lend an additional degree of selectivity to the distribution of attentional capacity among the input channels (Hillyard et al. 1973). Thirdly, psychophysical studies by Hockey (1970 a,b) indicate that a noise background can increase the selectivity of attention by a different mechanism, perhaps by altering subjects' arousal levels. Accordingly, the present study compared the effects of attention on N_1 under conditions where tone pips were presented alone (at 20 and 60 dB SL) and when white noise was added to make the tones barely above the threshold of detectability.

Because of the use of threshold level tones, subjects were not asked to make difficult pitch or duration discriminations as in previous studies but were asked simply to count the total number of tones in a designated channel. Use of this

simplified task will test whether or not the "target-detection" paradigm used heretofore (Hillyard et al. 1973; Schwent and Hillyard 1975; Schwent et al. 1976a) is a mandatory requirement for the modification of N_1 . Finally, since Schwent and Hillyard (1975) demonstrated that multiple channels of stimuli maximized the attentional changes in N_1 , the present study employed three spatially distinct channels of tone pips.

METHODS

Subjects

Ten normal young adults served as paid volunteer subjects. Five were laboratory personnel and five were inexperienced student recruits.

Stimuli

Acoustic stimuli were presented through a stereo headset while the subjects reclined comfortably in a sound-attenuated chamber (Industrial Acoustics). Tone pips of 50 msec duration (5 msec rise and fall times) were delivered over three spatially separated "channels": 2000 Hz tones were presented to the left ear, 1000 Hz tones to the right ear, and 4000 Hz tones to both ears at equal intensity to produce a subjective localization in the center of the head. The sequential order of presentation of the right, left and center tones was randomized (Bernoulli distribution with each channel equiprobable). The inter-stimulus

intervals (ISIs) between successive tones were also randomized with a mean ISI of 333 msec (range 200-1500 msec³), giving an average ISI within each channel of 1.0 sec. A five minute segment of this stimulus sequence containing approximately 300 tones per channel was pre-recorded on a 4-channel audio tape, so that all subjects would receive identical stimuli.

Two tone intensities ("loud" and "soft") were employed in separate experimental conditions. In the "loud" tone condition, the 4000 Hz (center) tones were set at 60 dB SL (sensation level, above a subject's absolute threshold for those tones), and the right and left tones intensities were then adjusted until they matched the center tones in loudness. In the "soft" tone condition, the center tones were set at 20 dB SL, with the others then matched to the center tones in loudness. On separate runs the tones were presented at each of these two intensity levels and with or without a binaural white noise background, giving four basic stimulus conditions. In preliminary runs for each subject, the intensity of the background noise was increased to the highest level at which the subject was still able to detect 100% of the tones in each channel. Thus, for loud tones considerably more noise had to be added to make them just barely "supra-threshold" than for the soft tones.

Procedure

On each run the subject was instructed to count the number of tones in one of the three channels and to ignore the other

tones; subjects registered their count by pressing a button after every tenth tone. Over the course of the experiment each subject paid attention to only two of the three channels, in order to reduce the total experimental time and subject fatigue. Over the course of the study then, each channel was attended by 6 or 7 subjects.

There were, therefore, a total of eight experimental conditions: attention directed to one of two channels, tone intensity loud or soft, and white noise present or absent. Each of the eight conditions was run twice, using the first 2.5 minutes of the taped stimulus sequence for the first run and the second 2.5 minutes for the replication. Each subject thus received sixteen 2.5 minute runs, each followed by a two minute rest period. The order of the experimental conditions, including channel attended, stimulus intensity, and noise presence were counter-balanced across and within subjects, insofar as was possible, to minimize possible order effects.

Recording System and Data Analysis

Cerebral potentials were derived from a central scalp (vertex) electrode referred to the right earlobe, amplified with a Grass 7P5 pre-amplifier (bandpass down 3 dB at 0.3 and 500 Hz), and recorded on FM magnetic tape for off-line signal averaging with a Nicolet 1072 computer. The vertical EOG was also recorded and averaged to guard against possible electro-ocular contaminants.

Separate EPs were averaged over 128 tone pips of each run for each of the three sound sources (one attended, two ignored). The EPs from replicate runs were summed to yield an averaged waveform containing 256 individual responses. The amplitude of the N_1 wave (90-160 msec) was quantified for each waveform with respect to its initial 20 msec average "baseline" voltage and with respect to the peak amplitude of the preceding P_1 wave (30-80 msec). Changes in the N_1 amplitude with shifts of attention were measured by two different methods. For each of the two attended channels of each subject and under each of the four noise-intensity combinations, an "attention coefficient" was calculated from the N_1 amplitudes as follows:

$$\text{Attention coefficient} = \frac{N_1 \text{ (attended)} - N_1 \text{ (non-attended)}}{1/2 \left[N_1 \text{ (attended)} + N_1 \text{ (non-attended)} \right]}$$

From the same values a "percent enhancement" score was also determined:

$$\text{Per Cent Enhancement} = \left(\frac{N_1 \text{ amplitude (attended)} - N_1 \text{ (non-attended)}}{N_1 \text{ (non-attended)}} \right) \times 100\%$$

These scores were averaged across subjects for equivalent conditions of noise and intensity, and deviations of the scores from zero were assessed by a Wilcoxon signed ranks test over all subjects.

RESULTS

Figure 1 illustrates the typical effect of selective

attention upon the N_1 waves evoked by one channel of tones, in this case by the 4000 Hz tones localized to the center of the head. In the low intensity (soft) condition, attending to the center tones (solid lines) greatly enhanced the N_1 wave in comparison to when attention was shifted to another channel of tones (dotted lines). This attentional enhancement of N_1 was not so marked for the loud tones, however, and was small or absent for the loud tones presented without noise. Figure 1 also shows that the peak latency of N_1 is increased considerably by the addition of masking noise at both intensities from: 90-120 msec (top tracings) to 130-160 msec (lower tracings).

INSERT FIGURE 1 HERE

Looking at the mean N_1 amplitudes and attention effects over all subjects for each condition (Table I), it is evident that little attentional enhancement of N_1 (15.5%, $p < .05$) occurs with the high intensity tones presented alone. Reducing the stimulus intensity and/or adding white noise, however, results in substantial increases in the attention-related enhancement of N_1 . In Table I the mean per cent enhancement scores and attention coefficients were first averaged over both attended channels for each subject and then over all subjects; the p values result from Wilcoxon tests of the null hypothesis that these coefficients are zero. Table II presents these N_1 amplitudes separately for each stimulus channel and attention condition. There were no significant differences between the three

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channels in the magnitude of the attention-related changes. The highly selective nature of the N_1 enhancement is illustrated by the similar decrements in amplitude for both in-attend conditions for a given channel.

INSERT TABLE I HERE

To examine the overall effects of stimulus intensity, a Wilcoxon test was performed on the within-subjects pairs of attention coefficients for loud and soft conditions collapsed over both noise conditions; the attentional enhancement of N_1 proved to be larger for soft stimuli ($p < .05$). Similarly, a Wilcoxon test performed on the pairs of attention coefficients for the effect of noise confirmed that the N_1 enhancement was greater with background noise ($p < .05$).

INSERT TABLE II HERE

DISCUSSION

As in previous reports from this laboratory (Hillyard et al. 1973; Schwent and Hillyard 1975), the N_1 component of the auditory vertex potential elicited by a "channel" of tone

bursts was found here to be incremented in amplitude when attention was focused upon that channel in relation to when competing auditory channels were attended. The magnitude of this attention-related variation in N_1 was found to be greater for low intensity tone bursts (ca. 20 dB SL) than for louder tones (ca. 60 dB SL), other factors being equal. The N_1 evoked by the louder tones was increased in amplitude by an average of 16% (marginally significant) when attention was shifted to the evoking channel. This enhancement was similar in magnitude to that obtained in the previous report (Schwent et al. 1976a) which also employed 60 dB tone bursts with similar ISIs. The less demanding attentional task (simple counting) may have contributed to the slightly smaller attention effect on N_1 in the present study (16% vs. 20%).

It is evident from the low intensity and noise-added conditions, however, that the simple counting task can result in an N_1 enhancement as great as with the difficult "target detection" tasks used in the studies cited above. This is consistent with the proposal (Hillyard et al. 1973) that N_1 amplitude indexes a "stimulus set" mode of attention whereby stimuli are selected for or rejected from further processing (counting in this case) on the basis of their "channel" of origin, defined in the present study by pitch and spatial location attributes.

These results suggest that the absence of substantial attention-related variation in the auditory vertex potential in some earlier reports, may, in part, have developed from the

relatively loud intensities used (Hartley 1970; Smith et al. 1970; Wilkinson and Lee 1972). The latter two studies are of particular interest, since they used fairly short ISIs which greatly facilitate the attentional enhancement of N_1 (Schwent et al. 1976a). Wilkinson and Lee did, in fact, find a somewhat larger attention-related enhancement of the N_1 - P_2 measure for 61 dB tones ($3.0\mu V$) than for 78 dB tones ($1.9\mu V$), but a statistical evaluation of the intensity effect was not reported. The results of these and other selective attention studies on the auditory vertex potential are plotted in Figure 2 as a function of the critical variables of stimulus intensity and ISI. Findings of little or no attentional enhancement (N.S.) are seen to have been obtained when louder intensities (above 60 dB SL) and/or longer ISIs were used, while the greatest enhancements occur in conjunctions with the shortest ISIs and lower intensities. While perhaps having some heuristic value, this analysis is not completely rigorous, since the different studies varied widely in their stimulus characteristics and task requirements; more over, some of the studies did not report a useful measure of stimulus intensity (indicated by question marks on Fig. 2), and others had a moderate amount of white noise in the background (Hartley 1970; Wilkinson and Lee 1972). Finally, no information is yet available concerning how far the "attention zone" for N_1 extends as a function of ISI duration at very low intensities.

INSERT FIGURE 2 HERE

The reduced effect of selective attention with the louder tones might be interpreted simply as an inability of the selection mechanism to "filter" or exclude intense sensory information. An alternate explanation, however, is that N_1 amplitude "saturates" or reaches a "ceiling" as stimulus intensity is raised in the vicinity of 60 dB (cf. Picton et al. 1970, Fig. 8). If one assumes that selective attention and intensity variations modulate a common N_1 generator via similar mechanisms, no further enhancement would be possible at stimulus intensities which are already driving the N_1 generator at its maximum output; moreover, a "saturated" N_1 generator might also be less responsive to diminution by shifts of attention, if the intensity-amplitude function had a "plateau" at that intensity. Such a physiological ceiling hypothesis could also be invoked to account for the effects of background noise on the attentional modulation of N_1 . The addition of background noise has been shown to reduce the vertex potential markedly as a tone is masked to near threshold levels (Davis and Zerlin 1966). Assuming that this masking of N_1 takes place at a peripheral input stage (e.g., at the cochlea), the level of activation of the N_1 generator would be lowered from the ceiling and again become labile to attentional enhancement. On the other hand, the noise may simply reduce the magnitude of the centrally transmitted signal, thus making irrelevant inputs more vulnerable to the "filter" mechanism.

Recent theoretical approaches to selective attention

phenomena emphasize that the amount of "attentional capacity" or "effort" that can be applied to a task is necessarily limited, so that commitment of these "processing resources" to one stimulus source limits the amount available for others (Kahneman 1973; Norman and Bobrow 1975). In this framework, it would seem that adding background noise in our tone detection task would influence the selectivity of processing in the same fashion as when the rate of stimulus delivery is increased (ISIs decreased). With the tones barely above the threshold of detectability in noise, more processing resources must be committed to the attended channel to achieve a high level of performance, leaving fewer resources available to deal with the irrelevant channels. Increasing the rate of stimulation would similarly demand more resources or effort and increase the differential allocation between attended and irrelevant inputs. If the N_1 component is indeed an index of the differential distribution of attentional capacity among competing input channels (Hillyard et al. 1973), any factor which increases the difficulty of the detections, discriminations, or identifications in one channel should increase the N_1 amplitude differential between attended and unattended channels.

SUMMARY

A randomized sequence of tone bursts was delivered to subjects at short inter-stimulus intervals (mean ISI of 333 msec),

with the tones originating from one of three spatially and frequency-specific channels. The subject's task was to count the tones in one of the three channels at a time, ignoring the other two, and press a button after each tenth tone. In different conditions, tones were given at high (60 dB SL) and low (20 dB SL) intensities and with or without a background white noise to mask the tones. The N_1 component of the auditory vertex potential was found to be larger in response to attended-channel tones in relation to unattended tones. This selective enhancement of N_1 was minimal for loud tones presented without noise and increased markedly for the lower tone intensity and in noise-added conditions. The selectivity of attention as measured physiologically in this multichannel listening task was thus greater when tones were faint and/or difficult to detect.

FOOTNOTES

1. This work was supported by NIH Grant MH 25594-01 to Steven A. Hillyard and NASA Grant NGR 05-009-198 to Robert Galambos and was conducted while Vincent Schwent held a NSF Fellowship. Address reprint requests to the second author.
2. Present address of Dr. Vincent Schwent, University of California, San Francisco, Department of Orthopaedic Surgery, San Francisco, California 94143.
3. The skewed temporal distribution of the stimuli in this study originated with a single computer-generated train of voltage spikes having a rectangular distribution of ISIs from 200-300 msec. The triggers from this single track were divided at random on to four tape recorded tracks (p=.25 for each channel). The triggers from three of these tracks was then used to generate the interval structure of the three tone sequences. Thus, while the minimum ISI between successive stimuli remained at 200 msec, occasional "runs" of triggers in the discarded train resulted in the ISIs over the remaining three sequences become as large as 1500 msec.
4. The paper by R. Hink and S. Hillyard, entitled "Auditory Evoked Potentials During Selective Listening to Dichotic Speech Messages" has been submitted for publication in Behavioral Biology.

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TABLE 1

Effects of noise, stimulus intensity, and attention on mean N_1 amplitude ($\mu V \pm S.E.$) and on the derived attention scores.

		Baseline- N_1	P_1-N_1
No Noise	Attended	4.76 0.37	5.31 0.56
	Non-Attended	4.22 0.51	4.44 0.54
	Percent Enhancement	15.5 8.3%	13.5 9.4%
	Attention Coefficient	(.231 .114)*	(.176 .096)
Noise	Attended	3.17 0.39	3.90 0.51
	Non-Attended	1.91 0.29	2.87 0.32
	Percent Enhancement	41.8 10.5%	21.1 7.6%
	Attention Coefficient	(.490 .144)**	(.236 .080)*
No Noise	Attended	3.78 0.40	4.46 0.44
	Non-Attended	2.34 0.27	2.78 0.33
	Percent Enhancement	51.3 7.2%	56.7 5.2
	Attention Coefficient	(.479 .096)***	(.458 .076)***
Noise	Attended	3.27 0.39	4.01 0.32
	Non-Attended	1.84 0.27	2.62 0.33
	Percent Enhancement	73.6 6.8%	53.6 7.1%
	Attention Coefficient	(.617 .107)***	(.465 .091)***

Significance levels (Wilcoxon)

* .05
 ** .005
 *** .0005

TABLE II

Mean baseline- N_1 amplitudes (in $\mu V \pm S.E.$) for each channel, attention condition, and stimulus condition

Evoking Stimulus Channel

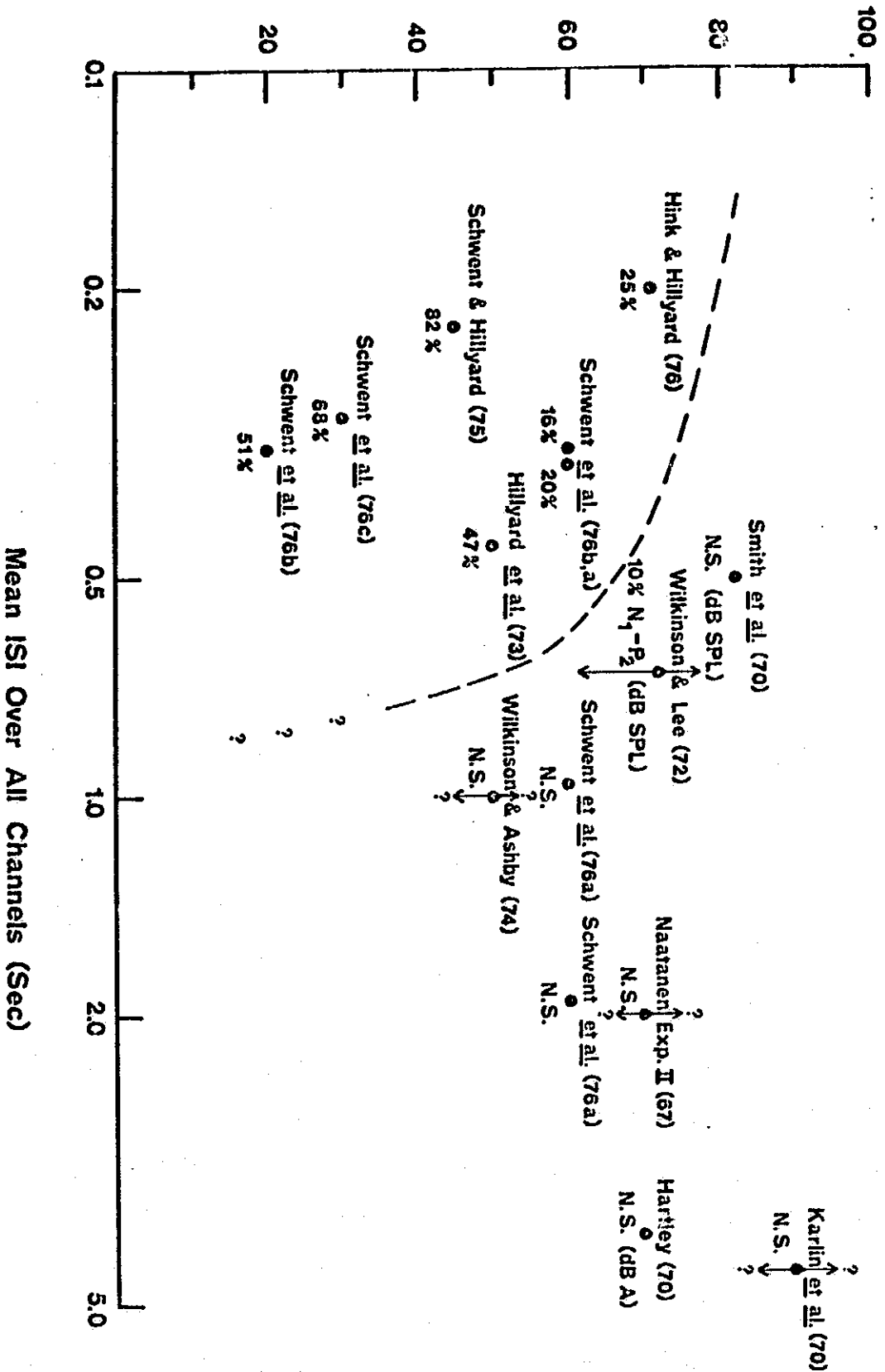
		Attended Channel	2KHz (Left)	4KHz (Center)	1KHz (Right)
No Noise	2KHz (Left)		5.16±0.64	3.55±0.96	4.27±1.48
	4KHz (Center)		4.35±1.45	4.39±0.37	4.37±1.61
	1KHz (Right)		5.39±1.65	3.58±1.28	4.73±0.94
Loud	Noise	2KHz	2.76±0.60	0.52±0.16	2.78±0.80
		4KHz	2.16±0.83	3.44±0.64	2.59±0.67
		1KHz	2.41±0.64	1.38±0.67	3.32±0.90
No Noise	2KHz		4.32±0.83	2.27±0.71	2.09±0.61
	4KHz		2.24±0.27	3.23±0.83	2.25±1.06
	1KHz		2.99±0.73	2.26±0.52	3.85±0.40
Soft	Noise	2KHz	3.33±0.39	1.93±0.73	2.33±0.89
		4KHz	1.45±0.20	3.61±0.93	2.41±0.97
		1KHz	1.26±0.24	1.56±0.66	2.87±0.59

FIGURE LEGENDS

Figure 1: Evoked responses of subject E.S. demonstrate the typical effects of attention upon the N_1 . The N_1 s to 4000 Hz tones (center of head) were larger in amplitude when those tones were attended (solid lines) than when they were ignored and 1000 Hz tones (right ear) were attended (dotted lines). This attention-related enhancement of N_1 was absent for the loud tones presented without noise.

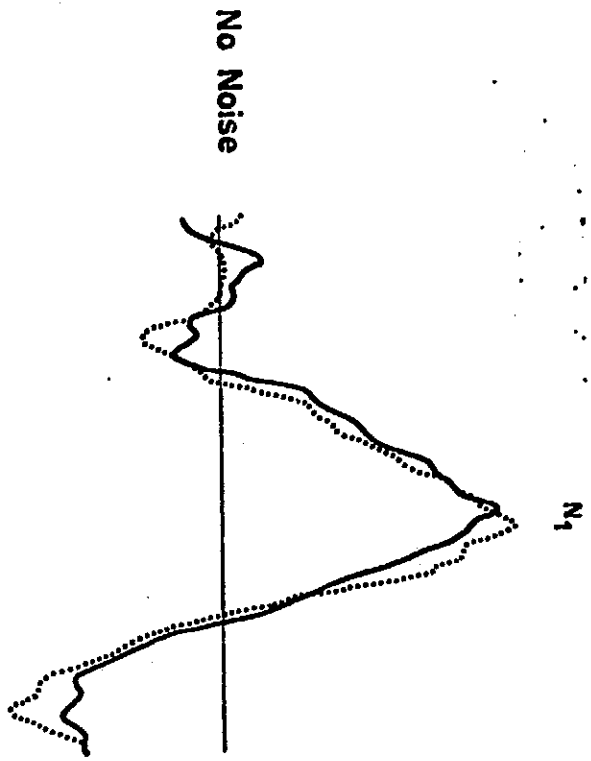
Figure 2: Studies which have attempted to relate the auditory N_1 component to selective attention are plotted as a function of their stimulus intensities (db SL, unless otherwise noted) and mean interstimulus intervals (ISI) used.⁴ To the left of the dotted line is an "attention zone" of shorter ISI's and fainter stimuli where selective listening produced a significant N_1 modulation (given in % enhancement) with attention. To the right of this roughly-placed line, non-significant (N.S.) effects on N_1 were the rule.

Stimulus Intensity (dB)

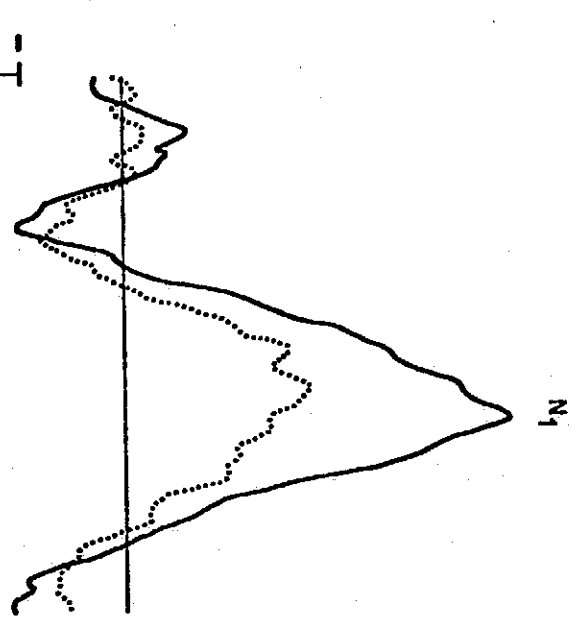


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Loud

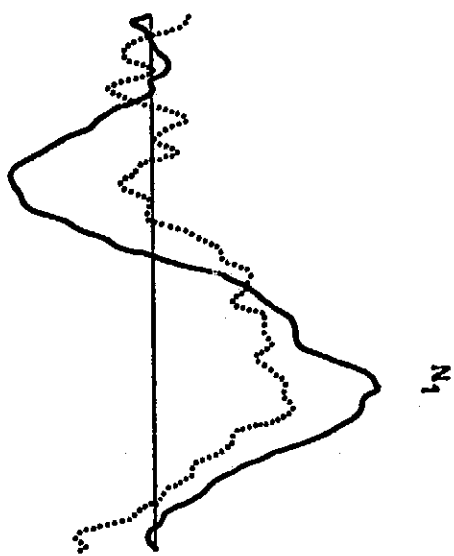


Soft



5μV
-
+

Noise



Time (msec)

