AVERAGE EVOKED CORTICAL POTENTIALS AS AN ELECTROPHYSIOLOGIC APPROACH TO THE STUDY OF TEMPORAL INTEGRATION

by

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ABSTRACT

This study attempted to examine the feasibility of using averaged evoked cortical potentials as a means of electro-physiologically studying temporal integration of acoustic energy. The hypothesis was that a linear relationship exists between the amplitude of the evoked response and the log of stimulus duration in milliseconds up to 200 msecs.

The testing of the hypothesis was carried out by measuring the peak to peak amplitudes of the averaged evoked response to 1000 cps tones presented at 6 different durations, and at 3 different refractory periods, and plotting these amplitudes against the corresponding stimulus durations. Such functions were derived for six subjects.

The results indicated that electro-physiologic evidence for temporal integration is not apparent. Possible reasons for the lack of evidence and suggestions for future research in this area are presented.

INTRODUCTION

The phenomenon of loudness has been of keen interest to many researchers in the field of auditory acoustics, and a perusal of the experimental literature would attest to this fact. Loudness has been defined (Davis and Silverman, 1960, p. 53) as the psychological attribute of sound that is most closely related to intensity. In general, as the intensity of the sound increases, the loudness of that sound also increases.

While many studies have been concerned mainly with the relationship between loudness and intensity, there also has been a long and continued interest in the relationship between stimulus duration and loudness. In 1929, Bekesy published data showing that loudness increased as the stimulus duration was increased. Studies subsequent to that of Bekesy (Hughes, 1946; Munson, 1947; Garner and Miller, 1947; Miller, 1948; and Dallos and Olsen, 1965) have substantiated the general relationship between loudness and duration observed by Bekesy. All of these studies indicated that (1) loudness increased with increases in signal duration and (2) in a comparison of loudness between two identical stimuli of equal intensity but of differing durations, the stimulus having the longer duration will appear louder.

From these two relationships between intensity and loudness, and duration and loudness, a third and important relationship follows. This third relationship is the trading relationship between time and intensity. By time-intensity trade it is meant that a constant loudness can be maintained for a signal with a diminishing intensity, simply by increasing the signal duration correspondingly. Mathematically, the relationship can be expressed by the simple equation,

$$T \times I = C$$

where T = a time value, I = intensity value, and C = a constant, e.g., loudness.

In applying this equation to loudness, one can see that it is possible to achieve a constant loudness for two tones of different intensity by altering their durations of stimulation.

The observations on time-intensity trading relationship and loudness growth have prompted researchers to make inferences about the underlying mechanism in the auditory system which could account for these phenomena. Certainly, the mechanical elements of the auditory system could not account for the loudness growth over duration and the trading between time and intensity, because the eardrum, ossicles and mechanical parts of the cochlea are known to be highly damped and would reach a maximum (Munson, 1947, p. 586). Therefore,

the only other alternative rests with the neural mechanism of the auditory system.

The brilliant work of Galambos and Davis (1943) has provided invaluable insight into the neural mechanism of loudness growth as a function of intensity and time. As a result of their study, it is believed, with considerable confidence, that the growth of loudness which accompanies an increase in the intensity of the stimulus is the consequence of two major changes in the response of the neural elements (Munson, 1947, p. 586). When a sound impinges upon the ear, the sensory cells in the cochlea initiate a series of impulses. These pulses are propagated along the eighth nerve fibers to the central nervous system (CNS) and signal the brain of the presence of a stimulus. When the intensity of the stimulus is increased, the rate at which these pulses are propagated increases and additional sensory cells are activated. These two changes, the increased rate at which pulses arrive at the CNS, and the arrival of pulses over additional nerve fibers, are the known neurological correlates for the increased loudness sensation experienced. "It seems essential, therefore, if the CNS is to make full use of the information coming to it from the peripheral organ, that there should exist an integrating mechanism for counting the pulses as they arrive" (Munson, 1947, p. 586). While the nature and location of the integrating mechanism is still obscure,

the existence of one seems mandatory for explaining duration time and intensity trading relationships. Therefore, it might be of value at this point to discuss a theoretical model of a neural integrating mechanism. Such a model will demonstrate how observations of time-intensity trade are possible.

Theoretical Model of a Neural Integrator

The neural integrator in the auditory system works on the principle of a counter. This counter has many input channels (sensory nerve fibers) over which electrical impulses arrive. The counter simply counts the pulses coming over each of the channels activated by the stimulus. The total number of pulses counted represents the magnitude value (loudness) of the stimulus. When the stimulus intensity is low, few channels are activated and the pulse rate over these channels is low. With a higher intensity stimulus, more channels are activated and the pulse rate increases. For example, assume that stimulus A is of a low intensity and that it activates five (5) channels with a pulse rate of one pulse per ten (10) msecs. If the duration of stimulus A is ten (10) msecs, then the counter will count a total of five (5) pulses--one pulse from each of the five channels (Fig. 1). Now, assume that a second stimulus, stimulus B, is of a higher intensity and that it activates ten (10) channels with a pulse rate of two pulses per ten (10) msecs. If the duration of stimulus B is also

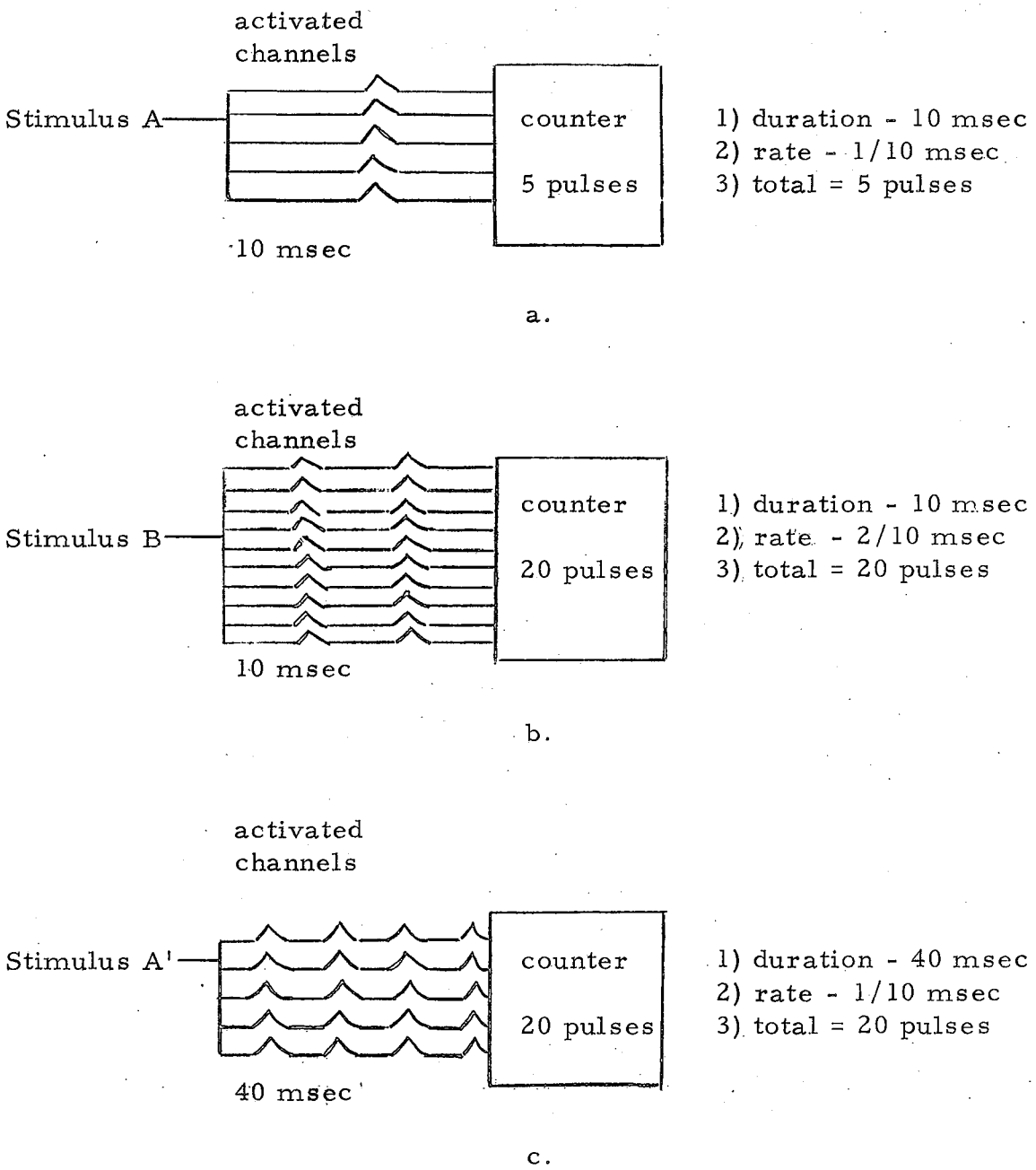


Fig. 1.--The Neural Integrator: Modeled After a Counter to Demonstrate Time-Intensity Trading.

ten (10) msecs, the counter will count twenty pulses--two pulses from each of the ten channels (Fig. 1b). Without changing the intensity of stimulus A, how would it be possible for stimulus A to have a total magnitude value equivalent to stimulus B? In order for stimulus A to achieve a total magnitude value of twenty pulses at a pulse rate of one pulse per ten msecs, the duration of stimulus A would have to be forty (40) msecs. In forty msecs, the counter will count four pulses from each of the five channels activated by stimulus A (Fig. 1c). Therefore, it is possible to attain equal magnitude values for both stimuli A and B by simply altering their duration of stimulation.

The Neural integrator model just mentioned will not, perhaps, explain all time-intensity trade phenomena. In auditory acoustics, the time-intensity relationship also involves transmission speed which is related to stimulus intensity. The responses to more intense stimuli travel the neural auditory pathways at speeds greater than those responses elicited by a stimulus of lesser intensity. The main effect on the speed probably occurs at the synapses of the nerve fibers. Thus, arrival time at the CNS of the eighth nerve response to acoustic stimulation can be varied by varying the intensity of the stimulus. Although the neural integrator model presented here does not truly explain all time-intensity trade phenomena, it could account for duration time-intensity trade in loudness growth.

In the auditory system, the total number of pulses counted by the neural integrator determines the loudness value of the stimulus. Auditory temporal integration, then, refers simply to this process of counting or summing the electrical impulses over a period of time which arrive from the auditory sensory nerve fibers.

Temporal integration of acoustic energy has been studied both at threshold and supra-threshold levels (Garner and Miller, 1947; Munson, 1947; Miller, 1948; Dallos and Olsen, 1964). These studies point out some interesting aspects, including some important limitations, of the auditory integrating mechanism.

Temporal Integration at Threshold

Garner and Miller (1947) studied auditory thresholds of pure tones as a function of stimulus duration. Their data revealed a linear relationship between the logarithm of duration and the threshold intensity expressed in decibels (dB). Specifically, they found that for every log unit of stimulus duration in milliseconds up to 200 msecs, the threshold intensity decreased by 10 dB. For durations longer than 200 msecs, the increase in loudness was slight and acoustic energy was considered complete after one second. Other studies of integration at threshold (Bekesy, 1929; Hughes, 1946; Pollack, 1958; Dallos and Olsen, 1965) show similar results with some differences in the rate of integration. The two outstanding features of integration at

threshold were the high rate of linear integration, nearly 10 dB per log unit of duration, and the relatively long time, about 200 msecs, for loudness to reach a near maximum value.

The fact that linear integration (and nearly all integration) ceased after approximately 200 msecs was a reflection of one of the limitations of the auditory integrating mechanism. Miller (1948) has shown that for a wide-band noise stimulus presented at threshold, maximum loudness was achieved at a stimulus duration of 140 msecs--considerably shorter than the 200 msecs required for pure tones. Also, with wide-band noise, the rate of integration dropped off to 8dB per log unit of time. It is known that more sensory cells are activated by a wide-band noise than by a narrow band. It might be concluded from Miller's study that as more cells are activated, the integrating mechanism becomes less efficient in the integration of energy pulses. There was also a progressive loss of efficiency of integration with successive increases in stimulus intensity as observed in studies of temporal integration at supra-threshold levels.

Temporal Integration at Supra-Threshold Levels

Munson (1947) studied loudness growth as a function of duration using pure tone stimuli presented at varying intensities. His data indicated that there was still linear integration at supra-threshold

levels, but that the rate of linear integration became less as the intensity of the stimulus was raised.

Miller (1948) studied loudness growth as a function of duration using wide-band noise stimuli presented at different intensity levels. His principal finding was that maximum or constant loudness was achieved by a high intensity noise in a time period shorter than one achieved by a lower intensity noise. For example, he found that the maximum loudness of a wide-band noise presented at 20 dB above threshold was reached at a duration of 140 msec, that is, loudness did not increase after the noise had been on for 140 msec. When the intensity of the noise was raised to 90 dB, maximum loudness was reached at 60 msec (Fig. 2).

Wright (1965) found that the rate of loudness growth was constant above 40 dB sensation level. In other words, further increases in the intensity of the stimulus above 40 dB did not produce a change in the rate that loudness increased. Below 40 dB, the rate of loudness growth increased as the intensity level of the stimulus decreased. It was mentioned earlier that when more sensory cells were activated either by using a wide-band noise stimulus or a stimulus of greater intensity, the integrating mechanism appeared to become less efficient. The fact that the rate of integration dropped off as the intensity of the

stimulus was raised up to 40 dB might have been further evidence of such an efficiency loss.

One may conclude, then, that the primary differences between integration observed at supra-threshold and integration observed at threshold are: (1) the rate of integration is less dramatic at supra-threshold, and (2) maximum linear integration is achieved in a shorter time at supra-threshold levels.

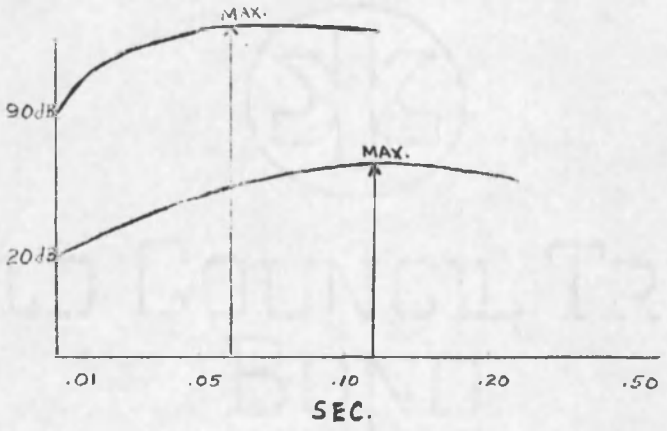


Fig. 2.--(Miller, 1948, p. 162) A Comparison of the Growth of a 20 dB and 90 dB wide-band noise.

Statement of Purpose and Hypothesis

Previous studies of integration have utilized subjective threshold measurements and loudness matching methods; thus, all of these studies have been psycho-acoustic in nature. The results of these studies manifest definitive psycho-physical evidence for integration of acoustic energy. The purpose of the present study is to seek

electro-physiologic evidence for auditory temporal integration. The specific problem of this study is embodied in a larger problem of auditory acoustics--the problem of finding neuro- or electro-physiologic support for an observed psycho-acoustic phenomenon.

The observations from the previous studies led to the following hypotheses: First, summing or integrating over time the electrical impulses coming from the sensory fibers, then the longer the duration, the greater the number of pulses integrated. Therefore, the output voltage of the integrator should increase as the stimulus duration increases. Second, if this increase were plotted against the log of duration, a linear relationship would result.

The hypotheses were tested by measuring the amplitude of the averaged, cortically evoked, potential change in response to 1000 cps tones of varying durations, and plotting these amplitudes against the logarithm of stimulus durations. It was also postulated that using a supraliminal stimulation level of 45 dB, some form of linear integration would be seen as evidenced by Munson's (1947) and Miller's (1948) data. The methodology employed in testing these hypotheses is described in some detail in the succeeding section.

METHODOLOGY

Subjects

Six young adult subjects, ranging in age from 21-24 years, were used in this study. The distribution of sex among the subjects was 5 males and 1 female. All the subjects demonstrated normal thresholds to pure tone testing.

Stimulus Control and Presentation

A. Control--Apparatus

The stimulus used in this study was a 1000 cps pure tone generated by a Hewlett-Packard, Model 200 Ab, audio oscillator. The signal from the oscillator was fed to a Grason-Stadler, Series 829D, electronic switch activated by a Grason-Stadler, Model 471, interval timer. The interval timer controlled the signal duration and the time between signal (refractory period) by triggering the electronic switch. The electronic switch controlled the rise and decay time of the signal. In this study, a "fast" (approximately .1 msec) rise and decay time was used. Such a "fast" rise and decay time gave the signal an essentially square wave form as observed on a Textronix Four-Trace oscilloscope, Type 564. The signal from the electronic switch was fed to both the oscilloscope

for stimulus monitoring purposes and to a Hewlett Packard attenuator, Model 350A. The attenuator was used to control the intensity of the signal and its output was fed to PMR Permoflux circumaural-cushioned earphones. The sound pressure level at the earphones was calibrated by an Allison audiometric calibration unit and attenuation of the signal was found to be linear within the range of the acceptable deviation of $\pm$ 2 dB as prescribed by the American Standards Association's calibration standard.

B. Presentation of the Stimulus

The stimulus was presented monaurally to the right ear of each subject at a sensation level of 45 dB. The stimulus was presented 100 times at each of the following durations: (1) 15 msec, (2) 25 msec, (3) 50 msec, (4) 100 msec, (5) 150 msec, (6) 200 msec. These durations are similar to those used by Garner and Miller (1947). Each of these durations was presented at refractory periods of 1, 5, and 10 seconds. In addition, a silent run (no stimulus) was taken of each subject in each test session to see if there was any systematic (e.g., electrical line hum) signal present which would affect the data to be recorded. Excluding this silent run, there were 18 conditions to be tested on each subject. Each of these conditions was given a code number from 1-18 (Fig. 3). Using these code numbers and a table of

random digits, the conditions were randomized in order of presentation for each subject (see Appendix A).

Durations	Refractory Periods		
	1 sec	5 sec	10 sec
15 msec	1	2	3
25 msec	4	5	6
50 msec	7	8	9
100 msec	10	11	12
150 msec	13	14	15
200 msec	16	17	18

Fig. 3.--Coding of Conditions

The subjects were instructed to lie quietly on a cot and to attend vigilantly to the stimuli. After each condition, the subjects were allowed to talk and rise from the cot. After three conditions had been presented, they were instructed to leave the test room and walk around. These periodic breaks between conditions served to guard against fatigue since such a change in the physical state of the subject can alter the electrophysiologic response to acoustic stimulation considerably (McCandless and Best, 1966, p. 271).

Procedure

A. The Method of Computer Averaging

The neural response to acoustic stimulation results in a rapid change in potentials along the membrane of the eighth nerve fibers and a slower potential change in the neural cells of the auditory projection areas in the cortex. These latter potential changes, though minute, can be picked up by surface electrodes attached to the scalp, and observed, after they have been sufficiently amplified and fed to some recording or write-out system. The principle of using electrodes to pick potential changes in the brain, amplifying and recording them, is well known in electroencephalography (EEG) where the general on-going neural activity can be observed.

However, in the study of EEG recordings, it is difficult to determine if there is a neural response to acoustic stimulation, even when the acoustic stimulus is intense. The reason for this difficulty lies in the small amplitude of the evoked cortical potential change to any given sensory stimulus in comparison with the amplitude of the random on-going neural activity. In other words, the potential changes evoked by auditory stimuli are obscured by larger random potential changes. Thus, EEG has not been very successful in determining a response to acoustic stimulation.

In 1954, Dawson described a summation technique for the detection of small evoked potentials. This principle of summation is not new and had been applied earlier in detecting systematic fluctuations among larger irregular ones. As an example, Laplace, in the eighteenth century, predicted that by averaging enough data it should be possible to demonstrate a lunar tide in the atmospheric pressure (Dawson, 1954, p. 65). Yet it has been within only the last decade or so that this technique of averaging has been applied to detect the small acoustically evoked potentials as demonstrated by Barlow (1957), Geisler (1960), Lowell et al. (1961) and McCandless and Best (1961). Such studies have been made possible by the advent of summing computers of average transients (CAT).

In this present study, a Technical Measurement Corporation Computer of Average Transients, Series 400 C, was used. The computer's function in the recording of these minute acoustically evoked potentials is described later in the succeeding section.

B. Recording of the Cortical Potential

The potential change evoked by the auditory signal was picked up by two silver disc electrodes attached to the vertex of the skull of the subject. The vertex was used as the pick-up point because the response to acoustic stimulation is best recorded there (Davis and

Zerlin, 1966, p. 109). A reference electrode was attached to the surface of a mastoid process and another electrode was attached to the other mastoid to serve as a ground point. The surfaces to which these electrodes were attached were cleaned thoroughly with acetone and coated with an electrolytic paste (a Bentonite mixture) to enhance the recording of these minute potentials.

The potentials from the scalp were channeled to two Textronix, Type 122, Model 151 A, low-level preamplifiers. The pass-band of the preamplifiers was set at .2-50 cps in order to minimize the recording of other extraneous systematic signals such as the 60 cycle of electrical lines. The potential at the first preamplifier was amplified 1000 times and fed to the second preamplifier where the signal was amplified another 100 times giving a total amplification value of approximately 100,000.

The output from the preamplifiers was fed to the computer of average transients. The computer, triggered by the interval timer, was set to sweep for 500 milliseconds after the onset of the stimulus. Thus, the sweep of the computer was time-locked to stimulus presentation. The indispensable function of the computer was to sample the incoming signal at fixed points along this 500 msec interval and to algebraically sum these potential changes recorded at each point. The averaged value at each point was stored in a "memory bin."

Theoretically, the averaged value for many recordings at each of these points would be zero for a truly random signal: for a random signal over a long-time sampling period would register at any given point a magnitude of positive deflections (+) equivalent to that of negative deflections (-). Therefore any systematic deflections, such as the potentials evoked by auditory stimulus, though small and submerged in larger random ones, would appear after many recordings because the random activity would have averaged out to zero or some minimal value. One hundred recordings, which are more than sufficient to average out the random activity to a functionally small and insignificant value (Davis and Zerlin, 1966, p. 110) were used in this study.

The averaged and stored waveform of the potential changes was fed from the computer to the oscilloscope and the trace on the oscilloscope was photographed by an oscilloscope camera. The amplitude of the peaks was measured in millimeters from the photograph (see Fig. 5). Since a baseline does not exist in electro-physiologic measurements, one must rely on these peak to peak measurements, and the N_1-P_2 pair is the most constant one seen in response to acoustic stimulation recorded at the vertex. A discussion and analysis of the N_1-P_2 data are presented in the following chapter.

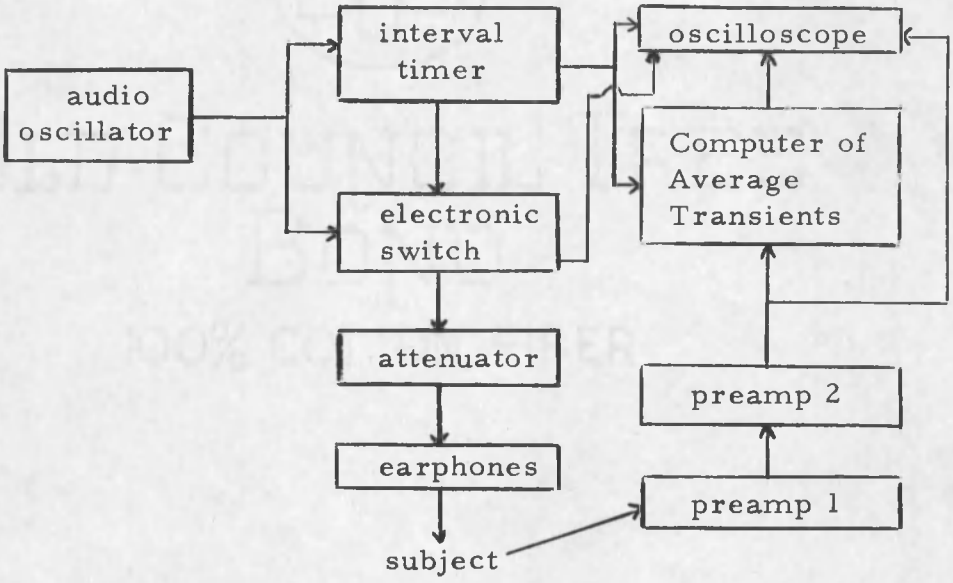


Fig. 4.--Block Diagram of Instrument Couplings

RESULTS AND ANALYSES

Amplitude Measurements and Statistical Treatment

The stored, averaged response to each condition was written out from the computer to the oscilloscope and photographed. An example of these photographs is shown in Figure 5.

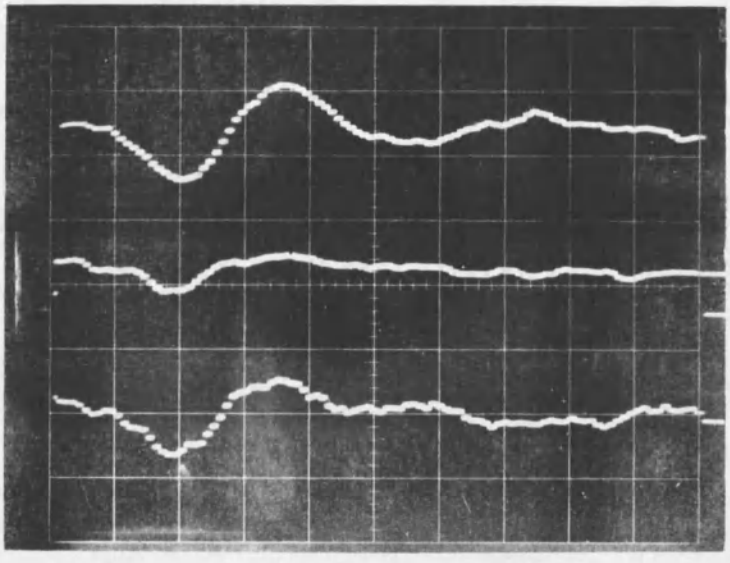


Fig. 5.--Averaged Response Curves Photographed From the Oscilloscope

The distance between the N_1 peak, which is the first negative (downward) deflection, and the P_2 peak, which is the succeeding

large positive (upward) deflection, was measured and used as the criterion for amplitude of response. The N_1 and P_2 peaks are usually observed at 90-100 msec and 150-180 msec respectively. These measurements for each condition and for each of the subjects appear in Appendix B.

The log of the stimulus durations and the peak to peak amplitudes were plotted on X-Y coordinates respectively, in order to show their relationship. Individual functions at each of the refractory periods for each subject were derived by the method of least squares.

The regression line which best fits the data, according to the principle of least squares, is that line from which the sum of the squares of the residuals is a minimum (Guilford, 1954, p. 63). A residual is a discrepancy between an obtained Y value and the value predicted from its corresponding X value on the basis of the equation being used (Guilford, 1954, p. 63). Since it was hypothesized that a linear relationship exists between emplitude and duration, the general equation takes the form of,

$$Y = a + bX$$

The method of least squares was used to determine the values of the constants "a", which is the Y-intercept, and "b", which is the slope of the regression line, in order that the sum of the observed Y-values (Y') subtracted from the predicted Y-values (Y) would be equal to a

minimum. That is, least squares method determines the line where,

$$(Y-Y') = \text{a minimum}$$

The least squares formulae for computing the constants are:

$$b = \frac{N\Sigma XY - (\Sigma X)(\Sigma Y)}{N\Sigma X^2 - \Sigma Y^2}, \qquad a = \frac{Y - b(\Sigma X)}{N}$$

After the individual functions had been determined, Pearson product-moment coefficient of correlation, r, was calculated in order to test the goodness of fit. This coefficient indicates how well the best fit line describes the data. Specifically, Pearson's r is the ratio of the predicted variance in Y to the obtained total variance in Y (Guilford, 1954, p. 68).

While r is the coefficient of correlation, r^2 is the coefficient of determination and determines the amount of variance that is accountable. That is, if X can be regarded as a "cause" of Y, then, r^2 tells what proportion of Y is determined by X (Guildord, 1954, p. 68). Since r^2 determines the amount of variance accounted for, then $1-r^2$ is the amount of variance not accounted for and is called the coefficient of non-determination. One can easily calculate r^2 by simply squaring r which is computed by the formula,

$$r = \frac{N\Sigma XY - (\Sigma X)(\Sigma Y)}{\sqrt{\left[N\Sigma X^2 - (\Sigma X)^2\right]\left[N\Sigma Y^2 - (\Sigma Y)^2\right]}}$$

The preceding discussion outlined the manner in which the data in this study were statistically treated. Graphical representations of the data collected from each of the six subjects appear in Appendix C.

Inspection of the data revealed that linearity between amplitude and log of stimulus duration from 15-200 msecs was not apparent. No subject at any refractory period exhibited a near linear or even monotonic function. Table I summarizes the statistics on the three "most linear functions"--the three with the highest correlation values.

Table I.--Three "Most Linear" Functions

Subject	Refractory	b	a	r	r^2
1	1 sec	3.7	.7	.834	.7
2	5 sec	2.9	7.5	.697	.5
5	10 sec	3.1	5.7	.536	.29

The table shows that the best linear function attainable had a correlation of only .834 between amplitude and duration, and only about .7 of the variance was accounted for as indicated by r^2. The second and third "most linear" functions show even less correlation. In all, these statistics were not compelling in terms of those found in psycho-acoustic studies of integration.

Despite this paucity of evidence for linear integration of acoustic energy over a duration of 200 milliseconds, some interesting statistics were noted in studying integration up to 50 or 100 msecs. Out of the 18 functions plotted in this study (three for each of the six subjects) 6 demonstrated a strong linear relationship between growth of amplitude and the log of the stimulus duration up to 50 or 100 msecs. The statistics of these 6 functions appear in Table II.

Table II. --Six Functions Showing Strong Correlation Between the Amplitude of Response and Duration of Stimulus up to 50 or 100 msec.

Subject	Refractory	Duration	r	r^2
1	1 sec	15-50 msec	.975	.950
2	1 sec	15-50 msec	.972	.945
2	5 sec	15-100 msec	.971	.943
2	10 sec	15-50 msec	.981	.962
5	10 sec	15-100 msec	.830	.700
6	1 sec	15-100 msec	.964	.930

Despite the strong correlations evidenced in Table II, it should be noted with caution that these statistics are the best obtainable. In addition, they are representative of only a minor portion (1/3) of the total data collected in this study.

The use of all of the data is imperative before one can make inferences about the experimental population. In this study, one can make only two general inferences using all of the data collected: (1) there appears to be electro-physiologic evidence of integration of acoustic energy between 15 and 25 msec, and (2) there appears to be a decrease in amplitude of the evoked response after 150 msec. These two inferences result from an analysis of the data summarized in Table III.

Table III. --Direction of Amplitude Change Between Each Stimulus Duration for 18 Functions

Duration Interval	Amplitude Change		
	Increase	Decrease	No Measurable Change
15-25 msec	12	2	4
25-50 msec	9	6	3
50-100 msec	8	9	1
100-150 msec	10	8	0
150-200 msec	3	11	4

Table III summarizes for the 18 functions whether there was an increase, decrease, or no measurable change in the amplitude of the evoked response between one duration and the succeeding longer duration. The rationale for treating the data in this manner is as

follows. If there is no relationship between amplitude and stimulus duration, then one would expect to find a varying distribution of amplitude increases and decreases in going from one duration to the next.

The data in Table III show that out of the total of 18 functions, the amplitude at 25 msec had increased over the amplitude recorded using a duration of 15 msec 12 times and decreased only twice. Such a distribution might well be indicative of integration of acoustic energy over this time interval. On the other hand, the intervals between 15-150 msec show a varying distribution; thus, nothing conclusive concerning the relationship between amplitude and stimulus duration can be inferred. Between 150-200 msec, amplitudes of the evoked response tended to decrease, suggesting a "breakdown" in the integrative process.

While varying amplitudes over stimulus duration tend to characterize all the functions, two trends emerge: (1) the apparent integration of acoustic energy between 15 and 25 msec, and (2) the reversal of temporal integration after 150 msec. Possible explanations for these two trends will be discussed in the subsequent chapter.

In addition to these peak to peak measurements, latency of the N_1-P_2 peaks was examined. It was noted earlier that latency for these peaks appears to be a function of intensity. It was considered

in this present study that latency might also be related to stimulus duration because of the relationship between neural transmission time and stimulus intensity. Since a longer stimulus has greater overall intensity, does it have a faster neural transmission speed than a shorter stimulus with less total energy? Latency of the N_1-P_2 peaks was measured in this study in order to determine if there was a systematic change as a function of duration.

Latency Measurements

The latent period between the onset of stimulation and the appearance of the N_1 and P_2 peaks was measured and recorded (see Appendix B). The N_1 peak latency ranged from 70-130 msec with a median value of 100 msec. The P_2 peak latency ranged from 160-250 msec with a median value of 200 msec. These latency ranges and median values are similar to those reported by Davis and Zerlin (1966) and McCandless and Best (1966).

Little information concerning any integrative process was provided by these latency measurements because of the large variability. No systematic changes in latency as a function of duration were observed in this study.

In general, no matter how the data are analyzed in this study, electro-physiologic evidence for acoustic integration remained obscured. In the ensuing chapter, a discussion of some of the events that were observed is presented.

DISCUSSION

It is evident from the data collected in this study that there is considerable variability in recording the evoked cortical response to auditory stimuli. McCandless and Best (1966, p. 270) assert that, ". . . considerable changes in the waveform may result from changes of stimulus parameters and subject state variability." Davis and Zerlin (1966, p. 114) reported that systematic changes in amplitudes of the evoked response recorded at the vertex as a function of duration was not evident at 80 dB SL. It is tempting merely to conclude that the variability in recording the amplitude of the evoked response is the main reason for not seeing acoustic integration in this study. However, it should be noted that considerable variability was also basic in the psycho-acoustic measurements and, yet, integration was still seen. Therefore, it might be beneficial to future research that some of the possible causes for the high degree of variability which obscured integration in this study be explored.

Variables

A. Stimulus

One question which arises from the data is, "If considerable variability obscured integration generally, why was integration

apparent between 15-25 msec?" The reason for this apparent integration, that is, the increase in amplitude recorded with a 25 msec stimulus duration over that recorded at 15 msec, may not necessarily be attributed to the increase in duration alone, but rather to the change in the type of stimulus used. This point will become clearer by examining the stimulus used in this study.

The stimulus in this study was presented with a "fast" (approximately .1 msec) rise and decay time. It is clear that this essentially square wave pulse would not have been reproduced faithfully by the transducer at the earphones. With the onset of stimulation, there was transient noise and with the 15 msec durations the stimulus was probably more like a burst of noise rather than a pure tone. Garner (1948) showed that the frequency spectrum of the stimulus affected the amount of energy integrated, and that with a wide-band noise, there is less integration in comparison with a narrow band or pure tone. Therefore, if it is assumed that a 15 msec tone presented at a fast rise-decay time is essentially a noise burst (this is reasonable because of transduction problems) and that a 25 msec tone is essentially a tonal stimulus (even though there is the same amount of transient noise, a large portion is tonal in nature), then this change in stimulus modality might account for the apparent integration between 15 and 25 msec evident in the present data. Along this same line of

reasoning, the fact that integration was not observed between 25-150 msec would suggest that amplitude changes as a function of duration were not sufficiently great enough to be seen in the variable evoked response. But, the amplitude change in going from a wide-band to a narrow-band stimulus might be great enough to be evident in the evoked response. Therefore, if a gradual rise-decay time had been used, the 15 msec stimulus would have been essentially a pure tone and, perhaps, the integration between 15 and 25 msec would not have been demonstrated.

It has been suggested (Dallos and Olsen, 1965) that using a gradual rise-decay time might enhance the rate of integration. Dallos and Olsen's (1965) data does not support this suggestion for they found that the rate of integration using a gradual rise-decay time was only 7 dB per log unit of duration. In addition, the evoked potential does not appear to be influenced by the rise-decay time of the stimulus as indicated by Davis and Zerlin (1966, p. 114).

Another parameter of the stimulus used in this study possibly is of importance in explaining the lack of electro-physiologic evidence for temporal integration. This parameter is the sensation level at which the stimulus was presented. It is possible that the researcher is attempting to measure systematic changes in the evoked response that are very slight because the stimulus was presented at 45 dB SL.

At this sensation level, loudness growth is minimal as asserted by Wright (1965, p. 1174).

Since the rate of integration becomes more dramatic as one approaches threshold, it might be wise for future researchers in this area to use stimuli of a sensation level near threshold. However, the problem here is that the evoked response is often difficult to record at these low sensation levels. That is, " . . . it becomes increasingly difficult to detect the evoked response from the background activity even though a summing procedure is used" (McCandless and Best, 1966, p. 270). Perhaps this problem can be resolved by using a large number of samples with these near-threshold stimuli. It has been stated by Rosenblith (1957) that the signal to noise ratio is improved by $\sqrt{N}$ in using N samples. Only future research will bear out the feasibility of using near-threshold stimuli in pursuit of electrophysiologic evidence of temporal integration.

There was also the problem of the long stimulus durations interferring with the recording of the evoked potential. That is, the latter portion of a long stimulus duration such as 200 msec was still impinging upon the ear when recording of N_1 and P_2 peaks was occurring. Perhaps such interference might be responsible for the reversed integration trend observed between 150-200 msec in this study. Also, the energy toward the end of a long duration stimulus

would not be integrated and reflected by the N_1-P_2 peaks, but would appear later. This brings up another possible source of error inherent in the experimental design--the error of measurement.

B. Measurement

In measuring the amplitudes of the N_1-P_2 peaks and plotting them as a function of duration as a means of determining the presence of integration, one might falsely assume that this peak to peak measurement is a reflection of the total amount of the integrated energy. However, it should be clear that these peaks do not reflect the total energy integrated if these peaks occur between 150-200 msec when the stimulus duration is 200 msec. If there is a latent period (to the order of 100-150 msec) owing to transmission delay, then energy impinging on the ear at 200 msec after onset of stimulation would appear in the evoked response around 300-350 msec. Perhaps, then, it would be wiser to integrate all of the area under the evoked response curve rather than measure peak to peak differences in studying integration. However, without a baseline, this method of measurement is a difficult task.

C. Subjects

The variables in the preceding section may account for why integration was not seen; however, they do not account for the large

variability of the amplitude changes observed. It is probable that subjects account for most of this amplitude variation, further obscuring the possible presence of electro-physiologic evidence for integration. For example, since the subjects were tested in 2 or 3 test sessions, each occurring on separate days, it is unlikely that the experimental conditions were the same from session to session. There were probable variations in electrode placement, electrode contact and physical state of the subjects. Even within a given test session the subject's physical state probably changed despite the use of rest periods.

Although the subjects were instructed to attend vigilantly to the stimulus, such vigilance probably was not maintained because some conditions ran as long as 17 minutes. In general, it is apparent that many of the subject variables such as attention, fatigue, and habituation are often beyond the direct control of the experimenter--variables which tend to affect the amplitude and waveform of the evoked response significantly (Davis and Zerlin, 1966, p. 112; McCandless and Best, 1966, p. 271).

Conclusion

The method of computer averaging of evoked responses to acoustic stimulation appears to have much merit as a tool for detecting the presence of acoustic stimulation. However, its use as an

experimental tool for fine measurements appears to be limited. The limitations arise principally from the great variability of the human physiologic processes and other parameters which are too complex for present systematic study.

The results of this present study do not show that temporal integration of acoustic energy can be clearly observed electro-physiologically. Perhaps with more stringent control, both in instrumentation and in subjects, and using stimuli at lower sensation levels, more conclusive evidence might be attained. It is also possible that temporal integration might not be evident electro-physiologically even if variability were greatly minimized. More research is required to determine another integration is amenable to electro-physiologic study.

It is hoped that this study has contributed useful information on the role of stimulus duration and the evoked cortical response to acoustic stimulation. Possibly, and hopefully, this study has stimulated and provided some insight for future research in this area; certainly, further research is needed. Then many of the compelling questions concerning temporal integration and the evoked cortical response may be resolved.

APPENDIX A

THE RANDOM ORDER OF PRESENTATION OF THE CONDITIONS FOR EACH SUBJECT

Subjects:	1	2	3	4	5	6
	4	8	6	5	6	6
	6	11	7	17	17	8
	14	4	11	2	13	4
	9	15	2	7	7	9
	1	14	10	13	15	15
	7	5	15	18	2	2
	15	10	4	3	9	13
	16	7	3	15	1	18
	13	18	1	6	3	7
	12	6	12	1	5	10
	2	1	13	14	10	1
	10	17	18	10	14	11
	3	9	14	16	18	16
	5	3	5	9	16	12
	8	2	9	11	12	17
	11	13	8	4	8	5
	17	12	16	12	4	14
	18	16	17	8	11	3

APPENDIX B

DATA SHEETS

Subject No. 1 Sex: F Name: Margery Yeung

Subjective Threshold of 1000 Hz: Test Dates: 1) 4/4/66

Right Ear: 21 SPL 2) 4/5/66 3) 6/16/66

Electrode Placement:

1) Distance along midline: 23.5 cm

2) Distance from midline: 5 cm

Condition	Latency N_1	Latency P_2	Amplitude mm
1	80 msec	180 msec	3 mm
2	100 "	190 "	12 "
3	100 "	190 "	10 "
4	100 "	200 "	6 "
5	110 "	185 "	11.5 "
6	105 "	200 "	18 "
7	100 "	190 "	8 "
8	100 "	200 "	13 "
9	110 "	200 "	9 "
10	100 "	160 "	7 "
11	100 "	185 "	10 "
12	120 "	210 "	15 "
13	100 "	190 "	8 "
14	130 "	200 "	13 "
15	100 "	190 "	19 "
16	100 "	180 "	8 "
17	110 "	175 "	10 "
18	105 "	190 "	12 "

APPENDIX B--Continued.

Subject No. 2 Sex: M Name: Kom Loh

Subjective Threshold of 1000 Hz: Test Dates: 1) 4/18/66

Right Ear: 18 2) 5/16/66 3) 5/17/66

Electrode Placement:

1) Distance along midline: 24 cm

2) Distance from midline: .5 cm

Condition	Latency N_1	Latency P_2	Amplitude mm
1	120 msec	200 msec	4 mm
2	130 "	210 "	9.5 "
3	130 "	220 "	14 "
4	140 "	210 "	9 "
5	110 "	250 "	12 "
6	120 "	210 "	17 "
7	100 "	180 "	12 "
8	140 "	220 "	14 "
9	130 "	230 "	19 "
10	130 "	205 "	10 "
11	120 "	200 "	15 "
12	130 "	230 "	16 "
13	100 "	170 "	11 "
14	130 "	210 "	13 "
15	125 "	220 "	17 "
16	130 "	210 "	6.5 "
17	120 "	240 "	13 "
18	120 "	240 "	15 "

APPENDIX B--Continued.

Subject No. 3 Sex: M Name: Steve Friedman

Subjective Threshold of 1000 Hz: Test Dates: 1) 6/9/66

Right Ear: 21 SPL 2) 6/12/66 3)

Electrode Placement:

1) Distance along midline: 23.5 cm

2) Distance from midline: .5 cm

Condition	Latency N_1	Latency P_2	Amplitude mm
1	80 msec	180 msec	3 mm
2	100 "	190 "	12 "
3	100 "	190 "	10 "
4	100 "	200 "	6 "
5	110 "	185 "	11.5 "
6	105 "	200 "	18 "
7	100 "	190 "	8 "
8	100 "	200 "	13 "
9	110 "	200 "	9 "
10	100 "	160 "	7 "
11	100 "	185 "	10 "
12	120 "	210 "	15 "
13	100 "	190 "	8 "
14	130 "	200 "	13 "
15	100 "	190 "	19 "
16	100 "	180 "	8 "
17	110 "	175 "	10 "
18	105 "	190 "	12 "

APPENDIX B--Continued.

Subject No. 4 Sex: M Name: Frank Gee

Subjective Threshold of 1000 Hz: Test Dates: 1) 6/20/66

Right Ear: 15 2) 6/22/66 3) 6/23/66

Electrode Placement:

1) Distance along midline: 24 cm

2) Distance from midline: .5 cm

Condition	Latency N_1	Latency P_2	Amplitude mm
1	100 msec	200 msec	4 mm
2	100 "	215 "	11 "
3	105 "	220 "	9 "
4	90 "	150 "	5 "
5	100 "	205 "	11 "
6	120 "	200 "	7 "
7	75 "	220 "	5 "
8	100 "	160 "	10 "
9	100 "	170 "	8 "
10	85 "	200 "	3 "
11	100 "	180 "	7 "
12	100 "	220 "	12 "
13	100 "	200 "	8 "
14	90 "	190 "	8 "
15	95 "	175 "	11 "
16	90 "	165 "	6 "
17	95 "	210 "	10 "
18	100 "	220 "	9 "

APPENDIX B--Continued.

Subject No. 5 Sex: M Name: Lenny Don

Subjective Threshold of 1000 Hz: Test Dates: 1) 6/29/66

Right Ear: 30 2) 6/30/66 3)

Electrode Placement:

1) Distance along midline: 25 cm

2) Distance from midline: .5 cm

Condition	Latency N_1	Latency P_2	Amplitude mm
1	80 msec	155 msec	6 mm
2	120 "	180 "	7 "
3	100 "	185 "	9 "
4	95 "	185 "	6 "
5	95 "	180 "	7 "
6	100 "	180 "	11 "
7	90 "	150 "	6 "
8	100 "	170 "	13.5 "
9	95 "	175 "	11 "
10	85 "	140 "	7.5 "
11	95 "	180 "	11.5 "
12	95 "	175 "	11.5 "
13	85 "	140 "	6 "
14	100 "	180 "	15 "
15	100 "	170 "	9 "
16	80 "	140 "	6 "
17	90 "	170 "	12 "
18	100 "	175 "	16 "

APPENDIX B--Continued.

Subject No. 6 Sex: M Name: Mike Tom

Subjective Threshold of 1000 Hz: Test Dates: 1) 6/22/66

Right Ear: 10 2) 6/23/66 3) 6/25/66

Electrode Placement:

1) Distance along midline: 24 cm

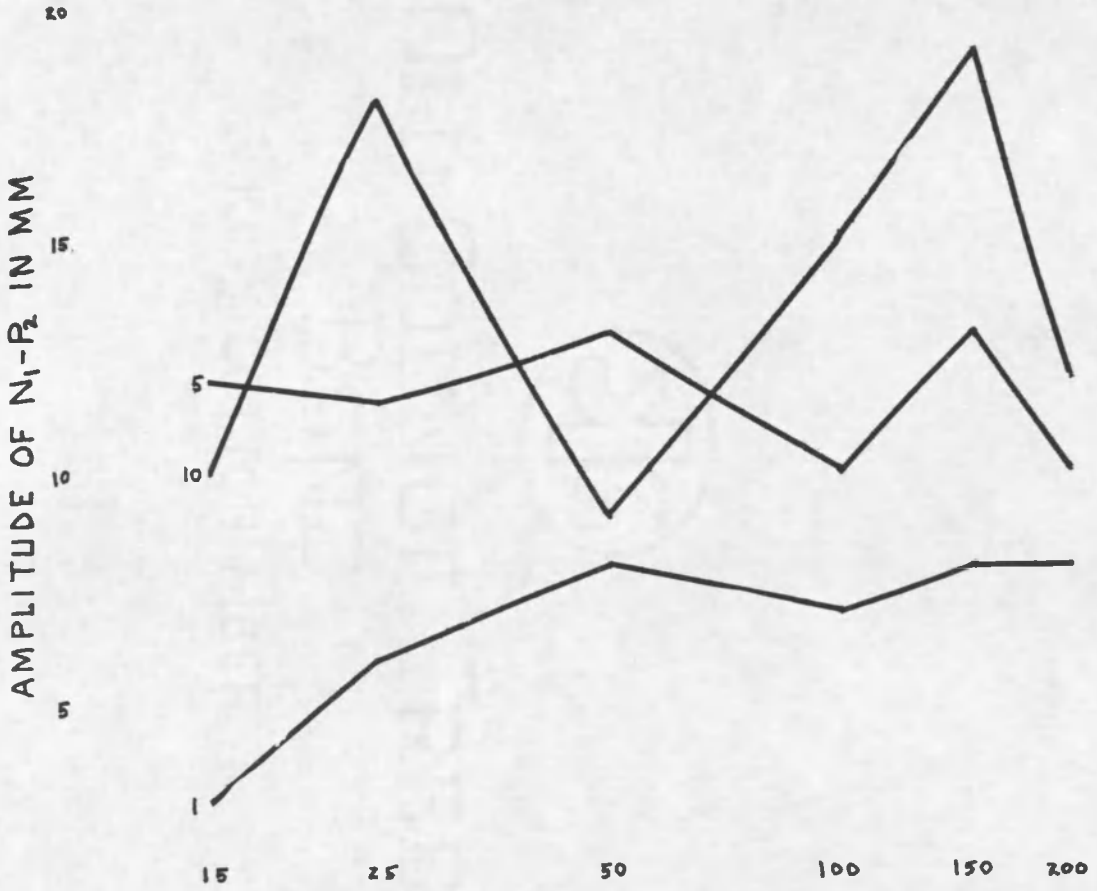
2) Distance from midline: .5 cm

Condition	Latency N_1	Latency P_2	Amplitude mm
1	70 msec	200 msec	4 mm
2	110 "	175 "	8 "
3	75 "	240 "	6 "
4	70 "	175 "	6 "
5	90 "	175 "	8 "
6	110 "	160 "	10 "
7	70 "	145 "	7 "
8	90 "	160 "	12 "
9	95 "	165 "	9 "
10	80 "	165 "	8 "
11	80 "	165 "	11 "
12	125 "	200 "	9 "
13	70 "	185 "	7 "
14	80 "	170 "	9 "
15	100 "	160 "	10 "
16	120 "	200 "	6 "
17	115 "	175 "	6 "
18	95 "	175 "	12.5 "

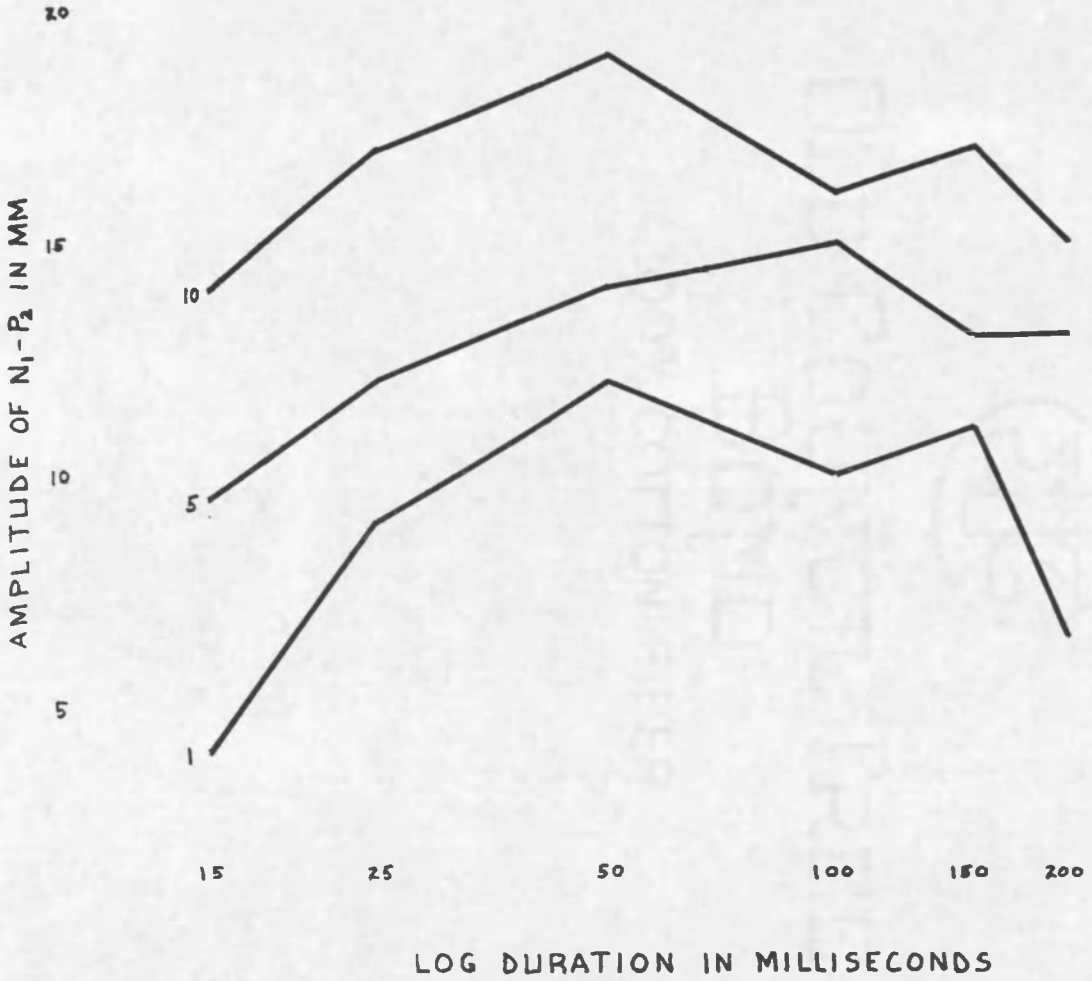
APPENDIX C

AMPLITUDE VS. DURATION FUNCTIONS FOR EACH SUBJECT

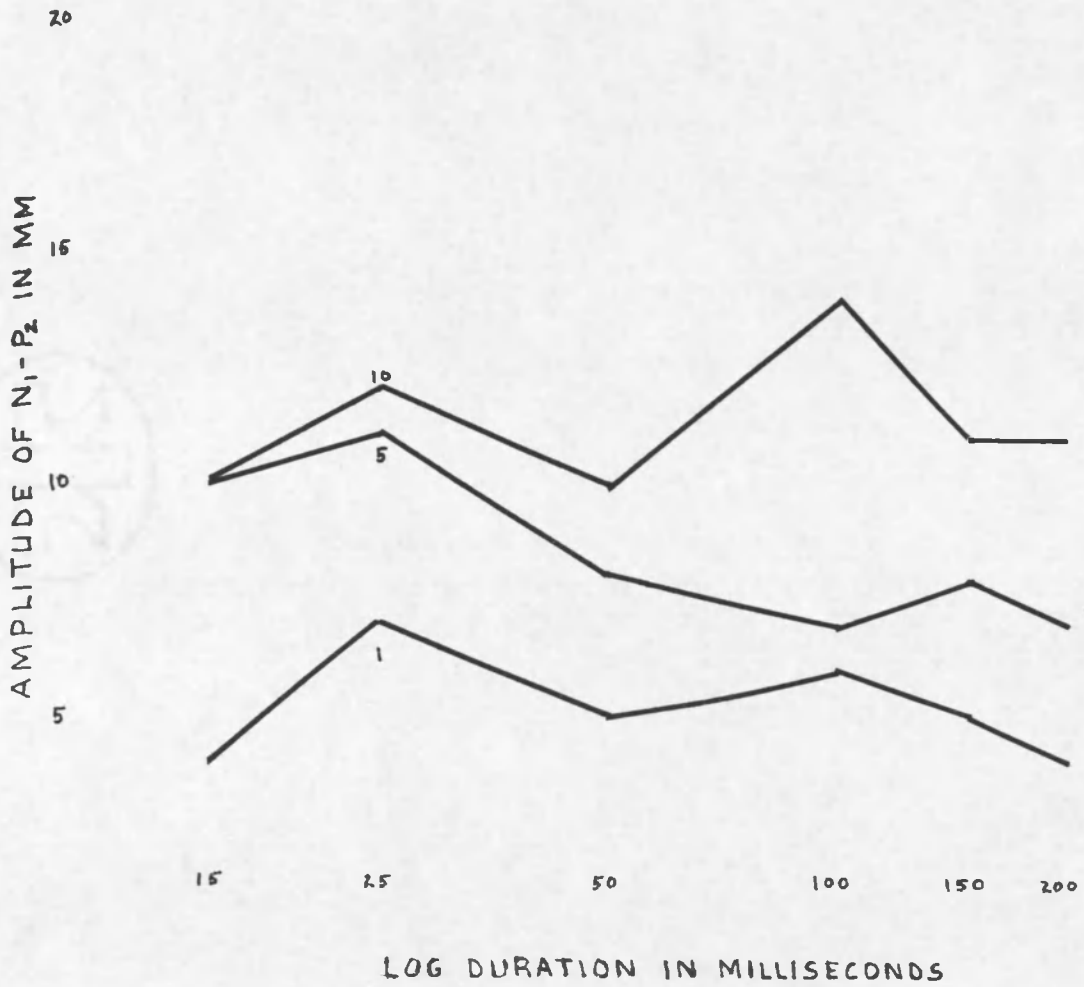
SUBJECT NO. 1 MY



SUBJECT NO. 2 KL



SUBJECT NO. 3 SF



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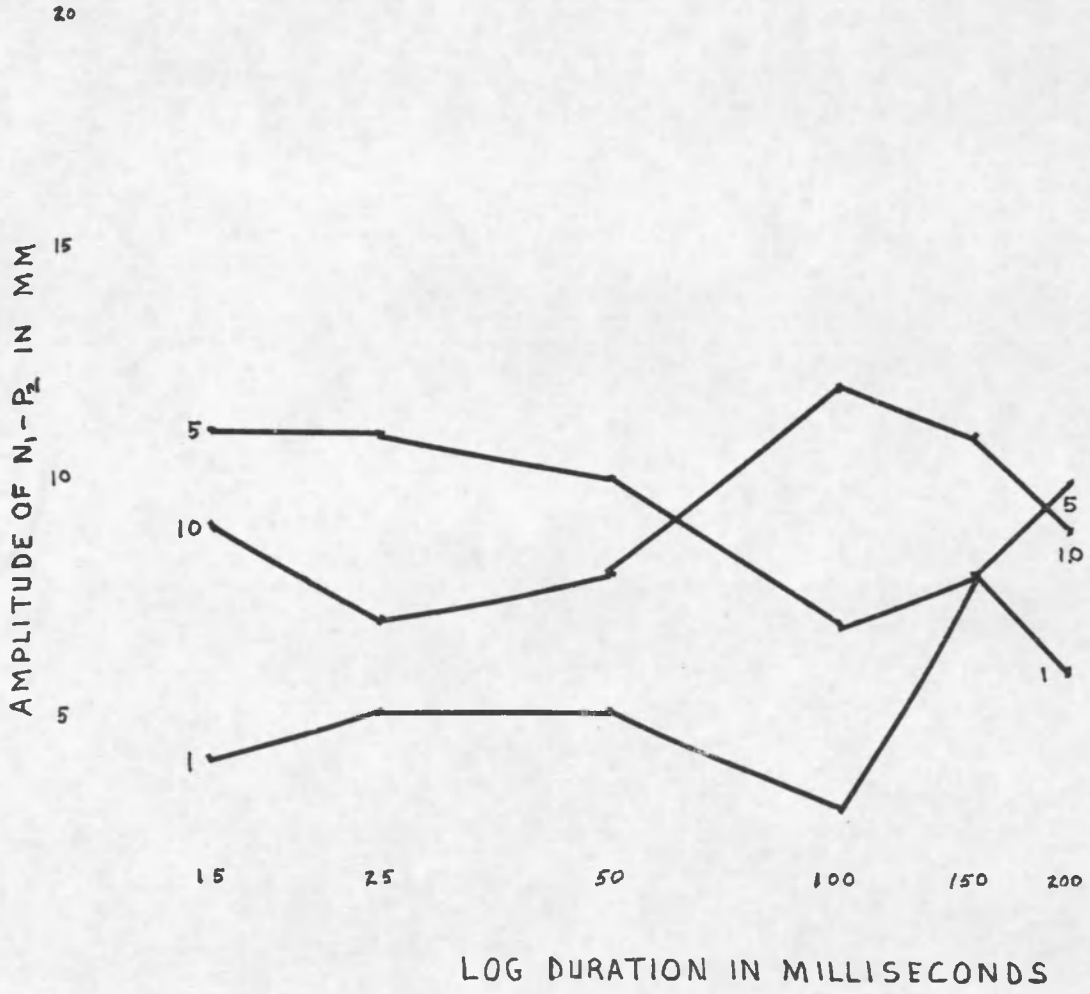
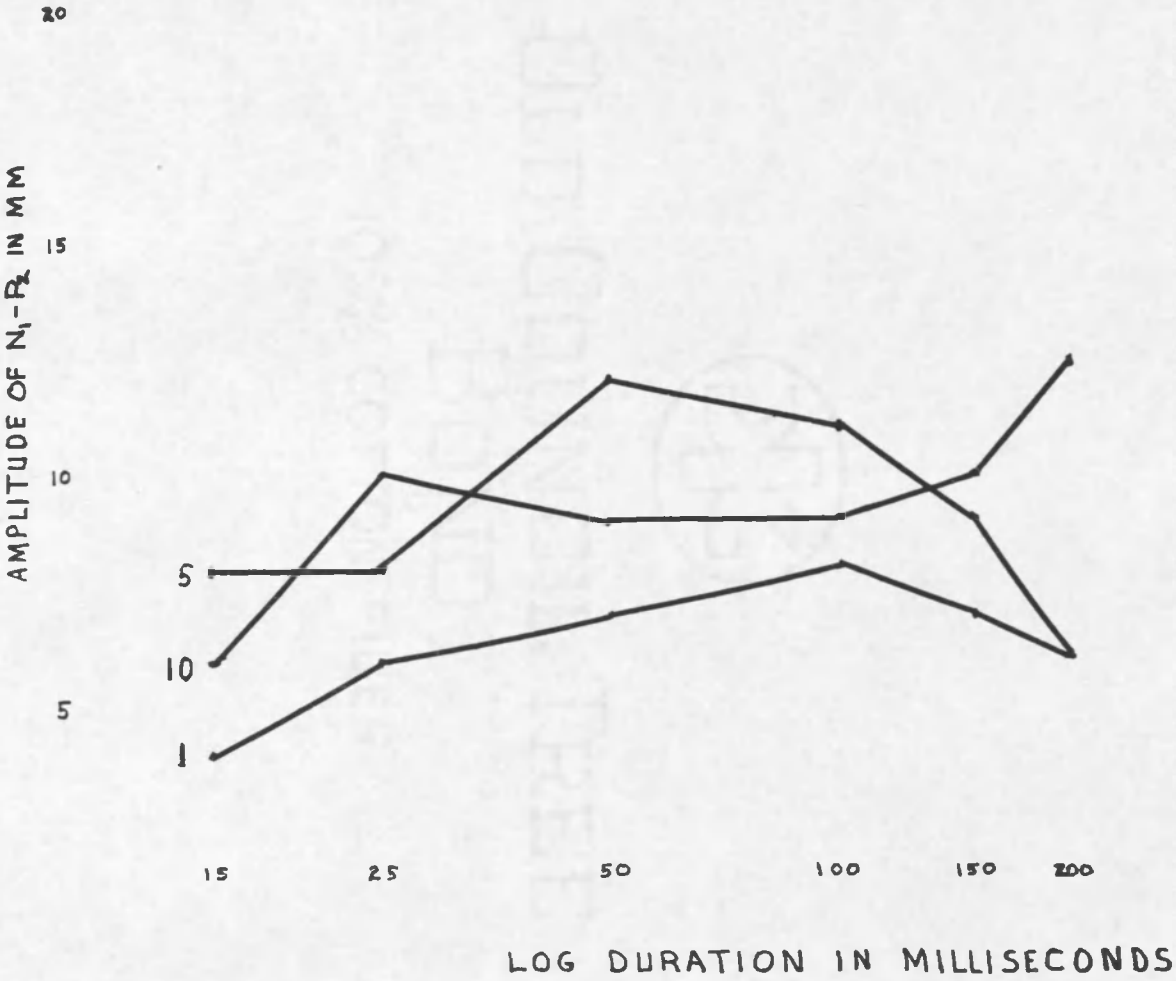


SUBJECT NO. 5 LD

SUBJECT NO. 6 MT



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