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A. JUDGMENTS OF THE LOUDNESS OF CLICKS

Many experiments have been performed in order to determine a relationship between the loudness of sounds and their intensity. These experiments have utilized either pure tones or white noise as stimuli. A review of the methods and results of many of these experiments was given by Stevens [1], and he proposed that for a 1000-cps tone, loudness is a power function of intensity (in accordance with his more general proposal [2] of a psychophysical law for certain kinds of sense dimensions). In particular, he proposed that

$$L = KI^{0.3}$$

where L represents loudness, and I is the energy flux density which is assumed to be proportional to the square of the sound pressure. In extensive experiments Stevens showed that this loudness scale is a good representation of median loudness judgments that are obtained by many different methods [3]. It has also been shown to give a good representation of loudness judgments for noise [4].

In the first group of experiments reported here, we have been interested in determining how listeners behave when they are asked to judge the loudness of clicks. This stimulus is of particular interest because a loudness scale for clicks might be correlated with the electrophysiological responses to clicks that have been obtained from humans [5].

Some preliminary experiments were performed to determine a loudness scale by the method of fractionation. The subjects were asked to adjust the intensity of a click until it was half as loud as a preceding standard click. The data indicate that the adjustments are quite sensitive to the time interval between the two clicks in the range from 0.25 to

3 seconds. Also, the subjects felt that they might have been making adjustments based on the difference in quality between the standard and the adjustable click rather than on the difference in loudness. Since these difficulties introduce considerable complication in the generation of a loudness scale, this method was not pursued any further.

We performed 3 experiments in loudness estimation on 7 "naive" subjects who had little knowledge of the stimulus range and intervals, and on 2 subjects who were the experimenters. In each of the experiments the subjects were asked to assign a number that would be proportional to the loudness of each of a series of 81 clicks. The clicks were presented to the subjects through PDR-10 earphones. The magnitude of the electric pulses, 0.1 msec in duration, which produced the clicks covered an intensity range from 3 to 83 db re median threshold of the listener in 10-db steps. Each of the 9 stimulus levels was presented randomly 9 times; the series was constrained in such a way that all transitions occurred at least once. The clicks were approximately 10 sec apart. A warning light flashed 1 sec before each click. In experiment A, the subjects were instructed to use any range of numbers they pleased. In experiment B, the subjects were presented with a 43-db click 10 times at the beginning of the experiment and told to call its loudness 100. Then the series of varying-intensity clicks was presented. The subjects were instructed to judge the loudness relative to the standard. In experiment C, the 43-db standard was presented at every other click, and the subjects were again instructed to call its loudness 100. Figures XV-1, XV-2, and XV-3 show composite curves of the median judgments of the 7 naive subjects for each of the experiments. Each point represents the median judgment of one subject at some particular intensity. When two subjects made identical median judgments at any particular intensity, the points are plotted side by side. The broken line connects the median of the medians and the straight line indicates the Stevens scale of loudness. In order to compare the responses of the subjects in experiment A, they were linearly normalized to 100 at 43 db by multiplying all the median judgments for a particular subject by a factor that made the median judgment 100 for the 43-db stimulus level. The fact that few subjects consistently heard the 3-db clicks accounts for the few judgments recorded at that intensity.

In experiments B and C, the S (Stevens) scale is as good a fit to the composite data as any straight line. In experiment A, a straight line of $L = KI^{0.2}$ is a better fit. The judgments of some individuals fall very close to the S scale (i.e., G.G. in experiment A, whose median judgment points are circled in Fig. XV-1); the judgments of others would fit much better on a straight line of half the slope (M.F. in experiment A, whose median judgment points are enclosed in squares in Fig. XV-1). One subject (W.P., one of the experimenters, whose judgments were not included in the data from the naive subjects) is quite consistent from A to C, as seen in Fig. XV-4, but his loudness scale did not fit on any one straight line very well. Hence, it can be concluded that the Stevens scale, insofar as it is a rough indication of the median judgments of several observers,
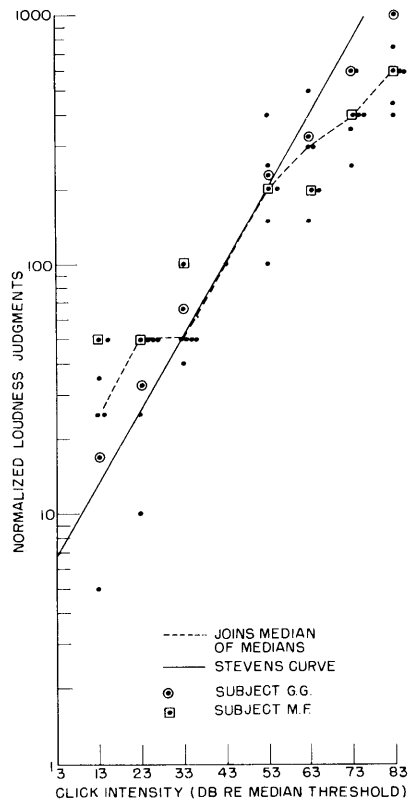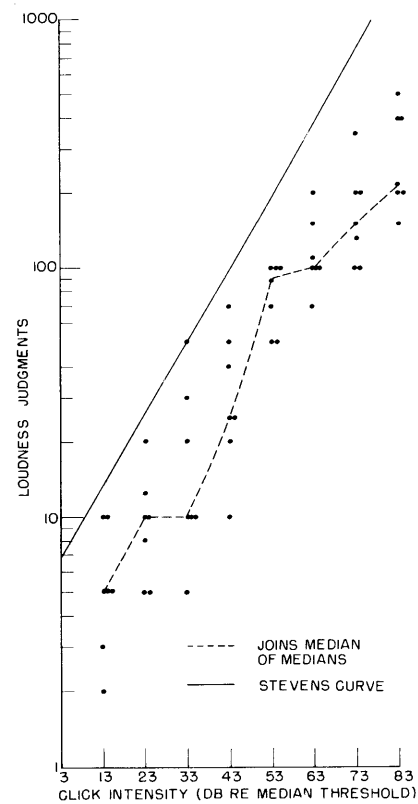
Fig. XV-1. Loudness judgments for experiment A.

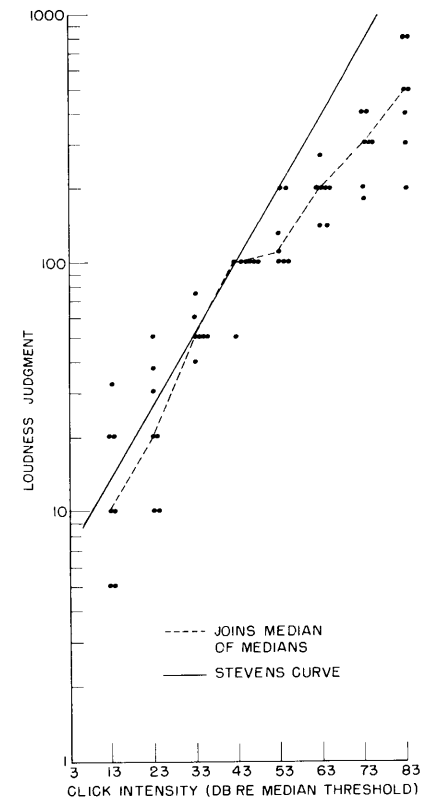Fig. XV-2. Loudness judgments for experiment B.

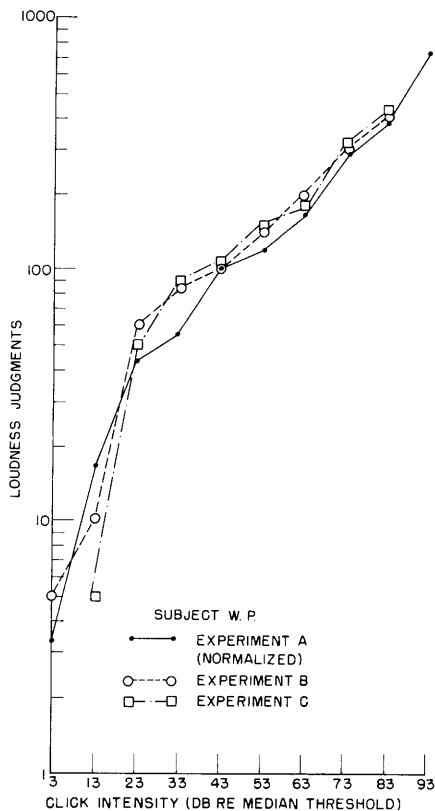Fig. XV-3. Loudness judgments for experiment C.

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Fig. XV-4. Median loudness judg-
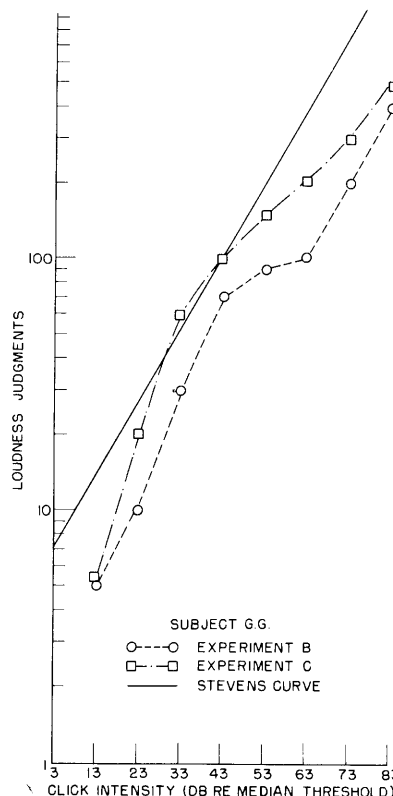ments for subject W.P.

Fig. XV-5. Median loudness judg-
ments for subject G.G.

holds quite well for clicks. Individuals may depart considerably from this scale, how-
ever.

Several more observations can be made upon the results: (a) No matter what the
instructions were, the range of numbers used by the subjects extended from 1 to 1000,
with very few judgments falling outside this range. This indicates that this kind of
experiment is strongly dependent upon the way people use numbers. (b) Many subjects
categorized their responses in as few as 7 categories, which would also indicate that
their behavior is not strictly governed by the judgment of loudness. (c) The ratio of the
two numbers assigned to the loudest and softest clicks, to serve as a measure of the
range of numbers used, was remarkably constant. Referring to the composite curves
of Figs. XV-1, XV-2, and XV-3, we can see that this ratio increases slightly from
experiment A to experiment B, and remains almost constant from experiment B to
experiment C. Some individuals, however, showed much greater variability in judgment
between tests. (d) In experiment B, all the subjects (except experimenter W.P.) judged
the standard click, presented in the random series, to be less than 100. They may have
been influenced by the particular series used, since the average intensity over the first

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15 clicks was approximately 6 db below the standard. (e) Several subjects showed an interesting difference between responses in experiments B and C: G.G. (as shown in Fig. XV-5) and C.D.G. (one of the experimenters) maintained their judgments at the extremes but raised their judgments to conform with the specified 100 at +43 db.

It should be pointed out that a sentence that was included in the instructions may have produced results that matched the S curve: "If a click sounds half as loud as the standard, write down 50; if it sounds twice as loud as the standard, write down 200; etc." This sentence was included in order to make it clear to the subjects what "proportional" meant. Apparently, it led all the subjects to use 50 and 200 as responses. Since the stimuli were spaced in 10-db steps, accurate category judgments made by using numbers that are powers of 2 × 100 will exactly match the S scale, since $L = KI^{0.3}$ gives a doubling of L for a 10-db increase in I. We feel that this is a serious drawback of the experiments. This difficulty could be removed by deleting that particular sentence from the instructions.

A second series of experiments was performed to determine how human subjects with normal click thresholds place acoustic clicks in loudness-categories. The clicks used in the experiments were in the range of intensity from 10 db to 80 db above the mean threshold of the subjects taking part in the experiment. Stimuli were presented at 5-second intervals to minimize time-order effects while the subject's attention was being held. Subjects were seated one at a time in an anechoic chamber and monaurally presented with 0.1-msec clicks through a PDR-10 headphone.

Before each of the experiments, the subjects were allowed to listen to samples of all the experimental stimuli and to practice categorizing the stimuli. In the experiments proper, the stimuli consisted of random sequences of clicks, with the constraint that each transition from one stimulus level to another would occur only once. Responses were recorded by having the subject press one of 5 buttons that were arranged in a straight line and marked with an arrow pointing from left to right, labeled "Increasing Loudness." Response times as well as category judgments were recorded, although the subjects were not instructed explicitly concerning response-time behavior.

Table XV-1 gives a descriptive summary of the three experiments. Figure XV-6a, b, and c summarizes the results of the category judgments. The mean percentage of

Table XV-1. Categorization Experiments.

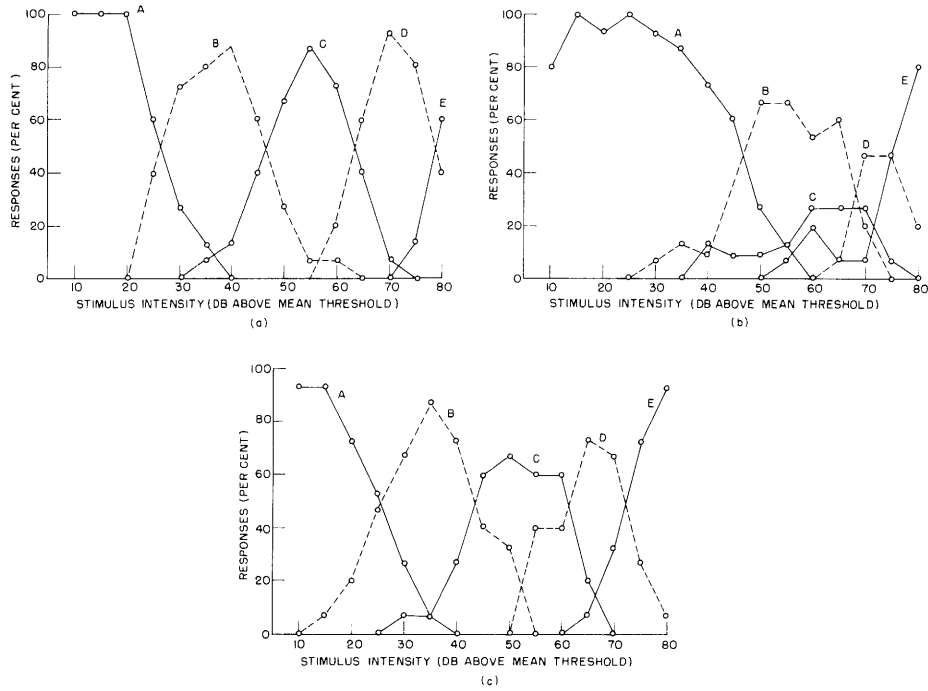| Experiment Number	Number of Subjects	Stimulus Range	Stimulus Interval	Stimulus Levels	Number of Stimuli
1	11	10-80 db	5 db	15	225
2	7	10-80 db	10 db	8	64
3	10	35-80 db	5 db	10	100

Fig. XV-6. Category scaling of clicks. (a) Experiment 1, average for 11 subjects; (b) Experiment 2, average for 7 subjects; (c) Experiment 3, average for 10 subjects.
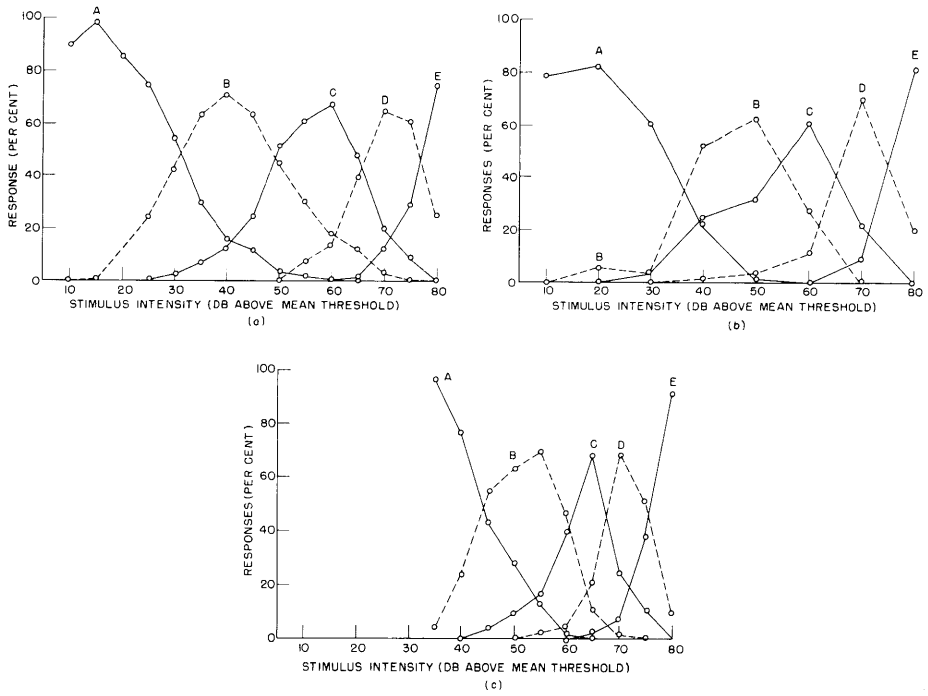

Fig. XV-7. Category scaling of clicks. (a) Experiment 1, Subject: C.D.G.; (b) Experiment 1, Subject: P.R.; (c) Experiment 1, Subject: W.T.P.

responses is plotted against the stimulus-intensity level for each of the five categories, (A, B, C, D, and E). Figure XV-7 shows the extreme behavior of several subjects.

The data show that the assignment of stimuli to loudness categories is dependent upon the stimulus ensemble, as well as upon the intensity of the particular stimulus that is being judged. In experiments 1 and 2, all subjects tended to place more stimuli in category A than in any other category. On the average, subjects placed more than 50 per cent of all of the stimuli that were lower in intensity than 30 db re median threshold in the first category. When the lower end of the stimulus-intensity range was raised from 10 db to 35 db, subjects still tended to put more stimuli into the lowest category than into the other categories. In the third experiment, the transition from the lowest category to the second category occurs at the 45-db re threshold level rather than at 30 db as was the case in experiments 1 and 2. The boundaries between the other categories were displaced upwards to a lesser degree.

The data were also analyzed to see if the response to a click is affected by the previous click intensity. It could be surmised, from the analysis, that the 5-sec interval between clicks effectively decoupled successive responses.

From the curves showing individual behavior in experiment 1 (Fig. XV-7), it can also be seen that the subjects differed quite widely with respect to the stimulus level at which the boundary occurred between response categories, and it is evident that these boundaries were not at all sharply defined.

The response-time data were analyzed and were found not to be significantly related either to the stimulus level or range. Mean response times were in the range of 1.6 sec to 3.3 sec, with mean variances of from 0.12 $\sec^2$ to 2.3 $\sec^2$ for the several subjects.

Some attempts were made to measure information transfer from stimulus to response. This was done by calculating the average information (entropy) in the response ensemble and subtracting a mean equivocation term calculated from each stimulus level (6, 7). This information-transfer term did not appear to be correlated with the mean response time or with the variation of the response time for each subject. We noted, however, that those subjects that were relatively sophisticated with respect to psychophysical experiments gave higher values for the information-transfer term (1.56 to 1.44 bits for 7 subjects in experiment 1), while the relatively naive subjects had lower values (1.23 to 1.11 bits for 3 subjects in experiment 1).

From all of the experiments that have been described one fact emerges clearly. In order to assess the results of the experiments a number of extensive control experiments are needed. Among the variables that may have contributed to the results that we have shown are:

1. Instructions to the subjects. In each experiment it can be said that to some degree the instructions biased the results in a reasonably systematic way. This is particularly noteworthy in the experiments on loudness-magnitude estimation. In this situation, it is

doubtful if any set of instructions can be given that does not introduce some sort of bias in the response behavior.

2.   Response patterns.   We cannot state exactly how much of the bias that we see in the results of the categorization experiments is attributable to the judgment of loudness alone.   The experiments were not controlled against any predisposed voting habits of the subjects.   It is possible that had the arrow that indicated the direction of increasing loudness been pointing from right to left, rather than from left to right, the results might have been different.

3.   The choice of stimulus range, level, order, and pattern may also operate to alter the subjects' behavior patterns.   Stevens (1) discusses these influences, as well as those of the methodological biases that were introduced.

We now feel that before any final statements can be made about our results, certain other experiments should be performed.   They can be described as follows:

1.   Ascertain any stereotyped number behavior exhibited by our subjects as a group. Present a subject with a stimulus sequence that has only one intensity value, and ask him to assign it to one of 5 categories.

2.   Ascertain whether the subject's voting behavior is consistent with the present results if he is asked to vote whether a stimulus is of a particular category or of some other category.   Run the experiment for each of the categories used in the present experiment.

3.   Ascertain whether deleting either the high and/or low ends of the intensity variable affects the categorizing behavior.   See if range compression affects behavior.

4.   Ascertain the smallest intensity range over which the subject's behavior exhibits an ability to continue categorizing.

5.   Determine the optimal number of categories for any given intensity range.

6.   Alter the spacing of the stimulus variable to conform with Stevens' loudness function, and see if the voting behavior exhibited becomes symmetrical.

C. D. Geisler, C. E. Molnar, W. T. Peake, C. A. Steinberg, T. F. Weiss

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B. HUMAN REACTION TIME TO A MASKED ACOUSTIC STIMULUS

In this study an attempt was made to determine how the slope of the curve of the reaction time versus stimulus-intensity function is modified as the stimulus is masked. The stimulus that was used was a click of 1-msec duration. The masking was by white noise that had been passed through a 7000-cps lowpass filter.

Four subjects took part. A subject was placed in the anechoic chamber and was presented with clicks and masking noise to his right ear only, through a PDR-10 earphone. A warning light prepared the subject for the coming click. An electronic counter that had been triggered by the click and that stopped when the subject pressed a microswitch
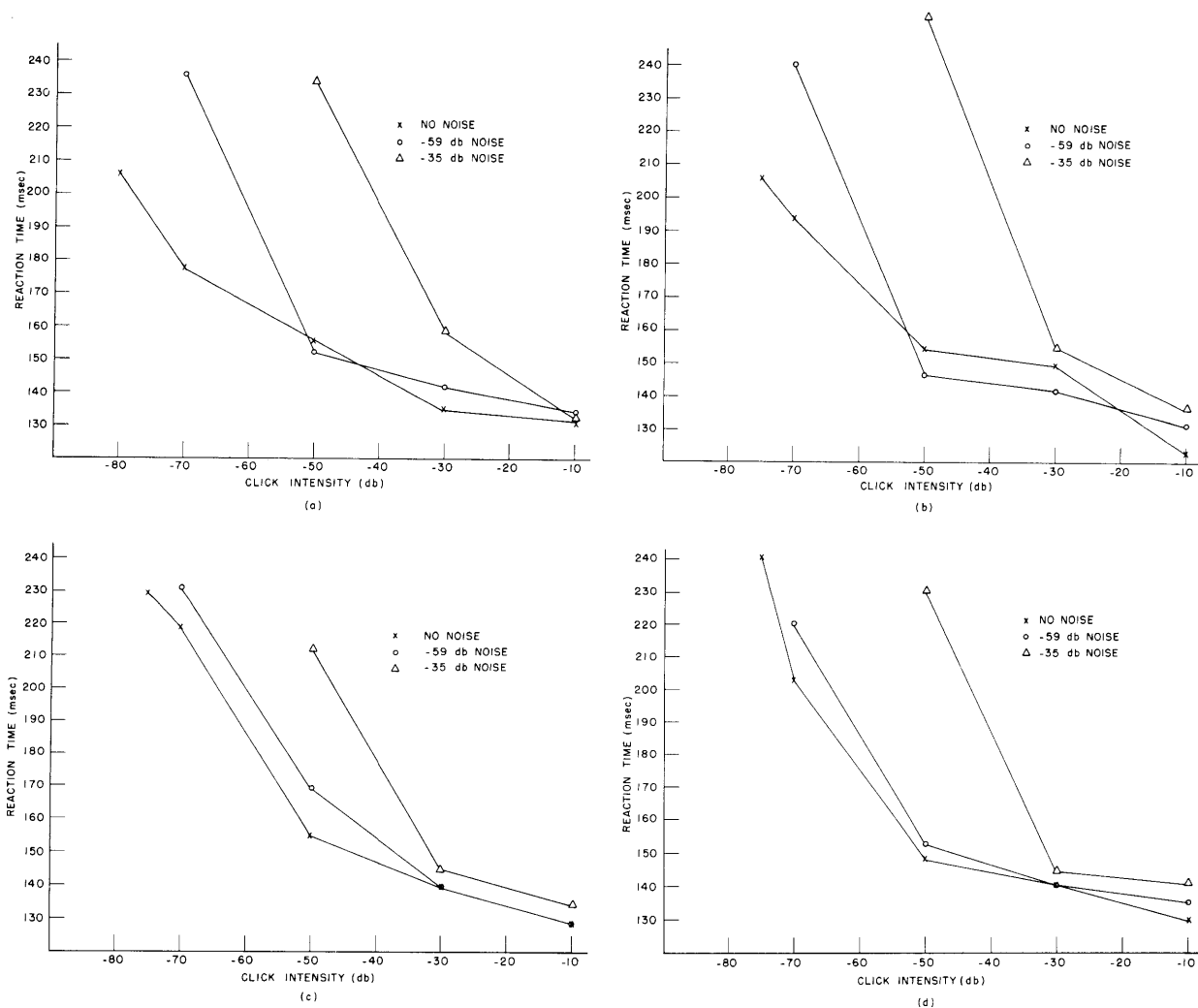

Fig. XV-8. Mean reaction time versus click intensity. (a) Subject A; (b) Subject B; (c) Subject C; (d) Subject D.

was used to measure reaction time.

Preliminary work consisted of an attempt to determine an appropriate time duration for the click and to determine a method of randomizing the time interval between the warning light and the click.

Five intensities of click and three intensities of masking noise were used. The first noise level was a completely unmasked click. The second noise level was so chosen that it completely masked the weakest click for all four subjects. The third noise level was so chosen that it completely masked the two weakest clicks for all four subjects.

The intensity scale that was used was a decibel scale. The zero db point of this scale corresponded to approximately 125 db re 0.0002 microbar.

One hundred points were obtained at each intensity of click with the 3 different noise-intensity levels. The masking noise was presented to the subject continuously while data were being taken; that is, the noise was not turned on immediately before each click and then turned off immediately after each click.

Graphs of mean reaction time versus click intensity, with intensity of masking noise as a parameter, were plotted for each subject (Fig. XV-8a, b, c, and d). It can be seen from the graphs that the reaction time is greatly increased when the stimulus (the click) is almost masked by the noise; but when the intensity of the stimulus is increased 20 db, it easily breaks through the masking barrier, and the subject's reaction time returns to what it was essentially when there was no masking noise present.

W. Thompson, Jr.

C. COMMENT ON THE "LAPLACIAN" ELECTRODE

The so-called Laplacian electrode, shown schematically in Fig. XV-9, has been used to measure currents rising normally towards the surface of the cortex (1). It is the purpose of this brief note to point out that normal currents are not uniquely determined by such an electrode array. Consider a cortex that occupies the region $z < 0$. Then a measurement of $V_a + V_b + V_c + V_d - 4V_o$ in the x-y plane gives the sum of second differences of the potential in the x and y directions. This is just the effective electrode area (dotted lines in Fig. XV-9) multiplied by the average over this area of the two-dimensional Laplacian. If the assumption is now
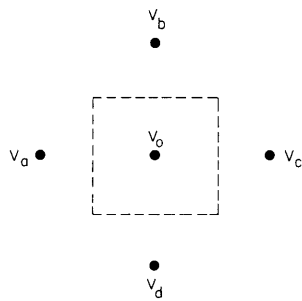
Fig. XV-9. "Laplacian" electrode array.

made that we are dealing with only the cortical surface as a two-dimensional (z = 0) problem, then application of Gauss' theorem gives:

$$(\text{Area}) \, \overline{\nabla^2 V} = R \, I(q_o)$$

where R is the resistivity of the equivalent two-dimensional medium, and $I(q_o)$ is the current source at the central point q_o. The $I(q_o)$ is the actual physical quantity measured by Perl and Casby (1).

Returning to the actual three-dimensional situation, we see that the currents that appear at the surface sources may originate in the depths of the cortex. However, such currents can come toward the surface at any angle. Knowledge of the effective surface-current sources does not give information about the current distribution in the depths of the cortex.

G. Gerstein

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