THE EFFECTS OF VARIABLE-INTERVAL AND FIXED-INTERVAL SIGNAL PRESENTATION SCHEDULES ON THE AUDITORY EVOKED RESPONSE

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Averaged auditory evoked responses to 1000-Hz 20-msec tone bursts were obtained from normal-hearing adults under two different intersignal interval schedules: (1) a fixed-interval schedule with 2-sec intersignal intervals, and (2) a variable-interval schedule of intersignal intervals ranging randomly from 1.0 sec to 4.5 sec with a mean of 2 sec. Peak-to-peak amplitudes ($N_1 - P_2$) as well as latencies of components P_1, N_1, P_2, and N_2 were compared under the two different conditions of intersignal interval. No consistent or significant differences between variable- and fixed-interval schedules were found in the averaged responses to signals of either 20 dB SL or 50 dB SL. Neither were there significant schedule differences when 35 or 70 epochs were averaged per response. There were, however, significant effects due to signal amplitude and to the number of epochs averaged per response. Response amplitude increased and response latency decreased with sensation level of the tone burst.

Investigations of the vertex potential evoked from the brain by an acoustic signal have utilized two general types of signal presentation schedule. Some investigators have used fixed intersignal intervals to obtain an averaged response (Davis, 1965; Barnet and Goodwin, 1965; Rose and Ruhm, 1966; Price et al., 1966; Liebman and Graham, 1967; Cody, Klass, and Bickford, 1967). Other investigators have employed variable-interval schedules designed with randomly chosen intersignal intervals (Williams and Graham, 1963; Keidel and Spreng, 1965; Rapin et al., 1966).

Evoked responses have been demonstrated to change as a function of the alerted state of the subject (Davis, 1964; Marsh and Worden, 1964; Teas, 1965; Satterfield, 1965; Gross et al., 1965; Spong, Haider, and Lindsley, 1965). In general, any change in the experimental conditions which required a subject to alert to the test signal resulted in increased response amplitude. It can be argued that the irregular and unpredictable nature of a variable intersignal interval schedule might contain special alerting properties not found in a fixed-interval schedule. The resultant averaged evoked response from a variable-interval schedule would thus be expected to be larger then the response from a fixed schedule.

Keidel and Spreng (1965) reported that a variable-interval schedule with a mean of 17 sec yielded twice the response amplitude produced with a 17-sec fixed-interval schedule. But a 17-sec interval is impractical for many clinical applications. David and Zerlin (1966) suggested that a fixed intersignal interval of 1 sec for a train of 64 acoustic signals yields maximum average response strength for overall test-time efficiency. They reported no advantage to the use of irregular-interval schedules, although systematic investigation of this issue was not described. Therefore, the question arises as to the relative advantage of a variable-interval over the more convenient fixed-interval schedule for faster repetition rates, repetition rates more suitable for clinical situations.

The purpose of this study was to compare the effects of fixed and variable signal presentation schedules on the averaged vertex response. Two schedules were chosen with short intersignal intervals: (1) repetitive tone bursts with 2-sec fixed intersignal intervals, and (2) repetitive tone bursts with variable intersignal intervals averaging 2 sec.

METHOD

Subjects

Twelve students and staff members of the University of Minnesota served as subjects. Ages ranged from 18 to 32 years with a mean age of 23.9 years. All were in good health and passed a hearing screening test for 20-msec 1000-Hz tone bursts in one ear at 30 dB SPL.

Test Conditions

A 1000-Hz tone burst with 20-msec rise and decay times and a peak duration of 20 msec served as the acoustic signal. Two signal presentation schedules were used: (1) a fixed-interval (FI) schedule with an intersignal interval (ISI) maintained at 2 sec, and (2) a variable-interval (VI) schedule with random variable ISIs ranging from 1 sec to 4.5 sec; the mean of the VI schedule was 2 sec. The eight different ISIs that made up the VI schedule were ordered by a random procedure to yield a relative frequency for each ISI as shown in Table 1.

TABLE 1. Relative frequency of intersignal intervals in the variable-interval schedule. Interval order is random. Mean intersignal interval is 2 sec.

Intersignal Interval	*Relative Frequency*
1.0 sec	22.88%
1.5	22.88
2.0	22.88
2.5	11.44
3.0	11.44
3.5	2.86
4.0	2.86
4.5	2.86

If a VI schedule were to result in increased response strength, expressed in larger voltages and perhaps shorter latencies, it might have greater utility in identifying the evoked response to low-intensity acoustic signals than to high-intensity acoustic signals. To explore this possibility, responses to signals of a low sensation level (20 dB) and a moderately high sensation level (50 dB) were compared.

In evoked response audiometry, a small number of epochs (time-samples of electrical potentials from the scalp), averaged over a short period of time, is usually preferred; yet when samples are averaged over less then 50 epochs, the response is often poorly defined. In this study, therefore, the number of epochs averaged to obtain a single evoked vertex response (EVR) was varied between two conditions: (1) 35 epochs (35N), considered to be a relatively small sample; and (2) 70 epochs (70N), a sample size within the range common to EVR audiometry.

TABLE 2. Schedule of experimental conditions. Sensation-level order was reversed for half of the subjects.

Sensation Level (dB) 20	50
1. VI (35N)	5. VI (35N)
2-min rest	2-min rest
2. FI (35N)	6. FI (35N)
2-min rest	2-min rest
3. VI (70N)	7. VI (70N)
2-min rest	2-min rest
4. FI (70N)	8. FI (70N)
5-min rest	end of exper.

Three independent variables—intersignal interval (FI vs VI), number of epochs averaged per response (35N vs 70N), and sensation level of the signal (20 dB vs 50 dB)—were organized into the schedule of experimental conditions shown in Table 2. Order of sensation level was counterbalanced, i.e., odd-numbered subjects received 20-dB signals first and even-numbered subjects received 50-dB signals first. A 2-min rest between each condition and a 5-min rest between the two sensation levels were used to minimize order effects. The experimental schedule was preceded by a control condition in which 35 "no-signal" epochs were averaged on a VI schedule.

Instrumentation and Procedure

Pure tones (1000 Hz) were produced by an audio oscillator (Hewlett-Packard, Model 201CR) and keyed by an interval timer (Grason-Stadler, Model 471). The tone bursts were recorded on one channel of a dual-channel tape recorder (Sony, Model 300). On the second channel, a square wave was recorded to trigger an averaging computer at 18 msec before the time at which 10% of maximum signal amplitude was reached. The tone bursts were delivered through a step attenuator (Hewlett-Packard, Model 350B) to an earphone (TDH-39) enclosed in a Maico Auraldome.

Calibration of output was accomplished with a sound-level meter (Bruel and Kjaer, Model 2203) and an NBS 9-A coupler. Before each test session, voltages across the earphone were calibrated with a vacuum tube voltmeter (Ballantine, Model 300C).

During the experimental session, each subject was reading silently while seated in a semireclined position on a comfortable leather chair. A silver cup-electrode was positioned on the vertex of the scalp with right-mastoid reference and right-forehead ground electrodes. The room was electrically shielded and sound treated.

An electroencephalograph (EEG) (grass Model 6) was used to amplify the electrical potentials. Five-hundred-msec epochs of the output of the EEG were summed and stored by a Computer of Average Transients (CAT, Model 400). An oscilloscope tracing of the summed evoked response was photographed for later analysis.

RESULTS

For all subjects, averaged evoked vertex responses (EVRs) to tone bursts were distinguishable from the wave forms derived under the control condition. Wave-form components, P_1, N_1, P_2, and N_2, each with its characteristic latency, were observed in the EVRs. Figure 1 shows the responses obtained under each experimental condition for one of the 12 subjects. Since the N_1 and P_2 components were the most consistent, and the transition between them was measurable for all experimental conditions and in every subject, $N_1 - P_2$ peak-to-peak amplitude (in millimeters) was treated as a dependent variable.

Latencies of the different components of the EVR were measured in milliseconds relative to the time at which the electrical signal had reached 10% of its maximum amplitude.

$N_1 - P_2$ Amplitudes

The sequence in which the eight experimental conditions were presented to a subject was designed only to control order effects due to sensation level. Hence, the data were examined initially for any significant effects attributable to the order in which the eight experimental conditions were presented. Since the 20-dB vs 50-dB dimensions had been counterbalanced among subjects, the amplitude measures at 20 dB and 50 dB were summed and averaged. In effect, the sensation-level dimension was collapsed and the amplitude of each response was assigned to one of eight categories corresponding to the order in which each condition was presented. The resulting $N_1 - P_2$ peak-to-peak amplitudes for each ordered condition are shown in Figure 2D. Conditions #1 and #5 of the experimental session were both presented at VI 35N, one at 20 dB and the other at 50 dB; conditions #2 and #6 were both presented at FI 35N, and so on.

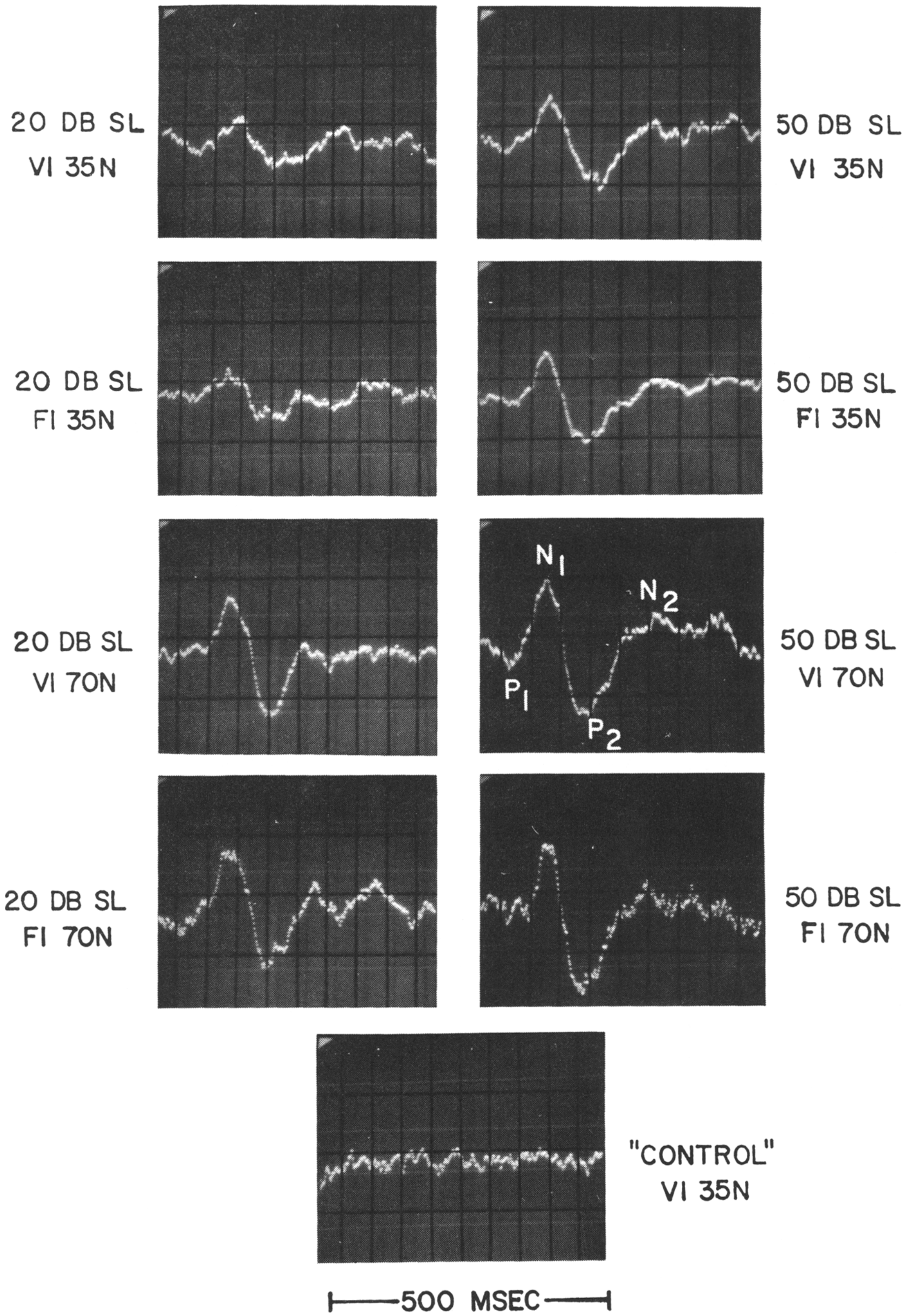

FIGURE 1. EVRs obtained from one subject under the different experimental conditions: VI (variable interval schedule), FI (fixed interval schedule); 35N and 70N (the number of 500-msec epochs averaged in the computer to obtain a single EVR).

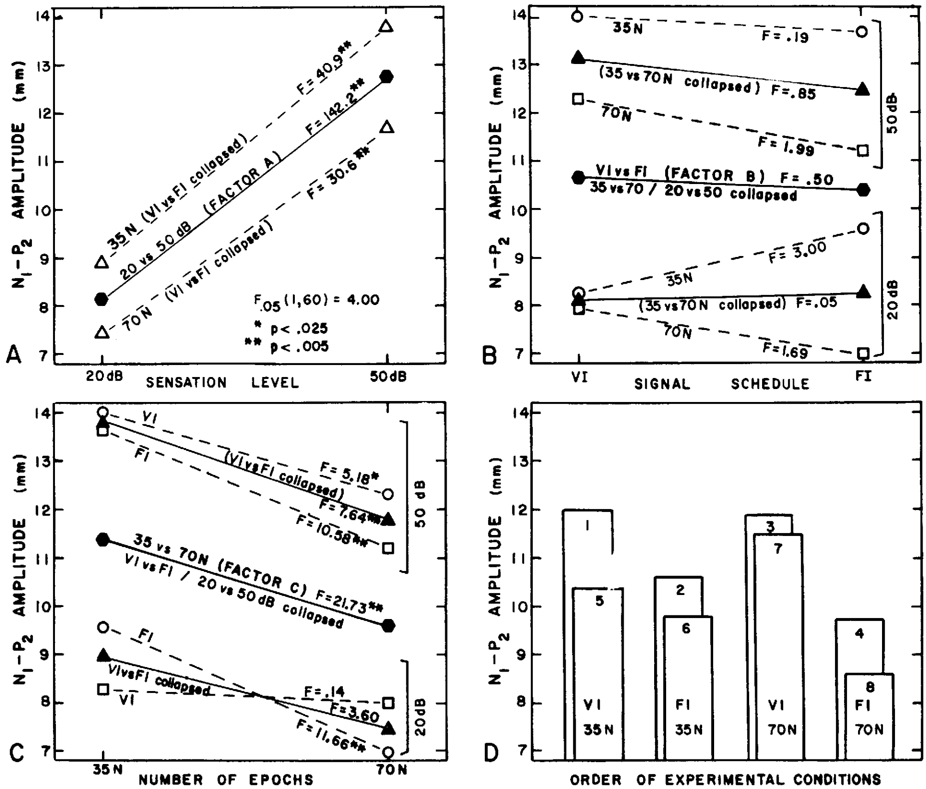

FIGURE 2. $N_1 - P_2$ amplitudes for different factors of the analysis of variance and for order-effects. (A) Factor A: 20 dB vs 50 dB SL; (B) Factor B: VI vs FI schedule; (C) Factor C: 35N vs 70N epochs per response; (D) Order in which experimental conditions were presented: #1 through #8, in order.

Examination of Figure 2D shows small order effects in the direction of smaller amplitudes for the conditions that occurred later in the test session. *T* tests of the differences between mean amplitudes for the different presentation orders—#1 vs #5, #2 vs #6, #3 vs #7, and #4 vs #8—were not significant at the 0.05 level of confidence. Although the mean differences are consistent from one condition to the next, it appears that the variance between conditions and within subjects was too great to show significant order effects. The $N_1 - P_2$ amplitudes between conditions were therefore regarded as relatively free from significant order effects.

An analysis of variance, repeated measures design (Winer, 1962), was performed on the mean amplitudes of the $N_1 - P_2$ transitions. Table 3 summarizes that analysis. *F*-ratios resulting from comparisons of the different factors are shown in A, B, and C of Figure 2.

Sensation level of the tone bursts (Main Effect A: 20 dB vs 50 dB) was significant ($p < 0.005$). Figure 2A shows that $N_1 - P_2$ amplitude is larger at 50 dB SL than it is at 20 dB SL. This relation holds true whether 35 or 70

TABLE 3. Summary of analysis of variance, repeated-measures design, on $N_1 - P_2$ peak-to-peak amplitude of the EVRs.

Source of Variance	*df*	SS	*MS*	*F*
Between Subjects	11	260.71	23.70	6.68**
Within Subjects				
A (20 dB vs 50 dB SL)	1	504.17	504.17	142.20**
B (VI vs FI schedule)	1	1.76	1.76	0.50
C (70N vs 35N)	1	77.04	77.04	21.73**
A-B Interaction	1	4.59	4.59	1.29
A-C Interaction	1	2.67	2.67	0.75
B-C Interaction	1	14.26	14.26	4.02*
A-B-C Interaction	1	3.76	3.76	1.06
Exp. Error	77	273.00	3.55	
Total	95	1141.96		

$F_{0.05}$ (1,60) = 4.00
**$p < 0.005$
*$p < 0.05$

epochs are averaged or whether a VI or FI schedule is used. Comparison of these results with input-output power functions obtained in another experiment by the authors yields excellent agreement. The exponent of the power function in both studies is 0.12 (in terms of sound pressure).

The number of electrical potentials averaged to obtain a single EVR (Main Effect C: 35N vs 70N) was also significant (p <0.005). Figure 2C shows that, except for responses obtained with a VI schedule at 20 dB SL, 35N always produced significantly greater average $N_1 - P_2$ amplitude than did 70N.

Signal presentation schedule (Main Effect B: VI vs FI) was not significant at the 0.05 level of confidence. Comparisons in Figure 2B show that under no conditions are there significant differences between a VI and FI signal presentation schedule. There is, however, a significant B-C interaction. There appears to be greater difference between 35 and 70 epochs in the FI conditions than in the VI conditions, especially at the low sensation level. Whether this is the differential effect of habituation during the larger averaging sample (70N) at the lower sensation level can only be conjectured. It should be noted that the 70N conditions (numbers 3, 4, 7, and 8 in the experimental session) occurred later in the session than did the 35N conditions (1, 2, 5, and 6). Although the order effects are not statistically significant by themselves, they may be contributing to the B-C interaction. Further investigation is needed to separate these effects.

Latencies of EVR Components

Figure 3 shows the mean latencies of EVR components obtained under the experimental conditions. An analysis of variance was performed on the mean latencies of the N_1 components and another on the mean latencies of the P_2 components. The sensation level at which the signals were presented

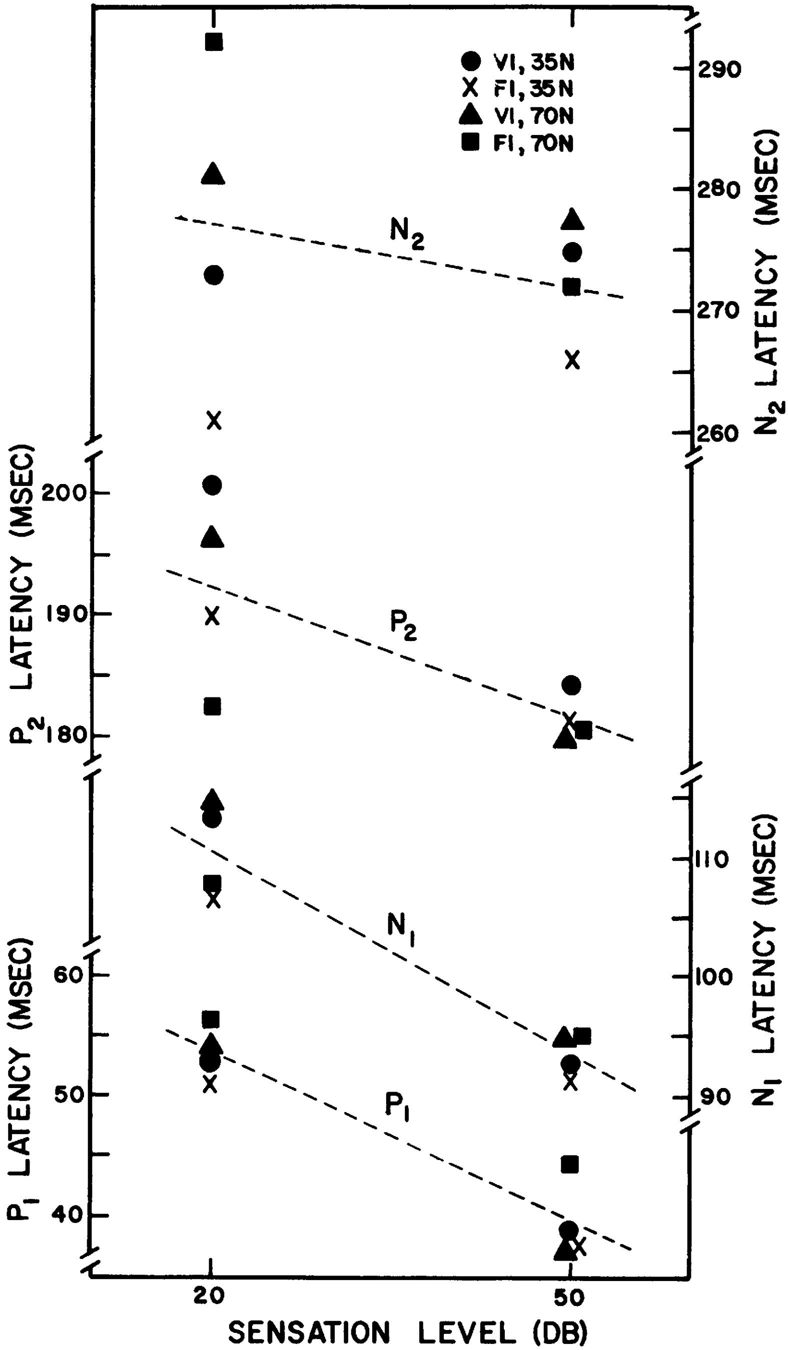

FIGURE 3. Mean latencies of various components of EVRs as a function of sensation level of the 1000-Hz tone bursts. Dashed lines connect composite means.

(20 dB vs 50 dB) was the only significant factor in either analysis of variance ($p < 0.005$). As shown in Figure 3, N_1 and P_2 latencies at 50 dB SL are shorter than at 20 dB SL. Somewhat greater variance is characteristic of the later components P_2 and N_2 than of the two earlier components, especially at 20 dB SL. Latency differences attributable to signal presentation schedule and number of epochs were not significant ($p > 0.05$).

DISCUSSION

VI and FI Schedules

It may be concluded that for 2-sec ISIs, there is little difference in the amplitude or latency of the response whether EVRs are obtained on a variable- or fixed-interval schedule. Davis and Zerlin's (1966) comment that "it is unnecessary to 'surprise' the subject by using irregular intervals" seems to be confirmed by these results.

The evidence against a difference between VIs and FIs is even more impressive when one considers that the experimental schedule was designed to favor a VI schedule. The VI schedule always preceded the FI schedule during a single session. If habituation mechanisms were influential in some way, they could be expected to affect the FI schedule more than the VI schedule, resulting in decreased amplitude for the later (FI) schedule. Even with this advantage, the VI schedule did not prove to be superior to the FI schedule in increased response "strength."

It is possible that the mean interval, 2 sec, was too short for CNS discrimination between VI and FI. In view of Keidel and Spreng's (1965) reported advantage for a 17-sec variable-interval schedule, study of intervals between 2 and 17 sec is indicated. The present evidence is certainly insufficient to argue for a VI schedule in EVR audiometry instead of the more convenient FI schedule, at least when intervals are near 2 sec.

Number of Epochs Averaged

That the number of epochs averaged by the computer to obtain each averaged response was a significant factor is surprising in view of two recent papers reporting this factor to be nonsignificant. Rose and Ruhm (1966), using clicks as stimuli, found no significant amplitude differences between four successive averages of 125N repeated on six consecutive days. Liebman and Graham (1967) reported that the number of epochs averaged per response was not a significant factor when the first 50N were compared with the first 75N or when 75N vs 100N and 125N vs 150N were compared.

In our study, 70N yielded significantly smaller amplitudes than did 35N for every condition except VI at 20 dB. One cannot conclude that this difference was only an effect of the independent variable (i.e., the number of epochs averaged per response), since the 70N conditions always followed the 35N conditions. But this decreased response amplitude over time suggests that habituation may be a possible factor in the EVR.

Walter (1964) has demonstrated the effects of habituation on the averaged evoked response from human nonspecific cortex. He suggests that cerebral attention is maintained until some "threshold of triviality is reached" when the sustained response level falls rather abruptly. Using consecutive averages of 12N, he saw a decrease in response amplitude after 48 stimuli were presented. The disagreement between the results of the present study and the findings of Rose and Ruhm (1966) and Liebman and Graham (1967) may be a dual function of a difference in the relative number of epochs averaged per response and a difference in the consecutive nature of the averages.

Both of the previous studies compared averaged responses obtained with data samples greater than 50N. Their responses were collected consecutively with no "time-out" period between each average. Our study compared responses averaged in samples of 35N and 70N with 2-min time-outs between each consecutive average. If one accepts the assumptions that habituation occurs somewhere around 35N but before 70N (using stimulus parameters as in our study), and that a 2-min time-out allows complete recovery from previous habituation, it can be conjectured that the 70N response would contain the effects of habituation but the 35N response would not.

Habituation may well be present in the averaged evoked response, but unless consecutively averaged responses obtained with small averaging samples are compared, the effects of habituation may not be discerned. These speculations suggest that careful examination of the earlier stages of the averaging process could be profitable.

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