CHANGES IN AUDITORY EVOKED RESPONSE WITH INTENSITY

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Introduction

THE average auditory evoked cortical potential in young adults is a waveform in which several well-marked components as shown in Fig. 1 can usually be identified. The P_1, N_1, and P_2, components are the most characteristic and the N_2, and N_3 are less constant. The amplitude of the main response, measured peak-to-peak (from N_1 to P_2) is related to intensity and decreases progressively as the stimulus is reduced towards the subject's threshold.

The waveform of the evoked response is a little different in young children where the later elements are larger than the earlier components and may in fact submerge them completely. A waveform from a child is seen in Fig. 2 showing the usual P_1, N_1, and P_2 components but with greatly enlarged N_2 and N_3 peaks.

Within broad limits, the latencies of the various major components of the averaged waveform are stable, but some lengthening of the latency has been noted in many normally-hearing subjects as threshold is approached. It was decided to investigate these changes in detail for it was felt that any positive findings could well have some predictive value when utilizing the evoked cortical potential as a practical test of hearing.

Method

The apparatus used in this investigation is slightly modified from that previously described (Beagley and Knight, 1967a) and is shown in Fig. 3. The auditory stimulus is derived from a pure-tone oscillator whose output is controlled by an electronic switch and variable attenuators, and is then amplified by a power amplifier matched to a loudspeaker placed directly facing the subject at a distance of 1 m. from the glabella. In this way, the subjects were stimulated binaurally but, for monaural applications, the signals can be routed to one of a pair of earphones. The sound intensity produced by the loudspeaker at the ear has been calibrated in terms of the I.S.O.* normal threshold of hearing,

* I.S.O./Recommendation 389–1964 only enables the normal threshold sound pressure level for monaural earphone listening to be standardized. A corresponding standard does not exist for listening binaurally in a free field but the binaural threshold is more sensitive by 5 or 6 db. When binaural hearing levels are stated in the text to be with respect to I.S.O. normal threshold, it is meant that the group of normally-hearing subjects used for establishing the binaural normal threshold in the free field have thresholds for earphone listening which conform substantially to the I.S.O. reference zero.

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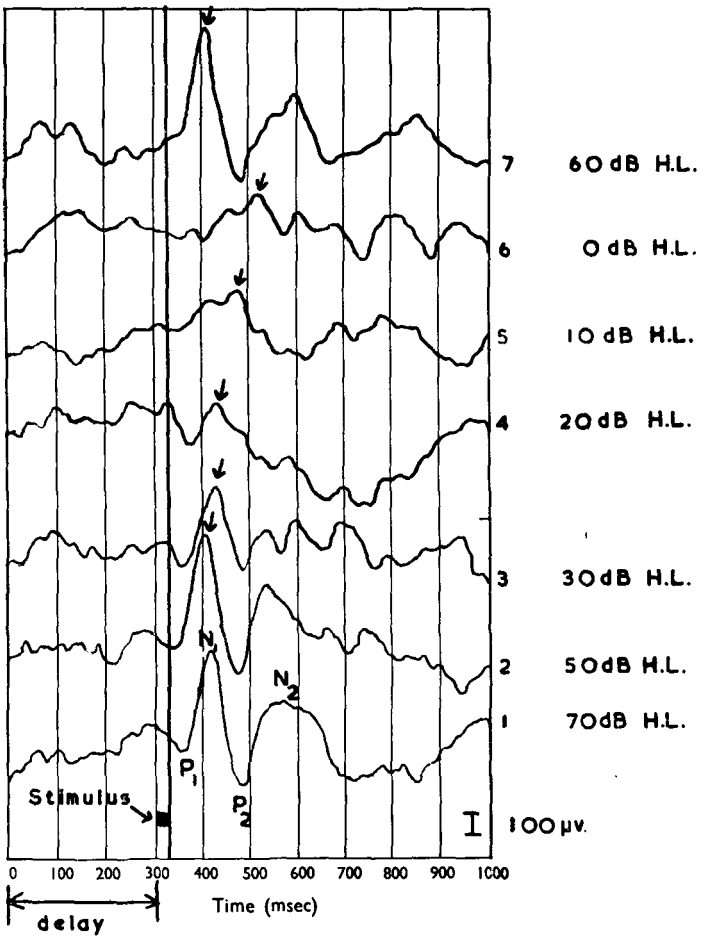


FIG. 1.

Average evoked response of a normally-hearing young adult, Miss P. K., at seven hearing levels from 70 db. (I.S.O.). Stimulus: 60 tone pulses at 1,000 c.p.s.

The P_1, N_1, P_2 and N_2 components are shown in the first trace, while the N_1 is marked with an arrow in the remaining traces. The shift in latency and the decrease in amplitude towards threshold is clearly shown. This set is shown because the traces towards threshold are difficult to identify. In the "blind" assessment (see text) the evoked responses in the 20 db. and 10 db. traces were not positively identified, but when the data were considered *en bloc* the response could be traced as far as threshold, 0 db.

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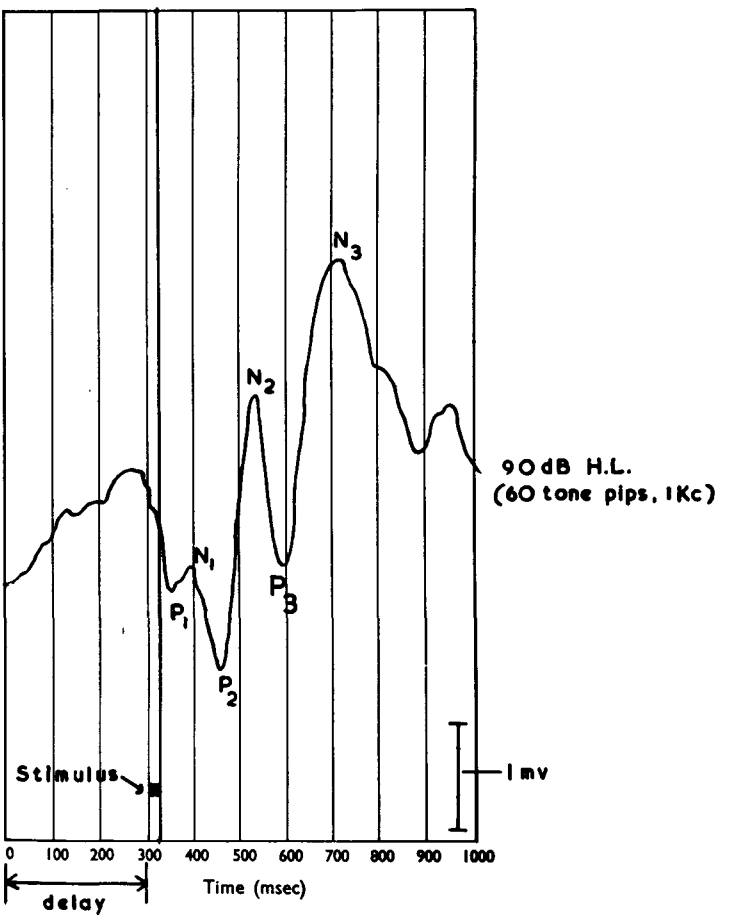


FIG. 2.

Average evoked response of a child, G. H., aged 6 years with 55 db. hearing loss. Stimulus: 60 tone pulses at 90 db. hearing level (I.S.O.). Note prominent N_2, P_3, N_3 components compared with Fig. 1.

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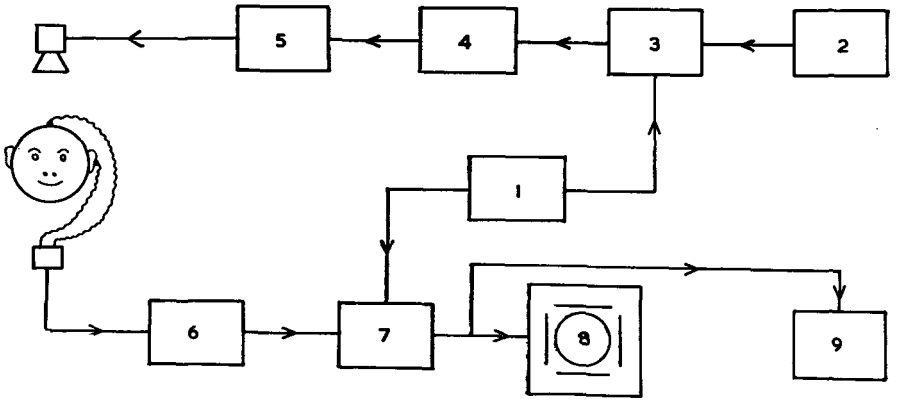


FIG. 3.

Block diagram of the apparatus.

(1) "Digitimer" interval timer with two isolated stimulators Mk.IV (Devices Ltd.)
(2) Wide range oscillator, type 400 B (Dawe)
(3) Electronic Switch, type 829 E (Grason-Stadler)
(4) Step attenuators, type A 64 (Advance Components)
(5) Audio amplifier, type TL/25 plus (Leak)
(6) Physiological amplifiers, Dynograph type R (Offner)
(7) Digital Computer, Enhancetron 1024, ND 800 (Nuclear Data Inc.)
(8) Oscilloscope, type 503 (Tektronix)
(9) X-Y recorder, type HR96 (Advance Components)

as is also the case for earphone listening (Beagley and Knight, 1967b). For the present experiment, the electronic switch was arranged so that pulses of pure tones were obtained with rise and decay times of 2·5 milliseconds, the duration and repetition rate being controlled by an interval timer set to 20 milliseconds and 1·25 seconds respectively.

The evoked cortical potential resulting from the stimulus is taken between the vertex and one earlobe by means of chlorided silver disc electrodes, with the indifferent electrode on the forehead. An impedance of 2 kilohms or less between any two electrodes was obtained throughout. The scalp potentials are of the order of 10 microvolts and may be amplified by a maximum of 86 db. by a transistorized physiological amplifier with a bandwidth extending down to 0·16 c.p.s. but deliberately limited to 22 c.p.s. in the higher frequencies, and with a time constant of 1 sec.

An on-line computer is used to average the amplified evoked potentials in digital form (using 1,024 data points) from sixty tone pulses controlled as described by the interval timer, which also triggers the computer 300 milliseconds in advance of the start of the tone pulse from the loudspeaker. This arrangement enables the situation prior to the onset of the stimulus to be recorded. The computer provides a 1 sec. timebase, allowing the running average of the amplified evoked responses to be displayed on an oscilloscope and the final average of the sixty responses to be recorded on an X-Y recorder. Alternatively, for special purposes

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the final oscilloscope trace may be photographed with Polaroid film. Further details and illustrations of the experimental layout are given elsewhere (Beagley and Knight, 1967b).

The main experiment was concerned with pulses of 1,000 c.p.s. tone and the sequence of test intensities was 70, 50, 30, 20, 10, 0 db., hearing level (I.S.O.), and finally 60 db. The signal stored in the memory of the computer from the sixty synchronized presentations of sound was written out after each run. The seven runs, each lasting 1·25 mins., were completed in a single session of about 30 mins. duration. Each subject was tested in this way on six separate occasions. In addition a seventh session was devoted to retesting with a different frequency from the 1,000 c.p.s. used on the previous occasions. The extra frequency was either 500, 2,000 or 4,000 c.p.s. and was introduced to give an indication as to whether any systematic frequency-dependent variations existed.

Later a subsidiary experiment was arranged to examine the variation of latency in greater detail towards the individual thresholds. For this purpose a similar train of tone pulses of 1,000 c.p.s. was used at intensities of 40, 20, 15, 10, 5, 0 db. (re individual threshold) followed by retest at 40 db., on a single occasion for each subject.

For both main and subsidiary experiments, eight normally-hearing young adults from the secretarial, technical and scientific staffs were used. All were female and had an average age of 28 years; two were graduates. Each subject was seated in a chair with the head supported. During the presentation of the stimulus, the subject was instructed merely to sit still and read a book. A number of young men also attended for a few sessions but, as the results of their tests appeared similar to those of the young women, these tests were not continued as the latter were more readily available for testing.

In order to measure amplitude and latency it was necessary in view of the background activity to recognize the selected components with reasonable certainty. This, of course, presented no problems at intensities well above threshold. Recognition at lower intensity levels was based on the triphasic entity composed of the P_1, N_1 and P_2 components. Of the three components the N_1 was perhaps the most stable, unlike the P_1 and P_2 peaks which tended to be modified by the preceding and following random fluctuations that the averaging process sometimes failed to eliminate. The P_1 was a fairly labile component and was quite often absent. The P_2 was rarely absent, but its measured latency was rather variable because it did not always appear as a sharp peak, and was occasionally influenced by the presence of the N_2 component, which is variable in the adult. The N_1–P_2 segment is a particularly characteristic feature for identification and, in fact, the peak-to-peak extent of this deflection was taken as the amplitude of the response for present purposes. The waveform traced by the X–Y recorder was used to determine the ampli-

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tude and the latency of the summated evoked responses. The amplitude was measured and converted to microvolts as a result of direct calibration with a known input to the amplifier. The latency of the response was measured from the time of onset of the sound stimulus at the loudspeaker to the peak of the N_1 component of the evoked response.

Results

The principal results are shown graphically in the text and the statistical details are given in tabulated form in the Appendix.

It was confirmed that, on average, a decrease in the intensity of the stimulus resulted in a decrease of the N_1–P_2 amplitude. A complete set of traces for one individual on a given occasion shows this distinctly (Fig. 1), although there were sometimes irregularities. For example, occasionally the amplitude of the 50 db. series exceeded that of the initial 70 db. series. Figure 4A shows the variation with intensity of the mean amplitude of the evoked response at 1,000 c.p.s. alongside corresponding data for the "extra" frequencies (three subjects tested at 500 c.p.s., two at 2,000 c.p.s., and three at 4,000 c.p.s.). Collectively these frequencies appear to produce smaller amplitudes than the 1,000 c.p.s. stimulus, but the difference was only statistically significant at 10 and 20 db. hearing level according to the "t" test. Table I (appendix) gives the means and standard deviations for 1,000 c.p.s. with the results of the "t" tests showing that the amplitude difference at each intensity step is statistically significant ($P<0\cdot05$). Also shown in Figure 4A are the mean amplitudes of the subsidiary experiment where each subject was tested only once and at intensities related to the individual threshold. As can be seen from the graph, the amplitudes indicated by the two curves are similar near threshold, but at higher intensities those of the subsidiary experiment are greater.

Fig. 4B shows that the latency of the N_1 component (main experiment 1,000 c.p.s.) systematically increases as the sound stimuli approach threshold. This trend is confirmed by the results of the subsidiary experiment which are also plotted. The third curve in the figure relates to the tests at the "extra" frequencies in which longer latencies appear to occur but were found to be significantly different ($P<0\cdot05$) from those of 1,000 c.p.s. only at 30 db. hearing level and above. Table II gives the means and standard deviations of the N_1 latencies at the seven chosen intensities of the main experiment. The differences in the means as the intensity was successively reduced is shown by the "t" test to be highly significant ($P<0\cdot01$) below 50 db. hearing level. In Table III are given the corresponding data for the subsidiary experiment at 1,000 c.p.s. in which intensity was related to sensation level. Table IV shows mean amplitudes and latencies for 500, 2,000 and 4,000 c.p.s. combined.

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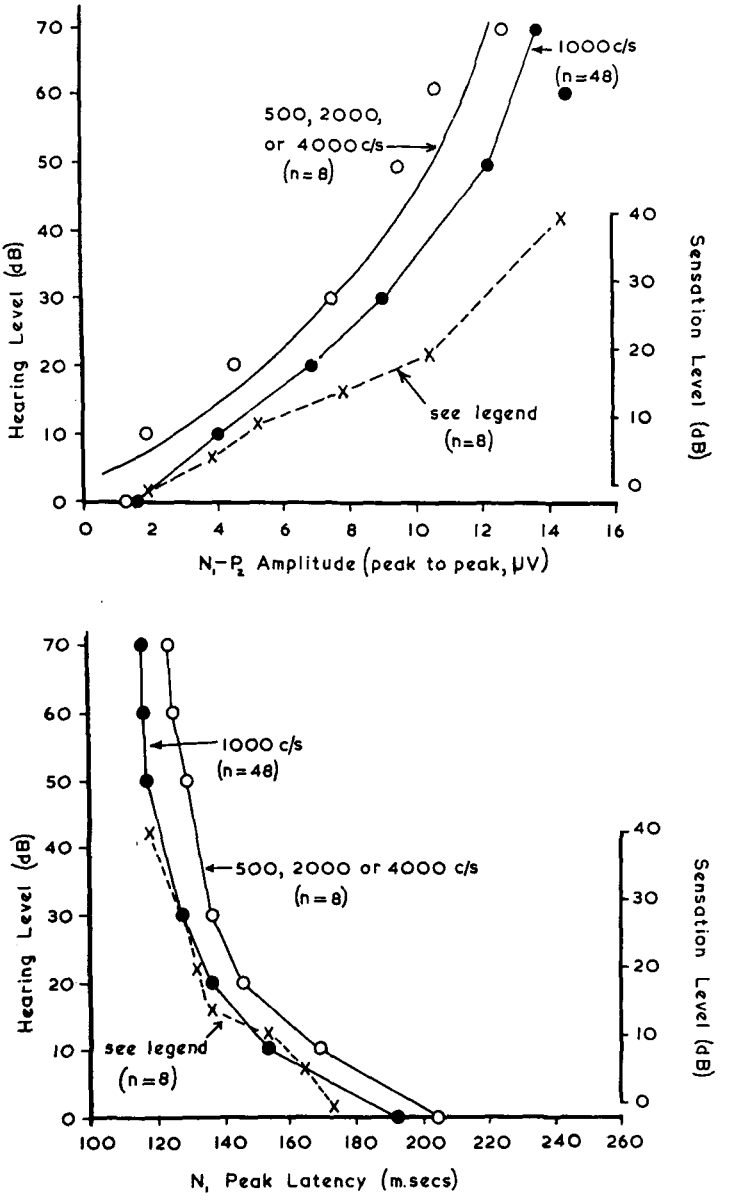


FIG. 4.

(Top): Variation of mean amplitude of evoked response with intensity of tone.
(Bottom): Variation of mean peak latency of N_1 component of response with intensity. Intensities in terms of hearing level in db. (I.S.O.) for main experiment at 1,000 c.p.s. (eight subjects tested six times), and other frequencies (eight subjects tested once). Sensation level was used in the subsidiary experiment at 1,000 c.p.s. (eight subjects tested once).

●———● Main experiment at 1,000 c.p.s. at various hearing levels.
○———○ Other frequencies at various hearing levels.
× - - - - × Subsidiary experiment at 1,000 c.p.s. at sensation levels.

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A two factor analysis of variance was performed to separate the systematic variance in latency between individuals and occasions from the residual variance including the inherent inaccuracies of the apparatus and the random errors in the whole experiment. These variances are given in Table V which shows the latencies to be significantly different ($P<0\cdot05$) among individuals down to 10 db. hearing level, with the exception of 50 db. where this degree of significance was not quite attained. The latencies for any individual on different occasions are seen to be non-significant at all hearing levels except 10 db., which alone reached significance ($P<0\cdot05$).

As stated above, the evoked response was easily recognized at high intensities, but towards threshold it was not always detected. The percentage of possible responses which were identified on the original traces at the different levels of stimulation is tabulated below. It shows the difference in detectability when the entire record as traced by the X-Y recorder is assessed from a descending series (as in Fig. 1) and compared with a "blind" assessment. For the latter estimate, reproductions of every trace were made, each on a single piece of paper and coded with a random number.

Hearing Level (db. re I.S.O.)	Recognition (%)	
	Definitive assessment	Blind assessment
70	100	100
50	100	100
30	100	100
20	100	98
10	96	85
0	57	60
60	100	100
All levels	95·4	91·3

When the actual traces shown in Fig. 1 were assessed "blind", those corresponding to stimulation at 20 db. and 10 db. hearing level were not identified. However, when the data were inspected as a series it was possible to identify the waveform of the evoked potential at all intensities, for it was easier to trace the diminishing waveform down from its typical form at high intensities to its attenuated form at threshold. The identification was also assisted by allowing for the increased latency.

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Discussion

The notion that the amplitude of the evoked response varies with intensity is not a new concept (Davis, 1965; Beagley and Knight, 1967a; Price *et al.*, 1966; Rose and Ruhm, 1966). The variability of the amplitude has also been extensively documented (Davis, 1965; Davis and Zerlin, 1964) and our data are in accord with these previous findings. However, the present amplitude data, using the mean of an adequate number of traces (n=48), indicate a systematic trend.

The observation that the latency of the evoked response is increased as the intensity of stimulation is decreased is well-supported by the results of the foregoing experiment and confirms the observations of earlier studies (Rapin, 1965; Beagley and Knight, 1967a; Price *et al.*, 1966; Rose and Ruhm, 1966). The successive displacement of N_1 along the time axis as the sound stimulus decreases, helps the observer to identify the much reduced responses at the lower intensities. This process is, of course, greatly facilitated by having a clear response from higher levels of intensity already written out, and it is generally possible to follow the waveform to within a few decibels of the subjective threshold with young adults, as Davis (1966) has shown with young deaf children. An isolated waveform produced as a result of a series of stimuli at low intensity would be much less easily discerned by the observer in the absence of well-defined waveforms obtained at higher levels of intensity. This is the reason why, in clinical tests of hearing by means of the evoked response, it is usual to start the auditory stimulation well above the subject's presumed threshold. The characteristic waveform so produced may then be followed at successively lower levels of stimulation until the region of threshold is reached. The majority can be assessed to within 5 db., and virtually all to within 10 db., of the subjective audiometric threshold. It is noteworthy that the latency of the N_1 which averages 116 milliseconds at levels of 50–70 db. above threshold is almost doubled (192 milliseconds on average) at threshold.

Conclusions

This study, with normally hearing subjects, has shown that as the intensity of the short pulsed stimulus of 1,000 c.p.s. is reduced, the N_1–P_2 amplitude decreases and the peak latency of N_1 increases. The latency of N_1 well above threshold, say above 50 db. hearing level (I.S.O.), is almost 120 milliseconds, while at 30 db. it is increased by about 10 per cent., and at threshold by about 70 per cent. Compared with 1,000 c.p.s., tests at other frequencies indicate that smaller amplitudes and longer latencies apply at corresponding hearing levels. With this knowledge, criteria can be established for identifying the evoked response in clinical applications, in particular when used as a hearing test.

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After 60–70 db. above threshold, further intensity increase produces little change in amplitude and latency, but, below 50 db., first a 20 db. step, and then 10 db. steps, produce significant changes in amplitude and latency as intensity is reduced.

Amplitude is shown to have greater variance than latency which can therefore be regarded as the more stable characteristic of the evoked response. Analysis of variance of the latency shows that significant variations were not obtained, in general, on different occasions. However, significant differences were found usually between subjects. The only exception was at 10 db. hearing level where the difference between subjects was not significant yet the difference between occasions was significant. This might be accounted for by physiological variation of threshold on different occasions.

The latency change in each individual is always towards increased latency as the intensity is decreased. Any component which resembles the N_1 at or near threshold and which apparently peaks at a shorter latency than the N_1 for a higher intensity must be regarded with suspicion and should be rejected. Repetition of the stimulation at the same intensity is the only safeguard if faced with this ambiguous situation during a clinical assessment of hearing using evoked potentials.

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Changes in Auditory Evoked Response with Intensity

Appendix

TABLE I.

MAIN EXPERIMENT—1,000 c.p.s. AND HEARING LEVELS

A. MEANS AND STANDARD DEVIATIONS OF AMPLITUDE OF N_1–P_2 WITH INTENSITY (n=48)

Hearing Level (db. re I.S.O.)	Mean amplit. (μV)	Stnd. Dvn. (μV)	Hearing Level (db. re I.S.O.)	Mean amplit. (μV)	Stnd. Dvn. (μV)
70	13·7	4·0	10	4·0	2·3
50	12·2	3·8	0	1·6	2·0
30	9·0	3·1	60	14·7	5·3
20	6·9	2·9			

B. RESULTS OF SIGNIFICANCE TESTS, AMPLITUDE AND INTENSITY (n=96).

Hearing Levels Compared (db re I.S.O.)	"t"	Significance
70 versus 50	2·3	P<0·05
50 versus 30	4·4	P<0·001
30 versus 20	3·9	P<0·001
20 versus 10	5·5	P<0·001
10 versus 0	2·9	P<0·01

TABLE II.

MAIN EXPERIMENT–1,000 c.p.s. AND HEARING LEVELS

A. MEANS AND STANDARD DEVIATIONS OF LATENCY OF N_1 WITH INTENSITY

Hearing Level (db. re I.S.O.)	"n"	Mean Latency (millisecs.)	Stnd. Dvn. (millisecs.)	Hearing Level (db. re I.S.O.)	"n"	Mean Latency (millisecs.)	Stnd. Dvn. (millisecs.)
70	47	116	8·6	10	47	153	20·8
50	48	117	7·2	0	37	192	37·3
30	48	127	10·6	60	45	116	7·9
20	48	136	13·0				

B. RESULTS OF SIGNIFICANCE TESTS, LATENCY AND INTENSITY

Hearing Levels Compared (db. re I.S.O.)	"n"	"t"	Significance
70 versus 50	95	0·3	N.S.
50 versus 30	96	3·2	P<0·01
30 versus 20	96	3·8	P<0·001
20 versus 10	95	4·9	P<0·001
10 versus 0	84	6·2	P<0·001

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TABLE III.

Subsidiary Experiment–1,000 c.p.s. and Sensation Levels

A. Means and Standard Deviations of Amplitude of N_1–P_2 with Intensity (n=8)

Sensation Level (db. re indiv. thresh.)	Mean Amplit. (μV)	Stnd. Dvn. (μV)	Sensation Level (db. re indiv. thresh.)	Mean Amplit. (μV)	Stnd. Dvn. (μV)
40	14·5	3·7	5	3·8	2·2
20	10·4	2·9	0	1·7	1·9
15	7·7	2·5	40	15·4	3·4
10	5·1	1·6			

B. Means and Standard Deviations of Latency of N_1 with Intensity (n=8)

Sensation Level (db. re indiv. thresh.)	Mean Latency (millisecs.)	Stnd. Dvn. (m.secs.)	Sensation Level (db. re indiv. thresh.)	Mean Latency (millisecs.)	Stnd. Dvn. (m.secs.)
40	118	5·0	5	162	21·1
20	126	9·8	0	170	16·4
15	130	15·0	40	119	4·7
10	151	19·0			

TABLE IV.

500, 2,000 or 4,000 c.p.s. and Hearing Levels

Mean Amplitude of N_1–P_2 and Latency of N_1 with Intensity (n=8)

Hearing Level (db. re I.S.O.)	Mean Amplit. (μV)	Mean Latency (millisecs.)	Hearing Level (db. re I.S.O.)	Mean Amplit. (μV)	Mean Latency (millisecs.)
70	12·6	123	10	1·9	168
50	9·4	129	0	1·3	203
30	7·5	136	60	10·4	124
20	4·5	145			

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TABLE V.

ANALYSIS OF VARIANCE—LATENCY

ANALYSIS OF VARIANCE OF LATENCY OF N_1 WITH INTENSITY (DATA OF TABLE IIA)

Hearing Level (db. re I.S.O.)	Source of Variation	Sum of Squares	Degrees of Freedom	Variance Estimate	"F"	Significance
70	Between Occasions	232·6	5	46·5	0·58	N.S.
	Between Subjects	1,353·0	7	193·3	2·33	P<0·05
	Residual	2,904·9	35	83·0		
60	Between Occasions	236·8	5	47·4	1·27	N.S.
	Between Subjects	903·4	5	180·7	4·83	P<0·01
	Residual	934·1	25	37·4		
50	Between Occasions	473·0	5	94·6	2·10	N.S.
	Between Subjects	666·7	7	95·3	2·12	N.S.
	Residual	1,577·0	35	45·1		
30	Between Occasions	663·9	5	133·2	1·99	N.S.
	Between Subjects	2,357·8	7	336·8	5·03	P<0.001
	Residual	2,345·3	35	67·1		
20	Between Occasions	115·1	5	23·0	0·26	N.S.
	Between Subjects	3,957·8	7	565·4	5·51	P<0·001
	Residual	3,589·1	35	102·5		
10	Between Occasions	18,583·4	5	3,716·7	4·67	P<0·05
	Between Subjects	4,983·4	6	830·6	2·05	N.S.
	Residual	12,138·0	30	404·6		

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