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DARRELL E. ROSE

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VARIABILITY OF PEAK LATENCY AND AMPLITUDE OF

THE ACOUSTICALLY EVOKED POTENTIAL

APPROVED BY

H B Rubin

M. Clinton Miller III

J. W. Keys

Bruce R. Pierce

DISSERTATION COMMITTEE

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CHAPTER I

INTRODUCTION

In recent years, numerous tests have been designed in an effort to determine specific sites of lesion within the auditory pathway (5, 7, 34, 35). In clinical application, these procedures have proven to be of primary value in differentiating between peripheral involvements and lesions to the acoustic nerve (5, 34, 35). In general, attempts to identify sites of lesion central to the eighth nerve have been either unsuccessful or inconclusive (5, 7, 8).

Traditionally, one of the more promising methods of assessing higher nervous system function has been electroencephalography (EEG). By this means, it is possible to obtain an index of electroencephalic function which is useful in neurological diagnosis. The information from such EEG tracings is usually derived from an analysis of the rhythmic display of on-going EEG activity. Relatively large deviations from normative data are evident to the trained clinician who can deduce from them gross loci of damage.

In spite of their obvious diagnostic value, neither EEG results nor information obtained from other extrasurgical diagnostic procedures have

have been exceptionally successful in specifying loci of CNS abnormalities of the higher acoustic pathways. In cases where the EEG procedure has been useful in specifying site of lesion, the damage was found subsequently to be limited to the cerebral cortex (2, 4, 16, 63). Obviously, a precise extrasurgical specification of site of lesion would facilitate medical and surgical intervention at the earliest time.

A promising variant of the EEG procedure is the analysis of electrical potentials evoked from the intact scalp by sensory stimuli. Since it is known that potentials are, in fact, evoked by sensory stimuli and can be recorded from a position over-lying the cerebral cortex, it is reasonable to hypothesize that they may represent the neural firings of various CNS pathways and levels. It is possible that the latency and amplitude of each component of an evoked potential may be indicative of a different point of origin and electrical contributions within the CNS. This concept derives importance from the possibility that, once the pattern of the normal evoked potential is established, deviations in the latencies and amplitudes of specific components of the response evoked from an individual may provide an indicant of the location of sites of lesion within the CNS.

If such information is to be of diagnostic importance, the latency and amplitude characteristics of the evoked potentials in subjects without auditory abnormalities must first be determined in order to provide the norms against which deviations can be compared. The present study was designed to help determine such norms by specifying the amplitude and latency characteristics of the acoustically evoked response from the intact scalp in man. Specifically, this study was designed to investigate and describe the peak latencies and amplitudes of the response evoked by acoustic clicks as a function of time and number of stimuli at two stimulus intensities. A discussion of pertinent studies of evoked potentials and the procedural variables that affect them are presented in the following chapter.

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CHAPTER II

REVIEW OF THE LITERATURE

The unavailability of some of the original articles concerning the discovery and early investigation of the electrical activity of the brain made the task of reviewing the literature a rather difficult one. In an attempt to keep the information consistent with generally accepted historical facts, the author has relied heavily on the works of Brazier (11). Where original works could be obtained, they were used.

The following review of the literature consists of the early history as a general introduction, then of more specific areas dealing with evoked auditory responses in humans. Information from related areas is discussed when considered pertinent to the present study.

History of Electroencephalography

The fact that nerves contain intrinsic forms of electricity was first noted and published by Galvani in 1791. It was left to Du Bois Reymond, in 1848, to demonstrate that peripheral nerve activity was associated with an electrical change. Concerning this most important discovery, Brazier has quoted Du Bois Reymond:

> If I do not greatly deceive myself, I have succeeded in realizing in actuality (albeit under a slight different aspect) the hundred years' dream of physicists and physiologists, to wit, the identification of the nervous principle with electricity.

Richard Caton, in 1875, reported "on the electrical relations of muscle and nerve"; his instrumentation consisted of a Thomson reflecting galvanometer, Du Bois Reymond's electrodes, and optical magnification. Later that same year, Caton reported a study of the possible electrical activity of the brain; according to Brazier, "This was the discovery of the electroencephalogram." Even as late as the 1890's, considerable controversy existed over certain aspects of these early electrophysiological studies. Hermann, for example, indicated that there "was no such thing as a resting potential".

Beck found that afferent stimulation, such as light (using a magnesium flare) or in stimulation to the hind leg of an animal, resulted in a desynchronization of cortical electrical activity. Brazier has quoted Beck as follows:

> In addition to the increase or decrease in the original deviation during stimulation of the eye with light, rhythmic oscillations that have been previously described disappeared. However, this phehomenon was not the consequence of light stimulation specifically for it appeared with every kind of stimulation of other afferent nerves.

Beck also felt that he could determine areas of cortical localization by observing the point of maximum negativity of the electrical activity when a peripheral area was stimulated. Consequently, he reasoned that he should be able to produce the same shift by the use of cortical stimulation and performed several experiments with the brains of rabbits and dogs. In this work with animals, Beck had far less success with the auditory area than with the visual area. He reasoned that this was due to difficulty in placing electrodes on the inner surface of the temporal lobe.

Some confusion exists, however, as to who was responsible for the initial research in the area of evoked potentials. Fleischl is reported to have written that his work antedated Beck's discoveries and that the information had been deposited in a vault at the Imperial Academy of Sciences in Vienna some seven years prior to Beck's report.

By amplifying the electrical impulses, Wedensky was able to listen to the nerve currents which activated a telephone receiver. He indicated that the auditory signal was extremely faint.

Larinov, who is reported to have made some of the first observations with regard to the localization of tonal stimuli in the auditory cortex, concluded that the center for audition exists in the temporal lobe.

According to Brazier, Kaufman, around 1910, ". . . was the first to express the concept that an epileptic attack would be accompanied by abnormal discharges and to test this postulate by examining the potentials of the brain during experimentally produced epilepsy".

Neminsky's investigation, published in 1912, was the first work reported to contain pictures of an electroencephalogram. Two years later, Cybulski also presented EEG tracings.

Berger found the counterpart of Neminsky's alpha and beta waves and suggested a change from the name of electrocerebrogram to "Elektrenkephalogramm". In referring to the work of Berger, Brazier stated:

> In 1924, in the seclusion of his laboratory, he returned to search for an electrical sign of sensory stimulation, and this time he looked for it in man. After many technical difficulties, he succeeded the following year in recording, with a Siemens double-coil galvanometer, the electroencephalogram of man, and in reproducing in man the decrease in activity of sensory stimulation that Beck and Neminsky had described in animals.

Adrian and Matthews (2) demonstrated conclusively that electrical changes recorded from the scalp have their origin in the brain, and thus, are similar to responses obtained from the cortex itself. They indicated that these findings substantiate the work of Berger in 1929.

Lindsley (38, 39) found that a potential recorded from the scalp is approximately ten times smaller than one recorded from the cortex and associated this reduction with the distance from the cortex to the scalp and the amount of tissue through which the potential must be conducted. Lindsley also indicated that, as the distance increases, the amplitude of the responses decreases. Domino (30), in 1964, stated that "the voltage attenuation is approximately twenty, depending on conditions". Cobb and Sears (18) reported that they recorded potentials from the cortex at a distance of five to six centimeters from the scalp.

Reports of new techniques designed to complement visual analysis of EEG data represent a sizable portion of the literature from the late 1930's to the mid-1950's. Knott (37) indicated that some of the techniques designed to complement visual analysis merely led to further visual analysis and that, as measuring tools, they were considerably limited. A review of these various methods will not be covered in this paper but may be found in another reference (63).

In 1936, Walter (57, 58) found that EEG tracings of patients with intracranial tumors had a high-voltage wave which was slower than that found in normals, substantiating the work reported by Berger as translated by Cobb (16). It was Walter's contention that the high-voltage, slow-wave components of the EEG tracing came from the area directly over the tumor, thus making possible a new technique for tumor location. Cobb (16) also reported that Foerster and Altenburger demonstrated that neoplastic tissue could not of itself give rise to the electrical activity. Foerster and Altenburger, as well as Walter, concluded that the electrical activity must, therefore, come from the area directly surrounding the tumor.

Several EEG techniques have been developed to aid in the location of CNS lesions. Perhaps the earliest of these was that developed by Adrian and Matthews (2) and later used by Walter (57) in which the scalp is searched electroencephalographically for an area in which the phase of the waves is reversed. Gibbs, Gibbs, and Lennon (33) felt that the amplitude of the EEG tracing was an important factor. It was indicated by the early investigators that the potentials from numerous positions on the scalp should be recorded in order to locate a lesion. Gibbs, Gibbs, and Lennon (33) indicated that as large an area of the scalp as possible should be encircled by the electrodes. Cobb (18), however, indicated that, by using twelve electrodes, instead of the sixteen recommended by Gibbs, Gibbs, and Lennon (33), the head could be covered with multiple triangular arrangements which would give a better picture of the electrical activity.

Gibbs, Gibbs, and Lennon (33) found that, occasionally, instead of a wide-spread change in the electrical activity, only one electrode will demonstrate the phase reversal of electrical change. Therefore, they have suggested that the recording be duplicated with another electrode near the point of the phase reversal and that a second recording be completed on a subsequent day to help reduce the possibility of an innaccurate reading.

Bagchi and Bassett (4) indicated that the use of the monopolar recording technique was of the utmost value in allowing the observation of electrical activity near a tumor, facilitating a more accurate indication of the exact location of the tumor.

Cobb (16) pointed out that it is hardly possible to determine the difference ". . . between tumor, acute head injury, vascular catastrophe, localized cortical atrophy, or a local inflammatory condition, damage, dystrophy, or degeneration". He further states ". . . a nearly normal record associated with a firm diagnosis of tumor, particularly of the accessible parts of the hemispheres, warrants the view that the lesion is probably benign".

Statistics vary regarding the reliability of EEG in the determination of a tumor site. It was reported by Yeager and Baldes (64) that 86% of the lesions of a superficial nature can be located. Gibbs, Gibbs, and Lennon (33) have written that, on confirmed cases, 90% were located correctly. Cobb (16) indicated that thirty-one of thirty-three cases were determined with reasonable accuracy; the cases reported were those involving cortical tumors only.

Auditory Assessment by EEG

P. A. Davis (22) and H. Davis, *et al*. (21) have demonstrated that changes occur in an EEG tracing as a result of stimulation by acoustic signals. The former described long latency responses to auditory, visual, and somatic stimulation in awake and sleeping subjects. Responses tended to be greatest in amplitude at the vertex and were represented diffusely over the scalp. It was also demonstrated by P. A. Davis that the potentials increase in amplitude and decrease in latency as the stimulus intensity is increased.

Doerfler (29) and Marcus (41) demonstrated some degree of success in determining auditory sensitivity thresholds by means of the EEG technique. Doerfler, however, found that the EEG records were inordinately complex and unwieldy, required excessive analysis after the completion of the testing procedure, and often did not yield a threshold measure which could be interpreted reliably.

Perl (46) found a reasonably high correlation between speech reception testing and the EEG response to auditory stimuli recorded in sleep from subjects with hearing losses. At approximately the same time, Derbyshire and Frazier (26) reported a complex waveform response to acoustic stimulation in subjects who were in light stages of sleep. The authors were able to obtain thresholds from twenty-two subjects which agreed within ± 18 dB with the thresholds obtained by standard audiometry. Withrow and Goldstein (62) reported thresholds from hard-of-hearing children that fell within ± 10 dB of thresholds obtained in a routine audiometric manner.

Mills, et al. (44) discussed a procedure called the "area-centroid method", which they say ". . . had objectivity, reproducibility, and precision. . ." in providing recognition of evoked potentials that are presented in on-going EEG tracings. In this method, the area under the middle of the curve of the evoked potential is subtracted from the portion of the non-stimulated area of the tracing and the difference is then used as an indication of the presence or absence of a response. According to these authors, the evoked potential responses probably last for several seconds after the presentation of the stimulus and sleep states of the subjects do not seem to alter an observer's ability to detect evoked responses. It is further reported that consistent responses were obtained with 10 dB of the subjects' voluntary thresholds.

Webb, et al. (60) presented information obtained by using on-going EEG procedures on four groups of mentally retarded children, classified on the basis of the results of previous audiological and otological tests: (a) normal-hearing patients with thresholds of no poorer than 20 dB or less hearing level, (b) hearing-loss patients with thresholds of poorer than 20 dB HL, or a confirmed loss by otological examination, (c) inconsistent responders, those who had failed a hearing test but passed it on a retest, (d) unknown hearing status patients, those who had failed to respond to every attempt at hearing assessment. The procedures used by Webb and his co-workers were similar to those used by Derbyshire and Farley (25) in testing EEG responses to auditory stimuli. Due to difficulties encountered in maintaining an electrode attachment to the scalp, only three electrodes were employed and fastened by Bentonite paste. The authors point out that, due to the small number of electrodes used, no attempt was made to determine "cortical" pathology. Auditory stimuli consisted of 1000-cps tones, three clicks in rapid succession, and three consecutive live-voice presentations of the patient's name. Various methods were used to determine, from the EEG tracings, the approximate auditory threshold. The results as reported ". . . indicate that in no case was it possible to discriminate a significant level between no-stimuli presentations and the 20-dB presentations. This was also true of all intensity levels for the hearing-loss subjects". One of the conclusions reached by Webb and his colleagues was that ". . . the utility of the EEG-audio in differentiating subjects with hearing loss from unknown or inconsistent categories appears to be slight".

A number of procedures used to facilitate the determination of thresholds through analysis of on-going EEG responses have been reported by Derbyshire and Farley (25), Derbyshire and McDermott (28), Doerfler (29), Withrow and Goldstein (62), and Rosenblut (50). These authors are in general agreement that the on-going EEG is of limited use in determining auditory threshold.

Averaging Techniques Used in Determining Presence of Evoked Responses

There have been various attempts to average the EEG response to stimulus presentation. The explicit purpose for developing an averaging procedure was to determine more accurately the specific latency (time after a specified event, usually the stimulus presentation) and amplitude (voltage differences measured between two given points in time) of the evoked response.

Chang (15) gave the following definition of an evoked response:

> . . . the detectable electrical change of any part of the brain in response to deliberate stimulation of a peripheral sense organ, a sensory nerve, a point on the sensory pathway or any related structure of the sensory system.

In an attempt to measure this electrical change, Dawson (23) developed an approach in which a number of evoked response records, similarly recorded, are superimposed on a single sheet of paper, thus allowing visual determination of the point or points at which the deflections are evoked with regular latency. By this technique, it is possible to differentiate the regularly evoked potentials from the background or spontaneous on-going activity.

Using the Dawson technique, Abe (1) reported results which indicated that the amplitude of the evoked potentials decreased gradually as the intensity of the stimulus was reduced. The latency of the evoked potentials became shorter as the intensity was increased. The earliest latency reported was 90 msec with the second deflection at 150 msec. He also found that the evoked response was maximum at the vertex. These findings support the earlier data reported by P. A. Davis (22).

Abe also noted that, with the subject anesthetized with pentobarbital sodium, the evoked response was greater in amplitude and duration than when no sedation was used. This increased amplitude and duration continued until the subject was under deep anesthesia, at which time the evoked response could not be determined by superimposed tracings. These findings of Abe confirm the on-going EEG findings of H. Davis, et al. (21).

Suzuki and Asawa (56), using the Dawson technique, measured evoked potentials to auditory stimuli from the human scalp. Positive responses were obtained 21.7% of the time at 0 dB sensation level (SL), 65.7% of the time at 30 dB SL, and 82.6% between 60 and 80 dB SL. The authors concluded that the use of the superimposed technique holds promise as an objective procedure for the determination of hearing thresholds.

Shagass and Schwartz (54) used the Dawson procedure, with minor modifications, to study the evoked responses of patients with mental disorders. They reported that different mental disorders may show different recovery times in the evoked response.

The Dawson technique has many advantages over the observation of EEG activity over time. The intensity of on-going activity is generally in the neighborhood of 10 to 50 microvolts, whereas potentials evoked by acoustic stimuli are generally believed to be 5 to 15 microvolts and thus can be "masked" by the on-going activity (23, 54). With Dawson's technique of photographically averaging the response, it is possible to detect the very small time-locked evoked response in the presence of larger background activity.

Rosenblith and his associates (48, 49) were among the first to use a digital computer for averaging the evoked response. They developed a procedure by which they averaged the voltage evoked for a specified length of time after the presentation of the stimuli. This method was used by Rosenblith (49) and Geisler and associates (31, 32) employing acoustic stimuli and by other investigators with other types of sensory stimuli (3, 6, 12, 14, 19, 20, 38, 51).

The use of an averaging technique is based on the assumption that the on-going activity, not initiated by sensory stimuli, is random in nature and that, as such, its additive voltage at any specific post-stimulus latency will equal zero as the number of stimuli approaches infinity. In the averaging technique, the stimulus onset is used as the starting or reference point (T_o) to an evoked potential. A given segment of the on-going activity for a specific element of time (T_1) can be stored in the computer's memory and added to a second response, which also is time-locked to the same aspects of T_o - T_1. This process, if carried out over enough stimulus presentations, theoretically allows the on-going activity to cancel and the evoked response to sum.

Geisler and his associates (32), using the averaging technique with a digital computer to measure the evoked response to acoustic clicks from the scalp of man, determined the onset of the evoked response to be approximately 20 msec with a peak latency of 30 msec. The amplitude and latency of the responses varied according to the stimulus intensity and repetition rate. Threshold for appearance of a detectable average evoked response agreed closely with the minimum intensity at which the subject reported hearing the auditory stimulus. Other longer latency responses were noted which correspond with the latency of the evoked response defined as the K-complex by H. Davis, et al. (21); however, these responses were merely mentioned and not discussed by Geisler and his associates. Their statement, "A given subject, under comparable conditions, yields similar average responses when he is tested repeatedly", indicates little intrasubject variability to acoustic clicks. They also noted responses over widely spread areas of the scalp and with bilateral representation of response to monaural clicks. It is further reported that the onset of the evoked potential was similar to those reported by Dawson (23) for somatosensory stimulation and by Brazier (12) for visual stimulation.

Geisler and his co-workers speculated that the widespread nature of the response may indicate the deep location of the auditory cortex in man. They, as had several previous investigators, indicated that, as the click intensity is increased, the amplitude of the evoked response increases and the peak latency decreases and that, with an increase in the rate of stimulation up to ten per second, the amplitude decreases. Also, thresholds of evoked potentials were obtained within approximately 5 dB of the psychophysical threshold.

Lowell and his colleagues (40) used a specially designed analog computer to average the evoked responses to acoustic clicks. Although they could measure at only three points in time after the presentation of the stimulus, they were able, by varying the three points measured, to demonstrate that a positive peak existed at 35 msec after stimulus onset.

According to Geisler (31), the early responses to acoustic clicks were largest in the occipital region of the scalp. The responses were essentially bilateral in nature and "substantially equivalent" when measured from corresponding points on the opposite side of the head from the ear stimulated. His data indicated that the earliest response had a peak negative latency of 30 msec. Considerable change in the response was evident with changes in the position of the subject's head, with changes in body position, and during sleep. Geisler concluded that the 30-msec response is likely to be a secondary cortical response. No attempt to determine the variability of the evoked response in amplitude or latency is mentioned. Geisler mentions latencies similar to Davis' K-complex but focuses his attention on the first 60 msec of the response.

Bickford and his group (6) have speculated that the early responses reported by Geisler are, in fact, myoclonic responses initiated by the vestibular mechanism. Borsanyi (9) also has contended that the early responses are myoclonic responses which are ". . . perhaps mediated through a short cochleomuscular reflex arc . . . processed through actually the vestibular system". In a later report, Borsanyi and Blanchard (10) concluded that ". . . we feel that no primary auditory potentials can be recorded by scalp electrodes in man by the method we discussed". They further indicated that the ". . . responses which can be obtained are non-specific, secondary responses with super-imposition of myogenic potentials, or an orientation reflex (myogenic or cortical)". In a later article, Cody _et al_. (19) reported that the late or secondary components are present and speculate that these are cortical in origin and mediated by the cochlea.

It is the present author's opinion that Bickford, Borsanyi, and Blanchard resolve very little in stating that the potentials are either "myogenic or cortical" potentials. Their findings do not eliminate either from contention, although this was the purported purpose of their studies. In a study by Ruhm (52), a subject who had undergone bilateral ultrasonic destruction of the labyrinth yielded excellent evoked responses to acoustic stimuli. By contrast, deaf subjects with normal labyrinthine function showed no response to acoustic stimuli. These findings suggest that the evoked response is a cochleo-neurogenic pehnomenon rather than a vestibulo-myogenic product. With sufficient tension and an extremely high level stimulus, a myogenic response can likely be elicited. The present author does not feel that this precludes the possibility of obtaining a cochleo-neurogenic response.

Williams and Graham (61) compared on-going EEG and computer averaging techniques and concluded that:

> Auditory stimulation produced an EEG pattern that was distinguishable from random cortical activity appearing in scalp leads. Monopolar scalp recordings of cortical activity associated with auditory stimulation was different in many aspects from bipolar recordings.

These results are similar to those reported by other investigators using both on-going EEG procedures and averaging procedures.

Latency-Amplitude Aspects of the Auditory Evoked Potentials

Although it is a common practice of many authors to display photographic reproductions of their obtained results of averaged evoked response, only a few have reported both the latency and amplitude of the representation. Among those who have labeled both parameters, there appears to be some difference of opinion regarding amplitude. However, the latency aspects appear to be fairly consistent. Keidel (36) presented responses obtained from the intact human skull which have a peak-to-peak amplitude of approximately 7.5 microvolts. He also presented some that display a peak-to-peak magnitude in the nature of nine microvolts. Unfortunately, no indication was given of the intensity of the acoustic stimuli used.

Bickford and his group (6) displayed amplitudes of approximately 60 to 150 microvolts in components of the evoked response with latencies prior to 75 msec. Bickford's reported intercerebral response, using depth electrodes, show a small early component (60 msec) and a later one (180 msec) in the nature of 70 microvolts.

It is interesting to note that Bickford used stimuli of approximately 130 dB sound pressure level (SPL) to evoke responses in which the latency shown exceeded 125 msec; he shows no late responses (170 msec). He has stated that ". . . even these late waves (after 75 msec) disappear with relaxation of the neck muscles, supporting the idea of a myogenic origin for these components". It should be pointed out that his analysis time was 500 msec and showed no late response at 150-250 msec. This is in contrast to his intracerebral recording, using the same level of stimulation (130 dB SPL) and the same number of averaged responses (150), where a rather large 150-250 msec component is evident. It is also of interest that Bickford attributed components after 200 msec to muscle noise. One is hard-pressed to explain the absence of the large (70 plus microvolts) intracerebral response to muscle noise, whether a result of vestibular or cochlear stimulation, in view of its apparent absence from the intact scalp recording. There appear to be three possible explanations for this apparent inconsistency: (1) the repetition rate used by Bickford may have been so rapid as to allow the mechanism to adapt sufficiently to eliminate the later firing of the neurons (although Borsanyi reports a similar finding with a stimulus rate of one per second), (2) the extreme amplitude of the early component may have made it necessary to restrict the display amplitude to a point where an evoked potential in the range of 5 to 30 microvolts could not be observed, (3) perhaps a more likely reason for the absence of the late component is the level of stimulation; it appears likely, in view of results reported by other investigators, e.g., Rapin (47) and Ruhm (52), that very high level stimuli cause a diminution of the late component.

Davis (20) found the slow response to be present with the largest positive peak at 160 msec. He stated, "The response approaches a maximum peak-to-peak of about 8 to 10 microvolts with clicks 70 dB above subjective threshold."

Williams and Graham (61), using a binaural acoustic stimuli at an intensity of approximately 80 dB SL and a rate of one per 1.6 to 2.0 seconds, found evoked potentials of slightly under 20 microvolts. The response shown in their report indicates a peak latency of 159 msec with an amplitude of approximately 8 to 9 microvolts.

Derbyshire and McCandless (27) presented a template of the evoked response in which the amplitude cf the late component (P_1 - N_2 - P_2) is approximately 50 microvolts; the latency of the component is 80 to 100 msec for P_1, 150 msec for N_2, and 220-250 msec for P_2. This template was obtained from the intact scalp with an electrode placed on the left central region in the interaural plan 3 cm lateral to the midline with common reference electrodes on both mastoids. Derbyshire and McCandless also represent the positive deflection (P_1 and P_2) as being toward the bottom of the graph representing a downward deflection. In a later article, McCandless and Best (43) indicate positive deflections as being toward the top of the graph although they make no mention of a change in basic procedure. McCandless (42) has since stated that the second article which shows the positive deflection toward the top of the graph is correct. The amplitudes reported by McCandless and Best for their 50-dB binaural stimulation for an N of 13 are presented in Table 1; the heading P-56 represents a positive peak at 56 msec post stimulus, N-95 a negative point 96 msec post stimulus, and P-163 a positive point 163 msec post stimulus.

TABLE 1

MEAN LATENCIES AND AMPLITUDES AS SHOWN BY McCANDLESS AND BEST FOR 50-dB STIMULATION

	P-56		N-96		P-163	
	Latency	Amplitude	Latency	Amplitude	Latency	Amplitude
Mean	56.76	9.61	96.46	21.15	163.07	39.46
SD	8.54	4.68	8.82	8.91	12.74	12.99

These investigators reported the amplitudes of evoked responses from nine subjects, in microvolts taken from the peak at N-96 to the peak at P-163 for sensation levels of 10 dB and 50 dB, as shown in Table 2.

TABLE 2

INDIVIDUAL SUBJECT RESPONSES TO 10 AND 50 dB SL STIMULATION AS SHOWN BY McCANDLESS AND BEST

Subject	G.M.	L.S.	R.G.	L.B.	L.H.	A.G.	J.L.	J.E.	N.M.
10 dB	13.6	17.6	13.6	15.2	12.8	7.2	25.6	8.8	9.6
50 dB	30.4	50.4	38.4	30.4	46.4	44.0	27.2	11.2	34.4

These responses give a mean amplitude of 13.7 microvolts for the 10 dB SL and 34.8 microvolts for the 50 dB SL.

McCandless and Best indicated that they were able to obtain responses from all subjects at 10 dB SL. They add, however, that there were considerable differences across subjects; one subject had a smaller response at 50 dB than did several subjects at 10 dB. They also show that responses obtained at a repetition rate faster than one per two seconds have an inhibitory effect, causing a decrease in the evoked response amplitude. This effect has also been pointed out by other investigators (12, 14, 17, 31, 43).

Other investigators who have studied the latency of the evoked response (12, 14, 59) indicate essentially the same configuration as McCandless and Best. Walter (59) reports that habituation takes place readily, after approximately 35-50 presentations, thus causing a diminution of the evoked response amplitude. It was impossible for the present author to determine the amplitudes of the late component as reported by Walter because no amplitude scale was given.

When obtaining evoked responses to visual stimuli from a cat, Brazier (13) found that, by breaking down the number of stimuli into samples of sixty:

> . . . a trend was seen to be developing in which the second late wave was decreasing in amplitude; the analysis was therefore continued to the fifth, sixth, seventh, and eighth series of sixty responses by which time the late response died out. The late wave, centering around 105 msec, underwent a serial change as the animal became used to the stimulus.

Brazier further pointed out that the latency of the evoked potential stays approximately the same as the number of stimuli increase. She further indicated that as the animal changes from a drowsy state to an awake state, the latency changes.

Morrell, et al. (45) reported a ". . . more or less orderly sequence of changes. . ." in the electrical activity of the brain of a rabbit in response to a noncyclic series of repetitive trains of light flashes when each train was preceded by a tone separated from the flashes by a constant time interval. Using the EEG tracings, they noted three specific stages of change in the potentials. In the first, long-lasting stage, the acoustic stimulus elicited an over-all desynchronization. The second stage, which was very short, sometimes lasting for as few as ten cycles, was characterized by a rhythmic wave from the visual cortex as soon as the tone was presented and prior to the onset of the light flash. The third and final stage was masked by the replacement of the rhythmic response by a local desynchronization from the visual cortex area.

Rapin (47) obtained evoked responses from children with communication disorders. The latencies reported in the study are essentially the same as those reported by other investigators. The amplitudes of the late components reported in this study range from 5 to 30 microvolts. Unfortunately, it is not possible to determine the SL of the stimulus presented by Rapin. Although she concludes that the early components obtained from the neck muscles are ". . . thought to confirm Bickford's suggestions that these waves are the results of reflex muscle contraction in response to the sound, and represent EMG and not cortical evoked response. . .", it is interesting to note that Rapin goes on to report a late component of approximately 30 microvolts. This component is absent from Bickford's data except in his intracerebral recordings. Rapin concludes, "Until the validity and reliability of the evoked potential technique can be established, it is unwarranted to consider clinically useful the thresholds which were obtained."

In summary, the findings regarding on-going EEG and the averaging techniques thus far reported indicate that the averaging procedure shows some promise as an objective technique in the evaluation of the function of the auditory mechanism. As yet, however, the primary focus of attention has been on the waveform of the evoked potentials, primarily at supra-threshold stimulation, and there has not been a careful analysis of the amplitudes and latencies of the various components of the evoked response. Numerous authors indicate that an increase in the magnitude of the stimuli results in an increase in the amplitude of the evoked response. They do not indicate whether all components of the evoked potential increase, and, if not, what the differential effect across components might be. It is also reported that an increase in intensity causes the latency of components to decrease; again, the specific differential aspects across components are not discussed. The usefulness of future investigations of acoustically evoked responses would be enhanced by a description of these parameters.

The present study was designed to investigate the variability of latency and amplitude of the late component of the evoked potential as measured from the scalp. A description of the experimental apparatus, subjects, and procedures is outlined in detail in the following chapter.

CHAPTER III

INSTRUMENTATION AND PROCEDURE

This experiment was designed to explore the characteristics of peak latencies and amplitudes of the human evoked auditory response as a function of time, intensity, and number of stimuli.

The apparatus utilized in this study consisted of a network of pulse and waveform generators, matching transformers, attenuators, headphones, pickup electrodes, amplifiers, computer, tape recorder, and monitor oscilloscope. The pulse and waveform generators were used to produce the auditory stimuli, which were then recorded on magnetic tape. The tape system initiated the trigger of a pulse generator which then fed the click through a selected matching transformer and an attenuator. The auditory stimulus from the attenuator was fed to the selected ear of the subject via the headphone.

Each electrode attached to the scalp of the subject went to a high-gain, low-level pre-amplifier, then into a differential amplifier for additional amplification. The signal from the differential amplifier passed through a switching circuit prior to being fed simultaneously into the computer, tape recorder, and monitor oscilloscope. The switch permitted the computer to be supplied either with the output circuit from the scalp leads for on-line analysis of evoked activity or with the output of the tape recorder for off-line analysis of previously recorded activity.

Responses were evoked at two stimulus sensation levels, using 500 epochs (an epoch is defined as one click stimulus) at each sensation level as a condition. Each condition was broken down into four experimental sets consisting of 125 epochs each. The experimental data were collected after a pilot study had been conducted to determine the length of time that a subject could maintain a quiet position and the number of event presentations that could be collected during an experimental session.

A detailed description of subjects, apparatus, and procedure is presented in the subsequent sections.

Subjects

Data were collected from ten normal-hearing adults. These subjects had a negative history of ear pathology and a negative neurological history. Normal hearing was defined as less than 5-dB HL thresholds at octave frequencies from 125 through 8000 cps measured by standard air-conduction audiometry. All subjects had completed high school and all but two were university graduates. Subjects consisted of four males and six females who ranged in age from eighteen to thirty-two years.

Apparatus

All testing was conducted in a sound-isolated, two-room suite at the Speech and Hearing Center, University of Oklahoma Medical Center.

Screening Apparatus

Pure-tone audiometers (Beltone, Model 10AW or 15A) feeding either of two air-conducted receivers (Telephonics, TDH 39, ten ohm) were used in the audiometric tests. The acoustic output of the audiometer was measured with an audiometric calibration unit (Western Electric 640AA Condensor Microphone: Western Electric-Acoustical Laboratory, Inc., Condensor Microphone Compliment, Type 100 D/E, or Allison Laboratory, Model 300).

Experimental Test Apparatus

The experimental test apparatus used in this experiment is represented by the block diagram shown in Figure 1. A square-wave pulse, initiated by a waveform generator (Tektronix, Type 162) was recorded on magnetic tape. This pre-recorded signal was then used to trigger the waveform generator which in turn triggered the pulse generator (Tektronix, Type 161), which generated a click stimuli of .1 msec duration. These stimuli were delivered to a test earphone (Sharpe, Type B, Model HA-10) through a voltage divider network, an attenuator (Hewlett-Packard, Model 350 AR), and an impedance-matching transformer (United Transformer Company, Model LS-33). These .1 msec clicks had a rise time of .09 msec to maximum amplitude at the output of the headphone. The same clicks simultaneously triggered the sweep of the computer. The rate at which clicks were presented was one per two seconds.

The electrodes which conducted the on-going electrical activity were connected to a low-level amplifier (Tektronix, Model 122) with a gain of 1000. This amplified signal was fed into a differential amplifier (Tektronix, Model 2A63) for further amplification. The differential amplifier gain was adjusted to allow for maximum gain without overdriving the computer system (maximum 3 volts). The output of the final amplifier was fed in parallel to a Computer of Average Transients (CAT), an FM tape system (Mnemotron, Model 700/1400), and a four-trace monitor oscilloscope

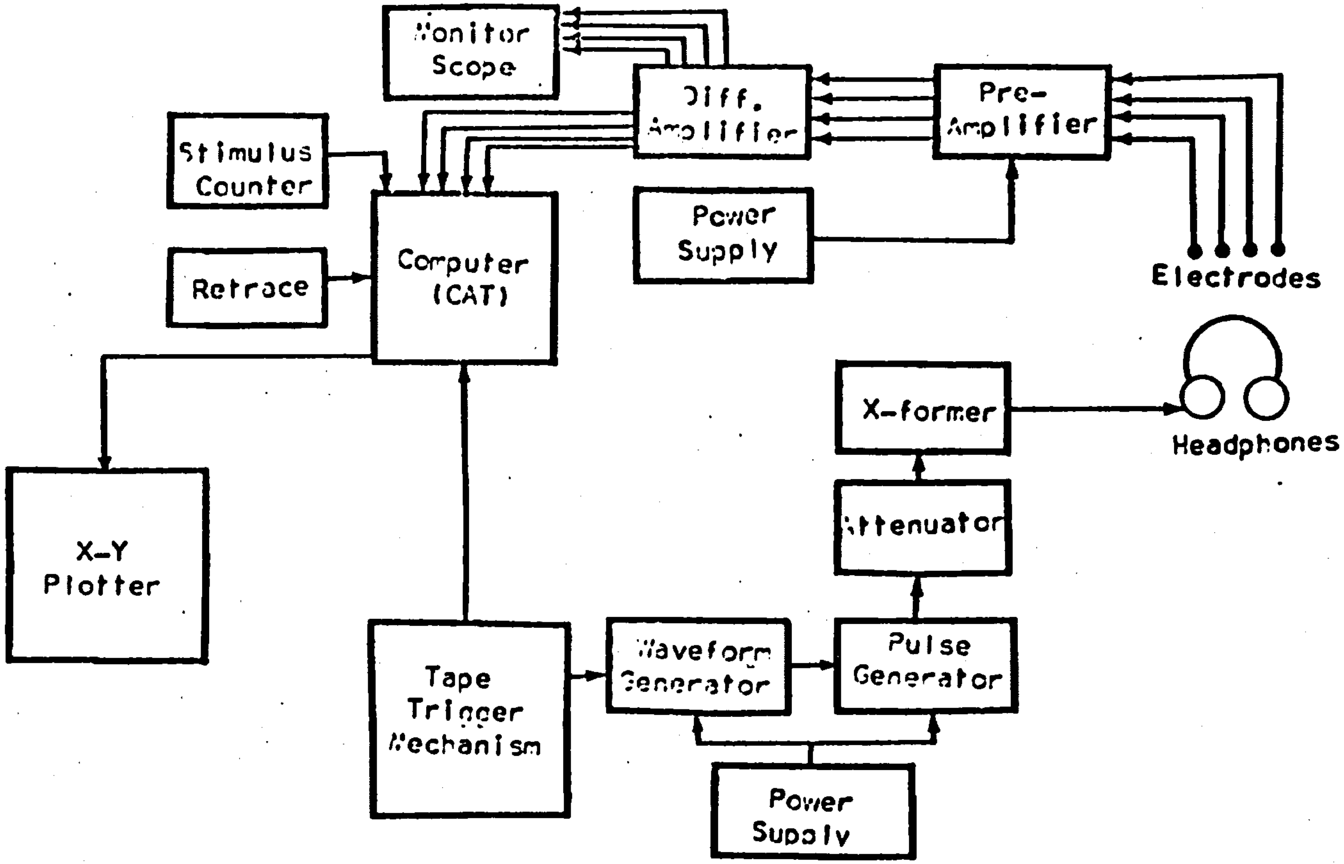

Figure 1. Simplified Block Diagram of the Experimental Apparatus.

(Tektronix, Model 561-A scope, Type 3A74 four-trace amplifier, and Type 2B67 base). The CAT was pre-set to analyze the incoming data over a 500-msec period after the onset of each stimulus. The FM tape recorder played the recorded pulses which, in turn, triggered the stimuli. The four-trace oscilloscope allowed constant monitoring of the voltage in each channel during the experimental runs, providing constant information regarding attachment of the electrodes and the state of the subject. A stimulus counter (Mnemotron, Model 562) was pre-set to count the number of presentations so that each experimental condition included the same number of presentations.

An X-Y plotter (Mosley, Model 2DR-2), in conjunction with a Retrace Eliminator (Mnemotron, Model M591) was used to make a permanent graphic record of the data analyzed by the CAT. The X-Y plotter was connected in such a way that the analyzed data from the CAT's memory could be plotted graphically on 11" by 17" graph paper. The amplitude, represented by the vertical display (Y), and the temporal aspect, represented by the horizontal display (X), could be varied by controls both on the computer and the X-Y plotter. It was possible, therefore, to present the data graphically on calibrated vertical (voltage) and horizontal (time) scales. By this means, a permanent graphic record was made of each of the four experimental sets in each experimental condition.

Calibration Procedure

The procedure used to calibrate the system is recorded in APPENDIX A.

Procedure

This experiment was designed to specify the characteristics of amplitude and latency of the auditory evoked response as a function of time and number of stimuli. The stimuli used were acoustic clicks of .1 msec duration presented at intervals of two seconds and intensities of 20 dB and 40 dB SL. A control condition in which no stimuli were presented (silent run) was also used. Summation of each serial 125 epochs were defined as an experimental set; the first set consisted of the first 125 epochs, the second set of the next 125 epochs, etc. Analysis of this method continued until 500 epochs had been analyzed. Each 500 epochs at each SL was considered to be an experimental condition. The variability of the evoked potential as a function of time and number of stimuli was then analyzed.

To facilitate this procedure, the leads from the four channels were attached to a single scalp location. By switching to the various channels of operation on the CAT, it was possible to observe each experimental set on a different channel without interrupting the serial sequence of epochs. An analysis of the serial presnetations of 125 epochs on the various channels of the CAT was made to determine the variability over time.

A pilot study was conducted which confirmed other investigators' results regarding the effect of stimulus presentation rate. At a rate of one every two seconds the likelihood of inhibiting some of the characteristics of the evoked response was decreased.

The order of presentation of SL's was determined by random selection without replacement. The electrode placement was on the vertex position with the reference electrode placed on nasion. Both of the SL conditions and the silent run were completed without the electrodes being removed, thus insuring that all measurements of the evoked potential were recorded from the same location on a given subject.

The equipment was calibrated both before and after each experimental condition. If, for any reason, the equipment was found to be out of calibration following an experimental condition, the data were discarded.

Prior to initiating the test procedure, the subject's scalp was measured with a metric rule to determine the exact location of the vertex, i.e., the intersection of a line from nasion to inion and a line between the two preauricular points. Prior to the placement of the electrodes, the subject's scalp around the vertex was cleaned with acetone and saturated with kaoline sulphate jelly to insure good electrical contact. EEG paste (Bentonite paste infused with a saturated solution of sodium chloride) was placed over the prepared vertex of the scalp. Four electrodes were then applied to this area and covered with a 2" by 2" surgical gauze sponge, both to prevent the electrodes from slipping and to mitigate photoelectrical transduction. The same procedure was used in placing one reference electrode at the nasion, except that it was covered with masking tape. The subject was seated in a comfortable arm chair and instructed to respond to each click in the earphone by pressing a button which turned on a signal light in the examiner's room. Headphones were then placed on the subject's ears and threshold determined using the lowest intensity which yielded two out of three correct responses. The stimuli were presented by an ascending intensity method from a subthreshold level. After acuity threshold had been obtained, the subject was instructed to remain awake and as still as possible until further notice.

Subjects were requested to be well-rested prior to participation in this study in order to reduce the possibility of a subject's sleeping during the test session. Those who reported fatigue were rescheduled. An oscilloscope (Tektronix, Model 561-A) was used to monitor the on-going activity to facilitate a determination of the presence of sleep activity.

Only one ear of each subject was stimulated. The stimulus presentation order was counterbalanced across subjects.

After a subject had been seated and the electrodes had been placed, he was instructed carefully for the determination of threshold and the experimental task. The earphones were placed on his ears and adjusted for comfort. The subject remained seated throughout the experimental condition. Thresholds to the auditory click, obtained using an ascending method in 2-dB steps, were determined prior to each change in SL. The lowest stimulus intensity at which the subject responded to at least two out of three presentations was defined as threshold. The stimulus SL was then set according to a random schedule and the experimental condition begun.

At the conclusion of each experimental condition, the data stored in the four channels of the CAT were plotted by the X-Y plotter under the control of the CAT.

In a silent run of the same time period as the experimental run, a certain amount of noise is present. During this study, the peak-to-peak noise levels of the silent runs did not exceed 1.6 microvolts. Therefore, only components which exceeded this amplitude were considered as responses for the purpose of this study. Other criteria for the selection of evoked potentials included:

1. the response must consist of a negative-positive-negative complex

2. Component One of the response was the most negative point after 40 msec

3. Component Two was the most positive point after Component One

4. Component Three was the most negative point after Component Two

Experimental and sampling errors, as well as inter-subject variability, were mitigated by using the following controls: (1) appropriate calibration checks prior to and following each experimental condition, (2) an experimental condition in which no stimulus was presented, (3) the use of young, alert, normal-hearing adults, (4) short experimental runs to reduce fatigue.

Statistical analysis of the data was undertaken by means of a randomized complete block design in which the experimental conditions or "treatments" were arranged in a factorial fashion (54). Each subject, therefore, was observed under (2 x 4 x 6) 48 different experimental conditions. These conditions represent all possible combinations of the two sensation levels, four sets, and six days.

It was anticipated from the pilot study, as well as from information reported by other investigators, that each subject would not produce data from each "treatment" combination. If, however, the lack of response among subjects is assumed to be a random phenomenon and the average subject effect zero, then the mean over all responding subjects in that particular cell may be used as the observation for that cell. The error term for the analysis of variance was chosen to be the third order interaction among levels, sets, and days, since this interaction was thought to be nonexistent.

These data are presented and discussed in the following chapter.

CHAPTER IV

RESULTS AND DISCUSSION

The purpose of the present investigation was to determine the latency and amplitude of the late component of the evoked potential as measured from the scalp. Potentials evoked by acoustic clicks (.1 msec duration) were recorded from ten subjects at two sensation levels, 20 dB and 40 dB, on six different days. Criteria for subject selection included normal auditory acuity and negative history of ear pathology and central nervous system disorders.

The effects of intensity and number of stimuli, as well as the effect of stimulus presentation on different days was determined by presenting a number of stimuli at each of two sensation levels over a period of six days.

Latencies of three points on the evoked potential, as well as the peak-to-peak amplitudes, were measured and compared with data reported by other investigators.

Each epoch consisted of an acoustic click of .1 msec in duration. A total of 500 epochs at each sensation level constituted an experimental condition, each sequential 125 epochs constituting an experimental set.

The evoked response for each experimental set was averaged over subjects. The mean data obtained from this procedure are discussed in terms of their amplitudes and latencies, as well as in relation to findings reported by other investigators. The data obtained from individual subjects can be found in APPENDIX B. The statistical analysis tables are located in APPENDIX D.

Number of Responses Obtained

The number of responses obtained from individual subjects summed over days for each set as well as marginal totals are recorded in Table 3. A total of 50 responses were produced in the first set across subjects at the 20-dB SL condition. Alternately stated, ten experimental conditions failed to produce a response. The total number of responses across sets at the 20-dB SL range from a high of 50, produced in the first set, to a low of 30, obtained in the third set. In view of the limited number of responses obtained from subjects, it was decided that a Friedman Two-Way Analysis of Variance (53) would be used to test for a difference between subjects and sets. Thus, the use of ranks avoids the assumption of normality implicit in the analysis of variance. A χr^2 of 3.54 ($P > .05$) was found, indicating that the number of responses at the 20-dB SL were not significantly different across sets.

At the 40-dB condition the total number of responses across subjects ranged from a high of 58 in Sets One and Four to a low of 54 in Set Two. The Friedman Two-Way Analysis yielded a χr^2 of .8 ($P > .05$). Inasmuch as no significance was noted across sets at either of the two levels, the Sign Test (53) was applied to totals of each set for the two levels. These were found to be significantly different ($P < .05$).

From the above information it can be seen that there is not a significant decrease in the number of responses as a function of number of stimulus presentations, although there is a significant increase in the

TABLE 3

NUMBER OF TIMES A RESPONSE WAS PRESENT IN EACH SET AT 20-dB AND 40dB SL FOR EACH SUBJECT. EACH SET IS PART OF A CONDITION WHICH WAS REPEATED SIX TIMES. MAXIMUM POSSIBLE FOR ANY GIVEN SUBJECT IN ANY GIVEN SET IS SIX RESPONSES

Subject	20 dB				40 dB			
#	Set #1	#2	#3	#4	Set #1	#2	#3	#4
1	6	4	5	5	6	6	6	6
2	6	6	4	5	6	6	6	6
3	4	6	5	5	6	6	6	6
4	1	2	3	1	6	6	6	6
5	6	5	5	5	6	6	6	6
6	6	1	2	2	6	6	6	6
7	6	5	5	6	6	6	6	6
8	5	5	4	6	6	6	6	6
9	5	3	4	3	6	5	4	5
10	5	5	2	2	4	1	3	5
Total	50	42	39	40	58	54	55	58

number of responses as a function of increased SL. Also it was found that the subjects did not respond differently within either the 20-dB or the 40-dB SL; however, a significant difference in the number of responses across SL was found as shown by the Sign Test ($P < .05$).

The data from each set as a function of days are recorded in Table 3. No difference was found in the number of responses across days at either the 20-dB or the 40-dB level ($P > .05$). There was a significant difference across subjects in the 20-dB condition ($P < .05$). However, no difference across subjects at the 40-dB SL condition was found ($P > .05$). In view of the fact that no significant difference occurred across days at either level, the responses within each level were combined and tested as a function of level. This test on pooled data resulted in a significant difference as a function of level (P .05).

From inspection of the individual subject's responses across days (see Table 4), it can be seen that only two subjects did not produce an averaged evoked potential in at least one of the experimental conditions at each level on each day. Subject Four on the fourth day at 20-dB SL and Subject Ten on the second day at 40-dB SL failed to yield at least one averaged response. No subject produced a response for every experimental condition on every day at the 20-dB sensation level. However, eight subjects produced all 24 responses at the 40-dB SL. It should be emphasized, however, that Subject Nine yielded a greater number of responses at 20-dB on the third day and Subject Ten also produced a greater number of responses at the 20-dB SL on the second, fourth, and sixth day than for the corresponding conditions at the 40-dB level. Thus, it can be seen that some subjects exhibited at least as many responses at the lower sensation level as at the higher sensation level on some

TABLE 4

NUMBER OF TIMES ON A GIVEN DAY THAT A RESPONSE WAS OBTAINED FROM EACH SUBJECT AT 20-dB AND 40-dB SL

SUBJECT		20-dB SL						40-dB SL					
#	DAY #	1	2	3	4	5	6	1	2	3	4	5	6
1		3	2	4	3	4	4	4	4	4	4	4	4
2		4	3	4	2	4	4	4	4	4	4	4	4
3		3	4	4	2	4	3	4	4	4	4	4	4
4		2	1	1	0	1	2	4	4	4	4	4	4
5		4	4	3	3	3	4	4	4	4	4	4	4
6		3	2	1	3	1	1	4	4	4	4	4	4
7		3	4	3	4	4	4	4	4	4	4	4	4
8		4	4	4	4	1	3	4	4	4	4	4	4
9		3	2	4	3	2	1	3	3	3	3	4	4
10		2	2	2	3	2	3	3	0	2	2	4	2

days and, in some instances, produced a greater number of responses at the lower SL. It should be emphasized that this discussion in no way reflects the amplitude or latency of the responses but merely considers whether or not a response was present in an experimental condition.

From the above information it is concluded that not every 125 epochs will result in an observable evoked response from all subjects when obtained by the procedure described in this study. It is further found that as the sensation level is increased, the likelihood of obtaining a response is increased.

Latency of the Evoked Potential

The analysis of the latency of the evoked potential are divided into three sections, one for each component.

The mean latencies of Component One of the evoked potential obtained from the ten subjects of this study are graphically presented in Figure 2. As can be seen in Figure 2 for Component One (first most negative point after 40-msec latency), the latencies of the 40-dB SL potentials are shorter than those evoked by the 20-dB SL stimuli in each set. Sets Two and Three at 20-dB show a decrease in latency with Set Four showing a subsequent increase in latency. The graphic representation of the latencies as a function of sets at 40-dB SL shows essentially a straight line. The difference between means for the two sets averages 8.53 msec. The statistical analysis for Component One is shown in APPENDIX D. This analysis shows that there is a significant difference between sensation levels ($P < .01$). There is no significant difference as a function of sets nor is there a significant linear component ($P > .05$). A lack of significance ($P > .05$) was also found as a function of days. There was

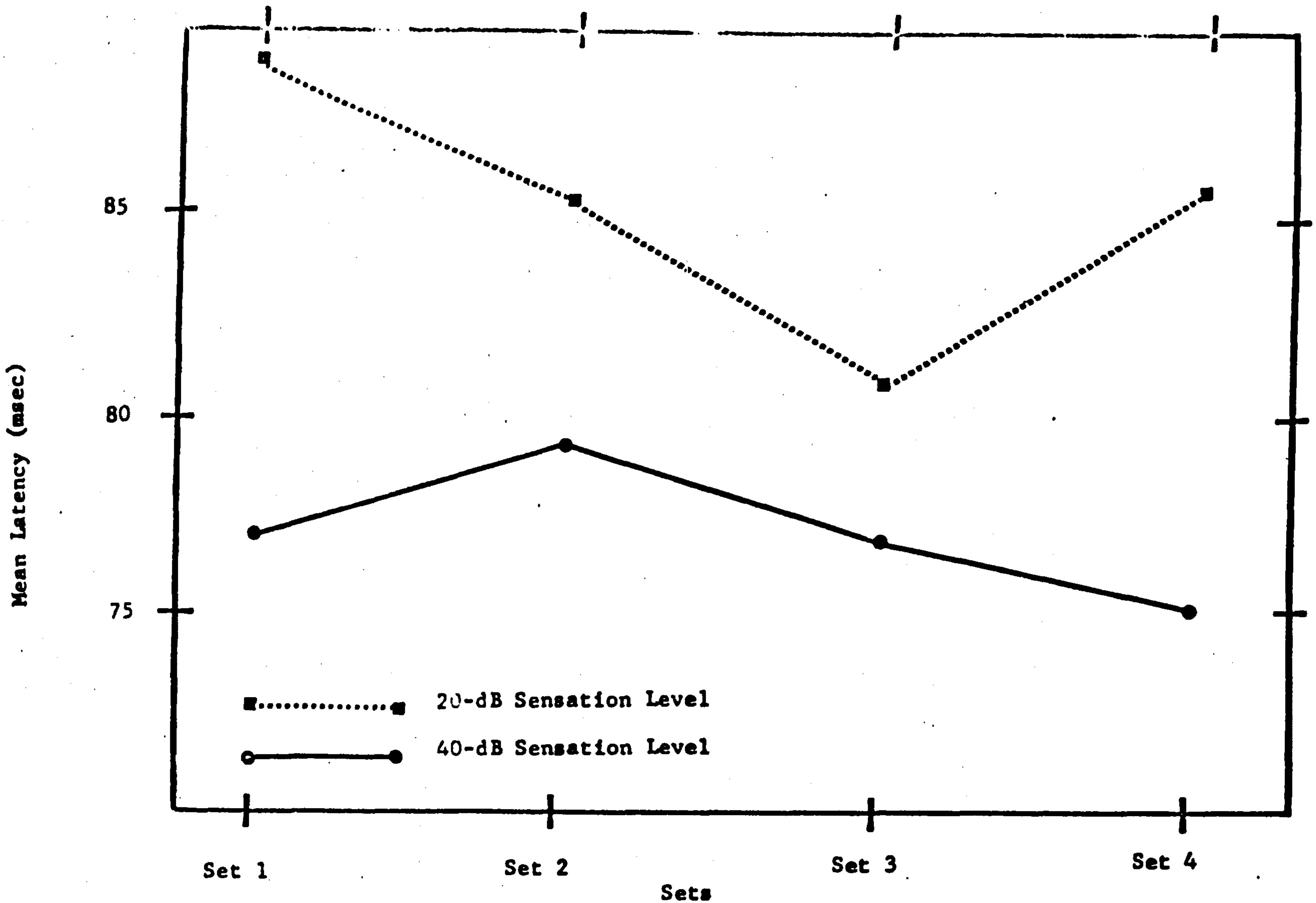

Figure 2. Mean Latency for Component One in Milliseconds as a Function of Each Set at Two Sensation Levels.

no significant linear component in the days source of variation. If adaptation were present, a unidirectional linear trend would be present and would be shown by a significant linear component. There was no significant difference as a function of the interactions between levels by sets, levels by days, or sets by days. Thus, there is not a significant shift in latency for Component One as a function of number of stimuli presented. This finding is essentially the same as was graphically presented by Brazier (13).

The mean latencies of Component One for each of the subjects at the two levels of stimulation are presented in Figure 3. With the exception of Subject Four, the mean latencies of the potential elicited at 40-dB are shorter than that elicited at 20-dB SL. The differences range from approximately 13 msec for Subject Four, in which the elicited potential to 20-dB SL is shorter than that at 40-dB SL, to the opposite extreme in Subject Six, where 20-dB SL produced a longer latency by some 30 msec.

It is concluded from these data on Component One, that as the intensity of the stimulus is increased, a significant decrease in latency is present. These findings support the reports of a number of other investigators (20, 22, 43, 54, 59). It was further found that the latency does not change significantly as a function of the number of stimuli presented on a given day or as a function of the number of days in which the stimuli are presented.

The latency characteristics of Component Two, as shown in Figure 4, follow the same general pattern as those of Component One with respect to sets and SL. The mean latency of each set for the 40-dB SL stimulus is shorter than its corresponding 20-dB SL set. The mean difference between the two SL's is only 3.99 msec, compared to the 8.53 msec mean difference

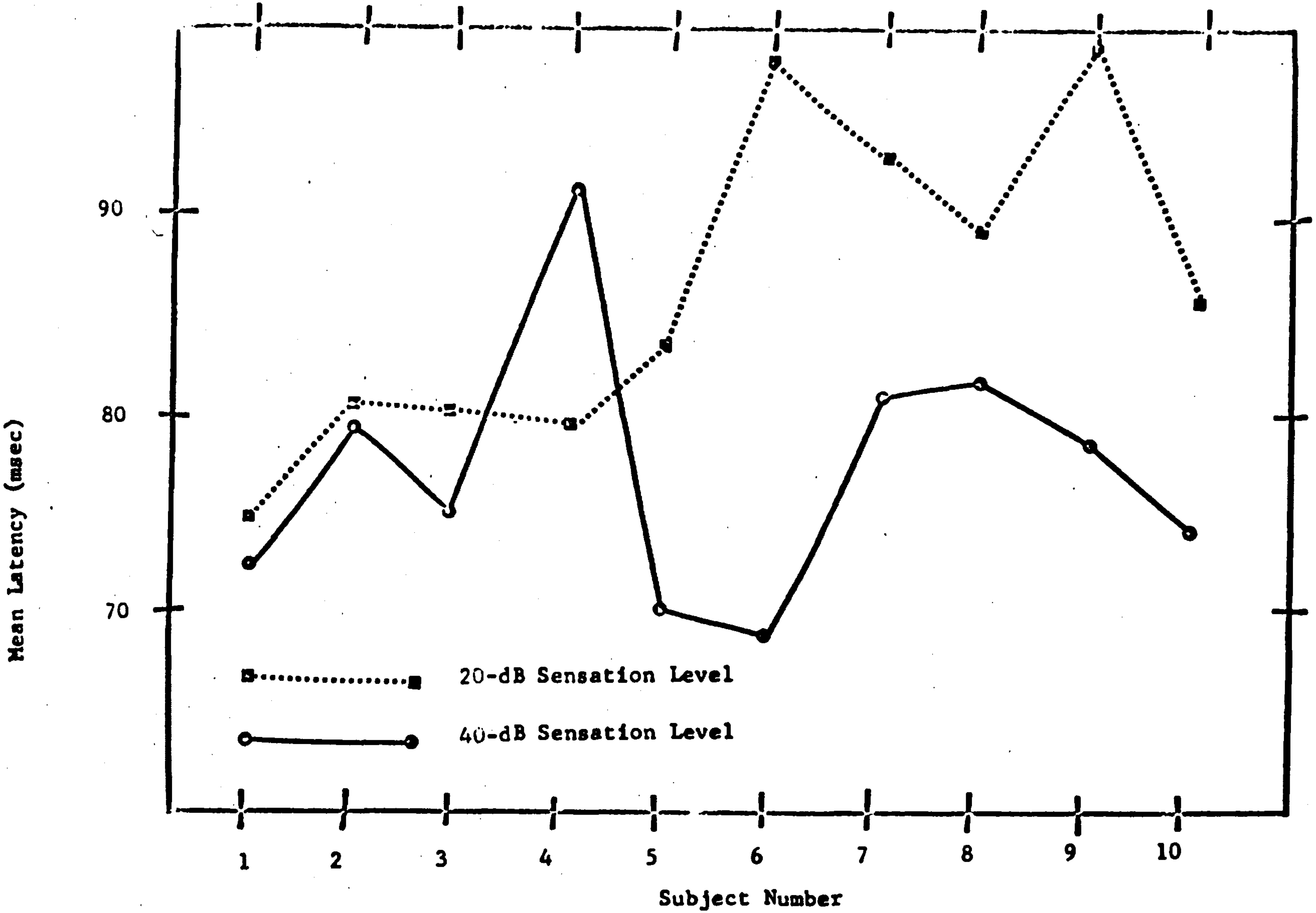

Figure 3. Mean Latency of Component One in Milliseconds as a Function of Subjects at Two Sensation Levels.

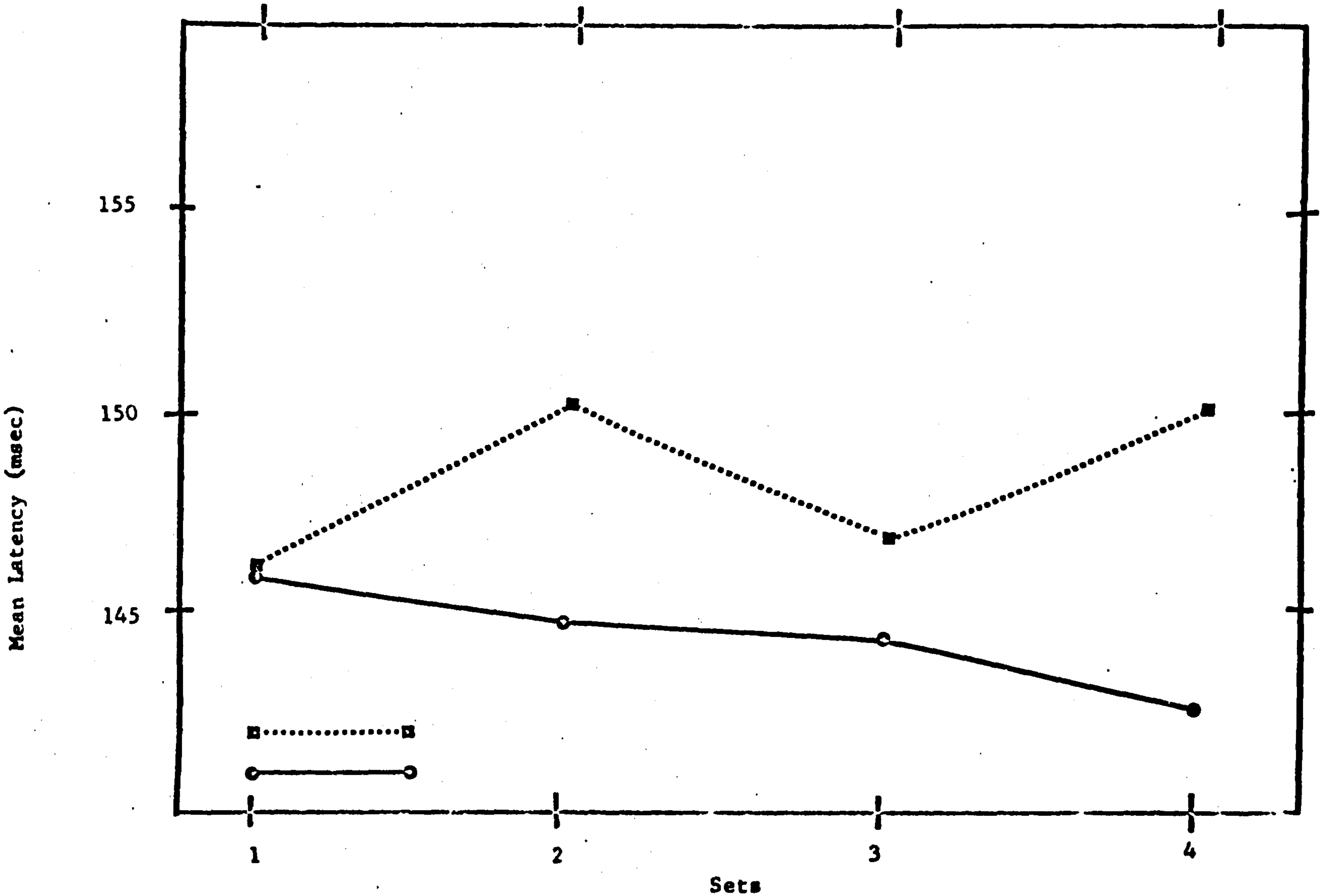

Figure 4. Mean Latency of Component Two in Milliseconds as a Function of Each Set at Two Sensation Levels.

between the two SL's for Component One.

The mean latencies of Component Two for each subject at both SL's are plotted in Figure 5. It should be noted that, although the mean difference between responses obtained under the two SL's is small, only Subjects Four and Ten exhibited 40-dB SL responses whose latencies exceeded their 20-dB SL latencies.

The findings for Component Two with regard to statistical analysis are shown in APPENDIX D. There is a significant difference between the two SL's ($P < .05$). As the intensity of the stimulus was increased, the resultant latency of Component Two decreased. The latency shift as a function of increased SL was not as marked as that found in Component One, but was present and supports the findings of previous investigators (20, 22, 52, 54, 59).

A lack of significance ($P > .05$) was found across sets. There was not a significant linear component as a function of sets. This finding fails to support the findings of Brazier (13), who used implanted electrodes on animals and elicited response with photic stimuli. It is concluded that there is not a significant shift in latency as a function of sets. No significance was found as a function of days. No significant interaction was found between levels and days, levels and sets, or days and sets. A breakdown of the day source of variance did not yield a significant F for the linear component.

The mean latency of Component Three as a function of sets and SL is graphically represented in Figure 6. Examination of this graph indicates that no latency difference is consistent as a function of SL. Sets One and Four have shorter mean latencies under the 40-dB SL condition, while Sets Two and Three have shorter mean latencies under the 20-dB SL

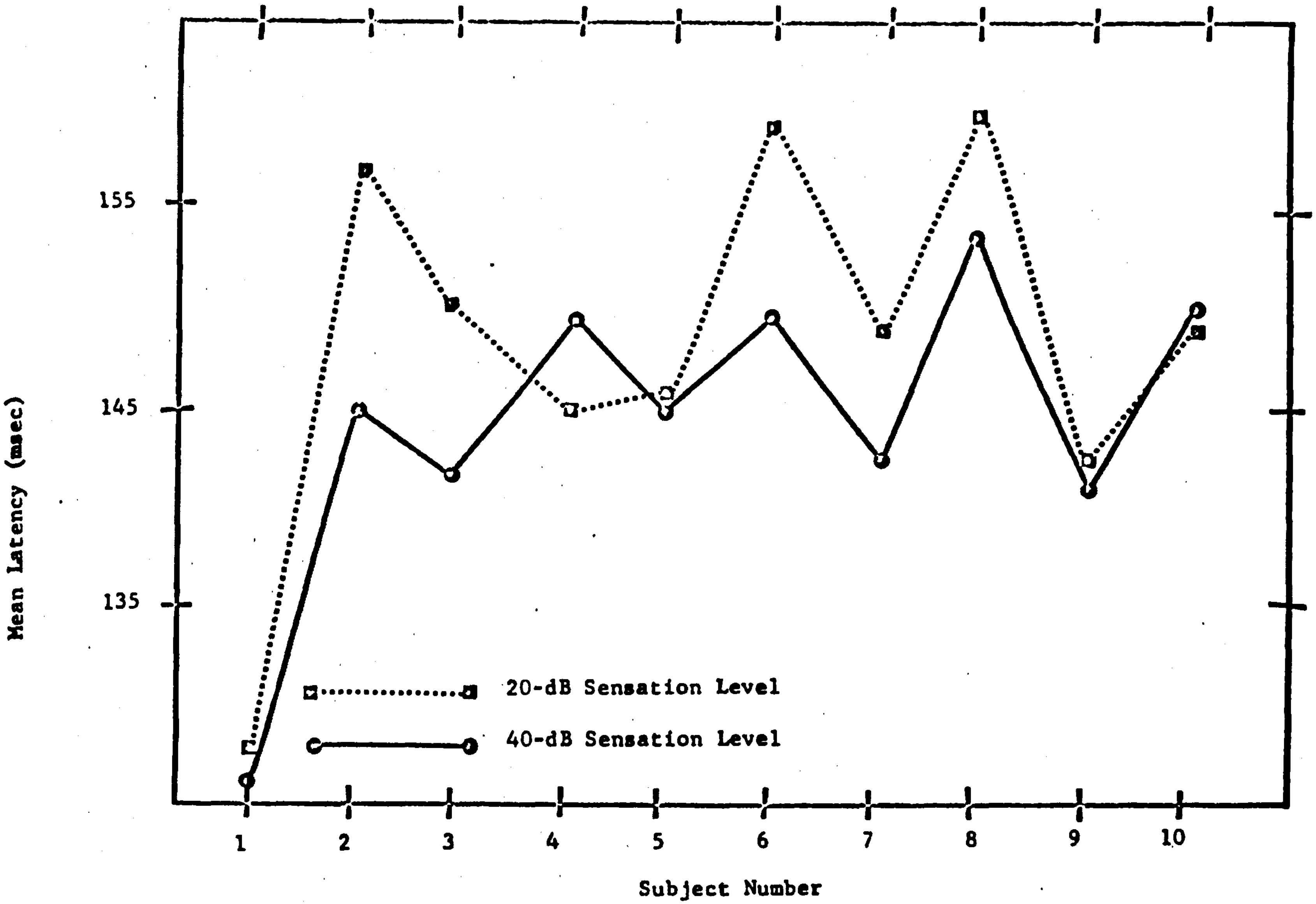

Figure 5. Mean Latency of Component Two in Milliseconds as a Function of Subjects at Two Sensation Levels.

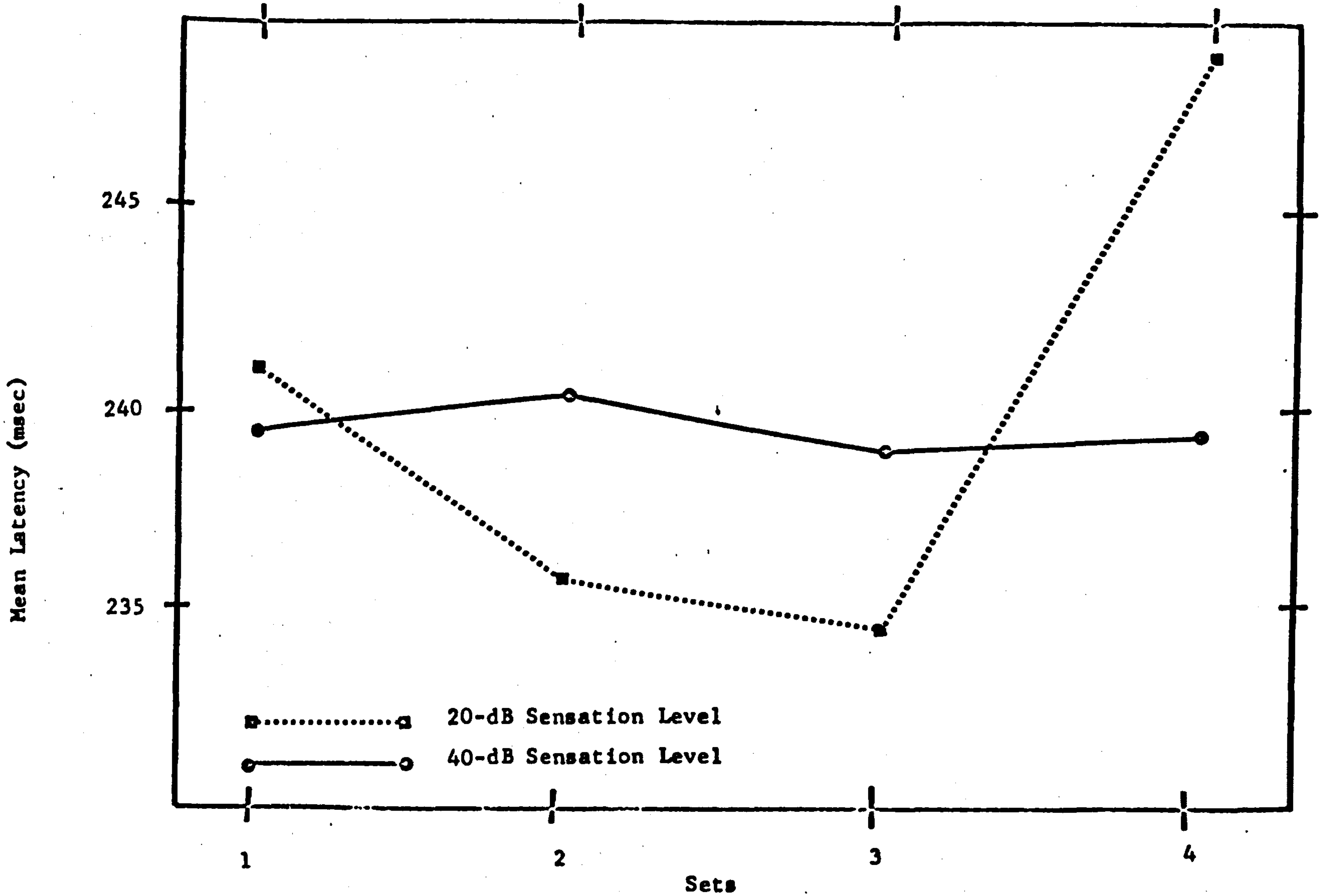

Figure 6. Mean Latency of Component Three in Milliseconds as a Function of Each Set at Two Sensation Levels.

condition.

Individual latencies for Component Three are plotted in Figure 7. Six subjects have shorter latencies under the 40-dB SL condition than under the 20-dB SL condition, and four subjects have shorter latencies under the 20-dB SL condition. The mean differences between the two SL conditions range from 19 msec (Subject Four), in which the 40-dB SL response latency was shorter, to 17 msec (Subjects Five and Ten), in which the 20-dB SL latency was shorter.

The latency of Component Three across days was more variable than were either Components One or Two at both sensation levels, as well as within sets on each given day (see APPENDIX B).

The above indications are supported by the statistical analysis for Component Three, shown in APPENDIX D. There were no significant differences in any of the sources of variation ($P > .05$). There was no significant shift in latency as a function of SL for Component Three, which is in contrast to the findings of Component One and Two. The analysis further indicates that there was no shift in latency as a function of the number of stimuli presented on a given day or as a function of the number of days on which these stimuli were presented. A breakdown of the sets and the days sources of variation showed no significant linear component ($P > .05$).

Other investigators have noted that an increase in stimulus intensity decreases the latency of the various components of the evoked response. This effect was especially salient in investigations which were concerned primarily with the earlier aspects of the evoked response, i. e., the response which does not exceed 80 msec in latency. In the present study, the data indicated the same characteristic for Component

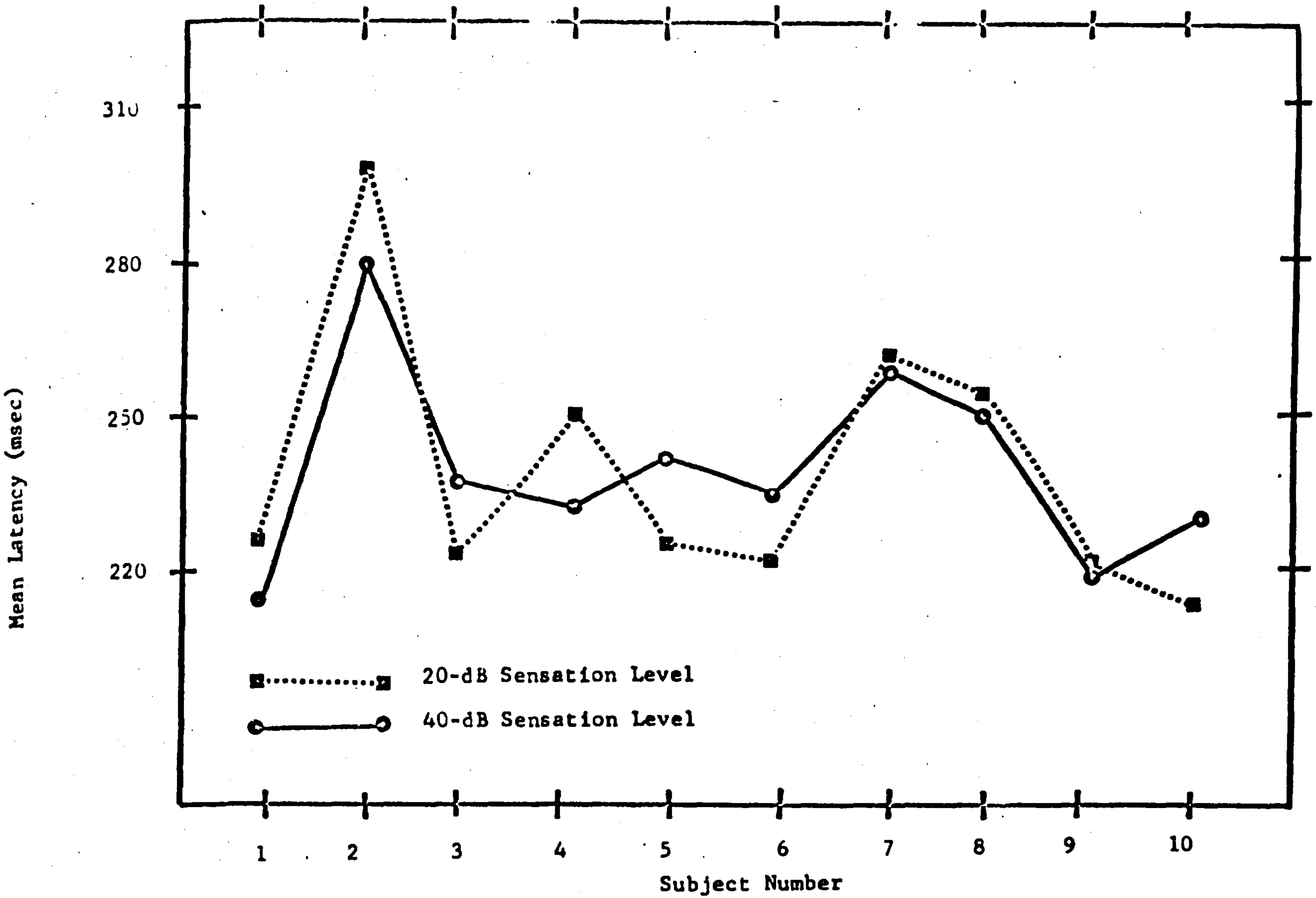

Figure 7. Mean Latency of Component Three in Milliseconds as a Function of Subjects at Two Sensation Levels.

One, which occurs at approximately 86-msec latency (see Figures 2 and 3). The same generalized pattern also appears in Component Two (mean latency of 145 msec) although the mean difference between the two SL's for Component Two is not as large as that of Component One (see Figures 4 and 5). In contrast, stimulus level did not significantly affect the latency of Component Three (mean latency of 240 msec).

The present study of latencies has shown that, as the intensity increases, the latencies of the first two components decrease significantly ($P < .05$). However, the third, or last, component studied remains unchanged as a function of the stimulus intensity. The latency of the response to a given stimulus intensity varies considerably across subjects, whereas the variability within a given subject is somewhat less.

Amplitude of Evoked Potentials, Component One-Two

The mean peak-to-peak amplitudes of Component One-Two (measured between the negative peak referred to as latency Component One and the positive peak referred to as latency Component Two) across sets are graphically represented in Figure 8. Those sets in which no response was obtained were omitted in calculating the mean amplitudes.

The mean peak-to-peak amplitudes of Component One-Two at 20-dB SL range from slightly less than 4.2 microvolts in Set One to a high of 4.3 microvolts in Set Four. The 40-dB condition, graphically represented in Figure 8, shows a greater amplitude in each of the four sets than occurred under 20-dB SL stimulation. The means of the sets range from slightly less than 6.2 microvolts in Set One to 5.7 in Set Three. Figure 9 shows intersubject comparisons of mean amplitudes of all sets combined, at the two SL conditions. The 20-dB SL condition ranges from a

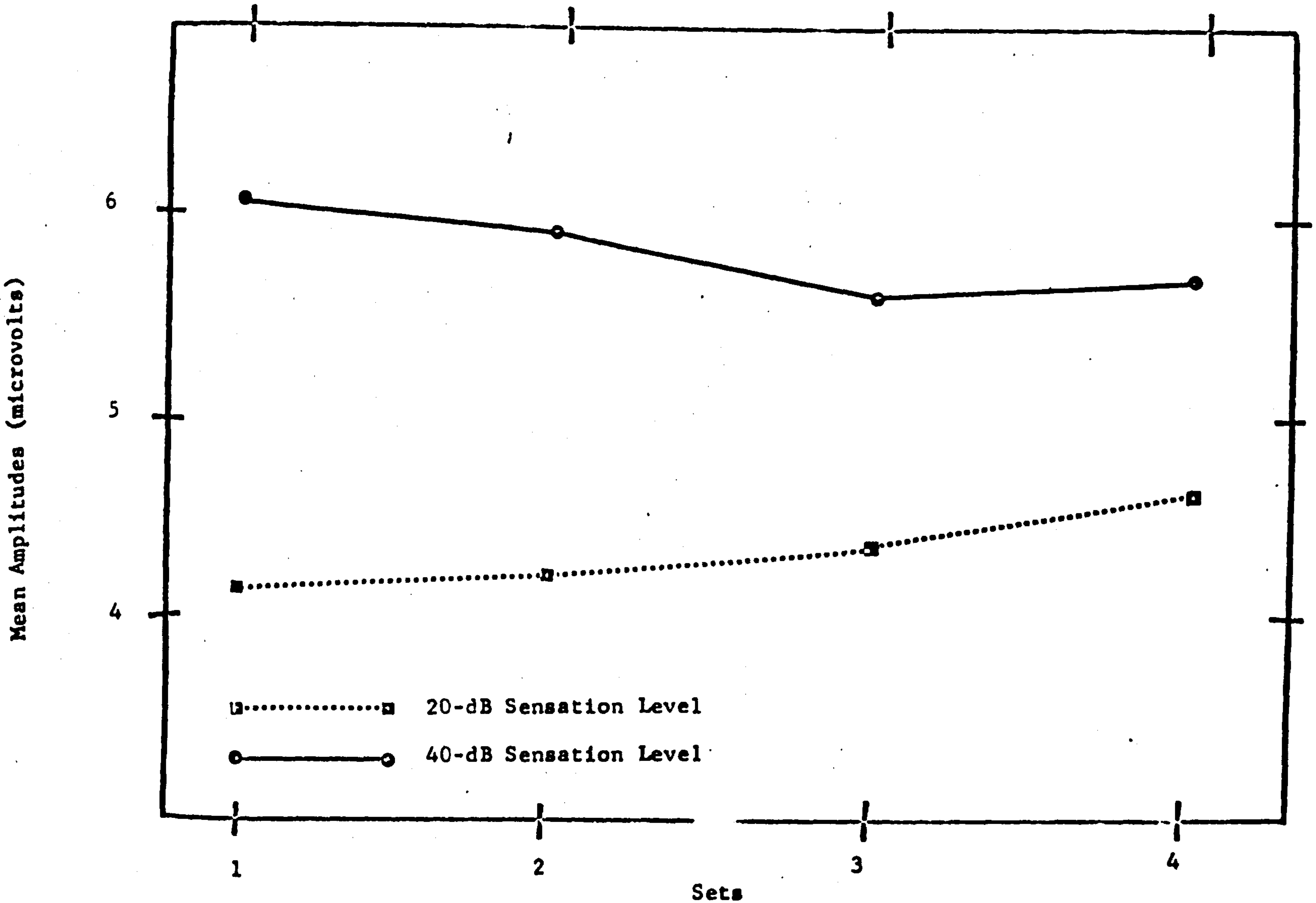

Figure 8. Mean Amplitude of Component One-Two in Microvolts as a Function of Each Set at Two Sensation Levels.

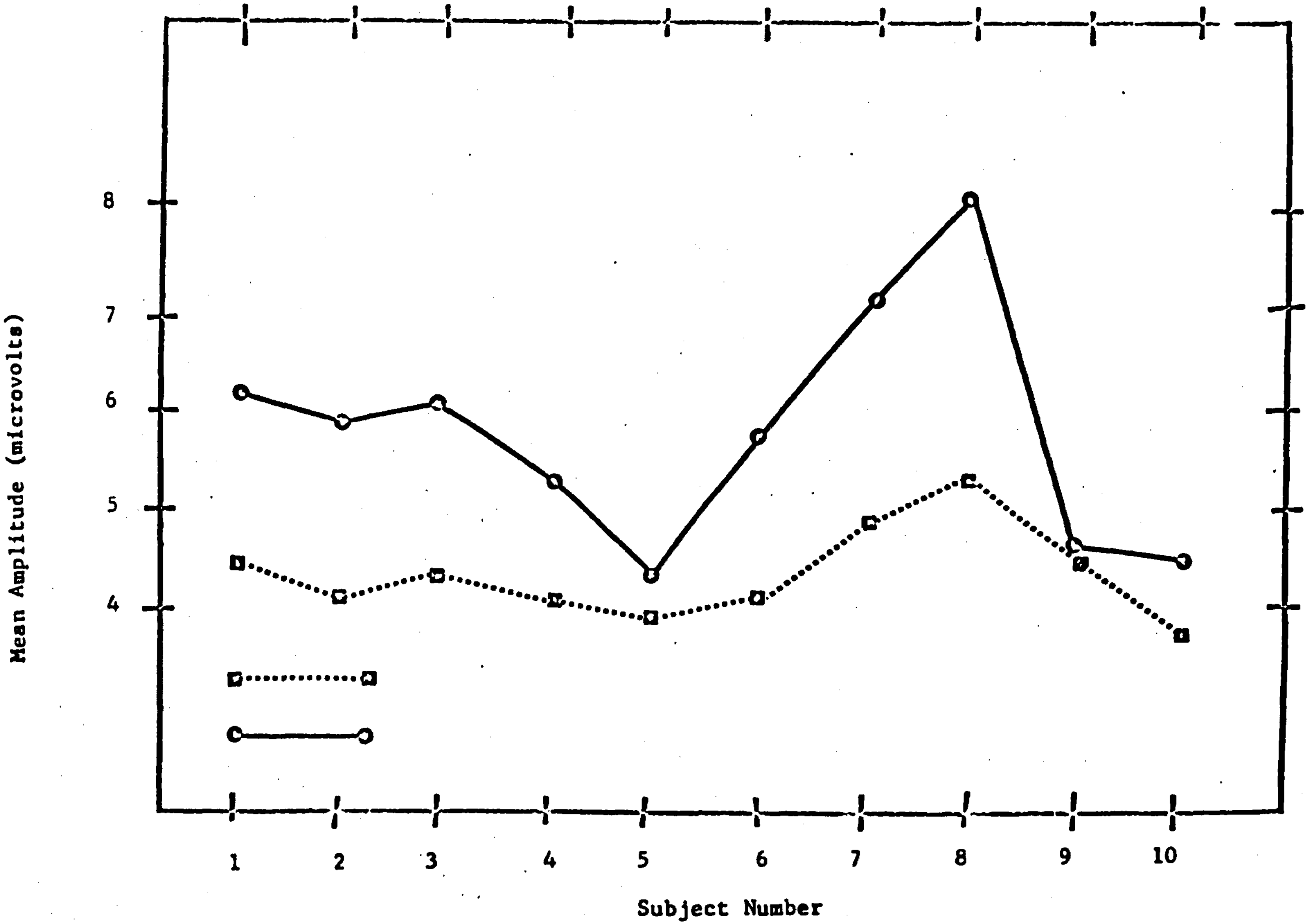

Figure 9. Mean Amplitude of Component One-Two in Microvolts as a Function of Subjects at Two Sensation Levels.

low of approximately 3.8 microvolts to a high of approximately 5.3 microvolts. The mean amplitudes at 40-dB SL are larger for each subject than those obtained at 20-dB SL. The intersubject differences range from approximately .2 microvolts for Subject Nine to approximately 2.8 microvolts for Subject Eight. The fact that the amplitude of the evoked potential increases with an increase in stimulus level has been mentioned by numerous authors (1, 19, 20, 21, 22, 31, 32, 44, 46, 47, 49, 50, 52, 56, 60, 61, 62) and is supported by the present study. However, the individual data of each set (see APPENDIX B) show that there is considerable intersubject and intrasubject variability. Some individual responses at the 20-dB SL reveal a greater amplitude than is present under the corresponding 40-dB SL condition. This variability is reflected in individual subject responses, examples of which are shown in APPENDIX B: Subject Ten, sixth day, fourth set; Subject Five, first day, third set.

From the statistical analysis, shown in Table 6, there is a significant difference as a function of SL ($P < .05$) with no significant difference as a function of sets, days, or interactions. The graphic representation as a function of sets as shown in Figure 8 and individual subjects as shown in Figure 9 indicate that the 40-dB SL produced a larger amplitude for Component One-Two than did the 20-dB SL stimuli. It should be noted, however, that the reverse is sometimes found when looking at individual subject sets.

Amplitude of Evoked Potentials, Component Two-Three

The peak-to-peak amplitude of Component Two-Three (measured between the positive peak referred to as Component Two and the negative peak referred to as Component Three) in both the 20-dB SL and the 40-dB SL conditions, as shown in Figure 10, follow a pattern similar to that of the earlier component. The 20-dB SL condition produced less amplitude than did the 40-dB SL in each of the four sets. Both levels follow an essentially flat function across sets, with the mean amplitude for all sets in the 20-dB SL response being 4.76 microvolts, while the mean of the 40-dB SL responses was 6.18 microvolts. The individual scores may be located in APPENDIX B, while the grand mean for the sets with their accompanying ranges are located in APPENDIX C.

It can be seen in Figure 11 that the amplitudes evoked by the 40-dB SL signal exceeded those obtained under the 20-dB level from each subject, with the exception of Subject Nine for whom the reverse was true.

As was evidenced in the amplitude of Component One-Two (see Figure 9), the means across subjects under the 40-dB SL condition follow essentially the same configuration as do those at the 20-dB SL condition.

The statistical analysis computed on Component Two-Three, seen in APPENDIX D, indicates a significant difference between the SL's ($P < .01$). No significant F ratio was obtained as a function of day or set, or for the interaction levels by days, levels by sets, or sets by days. Neither was a significant linear component found in a breakdown of the day and set source of variance.

In summary, the findings which are evident from this study indicate that the likelihood of obtaining a response is greater as the SL is increased. Also, as the intensity of the stimuli is increased, the latency of Component One (negative point with latency of approximately 80 msec) and Component Two (positive point with latency of approximately 145 msec) decreases. However, the latency of Component Three (negative

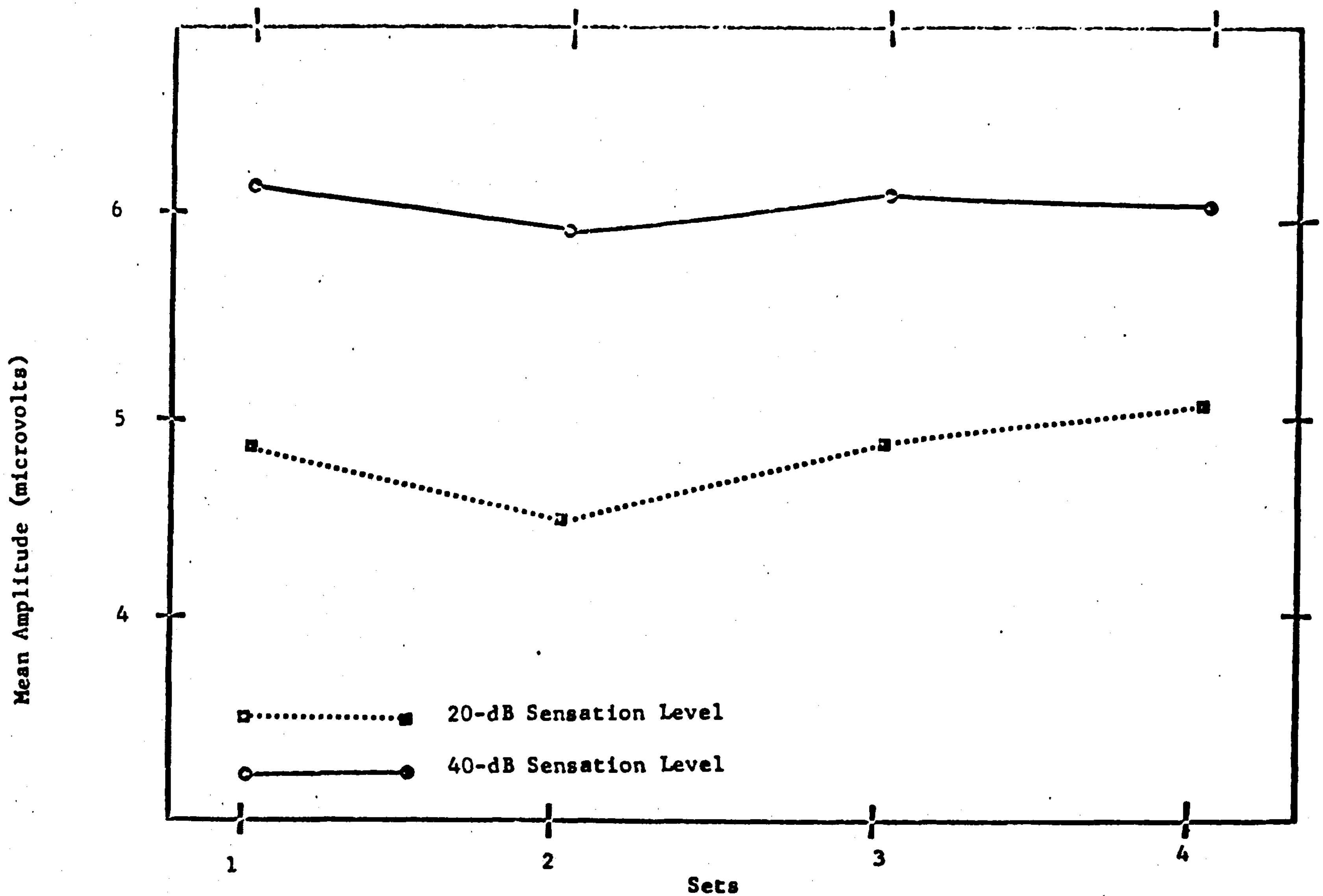

Figure 10. Mean Amplitude of Component Two-Three in Microvolts as a Function of Each Set at Two Sensation Levels.

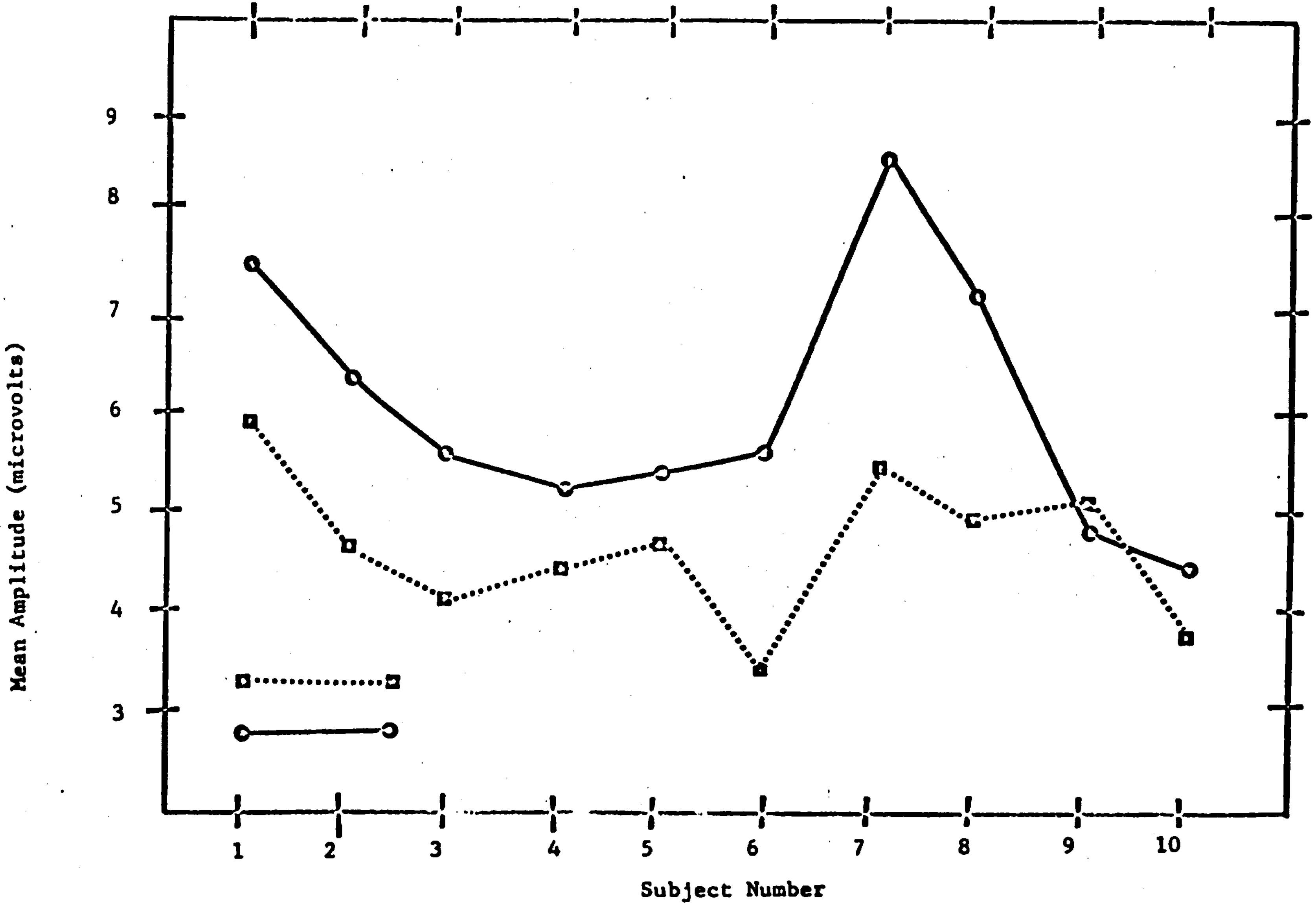

Figure 11. Mean Amplitude of Component Two-Three in Microvolts as a Function of Subjects at Two Sensation Levels.

point with latency of approximately 240 msec) does not decrease as a function of an increase in intensity. Component One shows a decrease in latency as a function of intensity increase ($P < .01$). The mean decrease in latency for Component Two with the increase in intensity is somewhat smaller than for Component One. From the present findings it appears that the longer the latency of a component, the less it is affected by an increase in stimulus level. The amplitude of Component One-Two (negative point called Component One to positive point called Component Two) and the amplitude of Component Two-Three (positive point called Component Two to negative point called Component Three) both increase as a function of an increase in sensation level. As is evidenced by the individual scores shown in APPENDIX B, there is considerable variability across subjects as well as within a single subject's response.

These findings agree in general with other studies which have been conducted using both human and animal subjects in which other sensory modalities, as well as acoustic stimuli, were used. The fact that, as stimulus intensity increases there is a progressively decreasing latency across components, has not been previously mentioned in the literature.

It has been suggested by Brazier (13) and Walter (59) that the evoked response shows a marked reduction in amplitude with an increase in the number of stimuli presented. In addition, Brazier presented tracings which demonstrated that there is also some shift in latency for Component Two as the number of epochs is increased. It would appear from the data obtained in the present study, that there is not a significant change in the latency of Component One, Two, or Three as a function of the number of stimuli presented. It was further found that there are not significant shifts in the amplitude of any of these components as a function of the number of stimuli presented on a given day or as a function of the number of days in which the stimuli were presented. These data do not support a hypothesis of adaptation in the evoked potential as a function of intensity level and number of stimuli, when the procedure used in the present study is employed.

If such a state of adaptation were to be evident from the tracings, it would seem that a decrease in amplitude and/or latency would be found. In view of the fact that there was not a significant decrease in either the amplitude or latency as a function of the number of stimuli, no evidence has been found supporting the presence of adaptation of the evoked response.

The lack of evidence of adaptation could be due to two possible factors. The first factor which may mitigate the detection of adaptation when, in fact, it exists, is the possibility that the scalp itself functions as an averager (24). Thus, even though some specific auditory tracts may adapt, the adaptation effect on the total output of the scalp might not be noted. The second possible reason for not obtaining a measurable amount of adaptation is the repetition rate of one per two seconds used in the present study. However, the repetition rate of one per two seconds is slower than those used by either Walter (59) or Brazier (13). It was shown by Allison (3), McCandless and Best (43), and by a pilot study conducted prior to the present investigation, that a repetition rate of one per two seconds does not markedly change the characteristics of evoked responses from those obtained with much slower repetition rates. A rate faster than one per two seconds does decrease the amplitude of the evoked response.

It is concluded from the findings of the present study that Components One and Two decrease in latency as a function of the stimulus increase. Component Three, however, does not show a significant change in latency with an increase in stimulus level. No significant change in latency was noted for any of the components as a function of number of stimuli or number of days the stimulus was presented.

The amplitudes of Component One-Two and Component Two-Three show a significant increase with an increase in SL of the stimulus. There is not a significant change in the amplitude of the two components as a function of number of stimuli or number of days in which the stimulus was presented.

CHAPTER V

SUMMARY AND CONCLUSIONS

Considerable information has been published recently regarding averaging procedures which allow for a reduction of the random on-going EEG activity and an enhancement of the specific potentials evoked by a given set of stimuli. These studies have concentrated on a determination of the characteristics of potentials evoked by various types of somatosensory, photic, and acoustic stimulation. It has been fairly well established that one can obtain an averaged evoked response from normal human subjects with these types of stimuli, providing that the stimuli are of sufficient magnitude. It is not yet clear, however, what specific neurological pathways are provided for the travel of the signals. Although the latencies of the various evoked responses have been described and labeled, there is little agreement regarding the amplitude and latency changes that occur as the stimulus is changed. There is a general agreement among authors that stimulus intensity and latency are inversely related.

The averaging procedure has been suggested as a possible tool not only to determine auditory acuity, but also to aid in determining sites of lesion. However, studies have not been specifically conducted to determine the magnitude of acoustically evoked responses and the specific effect on them of increased intensity, number of stimulus presentations, and testing time in normal-hearing subjects.

Experimental Design

The purpose of this study was to explore the characteristics of peak latencies and amplitudes of the late activity of the human evoked response to acoustic stimuli as a function of time and number of stimuli.

Evoked responses to acoustic clicks at two sensation levels (20 dB and 40 dB) were obtained. Clicks of .1 msec duration were presented in 500 serial epochs to ten normal-hearing subjects. It was possible to divide the 500 epochs into sequences of epochs of 125 each and to observe the effect of the number of epochs over time at the two sensation levels.

The experimental apparatus permitted close control of pulse duration, number of stimuli presented, amplifier gain, and storing of data in computer memory. The first 500 msec of EEG activity following each click was time-locked, stored in the computer memory, and added algebraically to all other responses under a given experimental condition.

Each subject was tested at 20-dB SL and 40-dB SL each day for six days.

The experimental procedure followed a randomized complete block design where the experimental conditions or "treatments" were arranged in a factorial fashion. Each subject was therefore observed under (2 x 4 x 6) 48 different experimental conditions. These conditions represent all possible combinations of the two sensation levels, four sets, and the six days.

Results and Conclusions

The results of this study agree with previous findings that an increase in stimulus intensity results in an increase in the amplitude of the evoked response. The degree to which the amplitude increases varied considerably across subjects, intrasubject variability being less than intersubject variability.

The latency of the first and second components (80 msec negativity and 145 msec positive peak) decreased significantly as the intensity was increased. The decrease in latency was greater for the first component than for the second component. The third component's latency (240 msec) did not decrease significantly as a function of stimulus level. Thus, it would appear that, as the latency becomes greater, it is affected less by variation of the stimulus level. The present author has been unable to find any previously published work which mentions this phenomenon.

The findings of the present study do not support those studies reported (13, 59) in which an amplitude shift was noted as a function of either time or number of stimuli. It should be pointed out, however, that other studies have used stimulus repetition rates which were faster than the repetition rate used in this study and utilized photic, not acoustic, stimuli. Comparisons across studies are obviously tenuous when many unexplored variables are involved, the two greatest variables possibly being repetition rate and the sensory modality stimulated.

The results of this study indicate that no amplitude or latency shift occurs as a function of number of epochs presented and that intersubject variability is greater than intrasubject variability in both amplitude and latency.

It should be emphasized that, contrary to the findings of McCandless and Best (43), a response was not obtained with every 125 epochs. However, as the intensity of the stimulus is increased, the likelihood of obtaining a response increases. Perhaps the reason for the difference in findings of the present study and the results reported by McCandless and

Best is that the stimuli were at different SL's in the two studies. Furthermore, the stimuli were presented monaurally in the present study, whereas McCandless and Best used binaural stimulation which has been found to produce larger amplitudes than monaural stimulation.

Suggestions for Additional Research

Considerable research into evoked potentials must be conducted prior to their utilization as a clinical tool. The ability of an individual to inhibit or amplify the evoked response must be investigated closely. The effect of other stimulus intensities should be investigated in order to determine not only if there is a level at which intersubject and intrasubject responses are more consistent, but also whether there is a level at which the subject ceases to respond to high-level stimuli.

Acoustic stimuli of various durations and frequencies should be studied to determine whether there is a change in the evoked response across levels of these parameters. It is further suggested that, since investigations of cross-modality effects have not been directed toward an establishment of norms (3,12,13,59), normative data should be obtained in order to determine the effects of inter-sensory stimulation on evoked potentials.

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APPENDIX A

Calibration Procedure

CALIBRATION PROCEDURE

Step 1. Turn equipment on and allow to warm up for one hour.

Step 2. Calibrate the DC level of the 122 amplifiers.

(a) Open the inputs of all four 122 amplifiers.
(b) Connect the output of the 122's to the input of the 561-A scope.
(c) Set scope to the .05 volts/div. setting.
(d) Set the time base to 5 msec/division. With the input position on ground, adjust the trace to the middle gradicule.
(e) Switch input switch of the scope from ground to dc position to determine the 122 output dc change from zero.
(f) If there is a change from zero, switch the input position from the ground position to the dc position and adjust the dc level. Adjust the dc level on the 122 until the trace appears on the middle gradicule. Switch back to the ground position and check for center positioning.
(g) On the .05 range, the dc shift should not exceed 1 cm; if it does, repeat steps (d) through (g).

Step 3. Calibrate the DC balance of the 2A63 amplifier.

(a) Open the input of the 2A63 amplifier.
(b) Connect the output of the 2A63 to the input of the scope amplifier.
(c) Set the scope input to .2 volts/div. position.
(d) With the input switch of the scope on the ground position, adjust the trace to the middle gradicule.
(e) Switch the input to the dc position and adjust the tracing to the center gradicule by rotating the dc balance control on the 2A63 amplifier.
(f) When this is adjusted, switch the input of the scope from dc to ground. The trace should remain in the same position. If the trace moves more than ½ cm, repeat steps (d) through (f).

Step 4. Calibrate the common mode rejection.

(a) The output of the 122 is connected to the input of the 2A63.
(b) The output of the 2A63 is connected to the scope inputs.
(c) The scope should be set at the 1 volt/div. setting and the time base at 5 msec/div. Set the input of the scope on the ac position.
(d) Connect the "calibrate out" from the scope to the input of the 122 amplifier using the differential amplifier patch cord (pin 1 - shield, pins 2 and 3 common to the hot line).
(e) With 1 volt out of the calibrate out position of the scope, a deflection of 1 cm represents a 60,000 rejection.
(f) To reduce the size of the common mode rejected signal, adjust the differential balance of the 122 amplifier for minimum signal size on the monitor scope.

Step 5. Calibrate the gain of the system.
(a) Leave everything as is connected for common mode rejection.
(b) Reduce the calibration out signal to .2 microvolt.
(c) Replace the differential amplitude patch cord with the amplifier gain patch cord (pin 2 hot, pin 3 ground, pin 1 open).
(d) Adjust the gain of the 2A63 so that a .2 microvolt signal gives a 12 volt scope reading. This is equal to a gain of 60,000.

Step 6. Calibrate the CAT and X-Y Plotter applying a known voltage to the input of the CAT and then plot this on the X-Y recorder. Do not exceed 3 volts input in this step.

Step 7. Calibrate the CAT and X-Y Plotter applying one-half as much voltage to the CAT as was applied in Step 6.

Step 8. To calibrate the voltage obtained from the experimental sets, apply the following formula. E_s is average input signal voltage in volts.

$$E_s = \frac{A_s \times E_c \times S_c \times R_s}{A_c \times S_s \times R_c}$$

where the following information is known:

E_c = calibration voltage in volts

A_s = amplitude of averaged input signal in inches or centimeters

A_c = amplitude of averaged calibration voltage in inches or centimeters

S_s = number of sweeps for input signal

S_c = number of sweeps for calibration voltage

R_s = vertical range switch setting when plotting the input

R_c = vertical range switch setting when plotting the calibration voltage

The calibration procedure for the CAT and X-Y Plotter were supplied by the manufacturer's representative.

APPENDIX B

Individual Subject Data

TABLE 5

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA
FOR THE 20-dB CONDITION. SUBJECT NUMBER ONE.

DAY	SET	LATENCY OF COMPONENT IN MILLISECONDS			PEAK TO PEAK AMPLITUDE IN MICROVOLTS	
		ONE	TWO	THREE	ONE-TWO	TWO-THREE
1	1	73	124	230	4.26	8.80
1	2	000	000	000	0.00	0.00
1	3	60	122	188	3.27	3.98
1	4	80	132	288	5.40	9.66
2	1	80	115	237	5.11	5.25
2	2	000	000	000	0.00	0.00
2	3	80	132	178	4.40	5.25
2	4	000	000	000	0.00	0.00
3	1	57	107	208	5.68	6.53
3	2	82	122	213	5.96	6.53
3	3	73	137	292	5.96	6.11
3	4	62	112	253	3.98	6.25
4	1	75	127	233	3.83	6.25
4	2	71	168	193	3.41	4.12
4	3	000	000	000	0.00	0.00
4	4	70	117	218	4.54	7.24
5	1	70	157	213	2.98	4.54
5	2	60	137	223	6.67	7.10
5	3	73	128	210	5.25	5.68
5	4	93	128	215	4.54	5.68
6	1	75	127	228	3.69	4.26
6	2	90	112	229	2.41	5.54
6	3	87	117	213	1.99	4.76
6	4	77	112	218	4.97	3.83

TABLE 6

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA FOR THE 20-dB CONDITION. SUBJECT NUMBER TWO.

DAY	SET	LATENCY OF COMPONENT IN MILLISECONDS			PEAK TO PEAK AMPLITUDE IN MICROVOLTS	
		ONE	TWO	THREE	ONE-TWO	TWO-THREE
1	1	90	152	278	4.54	5.68
1	2	102	203	340	3.83	5.68
1	3	85	132	324	2.63	3.27
1	4	77	142	337	4.97	5.54
2	1	70	172	308	6.67	8.38
2	2	71	147	293	3.83	4.54
2	3	000	000	000	0.00	0.00
2	4	85	135	323	2.27	3.69
3	1	83	148	230	2.56	1.99
3	2	77	133	283	3.55	4.83
3	3	86	148	278	3.27	3.55
3	4	65	158	288	6.11	8.66
4	1	91	142	258	2.98	2.98
4	2	80	157	293	4.54	4.54
4	3	000	000	000	0.00	0.00
4	4	000	000	000	0.00	0.00
5	1	72	153	290	3.69	4.40
5	2	77	138	295	2.98	2.84
5	3	82	168	297	3.41	2.70
5	4	87	128	290	3.27	4.26
6	1	70	163	200	6.67	6.53
6	2	80	165	286	3.69	4.12
6	3	85	201	262	4.97	4.40
6	4	80	222	367	4.83	5.40

TABLE 7

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA FOR THE 20-dB CONDITION. SUBJECT NUMBER THREE.

DAY	SET	LATENCY OF COMPONENT IN MILLISECONDS			PEAK TO PEAK AMPLITUDE IN MICROVOLTS	
		ONE	TWO	THREE	ONE-TWO	TWO-THREE
1	1	000	000	000	0.00	0.00
1	2	90	137	202	4.97	4.26
1	3	67	153	228	3.48	6.25
1	4	80	132	252	7.10	5.68
2	1	82	138	255	3.98	4.12
2	2	77	170	245	4.40	3.55
2	3	88	135	210	3.69	4.26
2	4	93	135	215	2.41	3.27
3	1	71	155	227	3.91	3.69
3	2	77	172	212	4.19	2.13
3	3	57	182	225	5.68	5.82
3	4	100	188	238	4.26	4.40
4	1	000	000	000	0.00	0.00
4	2	65	127	197	4.69	3.69
4	3	85	147	247	5.25	4.54
4	4	000	000	000	0.00	0.00
5	1	102	148	215	3.41	3.27
5	2	87	167	198	5.96	4.54
5	3	65	137	182	3.69	4.12
5	4	70	147	207	5.69	4.70
6	1	70	140	227	3.27	2.70
6	2	85	160	196	2.41	3.55
6	3	000	000	000	0.00	0.00
6	4	95	137	257	3.69	4.26

TABLE 8

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA FOR THE 20-dB CONDITION. SUBJECT NUMBER FOUR.

DAY	SET	LATENCY OF COMPONENT IN MILLISECONDS			PEAK TO PEAK AMPLITUDE IN MICROVOLTS	
		ONE	TWO	THREE	ONE-TWO	TWO-THREE
1	1	95	153	314	3.55	4.97
1	2	000	000	000	0.00	0.00
1	3	60	126	210	3.69	3.41
1	4	000	000	000	0.00	0.00
2	1	000	000	000	0.00	0.00
2	2	000	000	000	0.00	0.00
2	3	62	158	210	3.83	3.38
2	4	000	000	000	0.00	0.00
3	1	000	000	000	0.00	0.00
3	2	86	143	218	4.97	6.11
3	3	000	000	000	0.00	0.00
3	4	000	000	000	0.00	0.00
4	1	000	000	000	0.00	0.00
4	2	000	000	000	0.00	0.00
4	3	000	000	000	0.00	0.00
4	4	000	000	000	0.00	0.00
5	1	000	000	000	0.00	0.00
5	2	85	132	262	5.40	4.26
5	3	000	000	000	0.00	0.00
5	4	000	000	000	0.00	0.00
6	1	000	000	000	0.00	0.00
6	2	000	000	000	0.00	0.00
6	3	95	137	285	3.27	4.83
6	4	75	168	239	3.69	3.83

TABLE 9

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA FOR THE 20-dB CONDITION. SUBJECT NUMBER FIVE.

DAY	SET	LATENCY OF COMPONENT IN MILLISECONDS			PEAK TO PEAK AMPLITUDE IN MICROVOLTS	
		ONE	TWO	THREE	ONE-TWO	TWO-THREE
1	1	72	133	242	4.97	5.68
1	2	93	178	219	3.12	5.11
1	3	60	137	172	3.98	2.70
1	4	62	173	200	3.55	3.41
2	1	95	131	252	5.11	5.68
2	2	66	137	227	2.41	4.27
2	3	61	122	227	2.56	4.12
2	4	80	167	242	4.69	4.97
3	1	98	139	260	3.27	4.40
3	2	100	122	238	2.41	3.83
3	3	000	000	000	0.00	0.00
3	4	110	172	233	2.56	4.26
4	1	81	147	254	5.96	5.54
4	2	000	000	000	0.00	0.00
4	3	62	148	248	4.97	5.25
4	4	82	138	270	4.40	5.82
5	1	86	147	218	4.97	5.40
5	2	95	162	212	3.62	5.68
5	3	80	151	202	3.41	4.97
5	4	000	000	000	0.00	0.00
6	1	101	168	259	5.68	6.25
6	2	82	129	170	4.40	4.26
6	3	102	138	214	3.83	3.83
6	4	82	133	194	3.27	3.41

TABLE 10

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA
FOR THE 20-dB CONDITION. SUBJECT NUMBER SIX.

DAY	SET	LATENCY OF COMPONENT IN MILLISECONDS			PEAK TO PEAK AMPLITUDE IN MICROVOLTS	
		ONE	TWO	THREE	ONE-TWO	TWO-THREE
1	1	107	148	209	3.41	3.27
1	2	000	000	000	0.00	0.00
1	3	107	184	213	3.69	2.13
1	4	102	149	244	4.83	3.69
2	1	105	162	222	4.12	2.41
2	2	000	000	000	0.00	0.00
2	3	000	000	000	0.00	0.00
2	4	62	163	218	3.83	3.41
3	1	118	150	200	3.69	3.27
3	2	000	000	000	0.00	0.00
3	3	000	000	000	0.00	0.00
3	4	000	000	000	0.00	0.00
4	1	107	133	208	3.12	3.98
4	2	92	142	203	4.26	3.27
4	3	91	168	198	3.41	4.40
4	4	000	000	000	0.00	0.00
5	1	113	182	207	4.54	2.56
5	2	000	000	000	0.00	0.00
5	3	000	000	000	0.00	0.00
5	4	000	000	000	0.00	0.00
6	1	75	162	293	5.54	4.69
6	2	000	000	000	0.00	0.00
6	3	000	000	000	0.00	0.00
6	4	000	000	000	0.00	0.00

TABLE 11

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA
FOR THE 20-dB CONDITION. SUBJECT NUMBER SEVEN.

DAY	SET	LATENCY OF COMPONENT IN MILLISECONDS			PEAK TO PEAK AMPLITUDE IN MICROVOLTS	
		ONE	TWO	THREE	ONE-TWO	TWO-THREE
1	1	107	152	268	4.83	7.10
1	2	88	135	261	3.55	5.68
1	3	000	000	000	0.00	0.00
1	4	75	145	276	6.82	5.96
2	1	107	147	223	3.41	4.40
2	2	86	172	260	3.83	2.98
2	3	60	126	288	3.55	3.69
2	4	102	152	273	4.12	4.40
3	1	112	139	260	3.98	4.12
3	2	000	000	000	0.00	0.00
3	3	97	164	255	5.82	6.39
3	4	82	155	265	4.97	6.39
4	1	102	133	280	3.41	3.84
4	2	85	145	250	5.40	5.82
4	3	100	147	265	4.83	5.54
4	4	96	157	254	4.40	5.96
5	1	95	136	256	5.68	6.67
5	2	102	147	253	4.12	5.25
5	3	92	147	258	7.81	8.52
5	4	102	148	279	6.96	6.67
6	1	63	135	252	3.83	5.25
6	2	120	156	290	5.40	6.82
6	3	87	154	255	5.54	5.82
6	4	87	168	279	4.40	4.83

TABLE 12

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA
FOR THE 20-dB CONDITION. SUBJECT NUMBER EIGHT.

DAY	SET	LATENCY OF COMPONENT IN MILLISECONDS			PEAK TO PEAK AMPLITUDE IN MICROVOLTS	
		ONE	TWO	THREE	ONE-TWO	TWO-THREE
1	1	77	163	234	4.54	5.54
1	2	82	173	223	4.83	5.45
1	3	97	208	280	5.68	5.96
1	4	92	169	214	6.25	4.54
2	1	97	153	273	3.55	4.40
2	2	80	157	262	4.97	4.26
2	3	85	162	247	7.10	4.70
2	4	92	173	308	7.38	5.96
3	1	77	149	236	5.25	5.54
3	2	97	175	266	3.98	4.26
3	3	81	143	203	5.96	5.25
3	4	96	173	223	6.11	5.54
4	1	90	162	277	4.12	4.69
4	2	87	132	253	5.40	4.54
4	3	98	149	272	4.12	4.40
4	4	85	174	278	6.25	6.67
5	1	000	000	000	0.00	0.00
5	2	000	000	000	0.00	0.00
5	3	000	000	000	0.00	0.00
5	4	97	150	213	4.83	3.55
6	1	102	165	262	4.67	4.97
6	2	79	153	244	5.40	3.98
6	3	000	000	000	0.00	0.00
6	4	96	132	283	4.97	4.69

TABLE 13

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA
FOR THE 20-dB CONDITION. SUBJECT NUMBER NINE.

DAY	SET	LATENCY OF COMPONENT IN MILLISECONDS			PEAK TO PEAK AMPLITUDE IN MICROVOLTS	
		ONE	TWO	THREE	ONE-TWO	TWO-THREE
1	1	102	167	188	4.54	3.83
1	2	90	126	217	4.83	5.25
1	3	110	131	217	4.83	5.68
1	4	000	000	000	0.00	0.00
2	1	112	153	183	4.26	5.68
2	2	000	000	000	0.00	0.00
2	3	000	000	000	0.00	0.00
2	4	112	147	183	5.11	5.68
3	1	85	167	250	4.40	4.12
3	2	105	157	236	3.98	4.54
3	3	80	151	237	5.96	4.83
3	4	95	137	227	3.98	4.97
4	1	112	132	275	4.40	6.96
4	2	90	122	182	4.97	3.98
4	3	100	132	275	3.12	5.54
4	4	000	000	000	0.00	0.00
5	1	000	000	000	0.00	0.00
5	2	000	000	000	0.00	0.00
5	3	90	135	187	4.12	7.24
5	4	85	126	192	3.83	4.83
6	1	122	158	223	4.26	3.41
6	2	000	000	000	0.00	0.00
6	3	000	000	000	0.00	0.00
6	4	000	000	000	0.00	0.00

TABLE 14

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA
FOR THE 20-dB CONDITION. SUBJECT NUMBER TEN.

DAY	SET	LATENCY OF COMPONENT IN MILLISECONDS			PEAK TO PEAK AMPLITUDE IN MICROVOLTS	
		ONE	TWO	THREE	ONE-TWO	TWO-THREE
1	1	105	156	216	2.56	2.84
1	2	80	157	197	4.26	4.26
1	3	000	000	000	0.00	0.00
1	4	000	000	000	0.00	0.00
2	1	000	000	000	0.00	0.00
2	2	89	161	210	3.55	2.56
2	3	000	000	000	0.00	0.00
2	4	79	150	227	3.12	4.97
3	1	97	132	215	1.70	2.84
3	2	000	000	000	0.00	0.00
3	3	62	143	209	5.25	4.83
3	4	000	000	000	0.00	0.00
4	1	98	158	205	3.41	3.83
4	2	107	168	215	4.26	3.83
4	3	92	117	173	2.98	2.98
4	4	000	000	000	0.00	0.00
5	1	62	107	203	3.12	4.97
5	2	67	163	200	4.69	2.70
5	3	000	000	000	0.00	0.00
5	4	000	000	000	0.00	0.00
6	1	65	152	212	4.52	3.98
6	2	85	157	227	4.69	3.41
6	3	000	000	000	0.00	0.00
6	4	111	162	212	4.69	3.69

TABLE 15

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA FOR THE 40-dB CONDITION. SUBJECT NUMBER ONE.

DAY	SET	LATENCY OF COMPONENT IN MILLISECONDS			PEAK TO PEAK AMPLITUDE IN MICROVOLTS	
		ONE	TWO	THREE	ONE-TWO	TWO-THREE
1	1	78	140	222	9.09	8.23
1	2	70	132	217	7.46	11.22
1	3	78	110	210	6.39	8.66
1	4	45	102	202	5.11	6.24
2	1	72	142	204	5.18	7.55
2	2	72	115	194	6.04	6.46
2	3	82	112	198	5.75	6.46
2	4	75	154	196	7.24	9.37
3	1	75	145	212	5.04	7.38
3	2	82	117	230	7.46	8.52
3	3	77	142	225	5.68	9.09
3	4	70	122	217	4.60	8.17
4	1	86	122	203	5.68	7.81
4	2	83	123	225	7.74	6.96
4	3	72	122	220	5.68	7.38
4	4	67	160	225	8.52	7.95
5	1	75	107	200	4.40	6.10
5	2	77	122	217	6.96	4.19
5	3	55	126	228	6.67	7.95
5	4	74	119	201	5.96	7.38
6	1	40	127	218	7.81	6.11
6	2	80	122	198	3.27	6.96
6	3	75	117	203	6.25	7.53
6	4	68	115	206	6.53	8.45

TABLE 16

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA FOR THE 40-dB CONDITION. SUBJECT NUMBER TWO.

DAY	SET	LATENCY OF COMPONENT IN MILLISECONDS			PEAK TO PEAK AMPLITUDE IN MICROVOLTS	
		ONE	TWO	THREE	ONE-TWO	TWO-THREE
1	1	90	177	302	5.11	6.10
1	2	78	140	312	5.96	5.96
1	3	85	125	297	3.69	4.26
1	4	75	132	268	9.37	9.23
2	1	85	147	272	5.82	5.11
2	2	70	137	303	5.60	8.73
2	3	72	163	278	6.39	6.39
2	4	76	133	278	6.54	8.52
3	1	87	147	307	5.68	5.53
3	2	87	165	276	3.12	3.97
3	3	77	147	286	3.12	4.11
3	4	70	173	243	5.53	3.55
4	1	87	137	275	6.39	6.10
4	2	55	138	304	6.39	6.39
4	3	76	142	273	4.62	5.11
4	4	80	142	272	6.11	6.39
5	1	87	133	243	5.25	5.40
5	2	93	140	235	3.55	3.12
5	3	82	158	265	4.97	6.96
5	4	80	142	278	6.39	8.95
6	1	80	142	294	11.47	14.11
6	2	80	143	265	8.09	7.10
6	3	77	128	270	7.38	6.96
6	4	80	157	335	5.25	5.96

TABLE 17

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA FOR THE 40-dB CONDITION. SUBJECT NUMBER THREE.

DAY	SET	LATENCY OF COMPONENT IN MILLISECONDS			PEAK TO PEAK AMPLITUDE IN MICROVOLTS	
		ONE	TWO	THREE	ONE-TWO	TWO-THREE
1	1	71	152	200	6.25	4.40
1	2	75	152	217	4.12	4.87
1	3	65	132	236	7.10	7.53
1	4	59	136	220	5.82	7.38
2	1	80	152	222	7.81	5.82
2	2	77	138	224	6.39	2.57
2	3	88	143	229	5.11	4.97
2	4	62	153	213	6.25	6.11
3	1	84	160	243	8.38	8.09
3	2	90	145	258	6.25	5.25
3	3	90	122	233	5.11	5.54
3	4	81	126	293	5.68	4.97
4	1	75	152	213	5.82	4.69
4	2	75	137	228	7.67	5.68
4	3	75	122	207	6.39	6.39
4	4	80	117	263	6.96	7.10
5	1	72	142	258	7.95	7.67
5	2	82	137	243	7.24	6.39
5	3	60	122	213	6.25	6.82
5	4	61	122	287	4.97	5.54
6	1	65	142	252	4.40	3.69
6	2	72	157	262	5.25	5.68
6	3	80	173	243	3.98	4.69
6	4	75	177	242	4.54	3.48

TABLE 18

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA FOR THE 40-dB CONDITION. SUBJECT NUMBER FOUR.

DAY	SET	LATENCY OF COMPONENT IN MILLISECONDS			PEAK TO PEAK AMPLITUDE IN MICROVOLTS	
		ONE	TWO	THREE	ONE-TWO	TWO-THREE
1	1	85	147	257	6.39	7.53
1	2	89	150	228	7.10	6.82
1	3	83	153	219	7.53	6.96
1	4	77	143	243	3.69	3.83
2	1	97	143	219	5.68	4.97
2	2	96	173	229	4.12	4.12
2	3	93	144	200	5.11	4.26
2	4	93	135	251	5.96	4.79
3	1	97	163	254	5.68	6.67
3	2	102	148	212	6.32	5.11
3	3	92	153	207	5.11	6.53
3	4	91	152	228	5.40	5.11
4	1	90	154	227	6.39	9.09
4	2	90	147	242	4.69	4.54
4	3	91	152	212	4.97	4.82
4	4	85	162	212	5.25	2.41
5	1	131	146	217	3.12	3.69
5	2	110	150	295	8.80	4.69
5	3	93	150	242	4.26	4.83
5	4	83	135	215	3.55	4.12
6	1	92	180	215	4.12	3.69
6	2	87	143	220	5.11	4.26
6	3	82	137	230	4.54	4.82
6	4	87	138	243	5.68	6.39

TABLE 19

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA
FOR THE 40-dB CONDITION. SUBJECT NUMBER FIVE.

DAY	SET	LATENCY OF COMPONENT IN MILLISECONDS			PEAK TO PEAK AMPLITUDE IN MICROVOLTS	
		ONE	TWO	THREE	ONE-TWO	TWO-THREE
1	1	65	125	250	4.97	5.54
1	2	104	144	243	3.55	5.40
1	3	92	149	255	2.84	5.96
1	4	60	178	254	4.40	5.68
2	1	85	176	263	2.84	4.54
2	2	95	143	218	1.99	4.54
2	3	82	143	235	2.27	5.11
2	4	87	179	295	2.41	3.12
3	1	72	138	258	6.53	7.38
3	2	40	142	242	3.55	5.11
3	3	57	112	252	3.12	4.40
3	4	87	123	238	2.98	4.12
4	1	45	142	263	5.25	7.24
4	2	72	133	218	4.83	4.54
4	3	76	138	207	5.68	5.96
4	4	75	122	228	3.27	4.69
5	1	40	142	228	7.24	7.10
5	2	71	142	238	5.11	5.11
5	3	60	172	247	3.55	4.54
5	4	70	132	243	5.11	5.40
6	1	60	153	243	6.25	6.67
6	2	65	137	265	6.74	5.96
6	3	60	148	218	4.40	6.39
6	4	65	168	248	3.69	4.26

TABLE 20

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA FOR THE 40-dB CONDITION. SUBJECT NUMBER SIX.

DAY	SET	LATENCY OF COMPONENT IN MILLISECONDS			PEAK TO PEAK AMPLITUDE IN MICROVOLTS	
		ONE	TWO	THREE	ONE-TWO	TWO-THREE
1	1	64	150	302	6.53	6.25
1	2	67	149	204	3.55	4.54
1	3	67	160	210	3.55	5.18
1	4	88	150	225	4.12	5.68
2	1	72	158	238	5.68	4.76
2	2	57	157	223	6.11	4.54
2	3	87	163	218	6.11	6.11
2	4	77	153	198	5.54	4.19
3	1	63	153	238	6.11	6.39
3	2	87	157	263	6.18	3.41
3	3	78	153	273	6.11	4.40
3	4	87	152	227	5.68	5.40
4	1	62	142	257	6.39	6.82
4	2	72	151	222	5.82	5.96
4	3	62	142	217	5.96	7.03
4	4	67	147	204	4.97	5.89
5	1	57	143	225	6.39	5.68
5	2	62	153	257	6.82	5.68
5	3	52	143	215	5.82	4.83
5	4	60	157	243	5.68	5.82
6	1	63	149	240	6.25	5.54
6	2	66	143	208	7.10	7.10
6	3	65	137	228	5.11	6.53
6	4	66	134	238	6.96	6.53

TABLE 21

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA FOR THE 40-dB CONDITION. SUBJECT NUMBER SEVEN.

DAY	SET	LATENCY OF COMPONENT IN MILLISECONDS			PEAK TO PEAK AMPLITUDE IN MICROVOLTS	
		ONE	TWO	THREE	ONE-TWO	TWO-THREE
1	1	85	132	251	7.95	7.95
1	2	77	128	265	6.96	8.80
1	3	86	133	254	7.52	8.66
1	4	87	134	297	7.10	7.95
2	1	86	138	264	9.51	9.80
2	2	85	153	248	7.31	9.37
2	3	87	144	264	6.39	9.94
2	4	81	133	237	7.95	10.08
3	1	57	154	246	5.11	7.81
3	2	85	173	288	6.96	8.52
3	3	96	143	248	5.96	8.95
3	4	75	142	237	8.24	9.23
4	1	86	153	238	7.10	7.67
4	2	85	130	257	5.40	7.95
4	3	90	157	268	6.96	9.66
4	4	58	168	260	9.37	9.94
5	1	68	130	255	5.25	7.81
5	2	92	158	263	7.10	9.23
5	3	96	137	263	7.97	6.96
5	4	86	147	258	5.11	7.10
6	1	87	143	234	7.10	8.38
6	2	57	138	249	7.95	8.08
6	3	88	148	265	7.53	8.66
6	4	72	133	285	8.80	9.51

TABLE 22

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA FOR THE 40-dB CONDITION. SUBJECT NUMBER EIGHT.

DAY	SET	LATENCY OF COMPONENT IN MILLISECONDS			PEAK TO PEAK AMPLITUDE IN MICROVOLTS	
		ONE	TWO	THREE	ONE-TWO	TWO-THREE
1	1	82	154	270	8.24	9.09
1	2	86	164	249	9.23	8.80
1	3	80	162	267	8.52	8.80
1	4	77	158	259	7.24	7.24
2	1	75	157	236	7.81	8.80
2	2	66	147	212	8.38	7.67
2	3	70	156	257	8.09	7.10
2	4	85	133	257	10.93	10.65
3	1	92	163	259	8.80	7.53
3	2	82	148	275	5.68	7.38
3	3	82	178	233	8.52	7.24
3	4	82	138	270	7.24	6.67
4	1	82	158	243	9.66	7.10
4	2	82	168	269	8.95	4.69
4	3	77	163	253	10.08	7.53
4	4	92	168	243	8.09	5.96
5	1	80	145	240	8.24	6.11
5	2	82	142	234	5.40	4.54
5	3	72	157	243	9.66	6.67
5	4	86	178	253	6.53	7.67
6	1	80	146	217	8.09	6.67
6	2	86	157	218	6.25	3.98
6	3	90	131	262	7.24	7.24
6	4	94	140	255	7.38	8.52

TABLE 23

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA
FOR THE 40-dB CONDITION. SUBJECT NUMBER NINE.

DAY	SET	LATENCY OF COMPONENT IN MILLISECONDS			PEAK TO PEAK AMPLITUDE IN MICROVOLTS	
		ONE	TWO	THREE	ONE-TWO	TWO-THREE
1	1	87	128	270	4.26	2.84
1	2	000	000	000	0.00	0.00
1	3	82	158	198	4.54	3.69
1	4	70	137	213	5.82	5.11
2	1	86	157	268	4.69	5.68
2	2	85	142	207	3.98	6.82
2	3	55	132	162	4.40	3.27
2	4	000	000	000	0.00	0.00
3	1	62	127	162	3.27	3.12
3	2	90	156	242	3.27	2.84
3	3	000	000	000	0.00	0.00
3	4	87	128	207	3.40	4.97
4	1	90	152	203	3.83	4.21
4	2	90	126	257	2.98	4.69
4	3	000	000	000	0.00	0.00
4	4	85	125	213	4.83	6.39
5	1	90	147	212	4.40	4.97
5	2	66	173	223	6.11	4.97
5	3	86	163	238	4.26	4.12
5	4	55	147	193	5.11	4.54
6	1	83	138	198	6.96	6.25
6	2	90	151	202	4.12	5.40
6	3	60	125	233	6.53	7.38
6	4	55	122	173	5.11	5.11

TABLE 24

SUBJECT IDENTIFICATION AND INDIVIDUAL SUBJECT DATA FOR THE 40-dB CONDITION. SUBJECT NUMBER TEN.

DAY	SET	LATENCY OF COMPONENT IN MILLISECONDS			PEAK TO PEAK AMPLITUDE IN MICROVOLTS	
		ONE	TWO	THREE	ONE-TWO	TWO-THREE
1	1	70	161	245	3.83	4.69
1	2	000	000	000	0.00	0.00
1	3	73	148	228	5.54	6.11
1	4	57	138	197	4.26	4.26
2	1	000	000	000	0.00	0.00
2	2	000	000	000	0.00	0.00
2	3	000	000	000	0.00	0.00
2	4	000	000	000	0.00	0.00
3	1	000	000	000	0.00	0.00
3	2	000	000	000	0.00	0.00
3	3	67	178	318	6.93	5.34
3	4	78	150	224	3.55	3.41
4	1	76	127	203	3.97	3.83
4	2	000	000	000	0.00	0.00
4	3	000	000	000	0.00	0.00
4	4	70	137	223	3.41	4.54
5	1	65	152	193	4.26	3.55
5	2	72	143	190	5.68	3.55
5	3	76	168	250	4.26	3.69
5	4	95	138	218	4.26	3.83
6	1	71	162	227	4.97	5.25
6	2	000	000	000	0.00	0.00
6	3	000	000	000	0.00	0.00
6	4	70	132	217	3.55	4.54

APPENDIX C

Mean and Range Scores for Various Components

TABLE 25

MEAN OF INDIVIDUAL SET SCORES COMPRISING THE NUMBER OF RESPONSES, AMPLITUDES, AND LATENCIES IN EACH SET FOR EACH SENSATION LEVEL. MEAN AND RANGE SCORES FOR LATENCIES OF COMPONENTS ONE, TWO, AND THREE, AND AMPLITUDES FOR COMPONENT ONE-TWO AND TWO-THREE FOR EACH SENSATION LEVEL

			LATENCY			AMPLITUDE	
	Set No.	N	Component #1	Component #2	Component #3	Component 1-2	Component 2-3
20 dB	1	50	89.46	146.60	241.32	4.192	4.729
	2	42	85.45	150.31	235.55	4.290	4.474
	3	39	81.64	146.59	232.21	4.365	4.746
	4	40	86.33	150.15	249.80	4.683	5.116
	x		342.88	593.65	958.88	17.530	19.065
	$\bar{x}$		85.72	148.41	239.72	4.383	4.766
	Range		122-57	222-107	367-170	7.81-1.70	9.66-1.99
			LATENCY			AMPLITUDE	
	Set No.	N	Component #1	Component #2	Component #3	Component 1-2	Component 2-3
40 dB	1	58	77.05	146.41	239.10	6.149	6.353
	2	54	79.41	144.80	240.43	5.884	5.903
	3	55	77.29	144.29	230.24	5.718	6.299
	4	58	75.00	142.55	238.98	5.741	6.196
	x		308.75	578.05	956.75	23.492	24.751
	$\bar{x}$		77.19	144.51	239.19	5.873	6.188
	Range		131-40	180-102	335-162	11.47-1.99	14.11-2.41

APPENDIX D

Analysis of Variance Tables

TABLE 26

SUMMARY OF ANALYSIS OF VARIANCE FOR COMPONENT ONE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Level	1	80278	80278	59.917 **
Day	5	6060	1212	.904
Set	3	9751	3250.3	2.425
L X D	5	16658	3331.6	2.486
L X S	3	12305	4101.7	3.061
D X S	15	47774	3184.9	2.377
Error	15	20098	1339.8	

** Significant at the one per cent level of confidence.

TABLE 27

SUMMARY OF ANALYSIS OF VARIANCE FOR COMPONENT TWO

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Level	1	16133	16133	7.372 *
Day	5	16756	3351.2	1.531
Set	3	3379	1126.3	.514
L X D	5	10187	2037.4	.931
L X S	3	9169	3056.2	1.396
D X S	15	28030	1868.7	.854
Error	15	32819	2187.9	

* Significant at the five per cent level of confidence.

TABLE 28

SUMMARY OF ANALYSIS OF VARIANCE FOR COMPONENT THREE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Level	1	1925	1925	.115
Day	5	59646	11929.2	1.793
Set	3	41768	13922.1	2.092
L X D	5	55329	11065.8	1.663
L X S	3	40991	13663.6	2.053
D X S	15	93529	6235.3	.937
Error	15	99789	6652.6	

No significant levels obtained at the five per cent level.

TABLE 29

SUMMARY OF ANALYSIS OF VARIANCE FOR AMPLITUDE OF COMPONENT ONE-TWO

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Level	1	2699	2699	149.116 **
Day	5	33	6.6	.364
Set	3	31	10.3	.569
L X D	5	117	23.4	1.292
L X S	3	137	45.7	3.29
D X S	15	323	21.5	1.187
Error	15	271	18.1	

** Siguificant at the one per cent level of confidence.

TABLE 30

SUMMARY OF ANALYSIS OF VARIANCE FOR AMPLITUDE OF COMPONENT TWO-THREE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Level	1	2233	2233	105.829 **
Day	5	217	43.4	2.056
Set	3	139	46.3	2.194
L X D	5	150	30.0	1.421
L X S	3	90	30.0	1.421
D X S	15	478	31.9	1.511
Error	15	317	21.1	

** Significant at the one per cent level.