An Evaluation of Electrodiagnostic Measures of Hearing

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A Thesis
Submitted for
the Degree of

Doctor of Philosophy

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SUMMARY

The effectiveness of three non-invasive electrophysiological techniques in the assessment of the subjective hearing thresholds was evaluated in normal and hearing impaired populations.

1. The Vertex Potential was used to establish objective auditory thresholds in normal adults and in adults and children with known hearing defects. Comparison of subjective and objective hearing thresholds revealed the vertex potential to be most reliable as a measure of auditory acuity in the group of normal adults; the groups of adult and child hearing defects showed both greater discrepancies and variability between subjective and objective assessment.

2. The Post-Auricular Myogenic Potential was investigated in two groups of normal adults. It was found to provide a less reliable assessment of auditory acuity than either the vertex potential or the brainstem potentials mainly on account of its variability and dependancy on resting muscle tone.

3. Brainstem Evoked Potentials were recorded in a large group of normal adults. The N4 component (Jewett's V wave) was found to provide a close and reliable estimation of subjective hearing level. The observed stability in the characteristics of the brainstem potentials would support their use in neurological assessment, but initial findings indicate a need for the development of more comprehensive age and sex related normal data.

Further investigations of the vertex potential using linguistic and non-linguistic stimuli failed to produce any clear evidence of the reflection of stimulus meaning in the characteristics of the vertex potential. The results, instead, would support the on-response nature of the vertex potential whose characteristics are primarily determined by the physical properties of the stimulus.

Vertex Potential
Post Auricular Myogenic Potential
Brainstem Evoked Potentials
Audiological Assessment
Linguistic Processing

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CONTENTS

Chapter 8

Chapter 9

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

Introduction

1.1. Historical Introduction

The electrical activity of the brain was first observed and recorded by Caton in 1875 using electrodes placed directly on the surface of the cortex in rabbits, cats and monkeys. It was not until approximately 50 years later that Hans Berger (1929) reported similar activity recorded from scalp electrodes in man (Gloor, 1969). His subsequent studies over the following 10 years (1929-1938) led to the formulation of a theory regarding the psychophysiological significance of the electroencephalogram (EEG).

This early work was met with a great deal of scepticism chiefly on account of the relative insensitivity of Berger's recording system, which consisted only of the recording electrodes connected directly to a galvonometer with no means of amplification for these very small signals. However, the validity of Berger's findings were subsequently confirmed by Adrian and Matthews (1934) who increased the resolution of the EEG signals by the replacement of the original galvonometer with valve amplification coupled with a cathode ray display scope.

The first discrete changes in the EEG in response to auditory stimulation were recorded from the human scalp by Davis in 1939 and took the form of small negative and positive deflections which were consistently recorded

within a latency of 100-200 m.secs. of stimulus onset. These potential changes later became known as the slow cortical or vertex evoked potential. Similar potential changes were subsequently observed during light sleep by Davis, Davis, Loomis, Harvey and Hobart (1939).

Unfortunately, these initial findings of Davis were not really replicated, as in most individuals the responses to auditory stimulation are much smaller than the ongoing spontaneous EEG activity and are not easily detected by straightforward visual examination of the EEG recording. Thus, further progress in this area awaited the development of more sophisticated response detection procedures. The most successful of these were proposed by Dawson (1950 and 1954), whose superimposition and averaging techniques marked the beginnings of a new era in sensory and neurophysiological research, and today are the basis of many non-insultive electrodiagnostic tests used in the assessment of sensory and neurological function.

Averaging techniques, by enhancing the signal to noise ratio make it possible to detect the signal - the auditory evoked potential, from a background of higher amplitude unwanted noise, which in this case is the spontaneous EEG activity. For the effective use of both averaging and superimposition techniques the following conditions must be fulfilled:-

a) A consistent response must be elicited to a stimulus on each or most repetitions of the stimulus,

b) The response must be time-locked to the stimulus, that is, always occur at the same point in time after the stimulus. Thus, by adding together or averaging a large number of responses to a repetitive stimulus, the evoked potential, which is time-locked to the stimulus, will 'grow' in amplitude while the random background activity will be progressively reduced as the number of averages increases. (Figure 1.1.).

At present it is possible to record a large number of consistent and reproducible potentials from various scalp locations in response to auditory stimulation. These potentials not only provide information on the integrity of the auditory system from cochlea to cortex, but also assist in the identification and location of lesions, within the brainstem and in the detection of areas of demyelination involving the brainstem auditory system. Their application in psychology is also considerable, providing insight into the possible neurophysiological substrates for cognitive and perceptual processes.

Auditory evoked potentials may be classified according to several different criteria, i.e. by response latency; by scalp location; by source or nature of the response. The most common method of classification is that of latency and Picton, Hillyard, Krausz and Galambos (1974) propose three main categories:-

1. Early Latency Components - 0 - 8 m.secs.

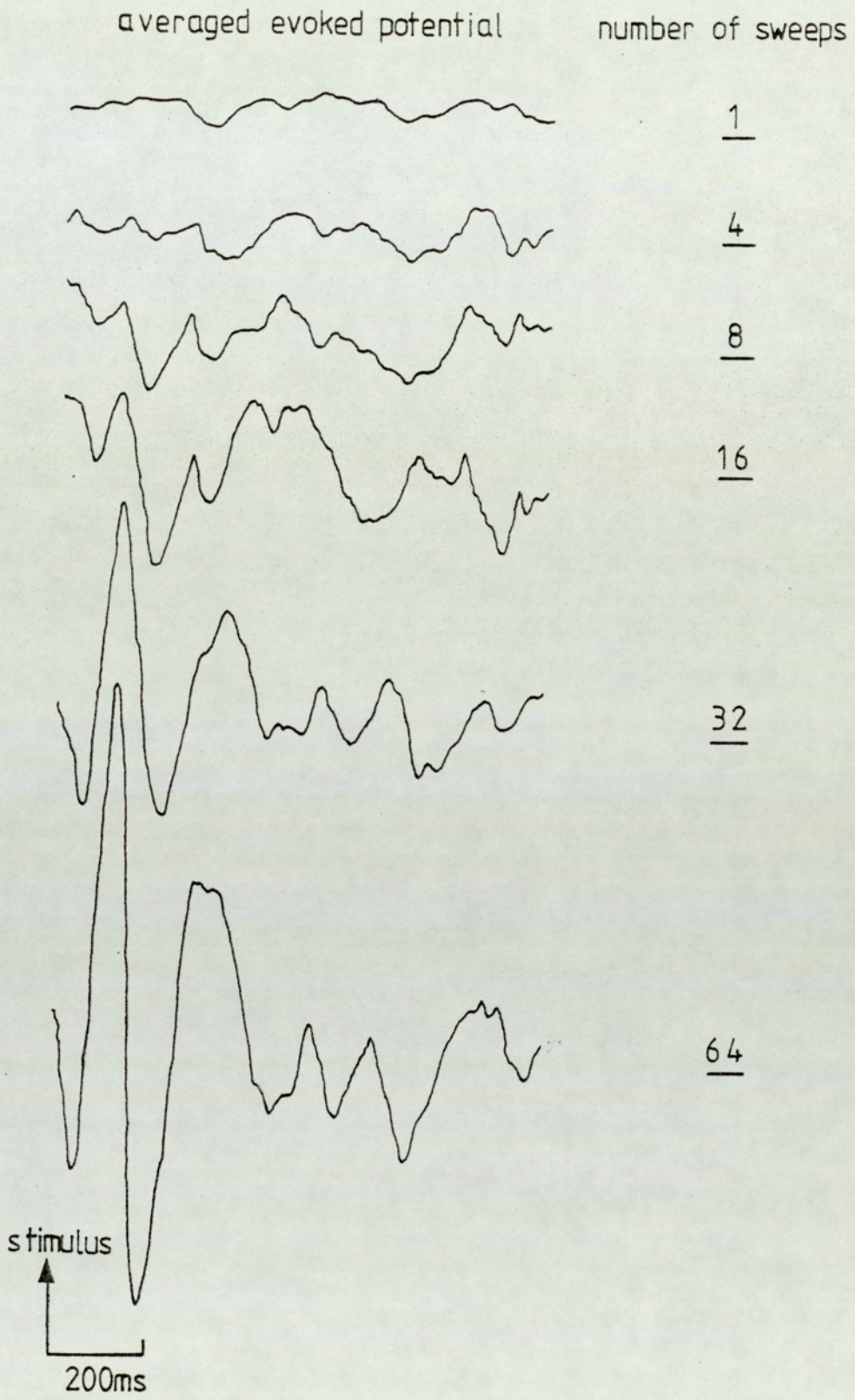


Fig 1.1.

The use of averaging techniques in the recording of the vertex potential.

2. Middle Latency Components - 8 - 40 m.secs.

3. Long Latency Components - 50 m.secs. onwards

(See Table 1.1.)

1.2. Early Components 0 - 8 m.secs.

1.2.1. The Cochlear Microphonic

The cochlear microphonic has no measurable latency and no threshold. It is of non-neural origin and its waveform exactly reproduces that of the stimulus. It is believed to originate from the sensory hair cells of the Organ of Corti within the cochlea and to reflect the receptor or generator potential produced by the mechanical distortion of the hair cells in response to sound stimulation.

1.2.2. The Electrocochleogram

The electrocochleogram measures the response of the auditory nerve to sound stimulation. The active recording electrode is usually a fine stainless steel needle which is passed through the tympanic membrane to rest on the promontory of the cochlea within the middle ear (Portman and Aran, 1971). The advantage of this transtympanic recording technique lies in the proximity of the recording electrode to the auditory nerve producing a very favourable signal:noise ratio. Characteristic changes in the parameters of this response (amplitude, latency and waveform) occurring in pathological conditions of both the cochlea and auditory nerve provide the basis

Table 1.1. CLASSIFICATION OF AUDITORY EVOKED POTENTIALS

RESPONSE	SOURCE	NATURE	TECHNIQUE insultive / non-insultive
Early Components 0-8ms			
Cochlear Microphonic	Hair Cells of Cochlea	Non-neural	Both
Summating Potential	?	?	Insultive
Electrocochleogram	Auditory Nerve	Neural	Insultive
Brainstem Evoked Potentials	Brainstem Auditory Nuclei	Neural	Non-insultive
Frequency Following Response	Inferior Colliculus - ?	Neural	Non-insultive
Middle Components 8-40ms			
Myogenic Responses	Scalp Musculature	Myogenic	Non-insultive
Fast Cortical Responses	Auditory Cortex - ?	Neural	Non-insultive
Late Components 50ms →			
Slow Cortical [Vertex] Response	Auditory Cortex and/or Association Cortex	Neural	Non-insultive
P 300	Association Cortex	Neural	Non-insultive
Contingent Negative Variation	Association Cortex	Neural	Non-insultive

for its clinical application. The disadvantages of this technique are that it requires perforation of the tympanic membrane and also anaesthesia in young children. Both of these factors introduce an element of risk into a procedure which is only diagnostic and in addition the need for the presence of a medically qualified otologist and anesthetist would preclude this technique from routine clinical use.

1.2.3. Brainstem Evoked Potentials

Advances in technology now enable the recording of not only the compound action potential of the auditory nerve, but also of the brainstem evoked potentials. Using vertex and mastoid or earlobe electrode derivations it is possible to record a series of up to seven positive and negative deflections occurring with latencies up to 8 m.secs. which reflect the activation of the auditory nerve and brainstem auditory nuclei (Figure 1.2.). The sources of these potentials have been located in depth recording and lesion studies in animals (Jewett, 1970; Buchwald and Huang, 1975) and by clinical studies on patients with known brainstem lesions, (Sohmer, Feinmesser and Szabo, 1974; Starr and Hamilton, 1976). Although the recording of brainstem evoked potentials are still essentially in early developmental stages they appear to offer great promise in both audiological neurological assessment.

1.2.4. The Frequency Following Response (FFR)

The frequency following response is a relatively new and

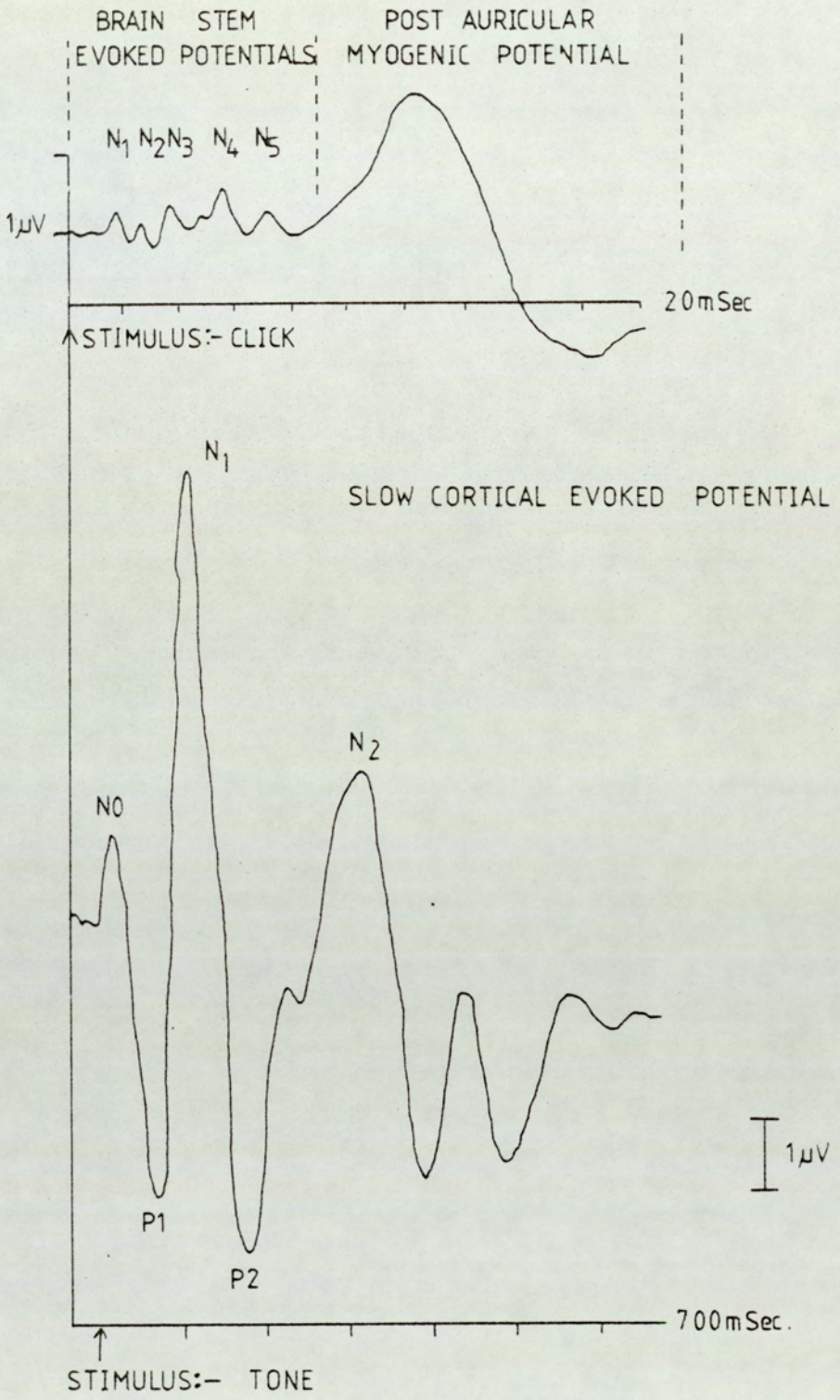


Fig 1.2.

The configuration of the brainstem evoked potentials, the post-auricular myogenic potential and the vertex potential.

poorly investigated phenomena and has as yet to be put to any definite clinical use (Davis and Hirsch, 1976). As with the cochlear microphonic the frequency following response follows the frequency of the incoming stimulus, but there are several important differences between the two:-

1. The FFR is recorded maximally at the vertex whereas the cochlear microphonic is only recordable close to the ear.

2. The cochlear microphonic alone can be abolished by the alteration of stimulus polarity while the FFR still remains with double the frequency of the incoming stimulus, indicating its neural origin.

3. The latency of the FFR of approximately 6 m.secs. suggests its possible source in the inferior colliculus.

1.3. Middle Latency Components

The middle latency components were recorded early in the history of evoked potential research. Their nature and source of origin still remain controversial, although it is generally agreed that they consist of a mixture of both myogenic and neurogenic components.

1.3.1. Myogenic Potentials

The first middle latency components recorded by Geisler,

Frishkopf and Rosenblith (1958) were thought to be of cortical origin on the basis of their reproducibility and comparable latencies with visual and somatosensory evoked potentials. However, these components which showed an unusual scalp distribution, being maximal in the occipital regions and, in addition, were enhanced by increased tension in the muscles of the neck were later shown by Bickford, Jacobson and Cody (1964) to be of myogenic origin and mediated by vestibular rather than cochlear mechanisms.

A more localised muscle response to auditory stimulation was reported by Kiang, Crist and French (1963) arising from a localised area in the post-auricular region. This response was found to be mediated through neural components originating in the cochlea and has been used as a clinical screening test for the evaluation of hearing in infants, (Douek, Gibson and Humphries, 1974). Figure 1.2.

1.3.2. Fast Cortical Components

With the appropriate relaxation of the scalp musculature, Mast (1965) recorded potentials of similar latencies to the myogenic components, but they differed in that they occurred with maximum amplitude at the vertex and were unaffected by changes in muscle tension. The neurogenic origin of these components was supported by Ruhm, Walker and Flanigan (1967) who found similar components recorded from both scalp and subdural electrodes in the region of the vertex. The response consisted of the following

components:-

Po at 13 m.secs., Na at 22 m.secs., Pa at 34 m.secs., and Nb at 44 m.secs. (Figure 1.3.) with an amplitude of 0.5-3uV.

Mendel and Goldstein (1969) suggested that these early components may be arising from the medial geniculate bodies or from the primary auditory projection areas, but this still awaits confirmation from depth electrode studies. The middle latency neurogenic components are used by a relatively small number of investigators (Mendel and Goldstein, 1969) in preference to the slow vertex potential for the clinical assessment of auditory function on the basis of their stability throughout subjective changes in arousal and attention. The majority of investigators however find these potentials relatively difficult to record.

1.4. Long Latency Components

1.4.1. The Slow Cortical or Vertex Potential

This is the largest and most easily recordable of all the stimulus related responses. Originally recorded by Davis in 1939 it shows a fairly wide scalp distribution (Picton et al. 1974) and occurs with maximum amplitude at the vertex. The response can be elicited to a wide variety of stimuli i.e. clicks, pure tones and verbal stimuli, and consists of a series of positive and negative deflections, (Figure 1.2.) which are relatively stable in each individual, but vary

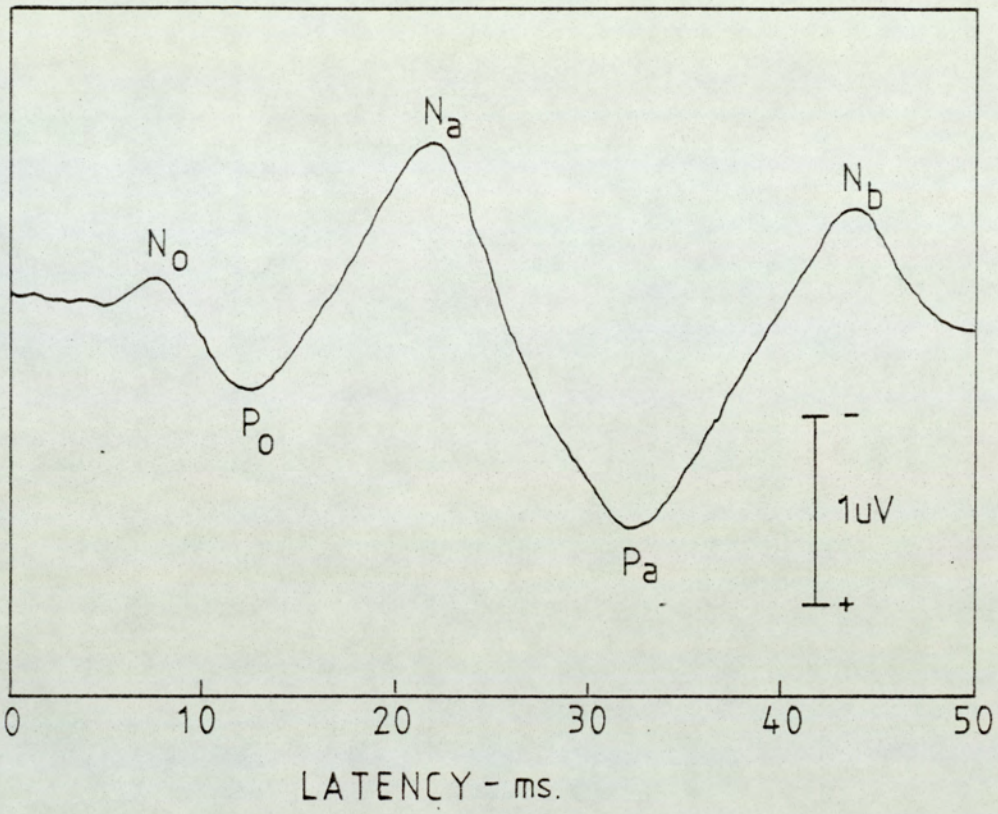


Fig 1.3.
The configuration of the fast cortical evoked potential. [Goldstein and Rodman, 1967]

considerably across individuals. (Table 1.2.).

Component	Latency - m.secs.
P_1	50 - 70
N_1	90 - 125
P_2	155 - 220
N_2	250 - 300

Table 1.2. The chief components of the slow cortical evoked potential recorded from an electrode at the vertex.

The vertex potential is now well established as an objective measure of auditory function and in addition some evidence also exists to support its possible role in the measurement of hemispheric specialisation and cerebral dominance.

1.4.2. The P300 and Contingent Negative Variation (CNV)

The last two potentials in this long latency group are of perhaps greater interest to the psychologist. The P300 and CNV, unlike all the previous event-related potentials, are relatively independant of stimulus parameters and even of stimulus modality, but are dependant almost solely on subjective factors such as selective attention and expectancy.

The P300 is a late positive component occurring in the evoked potential with a latency of approximately 300 m.secs. Its

presence is associated with stimulus information requiring a decision, or the detection of an infrequent stimulus amongst a train of frequent or standard stimuli (Picton and Hillyard, 1974). It can also be elicited by the detection of omitted stimuli amongst a train of frequent stimuli.

The CNV is a negative d.c. shift which occurs between 2 stimuli. When the occurence of the second stimulus is contingent on the occurence of the first, and when the second stimulus requires a motor or perceptual decision.

Thus, both the P300 and CNV are produced in association with stimulus meaning and the processing of stimulus information, and so provide opportunities for the psychologist to study the neurophysiological substrates of cognitive and perceptual processes. When studied together with the earlier evoked potentials they may provide information on the roles of peripheral and central factors operating in attention and habituation.

1.5. The Clinical Application of Evoked Response Audiometry

The intentions of this study are the development and validation of auditory evoked response techniques in both normal and clinical populations and their establishment as a routine clinical investigation within the Health Service.

Although the characteristics of most of the previously mentioned auditory evoked potentials are well established for

normal individuals (and even here there are considerable inter-laboratory differences), it is still not clear how far one can generalise and apply such findings to the field of clinical testing. Here the population is certainly not normal and not necessarily co-operative, and testing conditions cannot be adequately controlled.

The main areas of clinical application of evoked response audiometry (ERA) are in auditory and neurological assessment. As far as audiological problems are concerned, ERA usually deals with a clinical population who are untestable by conventional subjective audiometry. Thus, ERA has the initial disadvantage of a patient population who are untestable by most if not all other means of assessment. It is perhaps important to stress at this point that ERA is not designed as a replacement or alternative to conventional audiometry for not only is the former more time consuming and considerably more expensive, but also when subjective audiometry is possible this is usually more accurate and reliable than the objective assessment provided by ERA.

The patients requiring evoked response audiometry usually fall into the following groups,

A. CHILDREN

1) Infants with suspected hearing defects who are too young to be reliably assessed subjectively.
2) Children with behaviour and communication disorders, e.g. autism, who will not or cannot co-operate with testing.

3) Children with multiple physical and/or mental handicaps.

4) Children with suspected deafness of psychogenic origin.

Since the failure to receive and understand sounds and speech not only results in a failure to produce speech, but also in many cases in intellectual and emotional impairment, it is of great importance to establish the nature and extent of an auditory defect as soon as possible so that maximum use may be made of any residual hearing present in the infant or child, and appropriate treatment and schooling provided.

B. ADULTS

1) Physically and mentally handicapped.

2) Suspected deafness of psychogenic origin.

3) Medico-legal cases involved in compensation cases for industrial deafness where behavioural responses might be determined by financial motives.

The main questions to be answered are of a) how reliable are the different evoked response measures available in the above cases and b) which, if any, is the electrophysiological test of choice?

The use of ERA in the field of neurology requires the careful standardisation of normal response criteria. The development of adequate norms is essential if small changes in

response parameters are to be used in the diagnosis of neurological lesions. The question here is essentially whether the techniques are sufficiently sensitive for such diagnoses to be made reliably. This is especially important in middle and old age groups where neurological problems are more likely to occur. Here also the normal aging factors occur which may also produce changes in evoked response characteristics resulting in a greater variability in normal response characteristics.

The ensuing study is an attempt to provide further information through both normal and clinical studies which may help answer some of the previous problems and questions. Most of the investigations involve the recording of the vertex potential, the post-auricular myogenic potential and the brainstem auditory evoked potentials. Data from these investigations are discussed in the light of previous work. By definition the P300 and CNV require the active co-operation and participation of the subject and thus are not applicable to the population used in this study or the clinical population for which the tests have been designed. It is, of course, possible that the P300 and CNV may be of use in patients who have no pure tone loss, but have difficulty in understanding words.

CHAPTER 2

The Vertex Potential

2.1. Configuration

The slow cortical evoked potential or vertex potential is characterised by a series of positive and negative deflections which occur at relatively fixed latencies after the onset of the stimulus. This response may be elicited by a wide variety of auditory stimuli; to click stimulation and to the onset of pure tone, verbal or white noise stimulation. It is generally recorded from an electrode placed at the vertex and referred to mastoid, earlobe or post-temporal derivations.

Davis and Zerlin (1966) describe the vertex potential as a response to change in sensory input. It may be elicited to the onset or cessation of a stimulus, or to an abrupt change in stimulus intensity or frequency.

Cody et al. (1964) found that the vertex potential, occurring with response latencies of 40-250 m.secs. could be easily differentiated from the earlier latency myogenic responses of 10-30 m.secs. latency which were previously reported by Geisler et al. (1958) and maximum in the region of the inion. The neural origin of the vertex potential was suggested by the scalp distribution with a maximum at the vertex; by its relative stability with changes in muscle tension and by the similarity to the non-specific K complex which occurs during light sleep either spontaneously or in response

to external stimuli. The study of patients with inner ear lesions of either cochlear or vestibular origin indicated that the vertex potential was of cochlear origin while the earlier inion response was of vestibular origin.

The usual nomenclature of the vertex potential denotes the polarity of each component at the active recording electrode (usually the vertex). This is followed by a numerical subscript to denote the order of occurence of both positive and negative components (see Figure 2.1.). The labelling of each component with the latency of occurence, although obviously preferable in terms of the information it supplies, often leads to confusion on account of the variability in latency with changes in stimulus and subjective parameters.

The most consistent components of the vertex potential to both click and tone stimuli are the N_1 component at 90-115 m.secs. and the P_2 component at 170-200 m.secs. occurring with peak-peak amplitude of 8-20uVs. at moderate intensity levels (Rapin, Tourk, Krasnegor, Schimmel, 1964; Rapin, Schimmel, Tourk, Krasnegor, Pollak, 1966). The P_1 component at 40-70 m.secs. is inconsistent and the N_2 component is poorly delivered and of variable latency (Figure 2.1.).

Davis and Zerlin and Davis et al. (1966) reported similar major response components with P_1 at 50-60 m.secs., N_1 at 90-105 m.secs., P_2 at 170-200 m.secs. and N_2 at approximately 300 m.secs. all occurring with maximum amplitude

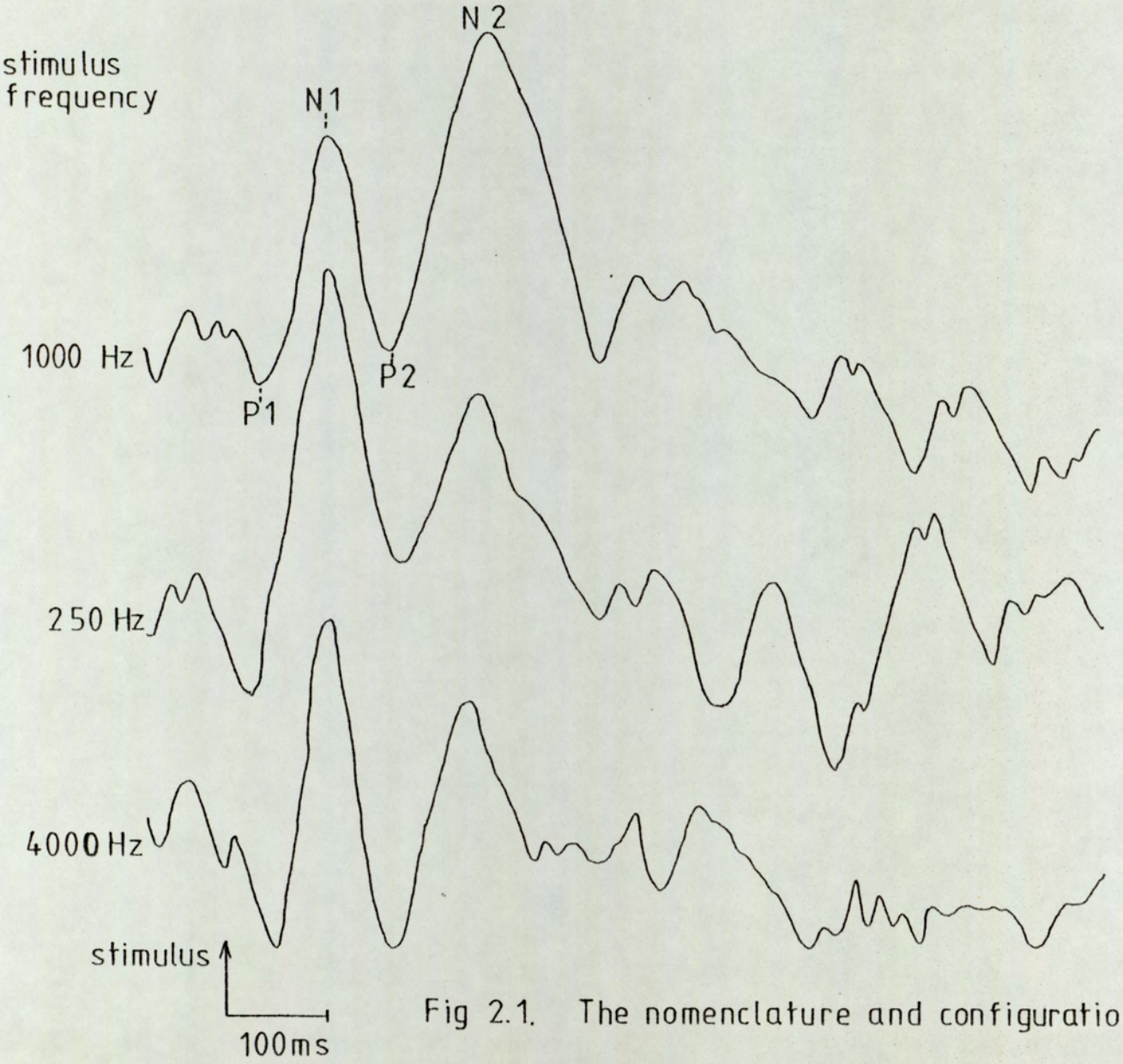


Fig 2.1. The nomenclature and configuration of the vertex potential.

at the vertex. All authors stress the extreme variability of this response in terms of latency and amplitude of the individual components and of the overall response configuration. This variability occurs within and between subjects, and across trials and laboratories. Price, Rosenblut, Goldstein and Shepherd (1966) report the presence of up to 8 individual components in a study of 160 subjects. The most frequently occurring component was P_2 (160 m.secs.) which was present on 90% of occasions, followed by N_1 with an 80% occurence, N_2 with a 65% occurence and P_2 with a 40% occurence. The peak to peak amplitude of N_1 - P_2 was found to vary between 0.5 - 28.0uV.

Variations in response amplitude can arise not only from the choice of response components but also from the method of amplitude measurement. The amplitude of each individual component may be measured to a calculated baseline level (peak-baseline) or may be measured between successive peaks (peak-peak). The former method is superior as it reflects the amplitude variation of each individual component whereas peak-peak measurement may obscure such individual variation. Difficulties often arise in peak-baseline amplitude measurement in the establishment of true or stable baseline values and peak-peak measures are generally used for their convenience and reproducibility. A summary of both amplitude and latency variations of the vertex potential is presented in Table 2.1.

Aunon and Cantor (1977) compared the variability of the

AUTHOR		LATENCY-MS				AMPLITUDE-uV		
		P1	N1	P2	N2	P1-N1	N1-P2	P2-N2
Cody and Townsend	1973	20-105	60-155				2-23	
Rapin et al.	1964		90-155	170-200			8-20	
Davis et al.	1966	50-60	95-100	170-200	300			
Price et al.	1966		85	160	260	5.01±2.69	8.85±4.02	8.04±3.90
Davis	1976	50	90	170	250		10	
Vaughan and Ritter	1970	16-60	100	200				
Beagley & Kellogg	1970	40-60	100	150-200	200-300			
Streletz et al.	1977	45-65	70-100	140-189	240-300			
Picton et al.	1974	50	83	161	290		N1 9.3	P2 10.7
Simson et al.	1977	5 ±15	122±14	213±21	284±21		N1 8.1±3.1	P2 7.5±3.0

TABLE 2.1

The Amplitude and Latency Characteristics of the Vertex Potential Recorded in Response to Click or Tone Stimuli of 50 - 85 dB.

vertex potential response of one subject obtained in 5 different laboratories with the variation in response from that same subject recorded on 8 consecutive weekly sessions in the same laboratory. They found that the standard deviation for inter-laboratory was twice as great as the intra-laboratory variation (Table 2.2.). This would indicate a fairly large contribution to response variability by equipment differences and this emphasises the importance of the establishment of normal control data for each individual laboratory.

2.2. The Nature of the Vertex Potential

The fairly universal assumption that sensory evoked potential are produced by an extra neurological event which is added to or superimposed upon the spontaneous background EEG activity has recently been questioned by Sayers and Beagley (1974) and Sayers, Beagley and Henshall (1974). The authors believe that if the vertex potential is the result of an extra neural event then comparison of the amplitude or power of pre and post stimulus EEG samples should reflect an increase in the post-stimulus sample. Since Fourrier analysis of such pre and post stimulus EEG activity revealed no significant difference in the average power (amplitude) of the frequency components of either recording, they concluded that the evoked potential was produced by the re-organisation of the phase relationships of the pre-existing frequency components of the spontaneous EEG and not by an extra neural event. To further this hypothesis

INTERLABORATORY VARIATION

LAB.	N1	P1	N2	P2	N3	P3
Latency (ms)						
CH	60	73	112	170	281	356
VA	30	49	92	150	242	328
ERF	38	62	96	164	266	343
Amplitude (ms)						
CH	-	2	14	28	28	16
VA	-	2	8	16	22	20
ERF	-	4	6	19	22	14
Mean Latency						
$\overline{X}$ CH VA ERF	43	63	100	161	263	342
$\overline{X}$ CH (one a week X 8 weeks).	41	62	100	159	261	333

(n = 1) (Aunon and Cantor, 1977).

TABLE 2.2.

Variation in Latency and Amplitude of the Components of the Vertex Potential Measured in 3 different Laboratories (CH, VA and ERF) on Two Consecutive Days.

they investigated the amplitude and phase spectra of post-stimulus EEG samples to high and low intensity stimuli. The phase values of the frequency components following low intensity stimuli were randomly distributed over repeated trials while those to high intensity stimuli were highly correlated over-trials; indicating the imposition of a phase constraint on the spontaneous background EEG activity.

However, their first assumption that the addition of an extra neural event to the spontaneous EEG would result in an increase in amplitude or power of the post-stimulus EEG is questionable and would depend on the relationship of the evoked potential to the phase of the background activity (see Figure 2.2.).

Thus, the addition of the evoked potential to the spontaneous EEG may result in an increase, decrease or no change in post-stimulus EEG amplitude. Conversely, the imposition of a phase constraint on the background EEG activity may also lead to a change in the power of the post-stimulus EEG. An example of this may be seen in the change in spontaneous EEG on eye closure. This state of visual inattention usually induces a clear alpha rhythm in the region of the occipital cortex. This alpha rhythm is believed to reflect the inphase alpha activity of large numbers of synchronised neurons. The disappearance of the alpha rhythm with attention marks the desynchronisation of this alpha activity. The presence of an observable

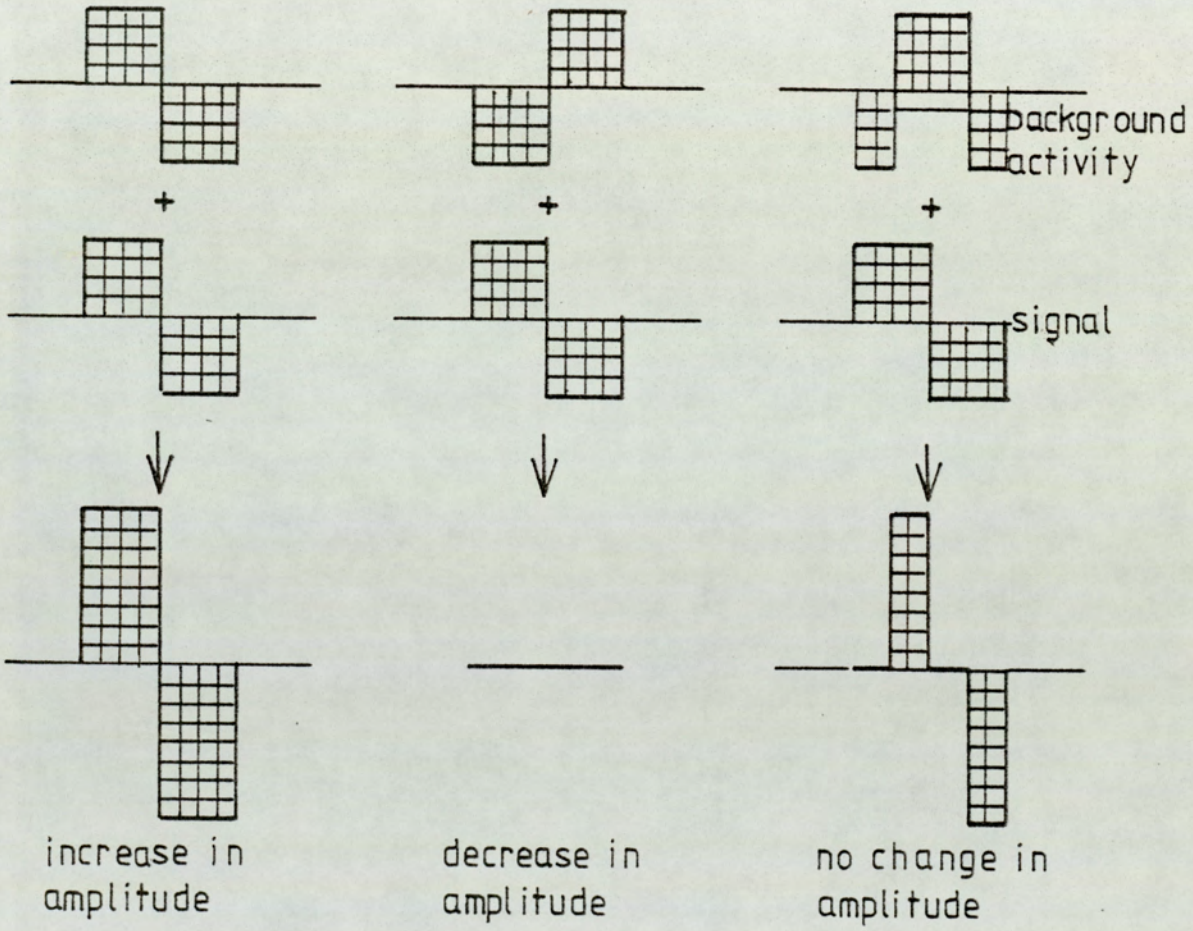


Fig 2.2.

The effects of different phase relationships between the evoked potential and the background EEG on the amplitude of post stimulus EEG activity.

alpha rhythm is accompanied by an increase in the power or amplitude of the EEG.

Davis (1976a) has also suggested a similar mechanism for the generation of the vertex potential which may result from the synchronisation of certain components of the evoked potential, conclusive proof has still to be provided and the validity of the averaging principles for evoked potential detection remains unaffected.

2.3. The Physiological Significance of the Vertex Potential

In 1966, Davis et al described the vertex potential as "a so-called secondary response of unknown physiological significance and mediated by unknown central pathways". The advances in this field of evoked potential research over the ensuing 10 years is adequately summarised in a second quote by Davis in 1976a where he says of the vertex potential "their interpretation in terms of neuronal activity or physiological significance is very obscure".

Although extensive research has been carried out on both animal and human subjects using scalp and direct cortical recording techniques, it has provided very little evidence for the source or sources of the vertex potential.

There are essentially two methods used to study the source of the vertex potential:-

1) It is possible to make certain inferences regarding the localisation of generator sources from the distribution and localisation of scalp recorded evoked potentials.

11) From the study of evoked potentials recorded from electrodes directly on or within the cortex itself. Such studies have been mainly carried out on animals with inferences to man. However, a few studies have been carried out in man, in patients undergoing neuro-surgery for the treatment of epilepsy or psychosis.

2.3.1. Topographical Studies

The dangers of inferring the source or generators of an evoked potential from its topographical distribution were emphasised by Goff, Matsumiya, Allison and Goff (1977). An amplitude maximum in the scalp recorded evoked potential will only correctly predict location of the source of a potential if the source consists of a dipole generator which lies parallel to the surface of the overlying scalp. Thus, in view of the orientation of the primary auditory cortical areas with respect to the overlying scalp, difficulties will arise in prediction of the possible source of the vertex potential from a given scalp distribution. The observation of an amplitude maximum of the vertex potential in the region of the vertex may be accounted for by either a dipole source parallel to and underlying in the scalp at the vertex or by a dipole layer along the

auditory cortex which would be perpendicular to the overlying scalp in the temporal regions. In both cases amplitude maxima would be recorded in the region of the vertex.

Several extensive topographical studies have been carried out on the vertex potential. Vaughan and Ritter (1970) observed a vertex maximum which they suggested would be consistent with a dipole source for the vertex potential originating in the primary auditory cortex (Figure 2.3.). The perpendicular orientation of this dipole source to the scalp in this area would result in an amplitude maximum at the vertex and minimum over the Sylvian Fissure. The most interesting observation to arise from Vaughan's topographical studies was the polarity inversion of the vertex potential components N_1 (100 m.secs.) and P_2 (200 m.secs.) in both mid-saggital and coronal electrode chains at the levelof the Sylvian Fissure (Figure 2.4.). Monopolar recordings were made using a nasal reference electrode. The P300 component produced a more posterior scalp distribution with no polarity inversion at the Sylvian Fissure.

The difference in properties of the P_2 and P300 components led Vaughan to propose two separate generators. The distribution and polarity inversion of the N_1 and P_2 components at the level of the Sylvian Fissure would be consistent with a dipole layer parallel to the auditory cortex and perpendicular to the overlying skull. The distribution of the P300 would be consistent with a dipole source

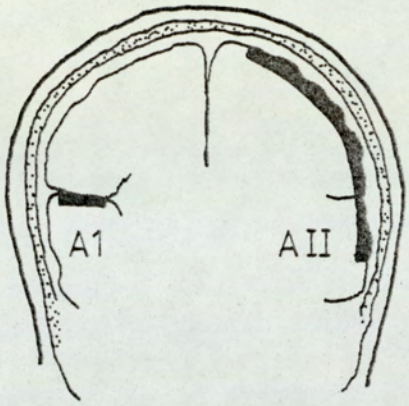


Fig 2.3.

The proposed locations of dipole generators of
a) the vertex potential - A I
b) the P300 - A II

[Vaughan & Ritter, 1970]

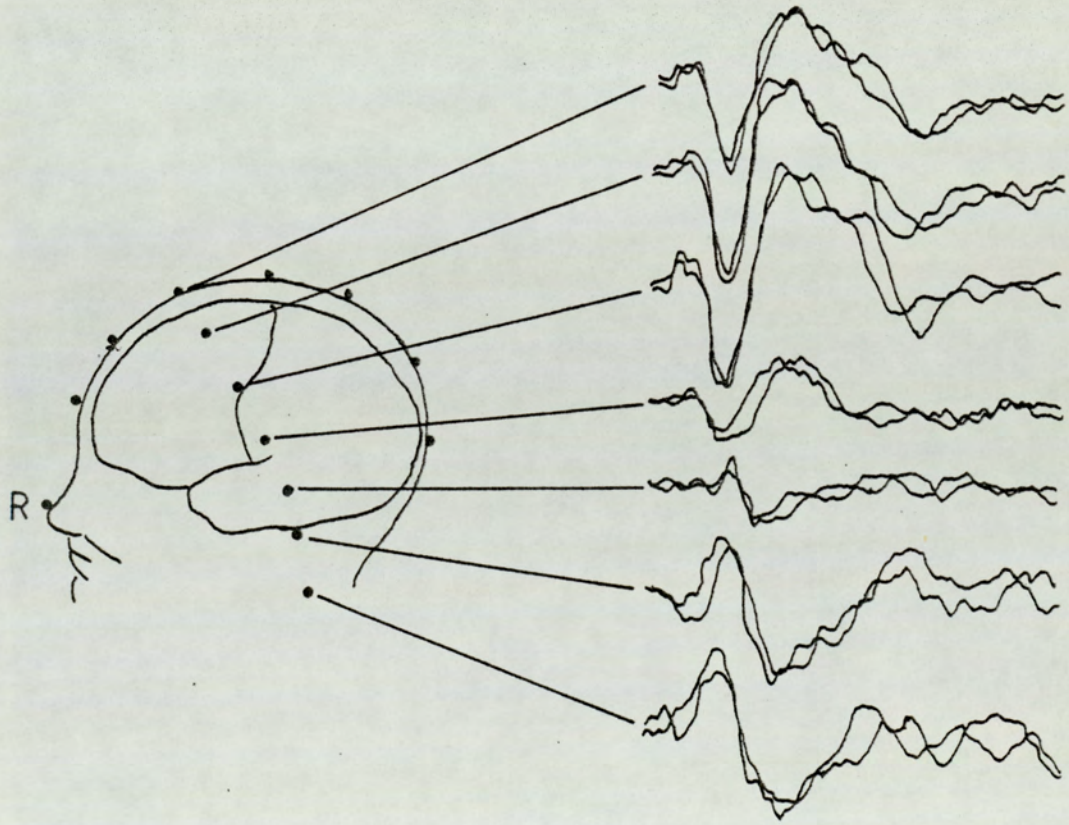


Fig 2.4.

Distribution of scalp recorded vertex potentials demonstrating the polarity inversion of all components in the region of the Sylvian Fissure.

[Vaughan & Ritter, 1970]

parallel to the surface of the temporo-parietal areas (Figure 2.3.). Vaughan concludes that the N_1 and P_2 components of the vertex potential are generated within or near the primary auditory cortex.

Although findings of a voltage maximum at the vertex could be consistent with a generator within the auditory cortex, the additional observation of a polarity inversion over the Sylvian Fissure may be otherwise explained. Problems continually arise in evoked potential studies in the choice of an appropriate site for the reference electrode which ideally should be electrically silent in terms of the particular signal being investigated. The phase inversion observed by Vaughan over the Sylvian Fissure may also be explained by an active reference electrode on the nose. Thus, at the level of the Sylvian Fissure, the reference electrode on the nose (G11) becomes equi-potential (with the reference to the vertex potential) to the active G1 electrode in the Sylvian region. Below the level of the Sylvian Fissure the nose electrode becomes more active (with reference to the vertex potential) than the G1 electrode and so produces a polarity or phase inversion. If this is so, then Vaughan's findings merely indicated that electrodes on the nose and in the region of the Sylvian Fissure are equi-potential with respect to the signal (which is maximal) at the vertex.

Supporting evidence was presented by Kooi, Tipton and Marshall (1971). Using a noncephalic joint sterno-vertebrar reference electrode they found no polarity inversion of

N_1 or P_2 components in either coronal or mid-saggital planes. A voltage maximum was observed in the region of Fz and Cz and clear activity was also recorded from a nasal electrode which in some cases was as much as 50% of maximum vertex amplitude. Picton et al. (1974) and Streletz, Katz, Hohenberger and Cracco (1977) failed to detect polarity reversals over the Sylvian Fissure and Streletz et al. also reported vertex potential activity in both nasal and mastoid regions. Polarity inversions of the vertex potential were reported by Simson, Vaughan and Ritter (1977) but again with the use of a nasal reference.

The observations of phase or polarity reversal of evoked potential activity have been used successfully in clinical electroencephalography in the localisation of cortical epileptogenic focii and space occupying lesions and also in visual evoked potential studies in the detection of visual field loss (Harding,1974). Also the use of a bipolar horseshoe electrode linkage from T4-T6; T6-O2; O2-O; O1-T5; T5-T3 in visual evoked potential studies has provided evidence through polarity inversions of distortion and abnormal localisation of the visual cortex which were verified by CATscan. However, because of the position of the auditory cortex and the unknown source of the vertex potential such bipolar recording techniques are not really applicable to localisation studies of the vertex potential.

Picton et al. (1974) and Streletz et al. (1977) carried

out topographical mapping studies of the vertex potential using noncephalic reference sites. Picton reported a maximum for N_1 (83 m.secs.) and P_2 (161 m.secs.) over frontal and central derivations (Figure 2.5.). Streletz also included P_1 (45-65 m.secs.) and N_2 (240-300 m.secs.) components in his analysis and these also provided amplitude maxima at or slightly anterior to the vertex. Picton concluded that in view of its relatively large amplitude the vertex potential was of cortical rather than subcortical origin and suggested that it reflected a composite of late waves arising from the primary auditory cortex together with waves from various association areas. Alternatively, Streletz suggests an origin in central association cortex.

Goff et al. (1977) attempted to deduce the myogenic or neurogenic origin of 22 scalp recorded auditory potentials from their cortical distribution, location and variability. The components with a clear vertex maximum were P_1 (50 m.secs.), N_1 (115 m.secs.), and P_2 (180 m.secs.).

Thus, topographical studies, although in complete agreement over the scalp voltage distribution of the vertex potential, unfortunately do not provide an answer to the generator/s or source/s of this potential. Although observations of a polarity inversion over the Sylvian Fissure cannot be taken as positive evidence of a source in the primary auditory cortex, neither can they preclude such a possibility.

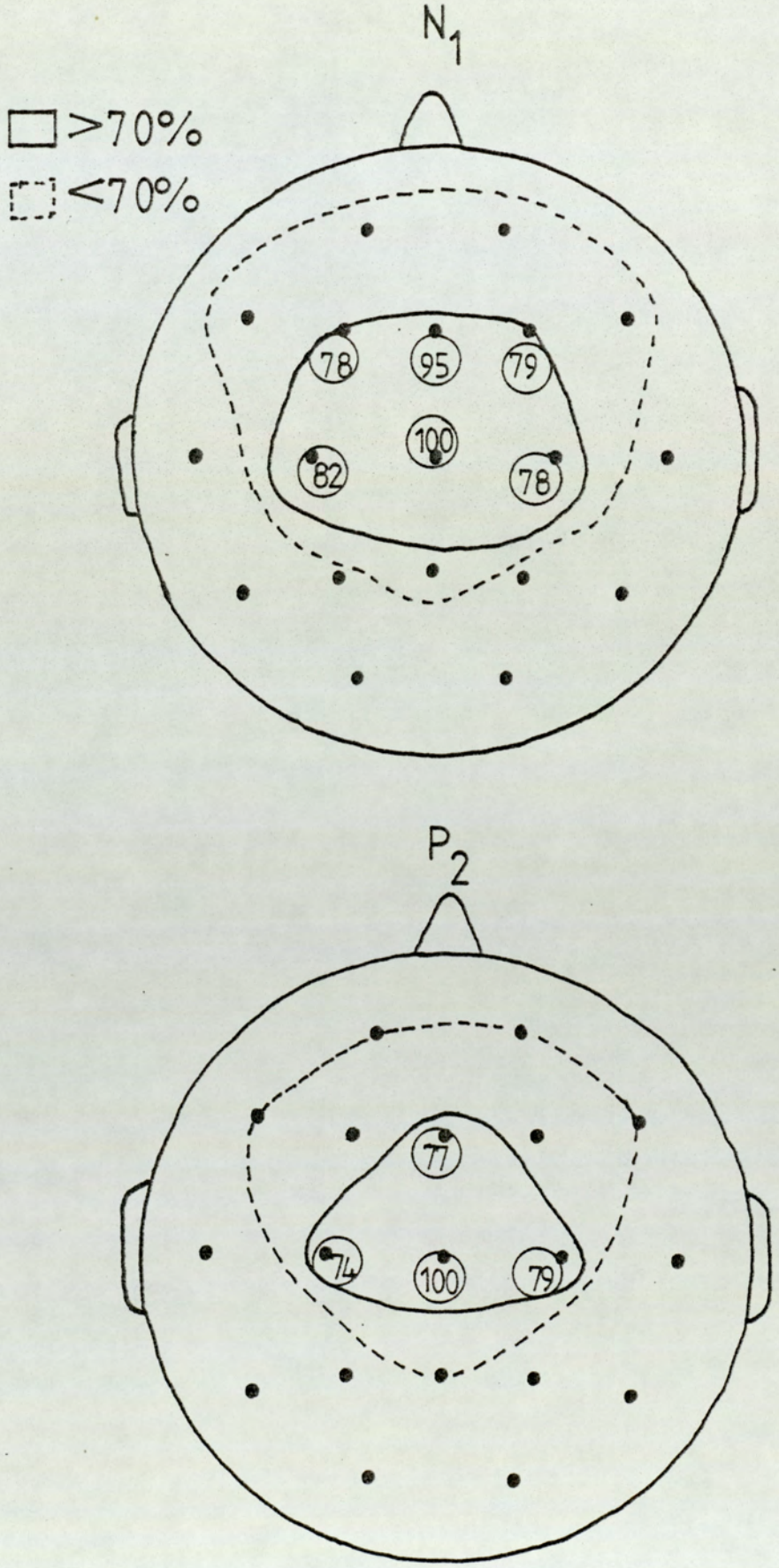


Fig 2. 5.
Mean distribution of the N_1 and P_2 components of the vertex potential for 10 subjects plotted as % maximum amplitude. [Picton et al. 1974]

2.3.2. Cortical Studies

i) Animal

A comprehensive review of animal research in this area was presented by Keidel (1976). Auditory responses were recorded from areas A1 and A11 in the cat (Keidel and Wigand, 1958 unpublished). The response from A1 occurred with an onset latency of 7 m.secs. and consisted of a positive at 10-11 m.secs. (500uV.amplitude), and a negative component at 19 m.secs. (350uV.). The responses from A11 were slightly later and of smaller amplitude with a negative at 11-12 m.secs. (60uV.), a positive at 15 m.secs. (170uV.) and a negative at 25 m.secs. (175uV.). All later responses were suppressed by anaesthesia. This depression of later waves by anaesthesia was also noted by Teas and Kiang (1964). Figure 2.6. shows the response of area A1 in the cat in both the awake state and under Nembutal anaesthesia. In the awake state the early responses recorded by K eidel were followed by a later positive component at 30 m.secs., a large negative at 66 m.secs. and a positive at 100 m.secs. Such components may possibly be analogues to the P_1 and N_1 and P_2 components of the scalp recorded vertex potential. They also show similar characteristics to the vertex potential in their modification by anaesthesia, while the early cortical components as with the early scalp recorded components (Mendel and Goldstein, 1969) are unaffected.

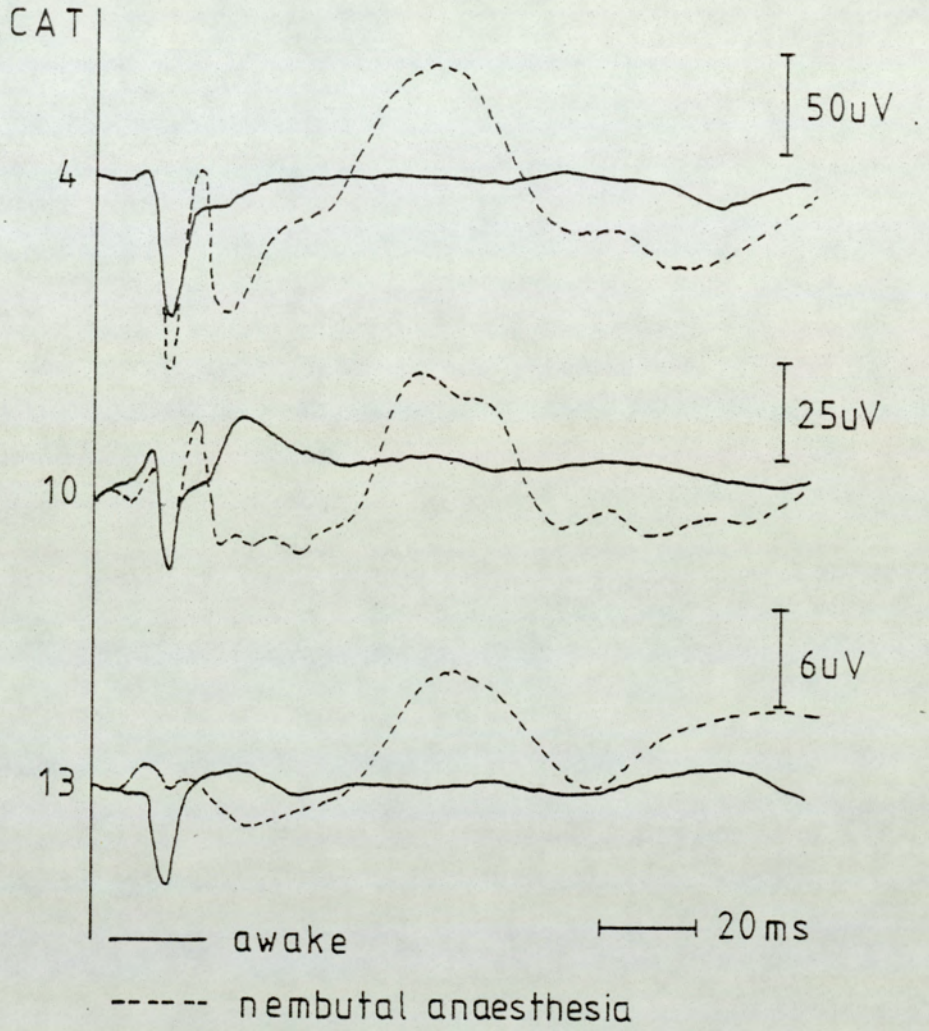


Fig 2.6.
The effect of nembutal anaesthesia on the electrocorticogram recorded in three cats.
[Teas and Kiang,1964]

Keidel also cites the work of colleagues David, Finkezeller and Spreng (1966) who studied evoked potentials recorded from the primary visual and auditory projection areas and surrounding cortical areas in the cat using supradural electrodes. The early responses were recorded in fairly small areas of primary auditory cortex and mapping studies indicated that the late components also originated in the specific primary projection areas for all sensory modalities with the exception of pain which provided more general cortical activation. They found no evidence of activity in the preferential cortex.

Recordings from the scalp and cortical surface in response to auditory stimuli were compared in unanaesthetised monkeys (Hardin and Castelluci, 1970). The response from scalp vertex to nose recordings consisted of:-

P1 at 19	m.secs. $\pm$ 3 m.secs.	(10-50uV.)
N1 at 29	m.secs.	
P2 at 55	m.secs. $\pm$ 8 m.secs.	(50-150uV.)
N2 at 94	m.secs. $\pm$ 12m.secs.	(50-150uV.)
P3 at 152	m.secs. $\pm$ 24 m.secs.	(10-40 uV.)

The response from the cortical surface was well developed in both the superior temporal gyrus near the auditory cortex and over anterior and frontal cortical areas, but the response of P_1 in the temporal region was 69 m.secs. earlier than that recorded from the vertex.

The response consisted of:-

P1 at 11 - 14 m.secs.
N1 at 16 - 30 m.secs.
P2 at 36 -115 m.secs.
N2 at 92 -140 m.secs.
P3 at 158 -160 m.secs.
N3 at 200 -270 m.secs.

From these studies it certainly appears possible to detect components from scalp vertex recordings which are of comparable latencies to the late components arising from primary auditory cortical areas. However, it has yet to be conclusively proved that the vertex potential represents a scalp recording of these components or whether they contribute to some degree or not at all.

ii) Man

Auditory evoked potentials were recorded from depth electrodes in 5 patients undergoing surgical treatments for psychosis by Chatrian, Petersen and Lazarte (1960). The exact placement of the recording electrodes differed in each patients, but all were in the region of the insular cortex. Responses to single and repetitive clicks in the conscious patients consisted of an early negative at 8-24 m.secs. of 30uV. amplitude. This was followed by a consistent positive component which varied in latency from patient to patient from 10-50 m.secs. with an

amplitude of 40-50uV. A negative component occurred at 65-130 m.secs. (60-85uV.) and a late positive at 90-175 m.secs. of 50uV. amplitude. The relatively large latency variation of the individual components may in part arise from the different placements of the recording electrodes.

Their responses were recorded from larger cortical areas than would be expected from activation of the primary auditory cortex alone. This, together with the relatively long latencies of some of the components and their excepta-bility to anaesthesia led Chatrian to suspect the involve-ment of secondary auditory areas in the generation of their responses.

More extensive mapping studies of the auditory evoked potential recorded from the exposed lateral cortical surface were carried out by Celesia et al. (1968) in 7 patients undergoing surgery for the treatment of focal epilepsy. These potentials were then compared to previously recorded scalp evoked potentials in the same subjects. Consistent auditory evoked potentials were recorded from the exposed cortex in each patient in the conscious state, but there was considerable variability in response characteristics across subjects. Positive components were observed at 26-28 m.secs., 35-40 m.secs., 38-42 m.secs. and 78-102 m.secs. in the different patients. This first positive was followed by a series of even more variable negative and positive deflections:-

N - 42 - 70 m.secs.

P - 75 -125 m.secs.

N - 100 -215 m.secs.

P - 300 -325 m.secs.

N - 350 -400 m.secs.

At least 28 electrode locations were studied in each patient. The early positive component was restricted to a small area of the lateral cortical surface in the region of the posterior 2/3rds of the first temporal gyrus (Figure 2.7.), while the later components were detected in practically all regions studied. The scalp auditory evoked potentials were less well defined than the direct cortical response and were reduced in amplitude by a factor of 10. (Figure 2.8.). The early positive component of the cortical recording was not detectable in the scalp recording, but the late cortical and scalp components were of comparable latencies. There were also several early components present in the scalp recording which were not seen in the cortical recording, these may have been of myogenic origin.

The relatively long latency of the first positive component of the cortical recording led Celesia to suggest its origin in secondary auditory areas in the region of Heschls Gyri and its subsequent spread to adjacent cortical areas by volume conduction.

Thus, although direct cortical recordings of evoked potentials both in animals and man have, as yet, failed to produce definitive evidence of the source of the scalp

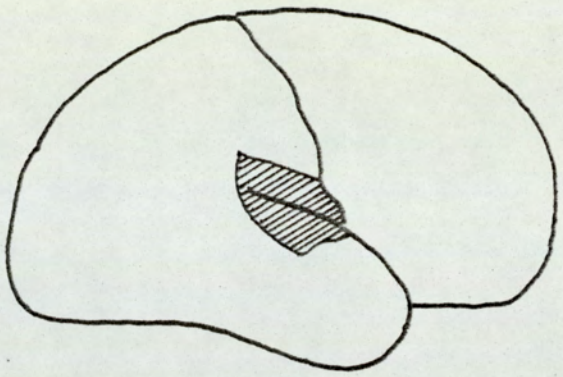


Fig 2. 7.

Cortex of man showing areas in hatching from which averaged responses to clicks were obtained.

[Celesia, 1968] et al.

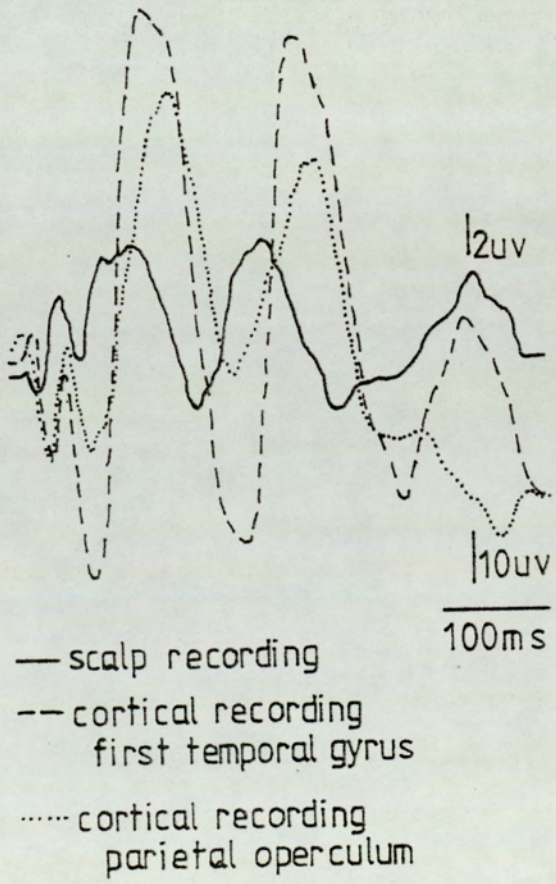


Fig 2. 8.

Comparison of auditory responses obtained from the scalp and from the cortex. (Note the 2uV calibration for scalp responses and 10uV calibration for cortical responses.

[Celesia, 1968] et al.

recorded vertex potential, they have made valuable contributions towards a possible solution. On the basis of their latencies, it seems unlikely that the potentials recorded either directly from the cortex or from the scalp reflect the primary response of the auditory cortex. However, the similarities between later cortical components arising from the auditory cortical areas and the scalp recorded vertex potential would suggest some positive relationship between the two. The observations have necessitated a revision of the original theories which favoured the complete non-specificity of the vertex potential arising from activation of the frontal association cortex (— Walter, 1964).

Today Davis (1973)b describes the vertex potential as a composite of many generators, including late waves from the primary auditory cortex together with parallel late waves from secondary and association areas. These result in a series of independantly varying components. Such a theory would help account for not only the inter and intra-subject variation in the vertex potential, but also for the differential effects of subjective and stimulus parameters on the individual components of the vertex potential. Vaughan concluded that the N_1 and P_2 components of the vertex potential are generated within or near the primary auditory cortex.

CHAPTER 3

The Effects of Stimulus Parameters and Subjective Parameters on the Vertex Potential

The variability of the vertex potential is a well known phenomenon. Davis et al. (1968) even goes as far as to say that variability is the most outstanding characteristic of the vertex potential. Some of the major contributing factors to this variability may be grouped together under the heading of stimulus and subjective parameters.

3.1. Stimulus Parameters

The physical parameters of the stimulus itself and also its method of presentation are known to exert considerable control over the characteristics of the vertex potential. Differences in these parameters, no doubt, account for a large part of the interlaboratory differences in the vertex potential.

The effects of stimulus parameters on the latencies and amplitudes of the components of the vertex potential will be reviewed in this Chapter while the implications and applications of such studies will be discussed in greater detail in Chapters 4 and 5 in relation to the use of the vertex potential in the objective assessment of hearing and to its clinical application.

Since the vertex potential is a multi-component response

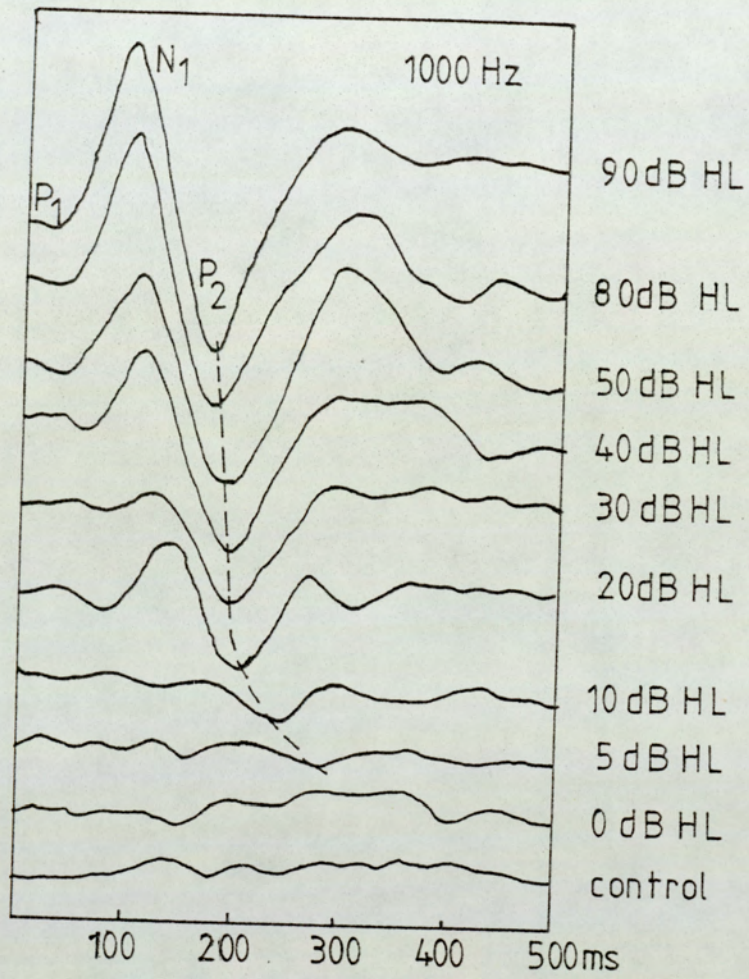
whose source is, too a large extent, unknown, problems often arise in the choice of components to be studied. The situation is further complicated if the vertex potential is considered as a composite of many generators, in which case it is quite possible for each component to vary independantly with changes in stimulus parameters. However, our choice of components to study is somewhat limited; the stability and consistency of the N_1 and P_2 components making them an obvious choice. The method of amplitude measurement has been previously discussed in Chapter 1.

3.1.1. Stimulus Intensity

i) The Effects on Vertex Potential Amplitude

It is well established that stimulus intensity produces clear and characteristic effects of the amplitude of the vertex potential, when decreasing stimulus intensity is accompanied by a progressive reduction in the amplitude of the vertex potential (Figure 3.1.).

The overall response morphology to both click and tone stimuli is similar (Rapin et al. 1964), but the exact relationship between stimulus intensity and response amplitude appears to differ for both. Rapin et al. (1966) found a 40% increase in response amplitude for both click and tone stimuli over intensity ranges of 10-50dBSL. The growth in response amplitude with increasing stimulus intensity was regular for tone stimuli, but not so for



[Madsen Electronics 1974]

Fig. 3.1.

The effects of stimulus intensity on the Vertex Potential.

click stimuli where the vertex responses to high and low intensity stimuli could not be reliably distinguished on the basis of amplitude. Although Davis et al. (1966) found larger amplitude responses to higher intensity stimuli, he could find no consistent relationship between the two for both tone and click stimuli. Over an intensity range of 0 to 70dBSL, Beagley and Knight (1967) found a general increase in N_1-P_2 amplitude with increasing stimulus intensity, but at higher intensities saturation, or in some cases a decrease in amplitude, was observed.

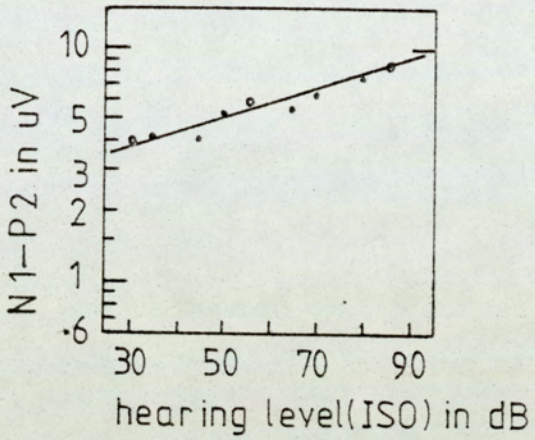
Amplitude saturation at higher stimulus intensities has been generally observed and Khechinashvili and Kevanishvili and Kajai (1973) found that the intensity level at which saturation occurred was lower in cases of unilateral deafness than in normally hearing individuals. In the later group, monaural stimulation resulted in a higher saturation point on account of bone conduction to the non-stimulation ear - a phenomenon which could not occur in the case of unilateral hearing loss. The authors attributed the occurence of amplitude saturation at high stimulus intensities to post-synaptic inhibition within the auditory system and discounted the peripheral involvement of middle ear muscle contraction. This would be expected to be more marked with low frequency stimulation whereas the vertex potential shows greater saturation at higher frequencies.

More recently attempts have been made to elucidate a more precise relationship between the amplitude of the vertex

response and stimulus intensity. Initially, it was hoped that the amplitude characteristics of the vertex potential would provide electrophysiological support for Stevens' Psychophysiological Power Law which relates estimates of the magnitude of sensation to stimulus intensity by a power function. Such evidence would be indicated by the production of a straight line relationship when the log of response amplitude was plotted against stimulus intensity. The data obtained by Keidel and Spreng (1965); Nelson and Lassman (1973) and Davis and Zerlin (1966) provide support for such a power function.

Davis and Zerlin (1966) reported a power relationship between the amplitude of N_1-P_2 components and stimulus intensity over a range of 20-100dB, but they stressed the widespread scatter and variation in the exponent of this power function with different individuals (Figure 3.2.). The exponent was approximately half that obtained by Stevens for subjective loudness judgements.

Although the data of Keidel and Spreng (1965) and Nelson and Lassman (1973) support this power relationship, they demonstrate that the exact value of the exponent relating vertex potential amplitude to stimulus intensity is dependant on factors such as inter-stimulus interval and stimulus frequency. Shorter inter-stimulus intervals and increasing stimulus frequency both result in a decrease in the steepness of the exponent.



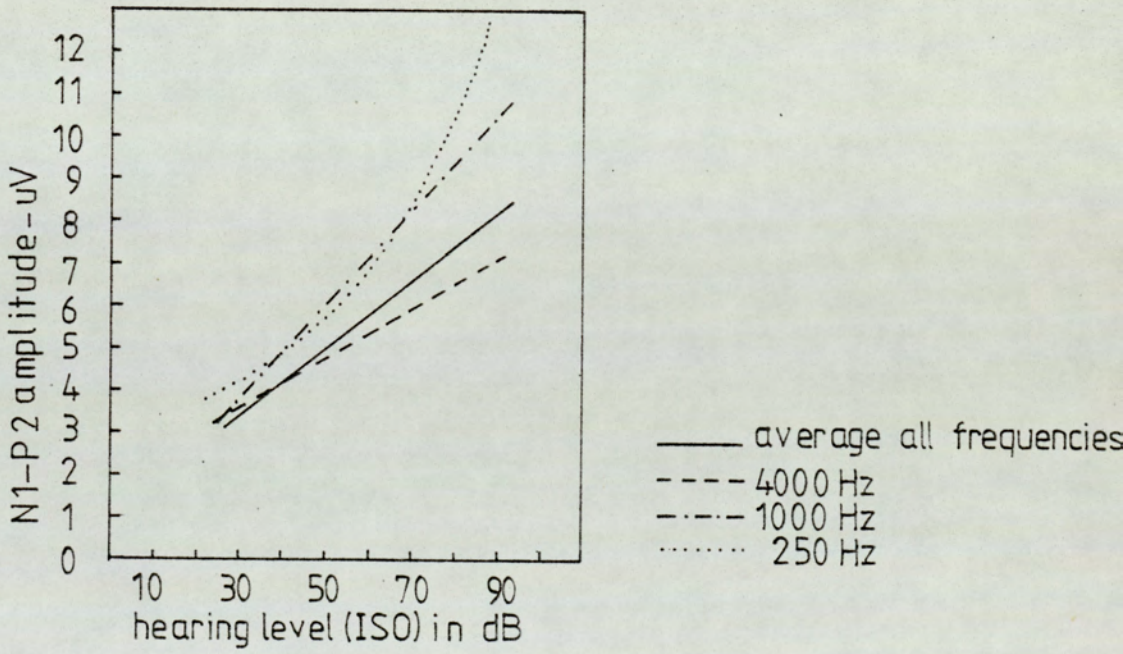


Fig. 3. 2.

Relationship between response amplitude and stimulus intensity expressed as power and linear functions. [Davis et al.1968]

Thus, although evidence exists for a power relationship between stimulus intensity and response amplitude, the exact nature of this relationship can be influenced by several factors including choice of response component, the stimulus frequency and inter-stimulus interval.

Many authors do not agree that the relationship between response amplitude and stimulus intensity is most accurately reflected in a power function. A large number of investigators remain undecided while others find the relationship is best fitted by a linear function when response amplitude is plotted against stimulus intensity. The exponent of this linear relationship (actually to linear-log plot) is also reported to vary with stimulus frequency (Antinoro, Skinner and Jones, 1969) and with placement of active recording electrode (Muller and Stange 1971).

On the basis of their own data, Davis et al. (1968) find it difficult to support either a power or linear function. The wide variation between individuals in the rate of growth of the vertex potential amplitude with stimulus intensity would allow their results to fit log or linear relationships equally well. Perhaps the situation is best summed up by Davis who describes a complex relationship between response amplitude and stimulus intensity which is characterised by a steep initial rise in amplitude at low intensities from 5-20dBSL, followed by a slower increase to double its size over 20-50dBSL. At higher intensities, the response can increase, decrease or remain

constant in amplitude. The rate of amplitude growth is too slow and inter-individual variability too great to enable the formulation of an exact relationship between response amplitude and stimulus intensity in the form of either a power or linear function.

ii) The Effects on Vertex Potential Latency

Differences in both absolute latency values and also in latency changes with intensity have been reported in responses to click and tone stimuli. A click response consisting of P_1 at 60 m.secs., N_1 at 110 m.secs. and P_2 at 190 m.secs. was reported by Davis et al. (1966) and found to be independant of stimulus intensity. Rapin et al. (1966) confirmed these findings and also found the latency of the click response to be 10-15 ms.ecs. shorter than the response to tones at high intensities. In addition, the response to tones only showed a progressive lengthening in the latencies of the response components as the stimulus intensity was reduced (Figure 3.3.). Rapin explained this latency difference in the response to tones and clicks by the occurence of tonal recognition in the case of tone stimuli. The time taken for the detection of the tonal quality of the stimulus is of the order of 10-15 m.secs. which is comparable with the latency difference for tone and click responses. She suggests that the mechanism generating the vertex potential is initiated following tonal recognition and that the actual processing time for both click and tone stimuli is the same. The progressive increase in latency

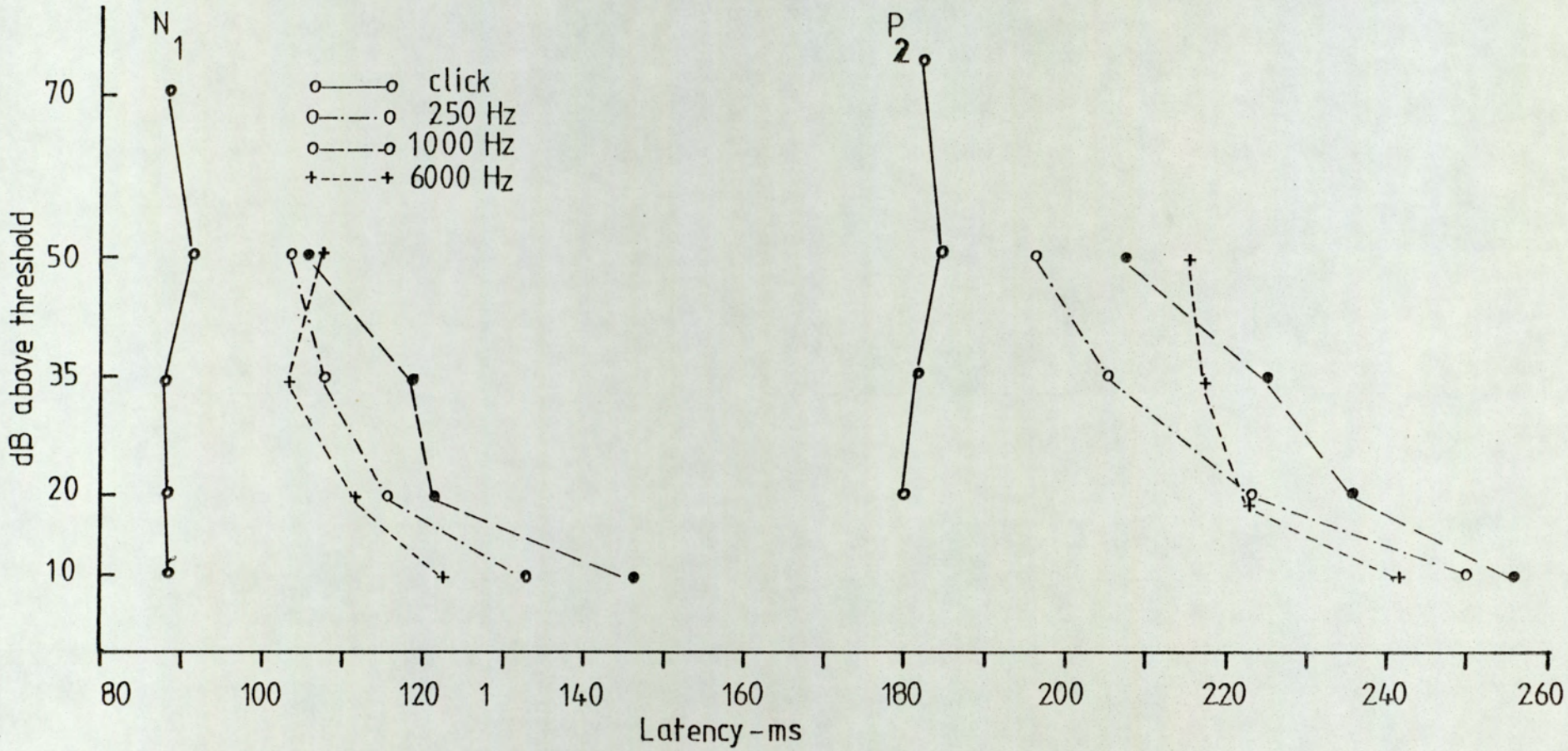


Fig. 3.3.
The effects of stimulus intensity on the latency of the vertex potential.
[Rapin et al, 1966]

of the response to tonal stimuli with decreasing intensity is accounted for by temporal integration.

It is also possible that the different physical characteristics of the click and tone stimuli, such as rise time, may account for differences in response latency.

The increase in response latency with decreasing stimulus intensity is a common phenomenon of most neural responses and in part reflects the longer time taken for generator potentials within the sensory hair cells of the cochlea to reach their critical level to fire the nerve impulse and also the poor synchronisation in the firing of nerve impulses.

The increase in response latency with decreasing intensity of tone stimuli are most marked close to subjective threshold levels (Davis et al. (1966). Beagley and Knight (1967) report a shift of N_1 latency from 116 m.secs. at 50-70dB to 192 m.secs. at threshold and Rapin et al. (1964 and 1966) report latency increases of 25-60 m.secs. when the stimulus intensity is decreased from 50dB to threshold.

3.1.2. Stimulus Rise Time and Duration

i) Effects on Vertex Response Amplitude

Rise Time

The rise time of the stimulus is defined at the time taken

for the stimulus to reach maximum amplitude. In general, shorter rise times have been found to produce larger amplitude vertex potentials for a given stimulus intensity (Rapin et al. 1966; Skinner and Jones, 1968 and Skinner and Antinoro 1970). Such observations may reflect the greater synchronisation in the firing of neural responses to abrupt stimuli resulting in larger amplitude responses.

Onishi and Davis (1968) investigated various combinations of stimulus rise time and duration and found that, with longer durations, rise times of up to 50 m.secs. had no significant effect on stimulus amplitude, but with shorter stimulus durations of 30 m.secs., the rise time should be equal to or less than 30 m.secs. With rise times longer than 30 m.secs. decreases in response amplitude were observed.

Duration

Using a constant rise time of 5 m.secs., Davis and Zerlin (1966) found no change in response amplitude of N_1-P_2 components over stimulus durations of 2-320 m.secs. They did, however, observe a slight amplitude maximum with stimulus durations around 20 m.secs. This was explained by maximal interaction of vertex on and off responses at this particular stimulus duration. Similar findings were reported by Skinner and Jones (1968) with stimulus durations of 25-30 m.secs.

The inter-active effects of rise time and duration were

investigated by Onishi and Davis (1968). They found that provided the rise time was 30 m.secs. the response amplitude was independant of stimulus duration, for durations of 0-300 m.secs., but with shorter rise times of 3 m.secs. the response amplitude progressively decreased when duration was decreased from 30 to 10, to 3 and to 0 m.secs. They concluded that the first 30 m.secs. of stimulus presentation were of greatest importance and that during this time the amplitudes of the N_1-P_2 components were determined.

The occurence of temporal integration is a well known psychological phenomenon which occurs at near threshold intensities. It was defined by Zwislocki (1960) as a decrease in threshold level with increasing stimulus length for durations up to 200 m.secs. For example, with a stimulus tone of 1000Hz, a 10 times increase in stimulus duration would result in a 10dB reduction in subjective threshold. A number of studies have looked for evidence of temporal integration in evoked potential amplitude studies. Davis and Zerlin (1966) were unable to detect any increase in response amplitude with increases in perceived loudness for tone durations up to 150 m.secs. Similarly, Skinner and Jones (1968) found no consistent trends in response amplitude with increasing response duration at intensity levels of 10-15dBSL. However, it is doubtful if evidence of temporal integration, even if present, could be reliably detected at threshold intensity levels as the poor signal: noise ratio and increase response variability may effectively obscure any evidence of temporal integration. The possible

effects of temporal integration on vertex response amplitude may be avoided by using tones of greater than 200 m.secs. duration.

ii) Effects on Vertex Potential Latency

Rise Time

Onishi and Davis (1968) reported an increase in response latency with increases in rise time, and the N_1 component with a latency of 120 m.secs. with a stimulus of 3 m.secs. rise time was delayed to 170 m.secs. with a 300 m.secs. rise time. However, providing the rise time was 30 m.secs. or less they found that the response latency was not significantly affected. Similar findings were reported by Skinner and Jones (1968).

Duration

As with response amplitude, response latency was independant of durations from 0-300 m.secs. provided the rise time was 30 m.secs. With shorter rise times the latencies were prolonged with short duration stimuli (Onishi and Davis 1968). Skinner and Antinoro (1970), however, found no change in response latency with a short rise time of 10us and stimulus durations of 10-1500 m.secs.

3.1.3. Interstimulus Interval (ISI) or Recovery Period

i) Effects on Vertex Potential Amplitude

Variation in I.S.I. was found to produce a marked effect on response amplitude by Davis et al. (1966). An I.S.I. of at least 10 seconds was required for maximum recovery of response amplitude, while shorter I.S.I's of 3 seconds, 1 second and 0.5 seconds reduced the response amplitude to 50%, 25% and 12.5% of its maximum respectively. The use of shorter I.S.I.'s resulted in distortion of the response on account of superimposition.

A marked interaction between I.S.I. and stimulus intensity was observed by Davis et al. (1968); Nelson and Lassman, (1973) and Keidel and Spreng (1965). Davis et al. (1968) noted a greater effect of I.S.I. at higher stimulus intensities and Nelson and Lassman (1973) found that response amplitude was linearly related to the log of the I.S.I. The slope of this function varied with stimulus intensity. The steeper slopes at high stimulus intensities indicating the positive interaction between intensity and I.S.I. (Figure 3.4.). Thus,

a) stimulus intensity has greater effects on response amplitude at longer I.S.I's and

b) recovery period has greater effects on response amplitude at higher stimulus intensities.

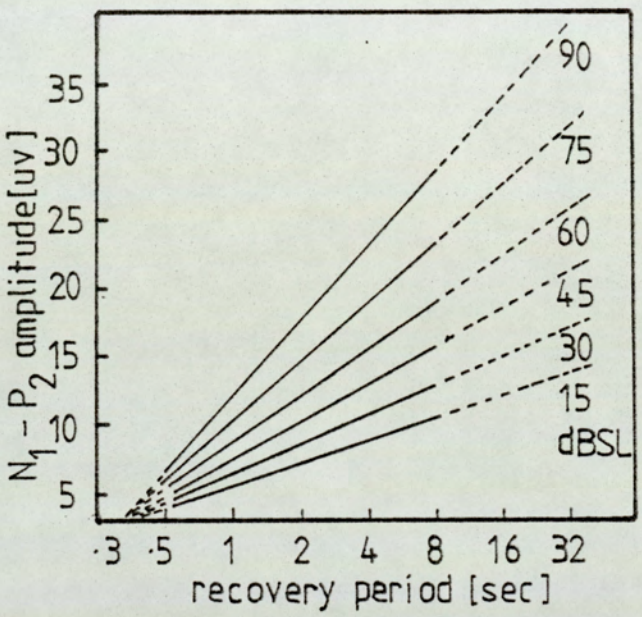


Fig. 3. 4.

The interaction of interstimulus interval and stimulus intensity on the amplitude of the vertex potential. [Nelson and Lassman, 1973]

Response amplitude has also been reported to vary with the periodicity of stimulation. Regular and irregular stimulus presentation rates (with the same overall rate maintenance) were investigated by Rothman, Davis and Hay (1970), but only a very slight increase in amplitude was observed with irregular presentation rates.

ii) Effects on Vertex Potential Latency

The I.S.I. has been found to have very little effect on the latency of the vertex potential components, except at very short I.S.I's of less than 0.5 seconds, (Davis et al. 1966) when the response is confounded by superimposition onto the previous response components.

3.1.4. Stimulus Frequency

i) Effects on Vertex Potential Amplitude

The effects of stimulus frequency on the amplitude of the vertex potential are controversial. (Davis and Zerlin,(1966) and Rapin et al. (1966) report no consistent difference in response amplitude or in intensity functions with changes in stimulus frequency, although Davis found the response to higher frequency stimuli to be more variable. Antinoro and Skinner (1970), however, present clear evidence of a decrease in the absolute amplitude of the response with increasing stimulus frequency. This amplitude reduction was present when intensity was expressed both in terms of

dBSL and in terms of equal loudness or phon level. Over the frequency range of 250-8000Hz the response amplitude was decreased by 70% in terms of dBSL and by 50% in terms of phon level. Linear intensity functions were observed at all stimulus frequencies (Antinoro et al. 1969), but the slope of the intensity function varied considerably with the stimulus frequency, being steepest at 250Hz to become practically constant at 8000Hz (Figure 3.5.). These findings were confirmed by Davis et al. (1968), but their intensity function was concave upwards at 250Hz and linear at 1000 and 4000Hz. However, Davis, together with Khechinashvili et al. (1973) and Rothman (1970) stress the variability of these findings across subjects. The latter two authors finding that the variability in the exponent of the intensity functions across subjects was greater than across stimulus frequencies and also that the response amplitude reduction with higher stimulus frequencies more marked at higher intensity levels indicating earlier saturation.

The overall reduction in vertex response amplitude with increasing stimulus frequency may reflect the displacement of a smaller portion of the basilar membrane in the cochlea to high frequency stimulation and the subsequent activation of a smaller population of neurons.

ii) Effects of Vertex Response Latency

No effects of stimulus frequency on vertex response latency

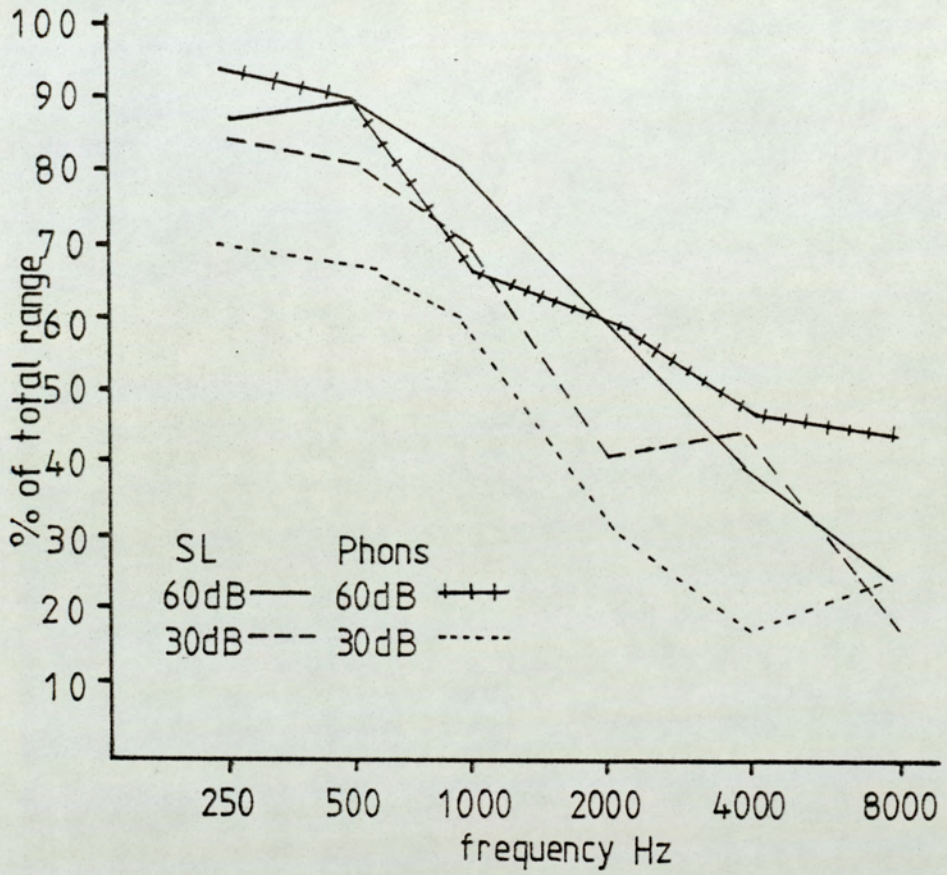


Fig. 3.5.

The effects of frequency on the amplitude of the vertex potential. [Antinoro and Skinner, 1968]

were observed by Davis and Zerlin (1966) and Antinoro and Skinner (1968).

Subjective Parameters

Subjective parameters may be further divided into physiological and psychological factors.

3.2. Physiological Parameters

Both waking and sleeping spontaneous EEG activity show marked changes in early childhood and especially during the first year of life. Such changes are believed to parallel post-natal maturational changes taking place within the central nervous system. In a similar way, the study of sensory evoked potentials during the first few years of life may provide valuable evidence of normal maturational processes taking place within the different sensory systems.

Examination of the current literature rapidly reveals the difficulties in separating the effects of sleep and maturational changes on the vertex potential in infants and young children, as most investigations involving these age groups are either by necessity or choice carried out during the sleeping state.

Since the majority of clinical investigations which use the vertex potential in auditory assessment are carried

out on young children, it is important to provide answers to the following questions:-

a) What are the effects of sleep and sleep stages on the normal characteristics of the vertex potential?

b) To what extent are maturational and aging processes reflected in the vertex potential?

3.2.1. The Effects of Sleep and Sleep Stage on the Adult Vertex Potential

Sleep may be divided into a number of clearly defined stages which are characterised by specific EEG, EMG and EOG activity (Rechtscaffen and Kales, 1968). Stage 0 or W - corresponds to the waking state, showing predominantly alpha activity at 8-13 c.p.s. This stage is accompanied by eye movements and blinks and relatively high muscle tone.

Stage 1 - the alpha rhythm is replaced by low amplitude activity of mixed frequencies and an increasing amount of theta activity at 4-7 c.p.s. Muscle activity begins to relax as seen by a decrease in EMG activity and slow rolling eye movements are seen.

Stage 2 - shows highly characteristic EEG activity in the form of sleep spindles or bursts of rhythmic 12-14c.p.s.activity

of K complexes and vertex sharp waves.

Stages 3 and 4 - are characterised by high amplitude slow activity in the delta range of 0.5 - 3 c.p.s. at an amplitude equal to or greater than 75uV. When this activity occupies greater than 20%, but less than 50% of the record, it is said to be stage 3, and when greater than 50% it is stage 4.

Throughout stage 2, 3 and 4, EMG activity is relatively high and EOG activity is quiescent. Stages 1 to 4 of sleep are collectively known as Non-REM or orthodox sleep and stages 3 and 4 alone are known as slow wave sleep. Stage REM - is characterised by an activated EEG of low amplitude faster activity, similar to that seen in stage 1. It is accompanied by periodic eye movements and greatly decreased EMG activity. REM is also known as paradoxical sleep.

Considerable changes are observed in the vertex potential not only in sleep but also within the individual sleep stages. The major components of the vertex potential recorded in Non-REM sleep by Weitzman and Kremen (1965) were:-

P_1 - 50 m.secs.
N_1 -100 m.secs.
P_2 -175 m.secs.
N_2 -325 m.secs.
P_3 -800 m.secs.

The chief difference in the sleeping and waking vertex potential lies in the late N_2 and P_3 components which are rarely seen in the waking adult response and occur almost exclusively in Non-REM sleep stages 2, 3 and 4. During these stages of sleep the amplitudes of the N_2 and P_3 components are very large and may reflect summed K-complexes (Figure 3.6.). The latencies of these components show a progressive lengthening through sleep stages 2, 3 and 4. The amplitudes of the N_2 and P_3 components are significantly reduced during REM sleep when the response configuration is comparable to that obtained in the waking state.

Ornitz, Ritvo, Carr, Panman and Walker (1967) obtained similar response components during sleep, but were unable to confirm the amplitude reduction of the N_2 component obscured during REM sleep by Weitzman. He attributed this to the greater inter-individual variation in response amplitudes occurring during REM sleep in comparison with other stages. He separated REM sleep further into tonic (reduced EMG activity) and phasic (eye movement bursts) stages, and comparing the vertex potentials obtained in these two stages found the amplitude to be selectively reduced during phasic REM sleep only. Thus, individual variations in the relative amounts of phasic and tonic REM during the acquisition of the vertex potential would account for the increased inter and intra subject variability in response amplitude during REM sleep. Significantly shorter response latencies were found in REM as compared to stage 2 sleep.

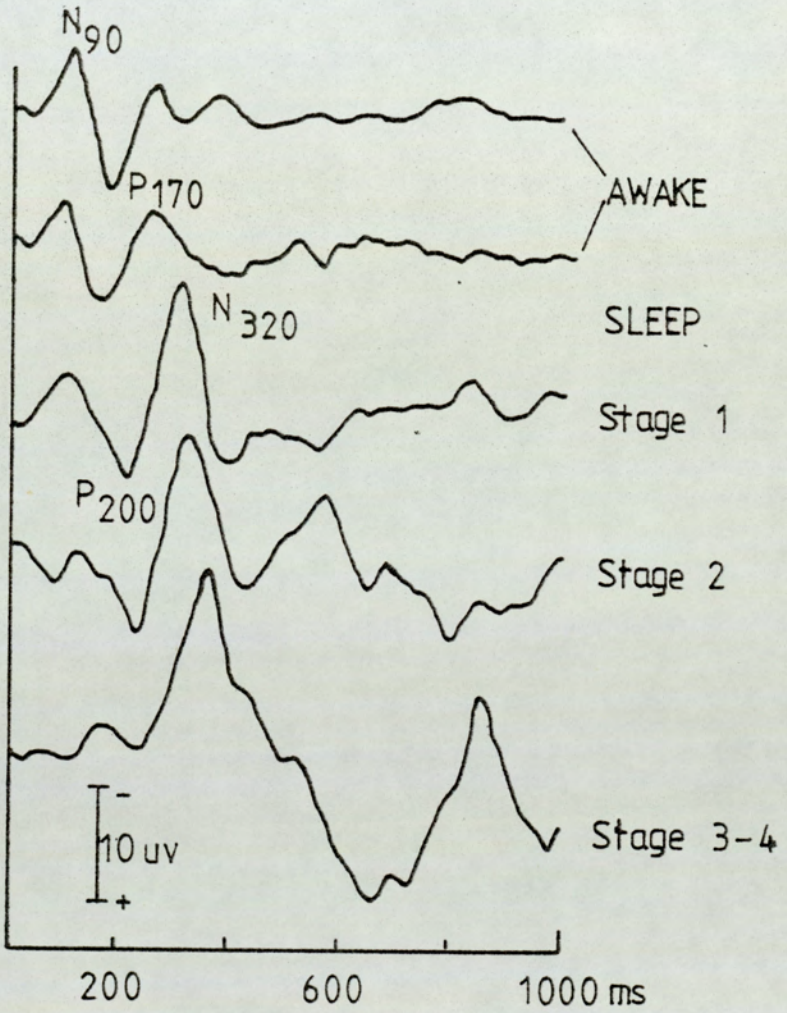


Fig. 3.6.
The effect of sleep on the vertex potential.
[Osterhammel et al, 1973]

Similar findings of increasing response amplitude and lengthening of latency of the P_2 (200 m.secs.) and N_2 (320 m.secs) were observed in stages 3 and 4 of sleep by Osterhammel, Davis, Wier and Hirsch (1973) and Mendel, Hosick, Windman, Davis, Hirsch and Dinges (1975) who in addition reported the presence of later positive and negative components with latencies of 500 - 800 m.secs. in deep sleep.

The effects of intensity on the sleep response were investigated by Buchsbaum, Gillin and Pfefferbaum (1975). He confirmed the increase in response amplitude in stages 3 and 4 which was significant for the later components only; P200 m.secs., P300 m.secs. and N500 m.secs. He also found that the amplitude-intensity functions of these components were steeper in stages 2, 3 and 4 sleep than in REM. This observation suggested that amplitude reduction during REM sleep was mediated by central mechanisms, for although the contraction of middle ear muscles, known to occur during phasic REM activity, would account for such amplitude reduction it does not easily explain the difference in the amplitude-intensity function during this stage. The central role of this mechanism is supported by observations that brainstem auditory evoked potentials and early cortical evoked potentials are stable throughout sleep.

An increase in response amplitude in sleep stages 3 and 4 was not observed by Anch (1977) and largest amplitudes

were reported in the awake state with sleep stages 2, 3 and 4 showing intermediate amplitudes and REM the smallest amplitudes. He interpreted these findings as indicative of underlying inhibitory processes during sleep. However, these differences appear to arise completely from his choice of response components. Amplitude measurements were made on early P_1 and N_1 components which do not change appreciably during sleep and often become undetectable in slow wave sleep because of their relatively small amplitude.

Other factors related to sleep cycle, in addition to sleep stage, have been found to influence the vertex potential. Ornitz, Ritvo, Carr, Lafranchi and Walker (1967) discovered that sleep onset itself produced a considerable enhancement of the N2 component of the vertex potential irrespective of sleep stage. The maximum amplitude of N_2 was observed within 10 minutes of sleep onset, in a sleep stage of drowsiness, or in stages 1 or 2 of sleep. The amplitude enhancement was greater than subsequent amplitude changes with sleep stage throughout the night. Ornitz suggested independant mechanisms for both phenomena and related the N_2 amplitude enhancement at sleep onset to the time of fantasy and hypnagogic imagery.

Finally, evidence of a 24 hour basic rest activity (BRAC) cycle in vertex potential characteristics was presented by Tanguay, Ornitz, Forsythe, Lee and Hartman (1973).

Regular increases and decreases in response latency and amplitude were noted during REM sleep as a function of time rather than sleep stage. The period of this cycle was determined by age. A 50-130 minute BRAC was observed in an infant, a 40-60 minute cycle in a 3 month old child, and an 85-100 minute cycle in an adult. The adult was also studied throughout the day when regular changes in vertex potential amplitude and latency were observed with the same periodicity throughout the day.

To summarise, the most marked changes in the vertex potential occur during stages 3 and 4 of sleep and to a lesser extent in stage 2. The response is characterised by greater amplitudes of the P_2, N_2 and P_3 components and the appearance of N_2 and P_3 in Non-REM sleep. In REM sleep response amplitude is reduced and comparable to the waking response. Further analysis reveals that the reduction in response amplitude during REM sleep is confined to the phasic stages or periods of occular activity.

3.2.2. The Effects of Maturation and Sleep Stage on the Vertex Potential in Children

Maturation of the vertex potential is reflected in a number of its characteristics; in changes in response amplitude and latency; in the number of components present; in the configuration and also the variability and stability of the components.

The observation of maturational changes in the vertex

potential may be somewhat confounded by concomitant changes in background EEG activity with increasing age.

The development and emergence of the adult EEG patterns and the greatest changes in amplitude and frequency of the background EEG occur in the early months and years of life. Thus, the resultant evoked potential is not only representative of the state of maturation of the sensory systems, but also may reflect the ongoing maturational changes in the neural substrates generating the spontaneous EEG. The changes in EEG activity with age may indirectly influence the vertex potential by altering the signal:noise ratio. Increases in the amplitude of background EEG activity would result in a decrease in the signal:noise ratio and thus decrease the reliability of response detection.

The sleep of neonates does not show the characteristic stages of 1, 2, 3 and 4 and REM seen in the adult and child, but is classified into two basic stages of quiet and active sleep. Quiet sleep is characterised behaviourally by the absence of body and eye movements and in terms of EEG by alternating bursts of high amplitude and lower amplitude EEG activity known as Trace Alternant. This stage is believed to be analogous to the Non-REM sleep of the adult. Active sleep is characterised by rapid eye movements, bodily movements, and irregular respiration, while the EEG shows continuous background activity. This stage is comparable to REM sleep in the adult.

In all studies on neonates clear auditory evoked potentials have been obtained (Akiyama, Schulte, Schultz and Parmalee, 1969; Barnet and Goodwin, 1965; Engel and Milstein, 1971 and Ellingson, et al. 1974).

Barnet and Goodwin (1965) detected seven components in 18 neonates of 2, 3 and 4 days old. Of these components (Table 3.1.) the most stable was a P_2 component at 267 m.secs. and the amplitudes of P_1-N_2 components and P_2-N_3 components were 2.5 and 19uV. respectively.

The vertex responses of 11 neonates during the first week of life were compared with a group of 6 premature infants of 32-37 weeks conceptual age by Akiyama et al. (1969). The responses obtained from the neonates showed a greater degree of complexity (5 components) and stability in the presence of components when compared with the responses in the premature infants. Responses in the full-term infants were compared in quiet and active sleep stages. The differences in response latencies between quiet and active sleep were not significantly different, but there was a tendancy for shorter latencies to occur in active sleep. Amplitude differences were observed in the responses of full-term infants between active and quiet sleep. The consistent amplitude reduction in active sleep would be consistent with the amplitude reduction observed in the adult during REM sleep. This amplitude reduction was not observed during the active sleep of the premature infants. The authors suggest that the failure to observe a response

AUTHOR		LATENCIES OF COMPONENTS - ms.						
NEONATES	EEG	Po	No	P1	N1	P2	N2	P3
Barnet 1965				95		267		
Akijama 1969	QS AS		(N1) 51.7±33 65.9±35	(P2) 127±31 116±46	(N3) 199±38 219±81			(P4) 515±89 514±13
Engel 1969	QS AS				100-141 100-141	230-260 230-260		
Ellingson 1974	QS AS	74 83	114 117	130 123	152 141	266 246	478 -	
Graziani 1974 prematures.					100	250		
0 - 12 Months								
Onishi 1969 4-12 months	l.v.f. h.v.s.				100 100	215±32 215±32		
Ornitz 1969 6-12 months	REM SII						262±70 298±31	
Ohlrich 1972 0-1 month 5-7 months 11-13 months	SII+SWS SII+SWS SII+SWS			63 89 66	92 120 95	220 193 170	475 425 372	678 622 601
0 - 3 Years								
Barnet 1975 10 days 3 years Average - 3yrs).	All Stages Sleep		33	70	104	230 150 186	538 320 396	785 625 714
Ohlrich 1978 0-3 years	-		38±10	79±24	109±39	186±35	409±97	728±128
Tanguay 1973	REM SII		33 33	63 64	78 88	104 129	229 283	346 414
Buchsbaum 1975	-			76-112	140	200		415-568
Weitzman 1965 Adult	SWS			50	100	175	325	800

QS - Quiet Sleep
AS - Active Sleep
lvf - Low Voltage Fast Activity
hvs - High Voltage Slow Activity

REM - Rapid Eye Movement Sleep
SII - Stage II Sleep
SWS - Slow Wave Sleep.

TABLE 3.1 Summary of the Effects of Maturation of the Vertex Potential.

amplitude reduction in the active sleep of the premature group may indicate that the development of phasic inhibition during active sleep is not fully mature at birth, but develops shortly afterwards.

Differences in active and quiet sleep were also observed by Ellingson (1974). The response in active sleep resembling that of wakefulness and the response in quiet sleep being characterised by more prominent late components (P_2 and N_2) of longer latencies (Table 3.1.).

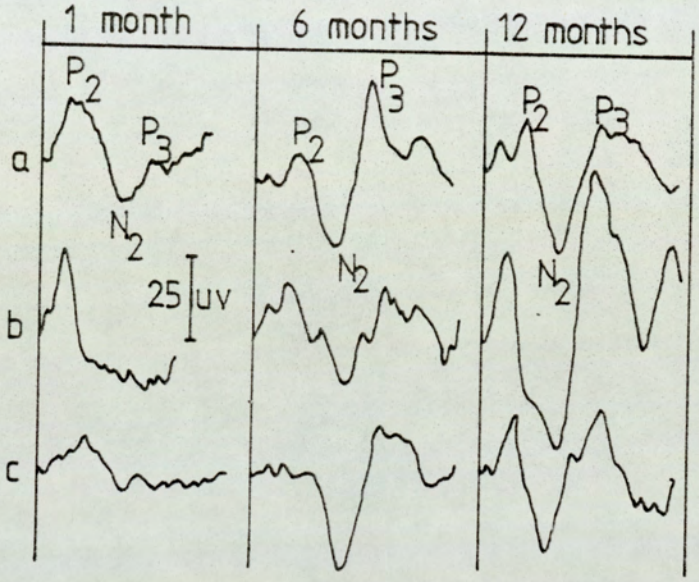
Maturational differences within a group of premature infants (27-37 weeks conceptual age) was observed by Graziani, Katz, Cracco, Cracco and Weitzman (1974). N_1 (100 m.secs.) and P_2 (250 m.secs.) components were detected, but P_2 only became prominent from 32 weeks onwards.

Ornitz et al. (1967) and Ornitz, Ritvo, Lee, Panaman, Walter and Mason (1969) reported a number of differences between the vertex potential obtained in a group of infants (0 - 12 months) and the adult response. The response was less complex than the adult vertex potential, showing only a single positive component prior to N_2. The latencies of N_2 were similar during REM sleep in both children and adults and were shorter than in stage 2 sleep. Whereas in stage 2 sleep, N_2 latency was shorter in the group of infants than in adults (295:325 m.secs.). He was unable to detect any consistent trends in amplitude in the infants due to the great individual variation. In a later study

(1969) Ornitz again found no evidence of phasic inhibition during REM sleep and the amplitude of N_2 in both REM and phasic REM was greater than in stage 2 in 8 of the infants and less in 4 infants.

A longitudinal study was carried out on 3 infants by Onishi and Davis (1969) at ages of 4, 6, 8 and 12 months. The characteristic vertex potential of N_1 at 100 m.secs., P_2 at 215 m.secs. and N_2 at 411 m.secs. was obtained during both high voltage slow activity (Non-REM) and low voltage fast activity (REM) with no obvious differences between sleep stages except for an increase in P_2-N_2 amplitude during high voltage slow activity. A larger number of infants (n=45) were studied by Ohlrich and Barnet (1972) over the first year of life. The infants were divided into ages of 0-1, 5-7 and 11-13 months and the vertex potentials in stage 2 and slow wave sleep compared. The latencies of all components present were found to decrease linearly with age, while the amplitude of P_2-N_2 components increased linearly with age (Figure 3.7.). The increase in response complexity with age was reflected in the percentage occurence of P_1 and N_2 components in the different age groups, with a 33% occurence in the 0-1 month, 80% in the 6 month group and 67% in the 12 month group. Ohlrich suggests that the different rates of maturation observed for each response component may reflect their individual neural substrates. The latencies of all components at 12 months are comparable to those of the adult response.

Barnet, Ohlrich, Weiss and Shanks (1975) and Ohlrich and



Click evoked responses in 1, 6, and 12 month old infants recorded from C_z. An upward deflection denotes positivity at C_z.

[Ohlrich and Barnet 1972]

Fig. 3.7.

Weiss and Shanks

Barnet (1978) extended the age range studied up to three years (n=130 and 16 respectively) and both reported the most rapid increase in vertex response latency and increase in amplitude over the first year of life. Ohlrich et al. (1978) found evidence of phase inhibition during REM with reduced amplitudes of P_2-N_2 and N_2-P_3 components in this stage in comparison with stage 2. (18:33uV. and 12.8:33uV. respectively), but they also emphasised the extreme variability in response characteristics where factors of age and sleep accounted for less than half the total variability.

Evidence of a reduction in N_2 amplitude during the phasic stage of REM was also found by Ornitz et al. (1967 and 1968) in a group of children up to 5 years of age. While the amplitude of N_2 during the tonic REM phase was similar to that in stage 2 sleep.

To summarise, the findings in infants and young children:-

i) Sleep

Differences in response characteristics of the vertex potential during active and quiet sleep stages are not seen in the premature infant. Such differentiation occurs in the neonatal period when vertex potential amplitude in active sleep (REM) is reduced and latencies shortened in comparison with those of quiet sleep. The emergence of the adult sleep patterns and the differentiation of sleep stages 1, 2, 3, 4 and REM are accompanied by the same

characteristic changes in the vertex potential that are seen in the adult.

ii) Maturation

Maturational changes in the vertex potential are seen from the premature stage onwards. The changes occurring with increasing age include:-

- an increase in response complexity usually associated with the progressive differentiation of the earlier response components
- an increase in the stability of response components
- an overall reduction in the latencies of the response components which is more marked over the first year of life
- increases in responses amplitude which are again most marked over the first year of life
- the development of phasic inhibition and response amplitude reduction during phasic REM sleep may represent a maturational change. However, the exact time at which this phenomena develops has not yet been clearly established

Comparison of the data in Table 3.1. and 2.1. illustrates the greater variability in the characteristics of the vertex potential in younger age groups. Possible sources of this variability include:-

- differences in individual rates of maturation
- the averaging of response latency and amplitude data across all sleep stages
- the averaging of response latency and amplitude data across wide age ranges
- methods of sleep scoring
- the use of sedatives to induce sleep (see Chapter 5)
- the effects of the BRAC and sleep onset

3.2.3. Age Changes in the Adult and Child Vertex Potential

The effects of age on the vertex potential were studied by Buchsbaum and Henkin (1974); Price et al. (1966); Cody and Townsend (1973); Suzuki and Taguchi (1965) and Goodwin, Squires, Henderson and Starr (1978). The findings, however, are by no means consistent. The vertex response in age groups of 6-10 years and 11-15 years were compared with the adult response by Suzuki and Taguchi. They found that the younger age groups were associated with longer latencies and smaller amplitude responses.

However, Price et al. (1966) in ages of 10-83 years found a greater amplitude of the N_1-P_2 components in the young and old with an amplitude minimum over ages of 30-50 years. They also report response amplitude differences with race and sex with significantly greater amplitude responses in whites than coloured and in females than males.

With age groups of 2 months to 76 years, Cody and Townsend (1973) found no linear relationship between vertex potential of latency and age. The response latency was shorter and amplitude small in the adult group (18-76 years) than in the child group (2 months-4 years), but there was considerable overlap between both groups. The use of stimuli at near threshold intensities may have increased the variability in these findings.

The effects of age on both the vertex potential and the P300 component were investigated by Goodwin et al. (1978) over an age range of 6-76 years. In the adult group of 15 years and over, the N_1-P_2 amplitude showed a regular decrease with age at a rate of 0.2uV./year from 15.6uV. at 15 years. The P_2 latency increased with age at a rate of 0.7 m.secs. per year from 165 m.secs. at 15 years while the N_2 component increased in latency only slightly with age. The latencies of N_1 and P_2 in the group of children (6-14 years) did not differ significantly from those of the young adults. The N_1-P_2 amplitude tended to be smaller than predicted from the linear relationship observed in the adult age range. Goodwin suggests that the slow increase in response latency with increasing age would be consistent with aging processes and a reduction in the rate of neural transmission possibly due to demyelination processes.

In general, the reported amplitude and latency changes of the vertex potential occurring in the adult population

with age, sex and race are very small and probably not of great significance when compared with the great inter subject variability of the vertex potential.

3.2.4. The Effects of Background EEG Activity of the Vertex Potential

No consistent or strong relationships have been established between the amplitude and latency characteristics of the vertex potential and various features of the background EEG activity.

Abe, in 1954, and Davis et al. (1966) found no relationship between the waveform of the vertex potential and states of high and low alpha activity in the spontaneous EEG. Evidence of a weak relationship between certain characteristics of the background EEG activity and the visual evoked potential was reported by Kooi and Bagchi (1964). The alpha parameters investigated included amplitudes, persistence over time and frequency. They found that the response amplitude tended to be greater with high background alpha activity and with increased alpha persistence. A similar relationship of reduced response amplitude with lower amplitude background EEG activity was inferred by Price et al. (1966) who studied the vertex potential in ages of 10-83 years. The observed amplitude minimum over 30-50 years was explained in terms of the reduced background EEG amplitude over middle age in comparison to youth and old age.

Although no clear relationship has been established in the normal subject between the vertex response and background EEG characteristics, changes in background EEG activity may influence the vertex potential indirectly by changing the signal:noise ratio. Although Abe (1954) reported a larger amplitude vertex response in high alpha states, he found that the response was more easily detectable in the absence of alpha activity. Similarly, Buchsbaum et al. (1974) report greater stability of the vertex potential with high signal:noise ratios.

3.3. Psychological Parameters

Attention and vigilance are psychological factors which can only be adequately controlled and manipulated in normal co-operative individuals who are capable of understanding and carrying out verbal instructions. Thus, although the study of the effects of attention on the vertex potential are of considerable interest to the psychologist and neurophysiologist, its relevance in the clinical field is somewhat limited as communication with the majority of patient population is difficult and control of attention impossible. Hence the effects of attention on the vertex potential will be briefly reviewed to determine the extent to which uncontrolled changed in the level of attention (as will occur in a clinical population) may influence the response characteristics of the vertex potential.

The effects of attention on all classes of auditory evoked potentials are comprehensively reviewed by Picton and

Hillyard (1974) and Picton, Hillyard and Galambos (1976). The directing of selective attention to the auditory stimulus is found not only to increase the amplitude of the N_1 (40 m.secs.) and P_2 (170 m.secs.) components of the vertex potential, but also under certain circumstances produce an additional later component known as the P_3 or P300. Picton et al. (1974) presented his subjects with repetitive 60dBSL click stimuli (non-signal) which were interspersed with less frequent click stimuli at 55-59dBSL (signals). In the attend condition, subjects were required to count the number of infrequent stimuli that had occurred, while in the non-attend condition the subjects were asked to ignore the stimuli presented and read a book. He found that in the attend condition the amplitudes of the N_1 and P_2 components to the frequent stimuli (non-signals) were increased in comparison with the non-attend condition, and in addition, the responses to the infrequent stimuli (signals) in the attend condition consisted of an additional large positive component at 450 m.secs. This late P300 component shows a different scalp topography to the earlier vertex potentials with a more posterior distribution. Unlike the components of the vertex potential which are markedly dependant on stimulus parameters, the P300 appears to be more or less independant of both stimulus parameters and modality, but instead reflects some form of perceptual decision process made by the subject regarding some characteristics of the stimulus.

Picton suggests that response to detected stimuli consist

of two distinct parts, of a sensory evoked potential - the vertex potential, and of a perceptual decision complex which does not require a specific stimulus, but is determined by some decision made regarding the stimulus. The P300 has been recorded to a wide variety of task relevant stimuli (Vaughan and Ritter, 1969 and Sutton, Braren and Zubin, 1965) and as such may be a measure of psychological processing.

Keating and Ruhm (1971) investigated the effects of attention on the vertex potential while their subjects were engaged in a number of different tasks. The conditions used were a) sitting quietly with no attentional control

b) counting the number of stimuli that occurred

c) a discrimination task involving some aspect of the stimulus

d) reading

The response variability was greatest in the quiet condition and least in the reading condition. In the quiet condition, there was no control at all over the level of attention which would account for the greater response variability while the reading condition, although not a condition of attention, produced a constant state of inattention where variability would be least.

Thus, the direction of attention to the auditory stimulus

in general produces an enhancement of the amplitude of the vertex potential, but from the clinical point of view the observations of Keating et al. (1971) are of greater significance when maintaining a constant level of either attention or inattention producing a more stable less variable vertex potential.

CHAPTER 4

The Role of the Vertex Potential in the Assessment of Auditory Acuity.

4.1. Objective or Physiological Audiometry

Most conventional audiometric techniques are based on the ability of the subject or patient to make a decision regarding the presence or absence of an auditory stimulus and to communicate that decision to the experimenter. Such procedures, which rely on the active participation and co-operation of the patient are collectively known as subjective audiometric techniques.

Subjective audiometry may be successfully used in the majority of the population, but there are a minority of cases who cannot or will not co-operate with such procedures. For this small group of patients a number of tests have been developed which remove the decision regarding the occurrence of an auditory stimulus away from the patient and transfer it to the experimenter who makes the decision on the basis of an observed covert or overt response. All such procedures are classified as objective or physiological audiometry techniques.

The term objective audiometry covers a wide variety of testing procedures, many of which involve the measurement of reflex or involuntary responses elicited by novel stimuli. Examples of such techniques include the measurement of orienting and pupillary responses. Also more sophisticated

measures are available involving classical and operant conditioning. In many cases these tests only provide a fairly crude assessment of hearing acuity, and the responses to auditory stimulation are measured indirectly through other behavioural or physiological responses and thus most also rely on the integrity of these responses systems.

Evoked response audiometry, by recording directly the effect of auditory stimulation on the electrical activity of the brain, provides a more direct measure of auditory function. Before the development of averaging techniques evoked response audiometry was based on such observations as:-

i) the attenuation of alpha activity in the background EEG in response to auditory stimulation.

ii) the production of K-complexes during light sleep.

iii) a shift in the depth of sleep in response to novel stimulation.

4.2. The Vertex Potential and Objective Audiometry

The recording of the vertex potential monitors directly the change in electrical activity of the brain induced by auditory stimulation and involves no other physiological systems. It is said to be an objective measure of hearing in the sense that it requires no activate participation from the subject other than to remain relatively

inactive. However, the objectivity of evoked response audiometry lies only within the recording procedure. The interpretation of the data obtained is carried out by the experimenter. Although guide lines and criteria have been developed in attempts to provide standardisation across experimenters in response identification, the final decision as to whether a response is present and on the relationship of this objective threshold the subjective hearing levels is still to a large extent subjective and based on experience.

Observations of the dependancy and systematic variation of the vertex potential with stimulus intensity have led to its development as an objective measure of hearing acuity. A gradual reduction in response amplitude and the lengthening of response latencies is seen with decreasing stimulus intensity, until at or near subjective hearing threshold the response is no longer visible (Figure 4.1.). The objective threshold of hearing is defined as the lowest intensity level at which the vertex potential is detected.

Before the vertex potential can become a valid technique in the assessment of auditory acuity in clinical populations two important conditions must be fulfilled:-

1) The objective threshold of hearing as determined by the vertex potential must lie close to the subjective threshold of hearing.

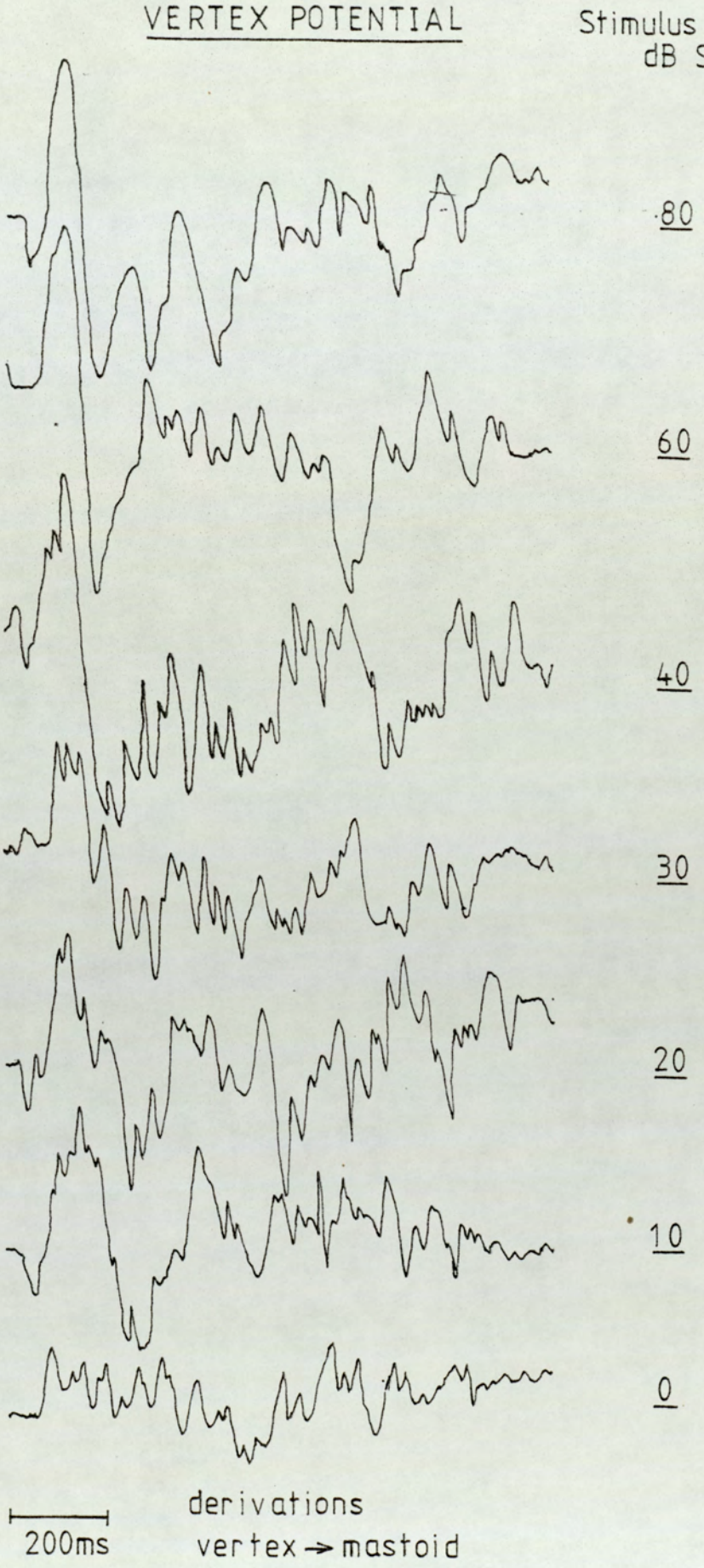


Fig. 4.1.
The effects of stimulus intensity on the amplitudes and latencies of the components of the vertex potential.

ii) Secondly and of greater importance the difference between subjective and objective hearing thresholds must be consistent and reproducible both within and across individuals.

From the characteristics of the vertex potential which have been reviewed in the previous chapters, it is evident that several factors grouped under the general headings of stimulus, physiological and psychological parameters must be considered when determining objective thresholds and their relationships to subjective hearing levels.

i) Stimulus Factors

Changes in stimulus parameters can profoundly influence the vertex potential (Chapter 3) as seen with changes in stimulus intensity which provide the basis of its role in objective auditory assessment. Other stimulus parameters may be optimised and held constant throughout the procedure.

ii) Age

The configuration and latencies of the vertex potential show marked changes in the vertex potential. These changes are most evident in the very young and probably reflect maturational processes. Age changes necessitate the use of different criteria for response recognition, but they may also affect the intensity above subjective

subjective threshold at which the vertex potential may be recognised and so produce changes in the relationship between subjective and objective thresholds.

iii) Background EEG Activity

Characteristic changes in the background EEG activity occur with age in terms of both frequency and amplitude. Activity is of higher amplitude and lower frequency in infants and young children. Such activity may decrease the signal:noise ratio of the vertex response and background EEG especially at near threshold levels and thus interfere with response recognition and increase the difference between subjective and objective thresholds.

The presence of a persistent alpha rhythm in the background EEG of the adult may similarly interfere with response recognition by decreasing the signal:noise ratio.

iv) Behavioural State

The general behavioural state of the patient or subject may also influence the difference between subjective and objective threshold estimations. Increased restlessness in younger groups will produce EMG and gross movement artifacts in the background EEG and so decrease the signal: noise ratio.

v) Level of Arousal

The differences in response characteristics observed during wakefulness and the different stages of sleep may produce differences in the reliability of objective assessment and also influence subjective and objective threshold differences within the individual sleep stages.

Procedures for the recording of the vertex potential have been designed to control for or hold constant as many variables as possible, but in practice, especially in young children, this is rarely possible. If such factors cannot be controlled, then their contributions to the results of clinical investigations must be assessed by the experimenter in his judgement of objective threshold and its relation to subjective hearing level.

A large number of studies have been carried out in attempt to validate the use of the vertex potential in the assessment of hearing in different age groups and under different testing conditions. The remainder of this chapter will review the findings in normally hearing adults, children and infants during wakefulness and sleep.

4.3. Methodology

4.3.1. Choice of Stimulus Parameters

Stimulus parameters are chosen to optimise the character-

istics and stable properties of the vertex potential (Chapter 3). The use of pure tone stimuli allows direct comparison with conventional pure tone audiometry especially if the tone length is of 200-300 m.secs. The choice of longer duration tones avoids the possibility of temporal integration at lower intensity levels. Rise times are generally less than 30 m.secs. and interstimulus intervals vary from 1-3 seconds. The frequency of the stimulus is usually varied between 250-8000Hz, although most work has been carried out at 1000Hz. Ideally, the stimuli are introduced through headphones so that monaural stimulation may be carried out, but this is not always possible in neonates and infants when binaural free field testing by means of a loudspeaker may be necessary.

4.3.2. Electrode Placement

The active recording electrode for the vertex potential is almost without exception placed at or near the vertex in investigations where threshold measures are made. Such an electrode placement produces the best signal:noise ratio with maximum amplitude of the vertex potential and steepest input-output functions of stimulus intensity and response amplitude. All are factors which provide the most favourable conditions for response identification. The site of all the reference electrode is somewhat variable, but the most popular derivations are the mastoid or earlobe which, according to topographical studies, are relatively inactive in terms of vertex potential activity.

In clinical studies it is often preferable to use additional reference recording sites in the temporal regions.

4.3.3. Control of Subjective State

Although attention is known to influence the amplitude of the vertex potential, studies by Cody and Bickford (1965) and Cody and Townsend (1973) find little effect on the determination of objective thresholds. The same subjective and objective threshold differences were reported whether attention was directed towards or away from the stimulus. Least variability in the vertex response was reported by Keating and Ruhm (1971) when subjects read quietly throughout auditory stimulation in comparison with conditions when the subject either sat quietly, counted the stimuli or performed a discrimination task on the stimulus. Thus it appears that not the degree of attention, but the constancy of subjective state, whether of attention or inattention, is the most important factor in reducing the variability of the vertex potential. Adult patients and subjects are usually asked to read during evoked potential recording and children are entertained with books, pictures or games to keep them amused and as quiet as possible. Alternatively, with very young children, many investigators prefer to carry out their investigations during natural or drug induced sleep.

4.3.4. Testing Procedure

It is usual to begin the investigation with a stimulus well

above normal subjective hearing levels of the order of 70dBHL so that a clear response may be elicited to act as a template to facilitate the subsequent identification of responses to lower intensities. If this intensity fails to elicit a response, intensity level is then increased. If a clear response is obtained the intensity is decreased in 20 or 10dB steps until objective threshold is approached (identified by greater decreases in response amplitude and lengthening of latencies). At this stage intensity may be reduced in 10 or 5dB steps depending on the accuracy required. Once objective thresholds have been obtained at one stimulus frequency, the procedure may be repeated at other frequencies.

4.3.5. Criteria for Response Identification

Responses at near threshold levels are usually of low amplitude and often variable, not only in latency but also in presence and absence. A number of criteria have been developed to aid the investigator in response identification,

i) The use of a template response. A clear response of high intensity stimulus is used as a reference.

ii) The combination of averaging and superimposition techniques. The superimposition of successive responses to stimuli of decreasing intensity allows the monitoring of response amplitude reduction and latency lengthening. Low responses at near threshold may be more easily rec-

ognised when compared in series, but often missed when viewed in isolation.

iii) In the presence of dubious responses or responses to low intensities, the number of individual averages obtained at each intensity may be increased.

iv) Problems of false identification of responses. A false positive result is obtained when the vertex potential indicates a hearing threshold lower than subjective responses. Such an occurence is of most serious outcome as it may prevent the early treatment of deafness in the young. A false negative implies a hearing loss when none is present. The use of the above procedures helps to minimise the possibility of errors, but in addition control runs are often recorded when no stimulus is presented. Amplitude and latency response criteria have also been developed to help accurate response identification. These criteria are based on an acceptable percentage of false positive results as determined in control runs. These criteria vary with sleep and wakefulness.

v) Another possible technique for the establishment of response thresholds is the use of input-output functions of stimulus intensity and response amplitude. Extrapolation of such functions should provide an estimate of threshold. However, as the exact relationship between stimulus intensity and response amplitude still

remains a controversy and shows a great deal of inter-subject variation, the reliability of such threshold estimations must be poor.

4.4. Differences in Subjective and Objective Assessment of Auditory Thresholds

4.4.1. Normally Hearing Adults

i) Wakefulness

Good correlations between subjective and objective thresholds were reported by early workers (Cody and Bickford, 1964; Suzuki and Taguchi, 1965). The response components used by Cody and Bickford were N50-100 m.secs. and P125-200 m.secs. They found that the vertex potential was detectable when their subjects were able to identify 50% or more of the individual stimuli in each averaging run. Twenty normally hearing adults (18-58 years) were presented with tones of various intensities at stimulus frequencies of 500, 1000 and 2000Hz. Combining the frequencies together they found that 43% had identical subjective and objective thresholds, while 83% were within 5dB, 95% within 10dB, and 100% within 15dB. The distribution and range of subjective and objective threshold differences illustrated in Figure 4.2. are obtained from data presented in their paper. The mean difference in subjective and objective thresholds was +0.42dBSL. The positive sign before the mean value indicates that objective threshold was higher

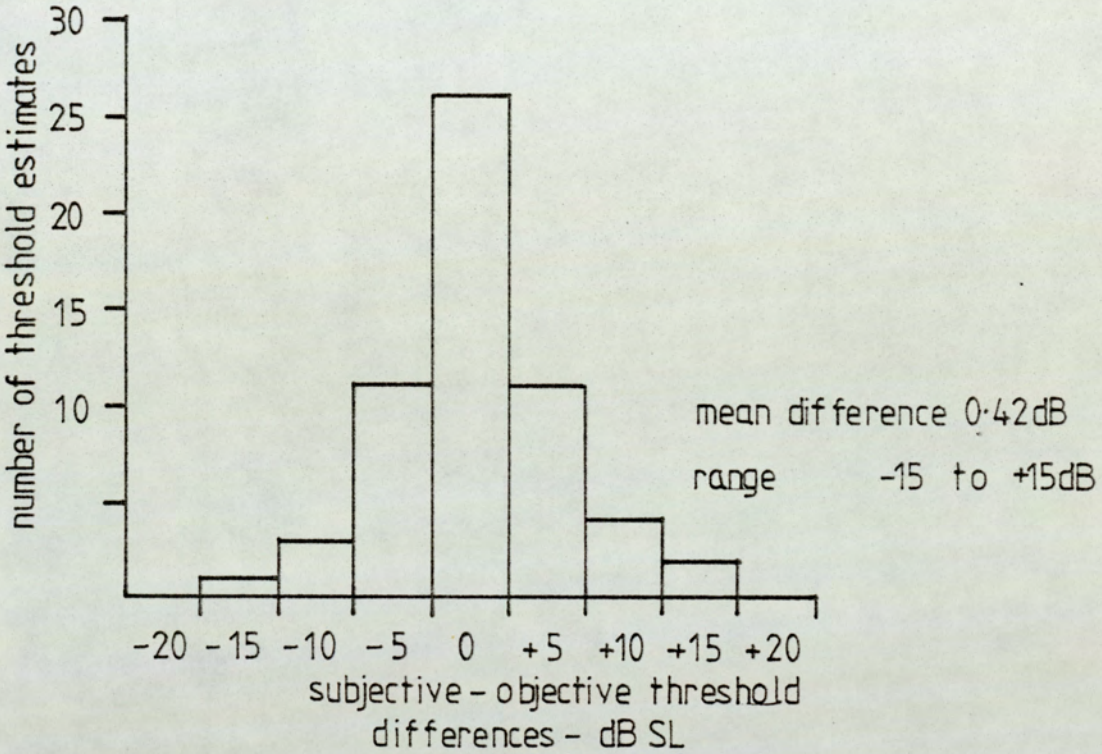


Fig 4.2.
Distribution of subjective and objective threshold differences in 20 normal adults. Average of stimulus frequencies 500, 1000 and 2000 Hz. Adapted from data in paper.
[Cody & Bickford, 1965]

or less sensitive than subjective threshold, and a negative sign that objective thresholds were lower than subjective thresholds. In calculation of mean values the sign of the subjective and objective threshold differences is usually taken into account and thus positive and negative differences will tend to cancel out giving a falsely low mean difference. Cody and Bickford concluded that their data was as reliable as that obtained by conventional audiometry and that the differences observed between subjective and objective threshold estimates no greater than those obtained in conventional audiometry by different testers.

An investigation carried out by Suzuki and Taguchi, (1965) at stimulus frequencies of 500, 1000, 2000 and 4000Hz in 19 normal adults produced similar findings. However, in this case no false positive results were obtained in the evoked response data - that is, the vertex potential did not on any occasion produce a lower estimate of hearing threshold than subjective audiometry. The same subjective and objective thresholds were obtained in 25.4% of threshold determinations with 69.7% within +10dB and 100% within +20dB of sensation level. The absence of false positive results raised the possible question of experimenter bias when dealing with normally hearing individuals. The expectation of a normal hearing threshold may influence the experimenter in his decisions regarding the presence and absence of vertex potential at threshold intensities. Price, Rosenblut and Goldstein (1966) also found no false positive

responses in 8 normally hearing young adults tested by evoked response and conventional audiometry. The mean difference in thresholds was +4.4dB and the maximum difference was 10dB.

A number of studies were carried out by Beagley to test the reliability of the vertex potential in predicting subjective hearing levels. Objective and subjective thresholds were compared in 8 normally hearing young adults (Beagley and Knight, 1967) at stimulus frequencies of 500, 1000, 2000 and 4000Hz at intensities of 0-70dBHL. The results were assessed in 2 ways:-

i) In series, comparing responses at all intensities.

ii) Each response was assessed 'blind' - that is- in isolation without comparison with responses at other intensities.

When responses were assessed in series 57% had the same subjective and objective thresholds with 96% within 10dB and 100% within 20dB, whereas when assessed blind, although 60% had identical thresholds only 85% were within 10dB and 98% within 20dB. (Table 4.1.).

These findings illustrate the value of a template in the recognition of threshold responses.

A further study was carried out by Beagley and Kellogg in 1969 on 40 adults of 18-36 years of age. Free field

Hearing Level (dB	% Recognition	
	In Series	Blind
70	100	100
50	100	100
30	100	100
20	100	98
10	96	85
0	57	60
60	100	100

Table 4.1.
The affects of methods of assessment on response recognition. Beagley and Knight, 1967.

testing was carried out at stimulus frequencies of 500, 1000 and 2000Hz. In order to try and reduce the possibility of false positive results, they incorporated the lengthening of response latency at near threshold intensities into their criteria for judgement of response presence. In this case vertex potential thresholds were defined as the intensity half-way between the 5dB step with a positive response and the one below with no response. They were aware of the problem of experimenter bias in the expectation of normal threshold levels and to try and assess its contribution in their results, a group of 36 clinical patients (18-52 years old) where normal hearing could not be assumed were used as controls.

The presence of experimenter bias in the normally hearing group was suggested by the occurence of a smaller number of false positive results in this group as compared with the clinical group. The normally hearing group produced 10% false positives at all frequencies tested while in the clinical control group the percentage of false positives was 21. The range of subjective and objective threshold differences in the normal group was -5 to +15dB with a mean difference of +4.0dB. The range and distribution of the data is shown in Figure 4.3.

Grimes and Feldman (1971) reported that 82% of vertex potential thresholds were within 5dB of subjective hearing levels with 100% within 10dB using tones of both 45 m.secs. and 200 m.secs. duration (n=7).

Mendel et al. (1975) and Osterhammel et al. (1973) investigated subjective and objective threshold differences using more strictly defined criteria for response identification. Mendel et al. using 28 normally hearing adults (22-89 years) recorded evoked responses to low intensity levels with threshold defined as the lowest sensation level at which 75% of responses were scored under ratings of clear or very clear. The response criteria he used were defined in terms of response latency and amplitude. The latencies of components N_1 and P_2 were 90 ± 10 m.secs. and 170 ± 10 m.secs. respectively, and N_2 - P_2 amplitude was 3.3uV. On the basis of these criteria he obtained mean subjective and objective threshold differences of

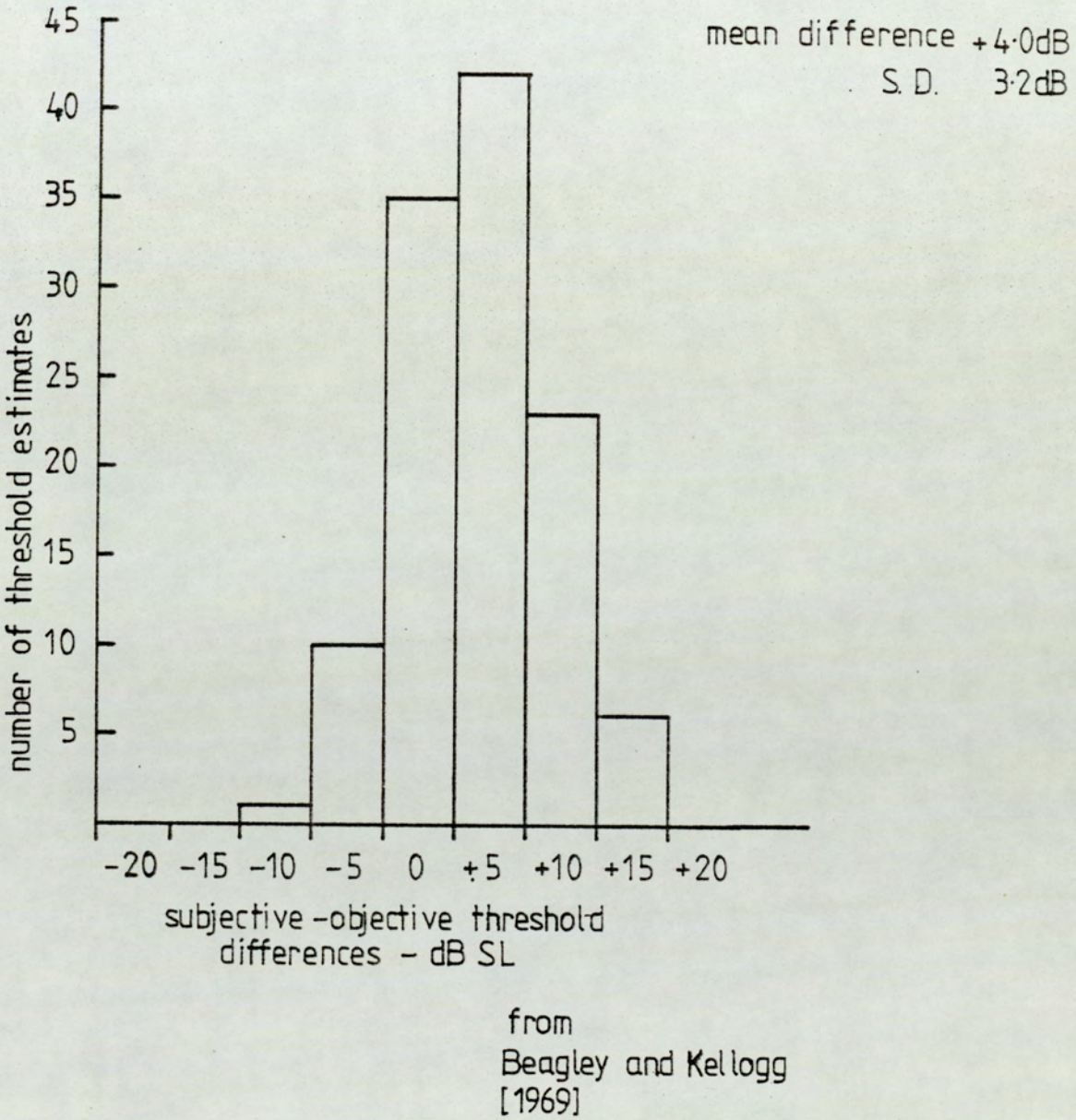


Fig 4. 3.

Distribution of subjective and objective threshold differences in normal hearing adults (n=40). The positive sign denotes higher objective threshold estimates. The negative sign denotes lower objective threshold estimates, at frequencies of 500, 1000 and 2000 Hz. (from data in paper)

+27dB. The greater subjective and objective threshold differences may be accounted for by the stricter response criteria. The latency limits of the components N_1 and P_2 are very narrow, especially for near threshold responses where much greater variation would be expected. In addition, responses were only recorded at low intensity levels and as Beagley and Knight (1967) have demonstrated responses to low intensity stimuli are more difficult to recognise without the aid of a clear template response.

Similar voltage and amplitude criteria were used for response identification by Osterhammel et al. (1973) in 11 subjects (22-74 years). The criteria were developed on the basis of an acceptance of a 17% rate of false positive responses amongst data obtained from no stimulus control runs (see this section - ii sleep). The discrepancies between subjective and objective thresholds were much smaller than those of Mendel with 57% of objective thresholds within 10dB of subjective levels, 80% within 20dB and 93% within 30dB. All were within 40-50dB.

ii) Sleep

The gross changes in consciousness that occur during sleep must raise the question of whether the vertex potential thresholds obtained during sleep and different sleep stages accurately reflect the subjective hearing threshold of wakefulness. The affects of the marked changes in the background EEG must also be considered in relation

to response threshold determination.

Most of the investigations relate the vertex potential thresholds obtained during sleep to the waking subjective level. Experimental differences arise in the sleep period investigated. This may be through the night or a day-time nap. Sleep may be natural or induced, in which case, different sleep inducing agents may be used. Various methods have been used to assess the stage and different manuels for methods of sleep scoring exist (Dement and Kleitman, 1957; Rechtscaffen and Kales, 1968). All such factors may significantly influence the results obtained and increase the variability of findings across experimental studies.

In terms of behavioural responses sleep stages 4 and REM were reported by Williams et al. (1964) to require higher intensity stimuli to evoke arousal responses both in behaviour and in the resting EEG than stages 2 and 1 of sleep. Such an observation, however, does not necessarily relate to the intensity level at which vertex potentials may be detected in the different stages of sleep.

Nodar and Graham (1968) measured vertex potential responses in 5 normal and 10 mentally retarded adults (20-30 years) during night sleep induced by Sodium Seconal. His investigations were confined to sleep stages 3 and 4 where a greater discrpancy between subjective and objective thresholds was observed than in the waking state. Only

a few positive responses could be identified at 10dBSL. (relative to the waking state), but 100% positive responses were obtained at 30dBSL.

The importance of control runs and the establishment of response criteria in order to avoid false positive results is of greater importance during sleep. The later and slower components of the vertex potential which predominate during sleep may often be confused with similar frequencies in the background EEG which because of their rhythmicity and high amplitude are difficult to remove by averaging.

Rapin, Cohen and Schimmel (1972) and Osterhammel et al. (1973) attempted to overcome this increased possibility of false positives during sleep by developing different amplitude and latency criteria for response acceptance during wakefulness and the different stages of sleep. In Rapin's study, vertex potentials were recorded in 4 normally hearing adults during natural night sleep. The possibilities of type 1 (false negative) and type 11 (false positive) errors were assessed in a group of control or non-stimulus runs. The type 11 error or false positive has clinically the most serious consequences at it may indicate no hearing loss or a less serious one than actually exists. The control subjects used by Rapin were a group of children (n=44) aged 2 months to 14 years where sleep was induced by chlorpromazine. From these children 48 no stimulus averages were obtained during wakefulness and 29 during sleep. These control runs were assessed for the presence

of a positive vertex potential and 14% of the control runs were reported as positive during wakefulness and 31% during sleep. This clearly indicates that the occurence of false positives is increased during sleep.

Evoked response thresholds were then ascertained in the 4 normal adults during REM, stage 2 and stages 3 and 4 combined. In stage 2 and 3-4 combined, evoked responses could not be reliably detected at 10dBSL as the percentage of runs scored positive at 10dBSL did not differ significantly from the percentage scored positive in the no stimulus runs. At 20dBSL the 60% positive score differed significantly from the control runs. The responses detected in REM sleep were significantly smaller than those of all other stages and thus were more likely to result in false negatives. In order to minimise the number of false negatives, Rapin suggests that each stimulus run is repeated 4 times and judged positive only if 3 out of 4 of these produce positive responses.

Thus Rapin's study indicates that vertex potentials are less reliably detected in sleep at lower intensity levels mainly because of the increased possibility of false positive results in sleep stages 2, 3 and 4 and of false negatives in REM sleep. However, the control data for the adult group is drawn from a much younger population. The EEG characteristics of this control group will be considerably different from the normal adults and so may give rise to a higher percentage of false positive runs than would have been observed in an adult control group. Ideally,

the adult group from which the vertex potentials were recorded should have acted as their own controls, and in addition, control runs should have been obtained for each individual sleep stage. Another important difference between experimental and control group was the induction of sleep by chlorpromazine in the latter. A similar study was carried out by Osterhammel et al. (1973), but in this case each of his 11 subjects were compared against their own control data. Sleep stage was assessed in terms of a delta index with values over a measure of 50 classified as stages 3 and 4, and less than 50 as stages 1,2 and REM and combined as light sleep. Sleep was induced during the day by Seconal. Control runs were recorded during wakefulness and sleep and the awake vertex potential was identified by N_1 at 90 m.sec s. and P_2 at 170 m.secs. and the sleep response by P_2 at 200 m.secs. and N_2 at 320 m.secs. By accepting an occurence of 17% false positives in the control runs during sleep and wakefulness, Osterhammel devised voltage criteria for the acceptance of a positive response in awake and sleeping records.

In the awake state, with a 17% false positive rate, the voltage criteria for N_1 - P_2 amplitude was 3.3uV. This produced 60% of objective thresholds within 10dB of subjective threshold and 80% within 20dB. In deep sleep the criterion for P_2 - N_2 amplitude of 5.7uV. produced 40% of objective responses within 10dB of sensation level, 60% within 20dBSL and 75% within 30dBSL. During light sleep P_2 and N_2 components were not always present and in order

to maintain a 17% false positive rate it was necessary to increase the voltage criterion to 8.2uV., but this resulted in only 35% of objective responses being detected at 20dBSL. Using the 5.7uV. voltage criterion of deep sleep 67% of objective responses were recorded at 20dBSL, but this was accompanied by an increase in the false positive rate to 33%. The poorer and less reliable threshold measures found in light sleep may be accounted for by the inclusion of REM sleep into this group. In this sleep stage response amplitude is consistently reduced and the response configuration is closer to that of the awake vertex potential.

Osterhammel's voltage criteria for response acceptance were also used by Mendel et al. (1975) in a study of afternoon sleep induced by Seconal in 28 adults. The criteria for the awake response were N_1 at 90 m.secs., P_2 at 170 m.secs. and N_1-P_2 amplitude of 8.3uV., and for the sleep responses P_2 at 200 m.secs., N_2 at 320 m.secs. and P_2-N_2 amplitude of 5.7uV. Objective threshold was defined as the lowest sensation level at which 75% of responses were scored as positive. Using these criteria the mean objective threshold stimuli was 27dB above sensation level during wakefulness, 27dB during deep sleep and 30dB during light sleep with ranges of +10 to +45dB; +10 to + 40dB and +20 to +45dB respectively. Since the same voltage criterion was used for both deep and light sleep then according to Osterhammel's findings the objective threshold level of 30dBSL in light sleep should contain a greater percentage

of false positive results than in awake or deep sleep stages. Unfortunately, REM sleep was again incorporated into light sleep. Mendel finds no differences in objective thresholds obtained during wakefulness and sleep, but his awake thresholds are considerably higher than those of most investigators.

4.4.2. Normally Hearing Children and Infants

i) Wakefulness

One of the earliest studies of subjective and objective threshold differences in children was carried out by Suzuki and Taguchi (1965). Groups of 10 children aged 11-15 years and 12 children aged 6-10 years were investigated using tones at 1000Hz. The results obtained are presented in comparison with a normal group of adults (n=19) in Table 4.2. Whereas 25% of the adults had the same subjective and objective thresholds, this occurred in only 10% of the 11-15 year old group and none of the 6-10 year group. Adult thresholds were all within 20dB but this only occurred in 90% of the 11-15 year group and 58% of the 6-10 year age group.

A similar group of 56 normally hearing children (4-11 years) was investigated by Beagley and Kellogg (1970). The children were further divided into 8 age groups. All groups were characteristed by higher amplitude background EEG's and by a greater degree of behavioural restlessness

Subjective-Objective Threshold Difference Intensity dBSL	Adults n=19 %	11-16 yrs. n=10 %	6-10 yrs. n=11 %
-10	0	0	0
0	25.4	10	0
+10	69.7	50	8.3
+20	100	90	58.3
+40	100	100	91.7
+50-60	100	100	91.7

Table 4.2. Comparison of Subjective and Objective Threshold Differences in Adults and Children (Suzuki and Taguchi, 1965).

than the adult. In most of the older children of 7-8 years and above, the adult vertex potential configuration was clearly discernable with predomination of the early P_1, N_1 and P_2 components. In the younger children, infantile responses remained with large late N_2 and P_3 components. Some children were found to oscillate between both types of response during the investigation. However, even in the presence of these confounding factors, Beagley found that in most children subjective and objective threshold differences were of the order of 10dB.

The importance of obtaining an individual template response for each child was stressed by Cody and Townsend (1973) to try to compensate and control for the great variability of response configuration in children.

A clinical study by Morgon, Charachon and Gerin (1971)

included the testing of 65 normal young children in whom vertex potential and subjective thresholds were combined at stimulus frequencies of 250, 1000 and 4000Hz. 81% of these children showed perfect agreement between subjective and objective assessment.

Many of the investigations on the subjective and objective threshold differences in infants and neonates have by choice or necessity been carried out during sleep. A few studies however have been attempted during wakefulness.

The difficulty of validating evoked response audiometry techniques in young children was emphasised by McCandless (1970). In most cases it is impossible to obtain reliable and accurate measures of subjective hearing levels, and the results of evoked response audiometry in infants may only be evaluated in comparison with that of adults and with normal adult hearing levels.

McCandless (1970) investigated a group of 70 infants at ages of 1,3, 6 and 12 months. The group consisted of 17 normal infants and 53 premature infants. The premature group was further divided into a pre-term group of birth weight 2000-1500gm. and a high risk group of birth rate less than 1500gm. Tones of 500 and 2000Hz were presented at 60dBHL and decreased in 20dB steps. McCandless found that he was unable to control the testing conditions as the infants behavioural and physiological stages continuously changes, and it was practically impossible to obtain a consistent evoked response waveform

and establish response criteria. He found that in all three groups more consistent response waveforms could be detected in the older infants and also that the initial differences observed in responses from the normal and high risk groups disappeared with increasing age. At one and 3 months of age, only 50% of the normal infants produced detectable responses at or below 40dBHL. This, however, increased to 60% at 6 months and 100% at 12 months. He concluded that the vertex potential could not be consistently and reliably detected in infants because of the great variation in subjective state and response waveform.

This study was elaborated further by Lentz and McCandless (1971). Using the same groupings of infants, evoked potentials were recorded during both sleep and wakefulness. At the age of one month the lowest objective response recorded in the normal group (n=13) were at 43dBHL and at 59dBHL in the pre-term and high risk groups (n=40). At three months the lowest response in the normal and pre-term groups were recordable at 40dBHL. While the high risk group remained at 60dBHL until the age of 6 months when it was reduced to 40dBHL. The comparison of lowest objective response thresholds and normal adult hearing threshold is illustrated in Figure 4.4. Although the behavioural state of the baby changes throughout the testing procedure, Lentz found no evidence that this affected the vertex potential threshold level (Figure 4.5.),

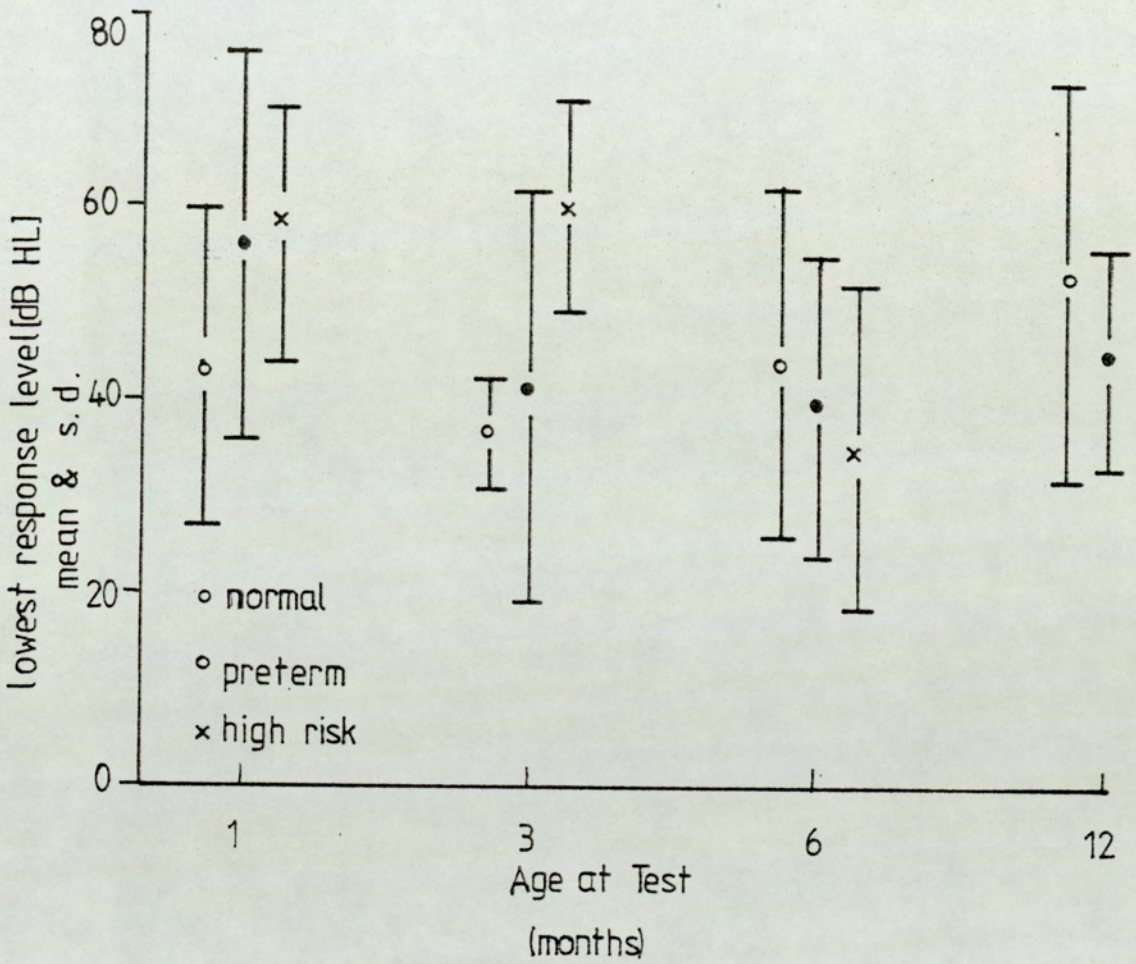


Fig 4.4.

Means and standard deviations of objective thresholds in normal, pre-term and high risk infants.

[Lentz and McCandless, 1971]

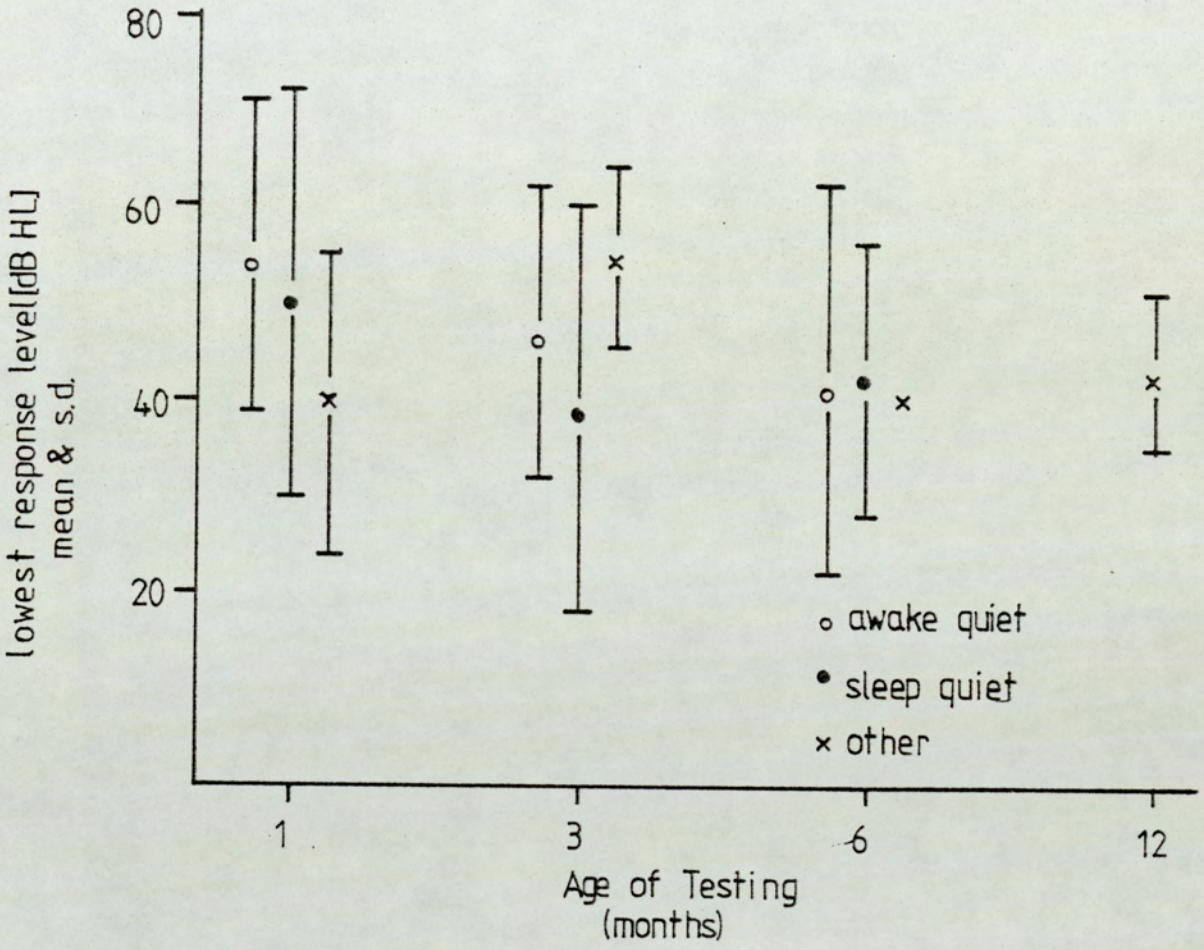


Fig 4.5.

The effect of behavioural state on the determination of objective auditory thresholds in infants.
[Lentz and McCandless, 1971]

ii) Sleep

Many of the vertex potential measurements in younger children and infants take place during sleep rather than wakefulness as the majority of investigators believe that, in younger age group, sleep provides the most favourable conditions in terms of reduction of movement and muscle artifact and in control of the level of arousal. Thus it is of great importance in these age groups to characterise subjective and objective threshold differences during sleep.

Rapin et al. (1972) in a sleep study previously mentioned (4.4.1.) also investigated subjective and objective threshold differences in four young children. In comparison with the adult findings of 60% positive objective responses at 20dBSL only 44% positive rate was detected at this intensity in children. This value is only just greater than the 31% positive scoring rate found in the control no stimulus runs during sleep. Rapin, however, reports the adult data in terms of sensation level (SL) whereas the child data are expressed in terms of Hearing Level (HL). Thus, there is also the possibility that the use of dBHL in the group of children may have exaggerated to some extent the subjective and objective threshold differences. At the 40-60dBSL, 91% of adults produce positive objective responses as compared with 68% of the children at 40-60dBHL.

The problem of threshold measurement in the different stages of sleep was considered by Onishi and Davis (1969)

in a small group of infants (n=3) from 4-18 months of age. Sleep was divided into low voltage fast activity analogous to REM sleep and high voltage slow and spindling activity, analogous to Non REM sleep. They reported the normal adult waking pattern in both sleep stages, present at 40-50dB above normal adult hearing threshold (HL). The response configuration of N_1 at 100 m.secs., P_2 at 215 m.secs. and N_2 at 411 m.secs. did not change significantly over the period of 4 to 12 months. Evoked responses thresholds in high voltage slow wave sleep were at 10-15dBHL while those in low voltage fast or REM sleep were raised to 45dBHL. This reduction in response detectability is almost certainly due to the decrease in response amplitude during REM. Onishi and Davis report smaller differences in subjective and objective hearing thresholds than Rapid (1972). They do not attempt to control for the occurence of false positive results. Both studies have the disadvantage of testing only a very small number of children and as response variability is much greater in the child than the adult then the reliability and general application of these findings must be limited.

A much larger group of normal children (n=140) was investigated by Barnet (1971)b in conjunction with 100 children with possible hearing defects. All children were under 3 years of age and Barnet found that the configuration of the vertex potential was profoundly influenced by background EEG, age and stimulus parameters

with greater variability between subjects. In general, all infants showed elevated auditory evoked response thresholds (as compared with adults) especially during sleep where only 68% of the presumed normals produced positive vertex responses at 50-35dBHL. In all ages REM thresholds were sometimes, but not always, reduced. Of the Non-REM stages, Barnet preferred stage 2 sleep for threshold estimation, as the high amplitude slow activity fo stages 3 and 4 interfered with response recognition by decreasing the signal:noise ratio. In all the presumed normally hearing children there was great variability in the subjective and objective threshold differences. Whereas in some children the vertex potential would be detectable within a few dB of adult hearing threshold, in others it could not be consistently detected at any intensity.

Earlier in 1965 Barnet and Goodwin carried out a similar study on a group of neonates at 2, 3 and 4 days old. Stimulus intensities of 35-65dB (relative to adult threshold) were investigated. The late components of the vertex potential P_2 (267 m.secs.) and N_3 were present in all children at 45dB and in 78% at 35dB. The responses were again more difficult to recognise during slow high amplitude sleep activity.

A large group (n=160) of 2-10 day old neonates were tested by Appleby (1964). The responses consisting of a positive component at 125 m.secs. and negative component at 250 m.secs.

were more easily recognisable in sleep than wakefulness. All babies produced vertex responses at 60dB, 85% at 50dB and less than 40% at 40dB.

Finally, a group of 75 neonates were studied at 0-3 days of age by Engel and Young (1969) at stimulus frequencies of 250 - 8000Hz and unlike Barnet and Goodwin (1965) and Appleby (1964) he reported recording responses within limits of adult hearing thresholds with only 10.4% of records classed as non-interpretable. The infants were recorded between feeding sessions during quiet sleep, the testing of each frequency taking a very long time, usually in excess of one hour. The means of the threshold estimates at each stimulus frequency were within the range of 0-20dBHL.

4.5. Summary

From examination of the data presented in Table 4.3. it is evident that close and consistent relationships are obtained between subjective and objective threshold estimates in co-operative normally hearing adult subjects. Estimates of objective threshold determinations range from 60-100% within 10dB of subjective hearing level and 80-100% within 20dBSL. There is a possibility that data obtained from normally hearing subjects is influenced by experimenter bias with the expectation of normal hearing thresholds influencing the judgement of response presence. Positive evidence for experimenter bias is presented by

Beagley and Kellogg (1969).

The mean values of subjective and objective threshold differences in Table 4.3. do not accurately represent the data. Most authors take the sign of the subjective and objective threshold difference into account. Thus, those who obtain both positive and negative differences in subjective and objective hearing thresholds will produce mean objective threshold values which lie much closer to subjective hearing thresholds than those who produce only positive subjective and objective threshold differences. Hence the importance is seen of also presenting information on the variance and range of threshold differences.

Various criteria have been used to judge the presence and acceptance of the vertex potential. The most rigorous criteria were developed by Rapin et al. (1972) and Osterhammel et al. (1973) and these stipulate amplitude and latency values for response acceptance in an attempt to reduce the number of false positive responses especially during sleep. The application of these criteria in general increase the subjective and objective threshold differences.

The effects of sleep on subjective and objective threshold differences are summarised also in Table 4.3. Direct comparisons between studies are difficult on account of the different stimulus intensities and reference intensities used; the different criteria used for response recognition; the different methods used for sleep scoring and the time and quality of sleep, whether natural or induced. However,

several important conclusions can be drawn:-

REM sleep is generally unfavourable for threshold determination, using the vertex potential, as the reduction of response amplitude in this stage of sleep makes response identification unreliable at low intensity levels. Threshold estimates show greater reliability in the Non-REM stages 2, 3 and 4, although greater discrepancies between subjective and objective thresholds are observed than in wakefulness. Few objective responses are detected within 10dB of subjective thresholds with approximately 60% within 20dBSL and 75-100% within 30dBSL.

Comparison of waking objective thresholds in adults and children (Table 4.4,) (4-15 years) reveals not only an increase in subjective and objective threshold differences in children, but also a greater range of differences. The discrepancy between subjective and objective thresholds tends to decrease with age (Suzuki and Taguchi, 1965).

The majority of objective thresholds are within 10-20dB of sensation level with 100% within 40dBSL. The variation of subjective and objective threshold differences with age illustrates the importance of developing normal control data for all age groups.

The small number of studies carried out on children of this age during sleep present variable data with threshold differences ranging from 10-60dB. The use of a very small

number of children in the studies does not allow any general conclusions to be drawn.

The increased accuracy of objective threshold determinations and the greater consistency between subjective and objective thresholds in both adults and children during the waking state in comparison with sleep indicate that, whenever possible, threshold determinations should be carried out during wakefulness.

However, in cases of infants and neonates the state of arousal and behaviour appears to have little effect on the determination of evoked response thresholds (Lentz and McCandless, 1970) which show no marked differences between sleep and wakefulness.

Validation of evoked response audiometry in the very young is difficult. The majority of evoked response threshold in infants and neonates lie well above normal adult hearing thresholds with the lowest response being detectable at 35-40dBHL with a 100% identification in the region of 45-60dBHL. Thus, evoked response audiometry using the vertex potential is at its least efficient in the very young, but even here is may provide a rough guide to hearing acuity and indicate the possibility of a hearing loss.

AUTHOR	n	% SUBJECTS Subj - Obj Differences dB 0	dB 10	dB 20	dB 30	MEAN $\bar{x}$	RANGE dBSL	FREQUENCY Hz	ADULT
Cody, Bickford. 1965	20	43	95	100		+0.42	-15 to +15	500 1000 2000	Awake
Suzuki, Taguchi. 1965	19	25.4	69.7	100		+10.4*	0 to +20	500 1000 2000 4000	
Price et al 1966	8		100			+4.4*	0 to +10	Click	
Beagley & Knight 1967	8	57	96	100				500 1000 2000 4000	
Beagley Kellogg 1969	40	30	95	100		+4.0	-5 to +15	500 1000 2000	
Grimes, Feldman 1971	7		100					500 4000	
Mendel et al 1975	28					+27	+10 to +45		
Osterhammel et al 1973	1		57	80				Sleep Stage	
Nodar et al 1968	10		few		100		+10 to +30	3 + 4	Sleep
Rapin et al 1972	4		not reliable	60				2, 3 + 4	
Osterhammel et al 1973	11 11		40	35 60	75			1, 2 REM 3 + 4	
Mendel et al 1975	28						+20 to +45 +10 to +40		

* Sign not taken into account

TABLE 4.3 Summary of Subjective and Objective Threshold Differences - Normally Hearing Adults - Awake and Asleep.

AUTHOR	n	% SUBJECTS Subj - Obj Difference					Mean $\bar{x}$	Age	Arousal Level
		dB 0	dB 10	dB 20	dB 30	dB 40			
Suzuki, Taguchi 1965	10 12		50 8	90 58		100 91.7	16 24	11-15 yr 6-10 yr	Awake Awake
Beagley, Kellogg 1970	56		Most					4-11 yr	Awake
Morgan et al 1971	65	81							
McCandless 1970	70					50 60 100		1m 6m 12m	Variable
Rapin 1972	4			44		68			S,2,3 & 4.
Onishi, Davis 1969	3		100			100		4-8m	REM N REM
Barnet 1971	140				100 →			2 yr	Sleep
Barnet, Goodwin 1965	18				70	100		2-4d	Sleep
Appleby, 1964						40		2-10d	Sleep
Engel, Young 1969	75	← 100 →						0-3d	TA

d = days
m = months
y - years

TABLE 4.4 Summary of Subjective and Objective Threshold Differences in Children, Infants and Neonates - Wakefulness and Sleep.

CHAPTER 5

The Clinical Application of the Vertex Potential

The main area of clinical application of the vertex potential is the establishment of auditory thresholds and the assessment of hearing loss. Investigations have also been carried out to assess its effectiveness in the localisation of neurological and audiological lesions and its possible application to psychiatry.

5.1. The Measurement of Auditory Acuity

The majority of patients arriving for auditory evoked response investigations are those on which conventional subjective audiometric assessment has failed. These patients may be classified as follows:-

A. CHILDREN

i) Infants too young to be tested by subjective audiometry

ii) Unco-operative children

iii) Children with behavioural problems

iv) Mentally and/or physically handicapped children

v) Children with psychogenic and emotional disorders

B. ADULTS

i) Adults with mental and/or physical handicap

ii) Psychogenic deafness

iii) Noise induced deafness

Many of the problems of establishing reliable objective auditory assessment and consistent subjective and objective threshold differences have been reviewed in Chapter 4. However, in a clinical population several additional factors must be taken into account and assessed. Most additional problems arise from the patients inability or unwillingness to co-operate with conventional testing. Factors such as increased physical restlessness or uncontrollable movement which are often encountered in behaviour disorders and physical or mental handicaps will reduce vertex response detectability by decreasing the signal:noise ratio through the production of EMG and movement artifact in the background EEG.

Continual fluctuations in the direction of attention of the patient may also increase vertex response variability.

In cases of brain damage of which epilepsy is a fairly common symptom, gross abnormalities are often present in the spontaneous EEG. These usually take the form of high amplitude slow activity or spike and wave activity which may completely obscure or block the generation or detection of the vertex potential.

In cases of young and difficult to control children, sedation is often used to produce sleep and thus control the level of behaviour and arousal. This however often introduces more problems into objective audiological assessment as the reported effects of sedation on the

vertex potential and subjective and objective threshold differences are controversial and divergent.

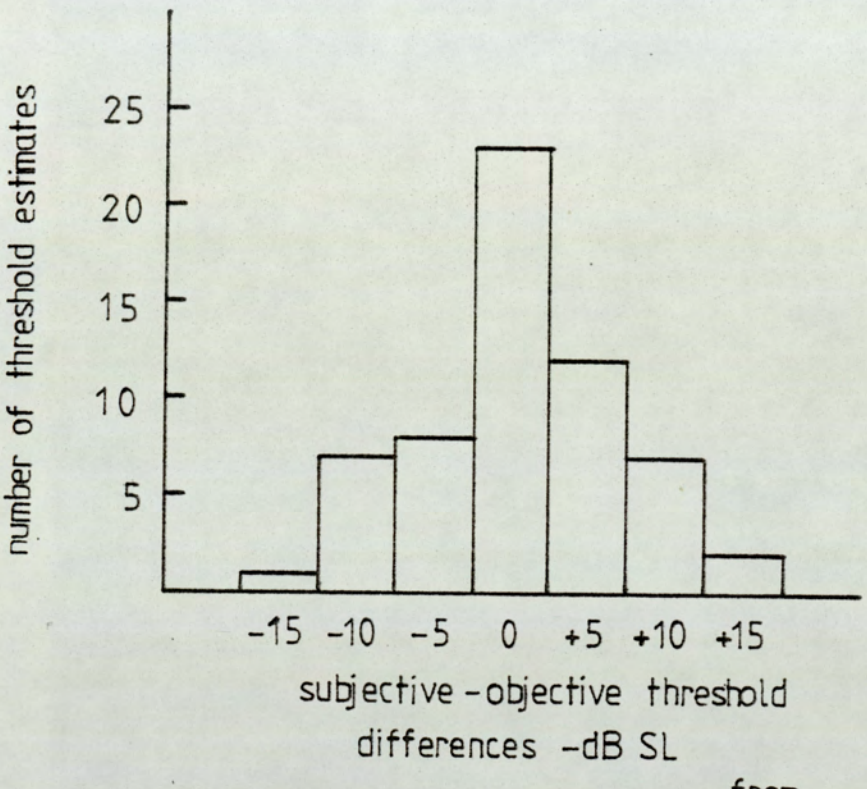
A number of studies have been carried out to assess the validity of objective assessment using the vertex potential in various behavioural and pathological states.

5.1.1. Suspected Hearing Loss

In cases of suspected hearing loss without any complicating additional factors such as brain damange, the vertex potential appears to provide a valid and reliable assessment of the degree of loss in both adults and children, whereas the findings with infants suggests that the technique is more limited (as is also found with normally hearing infants).

Evoked responses and pure tone hearing thresholds were compared in 20 adults (24-77 years) suffering from a sensori-neural hearing loss by Cody and Bickford (1965). Aetiology included presbycosis, acoustic trauma, Menières Disease, viral labyrinthitis, congenital syphilis and congenital deafness. Evoked response thresholds were obtained at stimulus frequencies of 500, 1000 and 2000Hz.

The mean and distribution of subjective and objective threshold differences are illustrated in Figure 5.1. 38% of the patients had identical subjective and objective thresholds (as compared to 43% in normal control group, see Figure 4.2.). With 71% of objective thresholds within



from
Cody and Bickford
[1965]

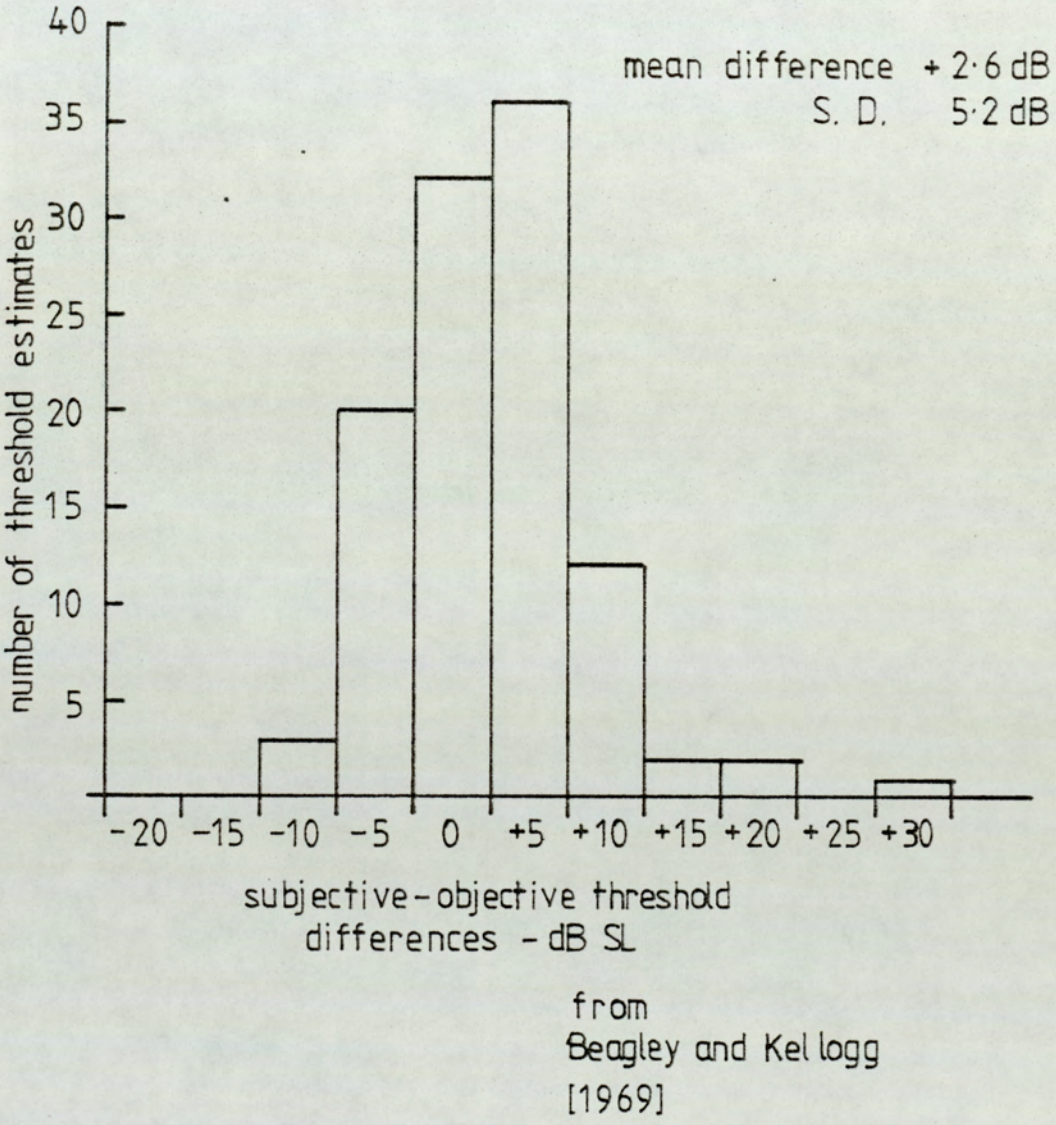
Fig 5.1.

Distribution of subjective and objective threshold differences in 20 cases of sensori-neural hearing loss. A total of 60 threshold determinations were made at frequencies of 500, 1000 and 2000 Hz.
The positive sign represents higher objective thresholds.
The negative sign represents lower objective thresholds.

5dB of sensation level, and 94% within 10dBSL.

Beagley and Kellogg (1969) assessed 36 adult patients whose hearing was in doubt by cortical and pure tone audiometry. Thresholds were determined at 500, 1000 and 2000Hz stimulus frequencies. The mean subjective and objective threshold difference was +2.6dB $\pm$ 5.2dB. S.D. However, their results contained 21% of false positive judgements (vertex potential gave a lower hearing threshold) as compared to only 10% in the normal controls. As already discussed in Chapter 3, this may in part be accounted for by experimenter bias in the normal control group. The distribution and range of subjective and objective threshold differences are shown in Figure 5.2. A T test revealed no significant differences between control and clinical groups. Evoked response and audiological assessment were carried out on 50 patients with hearing loss at stimulus frequencies of 500 and 2000Hz by Rose, Keating, Hedgecock, Miller and Schreurs (1972). Each author assessed 10 patients using his own criteria for response identification. The mean differences and ranges of subjective and objective threshold differences are shown in Table 5.1.

Although Table 5.1. shows a considerable range of subjective and objective threshold differences obtained by each investigator, examination of Table 5.2. will show that in 70% of the patients, objective and subjective threshold differences were within 10dB and 84% within 15dB.



from
Beagley and Kellogg
[1969]

Fig 5.2.

Differences between objective and subjective thresholds in 36 cases of auditory pathology. Adapted from data in paper.

Experimenter	Number of Patients	Stimulus Frequency 500Hz		Stimulus Frequency 2000Hz	
		Mean S-O* dB	Range S-O dB	Mean S-O* dB	Range S-O dB
A	10	8,5	-10 to + 20	6.5	0 to + 40
B	10	20.5	0 to +100	16.5	-10to + 80
C	10	13,0	0 to + 40	12.5	-10to + 70
D	10	16.5	-20 to + 60	13,5	- 5to + 30
E	10	9,5	- 5 to + 25	10.0	- 5to + 30

S-O - subjective and objective threshold differences

* the sign of the threshold difference was not taken into account.

Table 5.1. Mean and Range of Subjective and Objective Threshold Differences obtained in 50 Audiological Patients by Rose et al. (1972).

Subjective - Objective Threshold Difference dB	Percentage Patients (n=50)
0	16
5	40
10	69
15	84
20	89
25-60	96
60+	100

Table 5.2. Distribution of Subjective-Objective Threshold Differences in 50 Audiological Patients. Rose et al. (1972)

The considerable differences in range of subjective and objective threshold differences reported by the individual authors may be a reflection of the criteria used for response identification. This would seem likely as there is much greater consistency within the judgements of each experimenter at the two stimulus frequencies than across experimenters. However, it is also possible that the differences between authors reflect the different degrees of hearing loss in the patients tested. Table 5.3. shows that smaller subjective and objective threshold differences were obtained with more severe hearing losses.

Hearing loss dB HL	n	Stimulus Frequency 500 Hz		n	Stimulus Frequency 1000 Hz	
		$\bar{x}$	range		$\bar{x}$	range
0 - 24	28	17.5	-5 to 100	13	16.5	0 to 70
25 - 49	10	10.0	-20 to + 25	21	12.4	-10 to +80
50 - 75	12	7.5	- 5 to + 15	16	7.0	-10 to +20

n = number of patients

$\bar{x}$ = mean subjective-objective threshold difference.

Table 5.3. The effects of severity of hearing loss on subjective-objective threshold differences. Rose et al. (1972).

In cases of sensori-neural hearing loss the occurence of recruitment and steeper input-output functions of stimulus intensity and response amplitude may preferentially facilitate response recognition with more pronounced hearing losses.

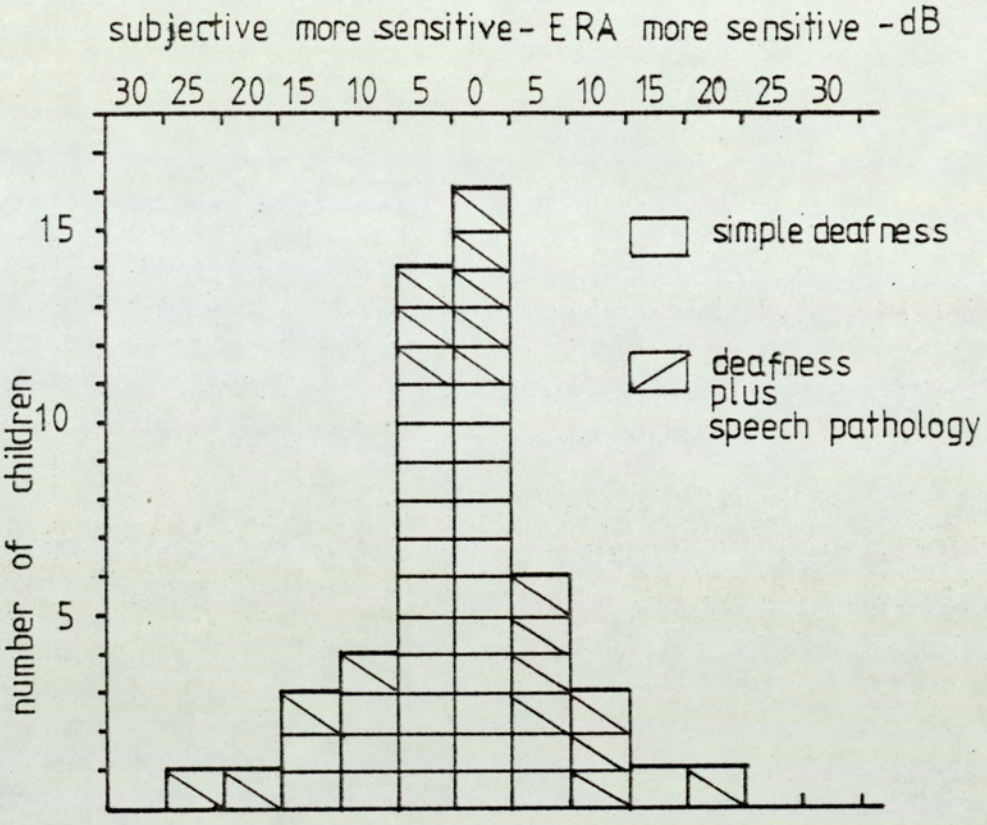
A group of children (n=60) of 7-16 years of age with hearing and speech problems were investigations by Davis (1965). Only 50 of the original 60 children were assessable by evoked response audiometry, the remaining 10 had too great a hearing loss. He then compared evoked response thresholds not only to pure tone audiometry, but also to subjective threshold using the same stimuli as for evoked response audiometry. The distribution and range of subjective and

objective threshold differences for both techniques are compared in Figures 5.3 and 5.4. for combined stimulus frequencies of 300, 600, 1200, 2400 and 4800 Hz. 86% objective threshold were within 10dB of sensation level for the same stimulus and 74% within 10dB of pure tone audiometry, the later showing a wider distribution of differences were no clear peak values. The subjective and objective threshold differences were also greater in children with additional speech pathology as well as a hearing loss than in the cases of simple hearing loss (see Figures 5.3. and 5.4.).

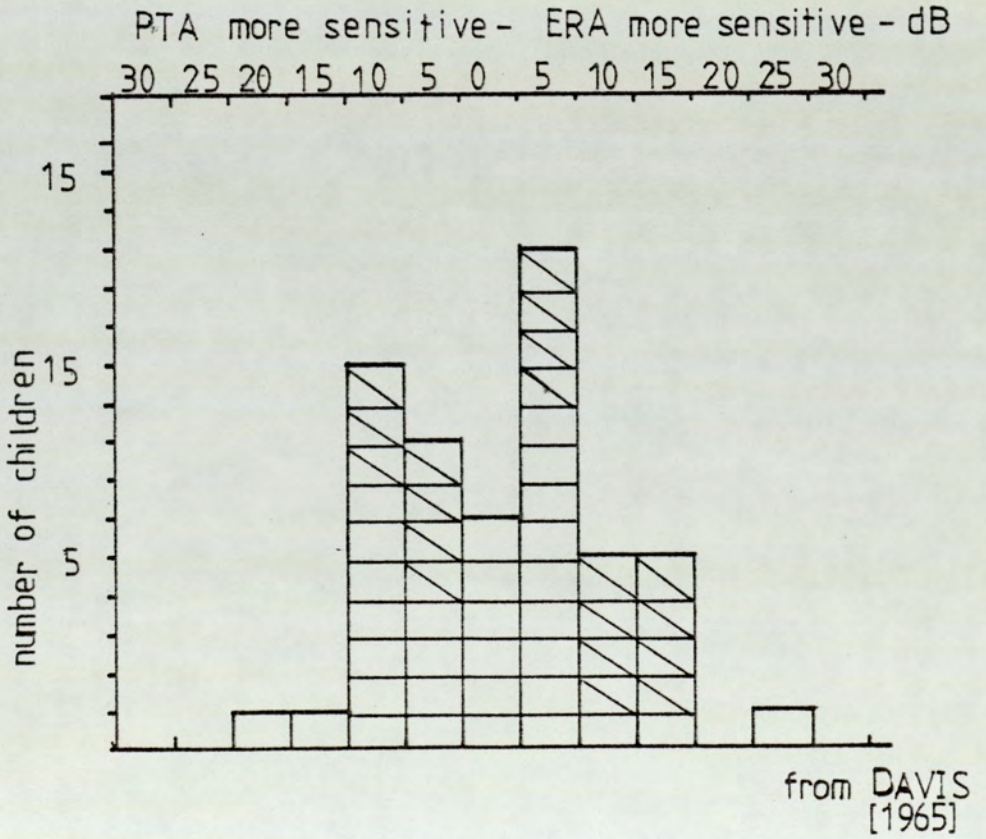
When comparing evoked response thresholds to subjective sensation levels for the same stimulus, 22% false positives occurred, but when compared with pure tone audiometry the false positives increased to 48%. This may be accounted for by an increase in subjective sensitivity with stimulus repetition as occurs in evoked response audiometry. Thus, the greater number of false positives when comparing evoked response and pure tone thresholds may reflect an increased auditory sensitivity with stimulus repetition. In addition, PTA was not carried out on the same day as the evoked response and subjective testing.

The validation of objective auditory assessment in infants presents many problems as accurate behavioural thresholds can rarely be obtained for comparison.

Serial evoked response audiometry was carried out on 18



a) comparison of objective and subjective thresholds, same stimulus



Figs 5.3. & 5.4.
Comparison of subjective and objective auditory thresholds in 50 children at stimulus frequencies of 250, 500, and 1000 Hz
b) comparison of objective thresholds with pure tone audiometry.

infants at 6 monthly intervals from 6-24 months of age. (Jones, Scott, Binnie and Roberts, 1975). Evoked response thresholds at stimulus frequencies of 500, 1000, 2000 and 4000 Hz were compared with estimates of subjective hearing obtained by behavioural testing. At the age of 6 months all evoked response thresholds at 1000 and 2000Hz were within 10dB of behavioural thresholds and at 500 and 4000Hz within 20dB. The threshold difference gradually decreased with age until all except one behaviourally difficult child had subjective and objective thresholds within 10dB.

Although close correlations are observed between objective and behaviour auditory assessment both may be well above true thresholds of hearing.

5.1.2. Physical and/or Mental Handicap

Retardation with physical and/or mental disability may seriously interfere with evoked response recognition and may increase the differences between subjective and objective auditory assessment. This may occur through:-

i) a decrease is the signal:noise ratio through movement or muscle artifact in the background EEG (Figure 5.5.)

ii) a decrease in the signal:noise ratio or the blocking of evoked response generation by abnormal EEG activity such as epileptic discharges.

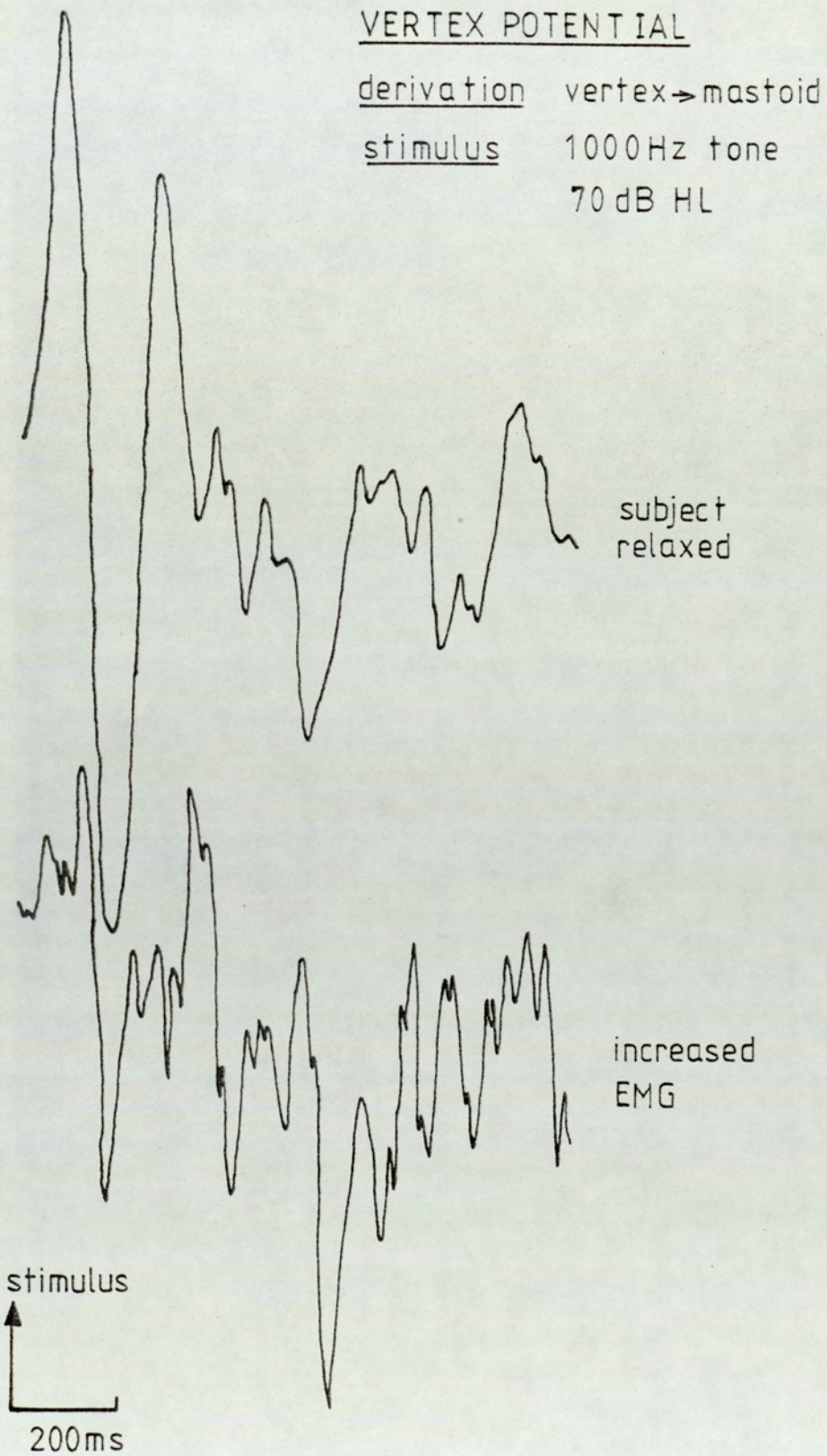


Fig 5.5.
The effect of EMG activity on the detection of the vertex potential.

Rose and Rittmanic (1968) selected a group of 35 mentally retarded adults (21-51 years) who were able to respond to pure tone audiometry and whose hearing loss was no greater than 30dBHL.

They also showed no motor abnormality which may interfere with response thresholds. 16 of the 35 patients were receiving anticonvulsants or tranquilisers or both. Mental retardation resulted from a variety of causes including metabolic disturbances, post-natal infection, mechanical injury, cranial anomoly, prematurity, mongolism and toxaemia, but in 17 patients was of unknown origin. Identical subjective and objective thresholds were recorded in 17% with 87% of objective thresholds within 5dB and 76% within 10dB. Subjective and objective thresholds were not obtained in 3 patients through failure of subjective (n=2) or of objective testing (n=1). Figure 5.6 shows the distribution and range of subjective and objective threshold differences calculated from data presented in their paper.

A more severely retarded group of adults (mean age 22.6 years) with gross psychomotor retardation was investigated by Shimizu (1970). The IQ of these patients ranged from 29 to 70, many were microcephalic, suffered epileptic seizures, para or quadriplegic, but all were thought to possess fairly normal hearing through everyday observations. In order to compensate for increased response variability in these patients, four individual

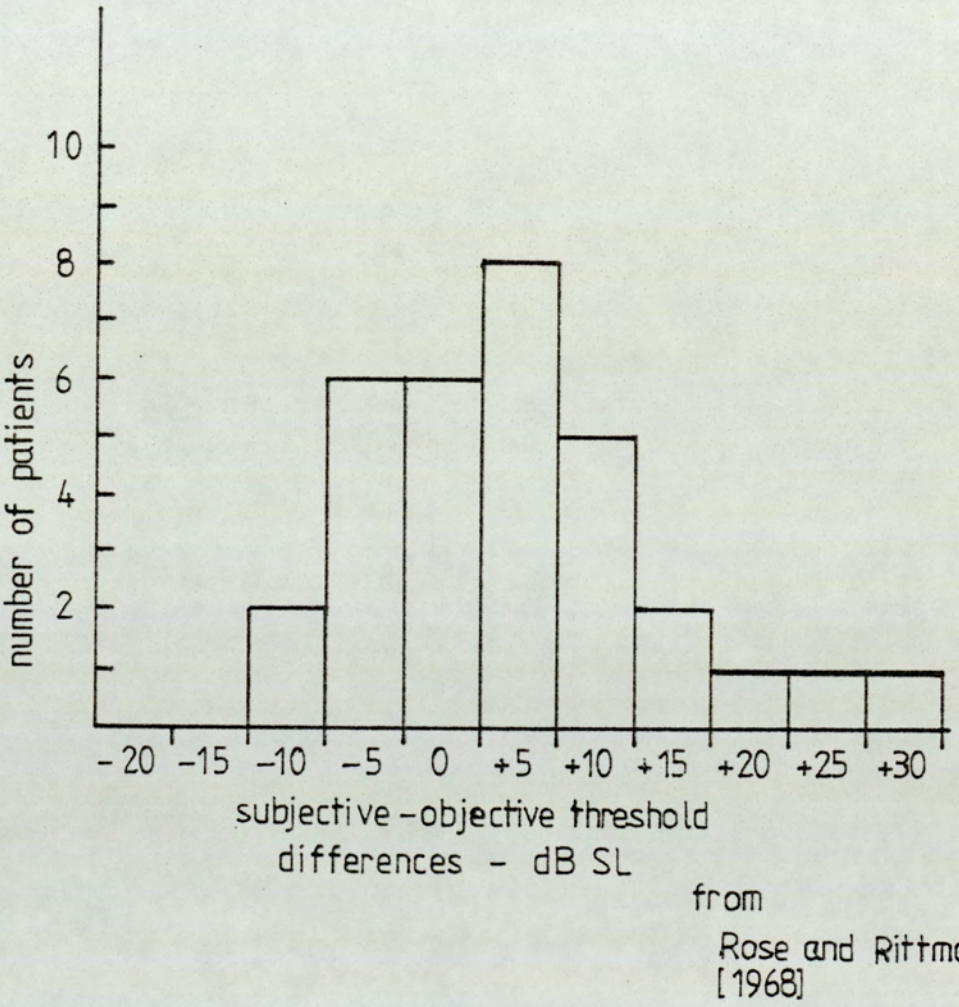


Fig 5. 6.
Subjective and objective threshold differences in 35 mentally retarded adults using a 1000 Hz stimulus. Adapted from data in paper.

evoked responses were obtained at each stimulus intensity level from 20-70dBHL. For purposes of comparison, 10 normal adults were included in the study.

The responses of the retarded group were of longer latency than the control group and showed a high percentage of sleep type responses. The responses were more variable in both latency and configuration and showed a greater discrepancy from the presumed normal hearing thresholds. In the normal group all objective thresholds were within 20dB of subjective thresholds while most thresholds in the retarded group were within 50dB, only 50% were within 30dB of presumed hearing level (see Table 5.4.).

Intensity dBHL	Evoked Response Present	
	n=35 Mentally Handicapped	n=10 Normal
20	7	10
30	10	
50	15	
70	2	
No response	1	

Table 5.4. Differences in auditory evoked response thresholds-normal and mentally handicapped adults with normal hearing thresholds. Shimizu (1970).

The majority of clinical evoked response studies in young

children are concerned with patients who have some additional abnormality usually in the form of brain damage as well as a possible hearing defect.

A wide variety of conditions were investigated by Rapin (1964). These included 50 children with simple deafness, 8 normal adults and 41 patients. The latter group was made up of 8 infants, 28 children (4-14 years) and 5 adults. Two of the adults, 4 of the children, and two of the infants had cerebral palsy. Good correlations between subjective and objective threshold estimates were obtained in the normal adults,and in the children with simple deafness evoked responses were obtained in 48 of the 50, and thresholds measured in 37. In the group of 41 patients one child with cerebral palsy was untestable and even in the 32 patients without cerebral palsy runs of continuous high amplitude background EEG activity interfered with response recognition. She concluded that vertex potentials could be reliably detected in normal adults and children and in some patients within 20dB of sensation level, but this reliability decreased in cases of cerebral pathology and especially with EEG abnormality.

Price and Goldstein (1966) investigated 70 children with auditory disorders, multiple handicaps and mental retardation.

The children were tested either awake or asleep. In a few cases sleep was induced with Nembutal. Responses were judged absent or present without knowledge of

stimulus intensity or frequency (500 or 3000Hz). For comparison of results the children were divided into groups according to their clinical histories:-

i) The 3 normal and 4 high risk children were grouped together as normal

ii) Sensitivity impairment alone - probable hearing disorders only

iii) Sensitivity impairment plus other symptoms, i.e. hearing disorder plus aphasia, mental retardation or emotional disturbance

iv) Other symptoms alone, i.e. mental retardation which produces an apparent hearing loss although the hearing mechanism is intact. Evoked response thresholds were compared with behavioural thresholds and the findings divided into categories.

i) Where evoked response and behaviour thresholds agree

ii/iii Both evoked response and behavioural thresholds indicate a hearing loss but of differing severity

iv) Where behaviour thresholds indicate a hearing loss with normal evoked response thresholds

Their findings are illustrated in Table 5.5.

	Normal	Sensitivity Impairment	Sensitivity Impairment plus other	Other problem alone	Total
Agrees	7	22	13	6	48
Sens.Imp. (ERA better)	0	3	7	2	12
Sens.Imp. (Behav.better)	0	1	2	0	3
Behav.Imp. (ERA normal)	0	0	0	7	7

Table 5.5. Comparison of auditory thresholds by objective and behaviour testing in cases of deafness and cerebral pathology.

Price and Goldstein (1966).

Good agreement between evoked response and behavioural auditory thresholds was obtained in both the normal and sensitivity impairment groups. Whereas in the patient groups with a sensitivity impairment plus additional cerebral disorder or cerebral disorder alone, 16 out of the 37 patients evoked responses gave lower thresholds than behavioural testing and in 7 of these evoked response thresholds were considered normal. It appears that in these cases that evoked response audiometry provides the true measure of subjective hearing levels rather than behavioural testing which may be influenced by the additional cerebral pathology. Thus, evoked response audiometry appears to be effective in distinguishing true hearing losses from apparent losses which often accompany mental disorder and retardation.

Clinical studies on multiply handicapped and brain damaged infants are almost always carried out in natural or drug induced sleep (Rapin, Ruben and Lyttle, 1970; Rapin and Schimmel, 1977). Their first study tested 86 infants of under one years of age in natural or drug induced sleep (chloral hydrate or chlorpromazine). Evoked response thresholds were ascertained and with the assumption of a 15dB difference between objective and subjective assessment during sleep, 15dB was subtracted from evoked response thresholds to obtain the hearing threshold of the infant. Hearing thresholds of 0-25dB were classified as normal; 30-60dB as a moderate loss; 65-90dB as a severe loss and 95dB+ as a profound loss.

Normal thresholds were found in 10 of the 15 normal infants (testing was not completed in the remaining 5). In the remaining 71 infants with possible hearing loss thresholds were established in 52 cases. They found that thresholds were more difficult, but not impossible, to evaluate in severe brain damage and EEG abnormality. They found evoked response audiometry useful in excluding hearing loss in the brain damage group where 14 out of the 30 infants produced normal evoked response thresholds with no behavioural responses. A review of their findings is presented in Table 5.6. Price and Goldstein, 1966, found similar results. The projection of a direct measure of subjective hearing thresholds from evoked response thresholds by the deduction of a standard 15dB is ill advised, especially in sleeping infants where there is great variability in subjective and objective threshold differences. The decision regarding possible subjective hearing level is made by the experimenter not only from the result of the evoked response threshold but also according to the age, behavioural state and pathology of the child.

Similar results were obtained by Barnet and Lodge (1966) and Barnet (1971)b. In the first study, evoked potentials were recorded in 22 infants (1-8 months) with possible deafness on the basis of pre-natal rubella. The infants were classified as normal if vertex potentials were detected at intensities of 65 and 50dB above adult hearing thresholds. The other stimulus intensity of 35dB did not consistently produce positive responses in normal infants. 55% (12 out of 22) of the infants were found to have a

Clinical diagnosis	n	Normal	Moderate	Severe	Total
possible hearing loss	21	9	0	3	12
Rubella	10	4	3	1	8
Hyperbilirubinemia	5	1	1	2	4
Genetic	5	2	0	2	4
Severe brain damage	30	14	2	4	20
Normal	15	10	0	0	10
Total	86	40	6	12	58

Table 5.6. Hearing levels as measured by evoked response audiometry in cases of hearing loss and additional cerebral pathology. Rapin et al. 1970.

hearing loss on the basis of evoked response audiometry and 10 of these cases agreed well with the results of behavioural testing.

In a second group of 100 children studied by Barnet (1971)b, in addition to possible deafness due to pre-natal rubella, many were also mentally and physically handicapped. Greater variability was observed in the responses of these infants and in 25% of the cases the results of evoked response and clinical testing differed considerably. However, most of the infants in this latter group were grossly handicapped and follow up studies obtained over periods of 2 months to 4½ years subsequently produced clinical data which confirmed the original evoked response diagnosis.

Rapin and Schimmel (1977) later presented a review of their clinical experience in testing 414 children over a period from 1968-1974. Over this period they became progressively disillusioned with the vertex potential as an objective measure of auditory acuity in young children. This, however, may have arisen from an expectation of the vertex potential to be as reliable in the assessment of hearing in infants and young children as was originally observed in co-operative adults. In attempts to increase the reliability of evoked response audiometry in young children, they repeated testing on different days and presented each stimulus condition at least 3 times. All their records were scored for presence and absence of evoked responses blind. The disadvantages and dangers of this method of scoring are discussed in Section 5.1.4. They conclude that, in young children, evoked response audiometry is useful in the exclusion of hearing loss in cases of brain damage, but that only broad statements regarding the degree of hearing loss may be made in young children on the basis of evoked response audiometry.

5.1.3. Non-Organic Hearing Loss

Evoked response audiometry can also play a central role in the diagnosis of a non-organic hearing loss in both adults and children. Non-organic hearing loss may be broadly divided into 2 categories as far as evoked response audiometry is concerned:-

i) Anomalies between different methods of subjective audiometric assessment and apparently normal social hearing

may lead the clinician to suspect a psychogenic deafness as a result of some trauma or emotional disturbance in the patients life. Evoked response audiometry provides the ideal method to verify such a diagnosis.

ii) Legislation now allows compensation claims to be made on the basis of industrial deafness. The offer of financial rewards occasionally leads to an exaggeration of the degree of deafness in these individuals. Evoked response audiometry may again be carried out when the inconsistencies of subjective audiometric testing raise some doubt about the degree of hearing loss.

Evoked response audiometry does not, however, distinguish between cases of malingering and true psychogenic deafness. Such a diagnosis is made on a clinical and preferably psychiatric basis.

Evidence that auditory evoked responses provide an accurate measure of the true state of hearing in both psychogenic deafness and malingering was provided by Cody and Bickford (1965) and Cody and Townsend (1973). Ten cases of suspected non-organic hearing loss were investigated by Cody and Townsend, five were malingerers and five had a psychogenic deafness. All patients had been intensively studied over a period of time so that their true subjective levels could be independantly established. In all cases the thresholds established by evoked response audiometry were within 10dB of their true organic thresholds and not their claimed thresholds.

5.1.4. Interjudge Reliability in the Measurement of Vertex Potential Thresholds

The variability of the vertex potential is a well known phenomenon and various contributing factors to this variability have been reviewed in the preceding chapters under the headings of Stimulus and Subjective Parameters. However, an additional source of variability appears to arise from both intra and interjudge variability regarding the decision as to whether an evoked potential is present or not. A large number of response criteria (Chapter 4 Section 4.3.5.) are available to help in the identification of threshold responses and the selective use of different criteria by the individual experimenters will almost certainly give rise to variation.

Problems of inter and intrajudge reliability are clearly highlighted in a paper by Rose, Keating, Hedgecock, Schreurs and Miller (1971). They studied not only the variability in determining objective thresholds between the five authors, but also the consistency of the judgements within each author. A total of 613 evoked response runs were obtained from 50 patients with suspected hearing loss at 7 stimulus intensities both above and below subjective threshold. Each average was labelled only with a run number and patient number. Each author then made a decision on each response run as to whether a response was present or not using his own personal response criteria. Universal agreement between all authors was reached on only 275 out of the total of 613 responses. The remaining 338 were then

rejudged on two separate occasions at weekly intervals to test the consistency within the judgements of each author, but again great inconsistencies were observed in threshold determination.

The authors conclude from these findings that the auditory evoked response is not the completely objective test that it was originally claimed to be, and that the validity of its general application is limited by the lack of objectivity in response identification.

However, it is not too surprising that large discrepancies existed between the judgements of the individual authors under the conditions imposed in the experimental procedure. They stress the importance of the use of response criteria and then remove most of these from the experimental situation so that the judgement on each response run must be made in isolation.

Only the run number and patient number were made available. Other valuable criteria for the evaluation of a response were removed.

i) the use of an intensity template with progressive amplitude reduction and latency lengthening with decreasing intensity

ii) the use of no stimulus control runs

iii) the opportunity to repeat individual runs at

threshold or to dubious responses to increase reliability.

iv) knowledge of the patients age so that appropriate response amplitude and latency criteria could be applied.

v) knowledge of the state arousal and whether awake or sleep responses were to be identified. In addition to these factors once the objective threshold has been obtained additional information must be considered when making a judgement as to the reliability of this threshold estimate and of its relation to subjective hearing levels:-

i) knowledge of the clinical problem

ii) the presence of cerebral pathology

iii) factors influencing the signal:noise ratio

a) Behavioural state - increased muscle and movement artifact.

b) Level of arousal - wakefulness, sleep and sleep stage.

c) The presence of abnormal EEG activity or persistent alpha activity.

Changes in all these conditions will produce changes in the signal:noise ratio and so affect the difference between subjective and objective measurements of auditory thresholds.

The importance of continuous monitoring of the background EEG activity throughout the evoked response investigation becomes obvious.

The failure to identify positive evoked potentials when judgement was made 'blind' as opposed to in 'series' was reported by Beagley et al. (1967) (Chapter 4 Section 4.4.1.).

A much greater interjudge consistency in the judgements of presence and absence of responses was found by Lentz and McCandless (1971) when all the necessary patient and response information was available. Even in children as young as 1-12 months of age, agreement on subjective thresholds was reached in 82% of cases, with a discrepancy of 20dB in 17% and greater than 20dB in only 1%.

5.1.5. The Effects of Cerebral Lesions

The vertex potential was used to assess objective hearing levels in 7 patients who had undergone surgical ablation of various cortical areas in either right or left temporal regions for the treatment of uncontrollable epilepsy or the removal of space occupying lesions (Ruhm, 1971)b. He found that in some of these cases that the vertex potential could not be reliably recorded or was of abnormal configuration even in cases where subjective hearing acuity was normal. He, therefore, suggests that the interpretation of auditory evoked response findings in such patients should be made with extreme caution.

In some of these patients active recording electrodes were

placed in temporal derivations and referred to mastoid electrodes. The smaller amplitude of vertex potential in the temporal derivations would certainly lead to a decrease in the signal:noise ratio and increased response variability. In addition, Ruhm makes no comment as to whether the failure of evoked response thresholds to reflect subjective hearing levels could have been due to the presence of abnormal EEG activity in the form of delta or spike and wave activity which may have persisted after surgery.

5.1.6. The Effects of Sedation on the Vertex Potential and on the Difference between Subjective and Objective Auditory Thresholds.

A knowledge of the effects of various sedating, anticonvulsant and tranquillising drugs on the vertex potential and on subjective and objective threshold differences is of importance on two accounts.

i) Many of the patients referred for evoked response audiometry will be on regular drug therapy for control of behavioural or epileptic disorders.

ii) Sedation may be required to induce sleep in hyperactive children and infants to allow evoked response audiometry to take place.

Although a considerable number of investigations have been carried out to assess the efficiency of the various sedating agents available, the drug of choice largely seems to be

a matter of the personal preference of each experimentor.

Sedation may change various characteristics of the evoked potential such as latency, configuration and amplitude, but from the clinical viewpoint only the affects on response detectability are of importance.

An ideal sedating agent for evoking response audiometry must fulfil the following conditions.

i) rapid onset

ii) last for 1-2 hours

iii) produce no adverse side-effects

iv) produce no marked changes in the vertex potential and the difference between subjective and objective threshold measurement.

Drugs may not only act by directly modifying the evoked potential, but also indirectly through its action on the background EEG activity. The barbiturates and benzodiazepams are noted for the production of fast activity or beta activity. This effect is most marked in conjunction with ACTH in the treatment and control of infantile spasms. This fast activity can sometimes be as large as 50uV. and completely obscures any evoked potential which may be present.

The drugs generally used in evoked response audiometry are sedatives which act as CNS depressants, or tranquillisers which reduce the level of anxiety. This latter group rarely induces sleep if given in normal standard doses.

Davis (1965) and Davis and Niemoller (1968) report that in most cases sedation is not necessary for evoked potential recording. However, in cases of extreme hyperactivity Davis (1973 and 1971) favours the use of the barbiturate Secobarbital (Seconal). This drug promotes deep sleep producing subjective and objective threshold differences of the order of 20-30dB, comparable to those of natural sleep. However, the use of barbiturates in evoked potential recording still remains controversial. Price and Goldstein, (1966) are in complete agreement with Davis; while a reduction in response amplitude was reported by Salomon, Beck and Elberling (1973); and Hosick and Mendel (1975) reported interference with response detection through the production of low voltage fast activity in the background EEG. Burian and Gestring (1971) also report the presence of after affects as well as a decrease in vertex response amplitude (Pentobarbital-Nembutal).

The use of tranquillising agents usually presents problems of administration. The normal oral doses do not induce sleep, and the requirement of intra-muscular or intravenous injection often present problems in audiological and neurophysiological laboratories. As with barbiturates the effects of tranquillisers remain controversial. Changes in response waveform and amplitude, but no effect on

threshold were observed by Burian and Gestring (1971) with diazepam (Valium). Spreng (1971) reported increased response variability and amplitude reduction. Chlorpromazine was successfully used by Beagley (1971) and by Rapin et al (1972).

Comparative studies by Stange (1972) of promethazine (Phenergan), pentobarbital (Nembutal), diazepam (Valium) and Mandrax found a reduction in vertex response amplitude with all drugs. The effect, however, was least with Phenergan (20-30% amplitude reduction) where normal response characteristics and objective threshold values were maintained. Similar findings were reported with Phenergan, Nembutal and Valium by Karnahl and Benning (1972) where latency and response variation was least with Phenergan.

A large number of drugs were compared in their effects of the vertex potential by Skinner and Shimoto (1975). They found that with all drugs the detectability of the vertex potential decreased in comparison with wakefulness and natural sleep and also that responses were more easily identified in non-barbiturates than barbiturates.

Since no general conclusions regarding the choice of sedation for evoked response audiometry can be made on the basis of information in the literature, the Table presented by Davis (1973)aTable 5.7. offers a summary of the most popular drugs in use today.

TABLE 5.7 Drugs used for sedation in evoked response audiometry.

A. Widely Used or Strongly Favoured

1. Triclofos (Tricloryl)
2. Chloral Hydrate
3. Promethazine (Phenergan, Atosil).
4. Ketamine (Catamin).
5. Barbiturates: Pentobarbital (Nembutal)
   Secobarbital (Seconal)

B. Favoured but more Controversial

1. Diazepam (Valium)
2. Chlorpromazine (Largactil).
3. Halothane (Fluothane).

C. Primary Choice of One Investigator

1. Alimemazine Tart (Vallergan).
2. Promazine (Protactyl, Talofen).

D. Less Satisfactory

1. Droperidol
2. Hydroxyzine
3. Mandrax

Davis concludes that the use of a particular sedative is not critical as none is perfect. However, the majority of more recent studies appear to favour promethazine. Perhaps the most obvious conclusion is to avoid sedation unless absolutely necessary.

5.2. The Diagnosis and Localisation of Specific Auditory Lesions

5.2.1. Sensory Disorders of the Cochlea

The phenomenon of recruitment is usually associated with dysfunction of the receptor of sensory hair cells of the cochlea and is commonly encountered in cases of Menière's Disease.

Recruitment may be simply defined as an abnormal growth in perceived loudness with regular increases in stimulus intensity. The distortion of loudness function usually takes the form of a compression of dynamic range of hearing into a shorter intensity range in the affected ear although the reverse situation may occasionally be encountered.

Conventional audiometric tests for recruitment such as the Alternate Binaural Loudness Balance Test for unilateral disorders usually require a high degree of subject co-operation in the balancing of tones of different intensities in both ears to equal loudness levels.

The vertex potential, because of the lack of need for active co-operation and the observations of systematic changes in response amplitude with stimulus intensity presented itself as a possible means of an objective measure of recruitment.

Evidence of abnormal input:output relations of stimulus intensity and response amplitude of the vertex potential in recruitment have been presented by Knight and Beagley (1968) and Uziel and Seneclause (1978). Knight and Beagley investigated 6 patients with unilateral Menieres Disease and recruitment as demonstrated by the ABLB Test. The amplitude of the N_1 and P_2 components was compared for affected on non-affected ears at a stimulus frequency of 1000Hz. Input-output functions of both affected and non-affected ears were compared with normal control data. While the input-output functions of the normal ear followed the control data, that from the affected ear showed an abnormally fast increase in response amplitude over lower sensation levels while at higher intensities both normal and affected ears followed the same input-output curves. (Figure 5.7.). From this data Knight and Beagley created an 'evoked response balance graph' which followed exactly the ABLB Test.

These findings were confirmed by Uziel and Seneclause (1978) in 18 cases of recruitment which in this case was detected by Fowler, and Reger Tests for unilateral and bilateral disorders respectively. Thus, it would seem that the psychophysiological phenomenon of recruitment is clearly reflected in the input:output relationship of stimulus intensity and response amplitude of the vertex potential, and thus may provide an objective measure of recruitment in difficult to test children and in the old and mentally ill.

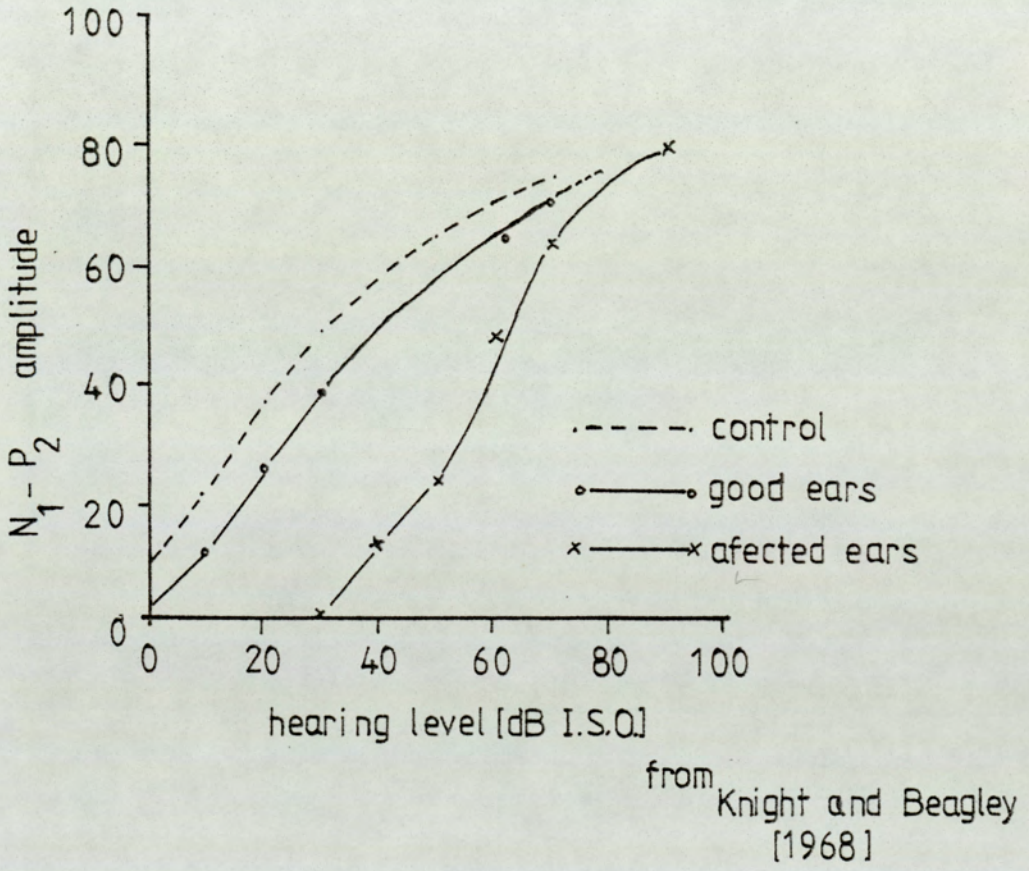


Fig 5.7.

Amplitude~intensity function of the vertex potential to a 1000Hz tone in six subjects with recruitment of loudness in one ear.

However, in view of the extreme variability in the amplitude of the vertex potential and in the slopes of individuals amplitude-intensity functions care should be taken in the application to the measurement of recruitment. It will undoubtedly be of greater use in cases of unilateral disorders where the non-recruiting ear may act as a control and remove the intersubject contribution to amplitude variability.

5.2.2. Disorders of Auditory Nerve and Brainstem.

Observations by Best and Tabor of disturbances in recovery functions in animals with different auditory disorders caused them to investigate the effects of analogous disorders in humans (1970). The recovery functions of hearing loss of conductive origin; in Menieres Disease; cochlear loss and possible VIII nerve tumours were compared with a group of normal controls. The recovery functions were measured to paired tones at interstimulus intervals of 200, 400, 600, 800 and 1000 m.secs. The recovery function was defined as the ratio of response amplitude of the second tone to that of a single stimulus. Differences in the recovery functions were observed in the various auditory disorders, but the small numbers of patients in some of the groups and the degree of overlap in recovery functions in the different disorders would limit its usefulness in clinical diagnosis.

5.3. Disorders of Speech and Language Development

Attempts have been made to discover different vertex potential characteristics in response to sound stimulation in children with speech and language problems (Beagley, 1971). It would obviously be an attractive prospect if the vertex potential could not only provide information regarding auditory thresholds for pure tones, but also provide some reflection of the comprehension of meaningful auditory material. Beagley investigated 22 children, 8 of which had simple deafness, 5 were partially hearing with an additional speech deficit and 11 had receptive aphasia (2 of developmental origin and 9 as a result of infection). Unfortunately, he found no evidence of evoked potential abnormalities in the group of receptive aphasics. However, the vertex potential still remains of considerable value in its ability to exclude the possibility of deafness in cases of aphasia.

5.4. Psychiatric Assessment

Schizophrenic and normal control subjects (n=21) were compared in their performance of an auditory evoked response task which required the detection of an infrequent auditory stimuli from amongst a train of more frequent stimuli (Roth and Cannon, 1972). P_2 and P300 components (to frequent and infrequent stimuli respectively) were compared and both were found to be much larger in the control group. The classification of subjects into normal

or schizophrenics groups on the basis of P300 amplitude was successful in 35 out of 42 subjects. However, these differences also correlated with the medication (chlorpromazine) used in the schizophrenic group. No changes in latency of response components was observed, and although the authors suggest that the amplitude reduction in the schizophrenic group may be due to decreased recovery functions, it seems more probable that the amplitude differences reflect not only the differences in medication, but also the differences in level of attention in both groups with increased variability in the schizophrenic group.

Significant differences in response latencies were reported by Itil, Hsu, Saletu and Mednicks (1974) in a group of children (n=31) at high risk for schizophrenia (schizophrenic parents) and a group of control children (n=50). The latencies were reported to be shorter in the high risk group.

A study by Ornitz et al. (1968) found differences in the sleep vertex potentials in normal and autistic children during REM sleep. Twenty-six normal children (19 months - 2 years) and 23 autistic (22 months - 8 years) were studied for a total of 52 nights.

They found that the normally occurring decrease in response amplitude during REM sleep was not as great in the autistic group as the normal controls. When REM sleep is further divided into tonic (ocular quiesence) and phasic stages (ocular activity) the reduction in vertex response ampli-

tude is seen to occur almost exclusively in the phasic REM stage. This decrease in amplitude was not present in the autistic group.

The decrease in response amplitude in phasic REM is generally related to the concept of phasic inhibition which is believed to be mediated through the vestibular nuclei. The authors conclude the lack of evidence of phasic inhibition during the ocular stage of REM sleep may be related to clinical observations in autistic children which are suggestive of vestibular dysfunction.

5.5. SUMMARY

The most important area of clinical application of the vertex potential is in the assessment of hearing in infants and young children. In such cases, the early diagnosis of an auditory deficit enables the maximum treatment and rehabilitation which is necessary to avoid impairements in language development and possible delays in emotional and intellectual retardation.

The vertex potential appears to provide a reliable measure of subjective hearing levels in children and adults with simple or straightforward hearing defects. This reliability decreases in infants in general and in both adults and children where there are additional mental or physical handicaps (see Table 5.8.).

TABLE 5.8 Summary of Subjective and Objective Threshold Differences in Adults and Children with Hearing Loss and Mental Handicap.

AUTHOR	n	% Subjects Subj. - Obj. difference dB 0	dB 10	dB 20	dB 30	Mean difference $\bar{x}$ dB	Range dB	
Cody, Bickford (1965)	20	38	94	100		+0.58	-15 to +10	Adult Hearing Loss
Beagley, Kellogg (1969)	36	30	95			+2.6	-20 to +30	
Rose, Keating et al. (1972)	50	16	69	89		+12.7*	-20 to +100	
Rose, Rittmanic (1968)	35	17	76	86			-10 to +30	Adult Hearing Loss and Mental Handicap
Shimizu (1970)	35			20°	48°			
Davis (1965) SL	60	32	86	98			-20 to +25	Children Hearing Loss.
PTA		12	74	98			-25 to +20	

* Sign not taken into account

° With reference to HL

A great deal of the present dissatisfaction with the reliability of the vertex potential in auditory assessment in young children stems from too great an initial expectation and the tendancy to generalise the findings of a co-operative adult population to a less co-operative clinical population.

However, the vertex potential still plays a vital part in the exclusion or detection of deafness as a contributory factor in retardation or behaviour disorders. Evidence of this is seen in many cases of handicapped children who are unable to respond behaviourally, but produce normal vertex potential thresholds. The vertex potential does not provide information regarding the processing and integration of auditory information received and thus may exclude the possibility of hearing loss in cases of aphasia and delays in language development.

The differentiation between a true hearing loss and one of psychogenic origin enables the correct method of therapy to be initiated.

Because of the increased variability of the vertex potential and greater discrepancy between subjective and objective thresholds in infants, great care should be taken in the interpretation of these recordings and hearing assessed only in broad terms of slight, moderate or severe hearing losses.

There still remains much controversy regarding the merits

and drawbacks of the various sedatives and their actions on the vertex potential. In the light of this evidence it would seem advisable to avoid sedation unless absolutely necessary.

As most adults are amenable to subjective audiological assessment, vertex response audiometry in this population deals mainly with cases of suspected psychogenic deafness and with noise induced deafness. An objective measure of auditory acuity is extremely useful in the latter group where the prospect of compensation often leads to somewhat exaggerated behavioural or subjective losses of auditory acuity.

5.6. Experimental Section

Vertex potentials were recorded in three experimental groups:-

i) Normal Young Adults
ii) Adults with known hearing defects
iii) Children with known hearing defects

Objective hearing thresholds were measured using the vertex potential and compared with subjective hearing levels. In addition, the effects of stimulus intensity and frequency on the characteristics of the vertex potential were also investigated in the group of normal adults.

5.6.1. Method

Subjects

i) Normal Young Adults

26 young adults, (17-24 years) with no known hearing defects were selected from amongst University Undergraduates and 6th form students from the local schools.

ii) Adults with known hearing defects

With the assistance of Mr. P.E. Robin, E.N.T. Consultant at Dudley Road Hospital, Birmingham, 22 of his patients

with known hearing defects were contacted and agreed to attend the Neuropsychology Unit for further investigations on a voluntary basis.

iii) Children with known hearing defects

The parents of 32 children who had recently attended either Birmingham Children's Hospital or the Aural Clinic were contacted, and 23 agreed to bring their children along for further investigations on a voluntary basis. The hearing thresholds of all the children had been satisfactorily assessed at one of the above clinics by subjective audiometry.

Equipment

The equipment and experiment procedure used in each investigation were similar.

The stimuli were pure tones generated by a Peters Audiometer. This had been modified by means of an interrupt circuit so that the onset of each tone burst was controlled externally by a trigger stimulus from the averager. The stimuli were relayed to the subject through TDH 39 Headphones.

EEG activity was recorded from the scalp by silver/silver chloride disc electrodes and monitored by an 8 channel SLE EEG machine.

The averaged evoked responses were recorded by a Computer of Average Transients (TMC, 400C), and a permanent record of each response was produced on an X-Y Plotter.

A Calibration System designed in the Unit (Lindley and Harding, 1974) was introduced into the recording system at the level of the EEG headbox.

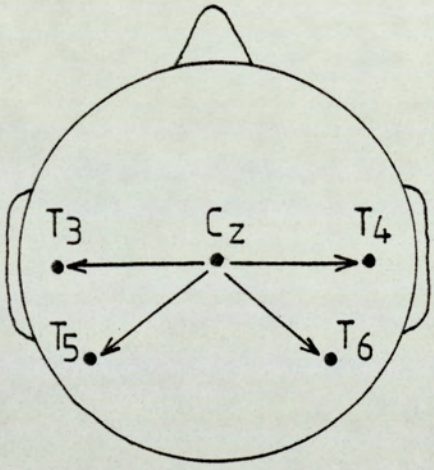


Fig 5 8
Montage for recording the slow vertex potential.

Procedure

Each subject was seated in a sound-damped room. Silver/silver chloride discs were attached to the scalp with collodium. The active recording electrode was placed at the vertex - C_z (according to the 10/20 system of electrode placement, Jasper, 1958) and referred to electrodes in both right and left mid and post-temporal regions, T_3,

T_4, T_5 and T_6. (see Figure 5.8.).

Temporal electrodes were used in preference to mastoids at this stage as they appeared to cause the patient less discomfort in conjunction with headphones and were also less susceptible to sweat artifact which often resulted from the pressure of the headphones. Comparison of the vertex responses using temporal and mastoid reference electrodes showed little difference in response amplitude and detectability. All electrode resistances were below 5Kohm. and the electrical activity was recorded on 4 channels of an 8 channel SLE EEG machine. The EEG machine was calibrated to 100uV./cm. and band-pass filters set at 0.5 to 25Hz.

Initially, all 4 EEG recording channels were fed onto the CAT and the two channels which produced the clearest evoked potentials and showed the least muscle artifact were then used throughout the investigation. Each evoked response average consisted of 32 or 64 sweeps (the number was held constant for each investigation) with an analysis time of 1000 m.secs. Using the two channels only of the CAT this produced a sample time of 5 m.secs. per data point.

The analysis sweep was internally triggered by the CAT, which in addition produced a second trigger pulse at its 20th address which was used to trigger the audiometer. This resulted in a 100 m.secs. pre-stimulus averaging and during this time a 5uV. calibration pulse of 20 m.secs. duration was introduced into the system. This calibration signal was again triggered by the CAT simultaneously with the onset of its analysis sweep. The calibration pulse was introduced into the system at the level of the EEG headbox at the vertex or C_Z electrode and thus appeared in all recording channels. (Lindley and Harding,1974).

This calibration pulse produced a standard signal which enabled response amplitude to be measured in terms of microvolts. It also produced an additional measure of the reliability of the recording system, in that if the 5uV. signal could not be detected in the resultant averaged response (possibly due to muscle or movement artifact) then the resultant evoked potential must also be considered to be suspect.

The stimuli were presented to each subject monaurally at frequencies of 250, 1000 and 4000Hz. Stimulus duration was 280 m.secs. with rise and fall times of 15 m.secs. Initial stimuli were presented at 60-80dBHL to establish a clear template for comparison with subsequent responses to lower intensity stimulation. Responses were initially recorded to a 1000Hz stimulus and the intensity for each subsequent average reduced in 20 or 10dB steps until

objective threshold was reached. Objective threshold was defined at the lowest intensity level at which an evoked response could be detected.

In cases where doubtful responses were recorded the response was repeated at the same intensity, this applied especially with near threshold responses where a response was identified as positive if detected on 2 out of 4 occasions.

In cases of possible hearing loss, if no response could be detected at 60-80dBHL, stimulus intensity was increased until the response threshold was found. Once objective thresholds had been satisfactorily obtained at stimulus frequency of 1000Hz the procedure was repeated at 250 and 4000Hz.

The assessment of objective thresholds to within a greater accuracy than 10dB was not attempted since this level of accuracy was considered adequate for most of the patients referred for evoked response audiometry. This is especially so for young and unco-operative children where subjective assessment has been unable to provide any satisfactory measure of auditory acuity.

In addition, the measurement of response threshold with a greater degree of accuracy would considerably increase the time of the investigation, a factor which is critical in young children. It was considered more important to

use the time available to test as many stimulus frequencies as possible to provide the Otologist with an objective audiogram similar to the subjective audiogram obtained with pure tone audiometry.

Each subject was present usually for approximately 1½ hours with a maximum of 2 hours. When time and the behavioural state of the subject permitted, evoked response thresholds were recorded for both ears independantly.

Each subject was given relatively few instructions to approximate as closely as possible to the clinical testing situation . The adults were asked to remain relatively still throughout each stimulus presentation and to avoid gross movement and EMG artifact. They were provided with reading material and asked to keep their eyes open and not to sleep. The young children were kept amused with books and games.

When possible, at the end of each evoked response investigation, a subjective audiogram was recorded from each subject under the same conditions by an independant experimenter. This was later used for comparison with thresholds obtained by evoked response audiometry. Not all the children tested would co-operate with subjective testing and in these cases previous or subsequent audiograms obtained at Birmingham Children's Hospital or the Aural Clinic were used for comparison.

A diagram of the apparatus and recording system is shown

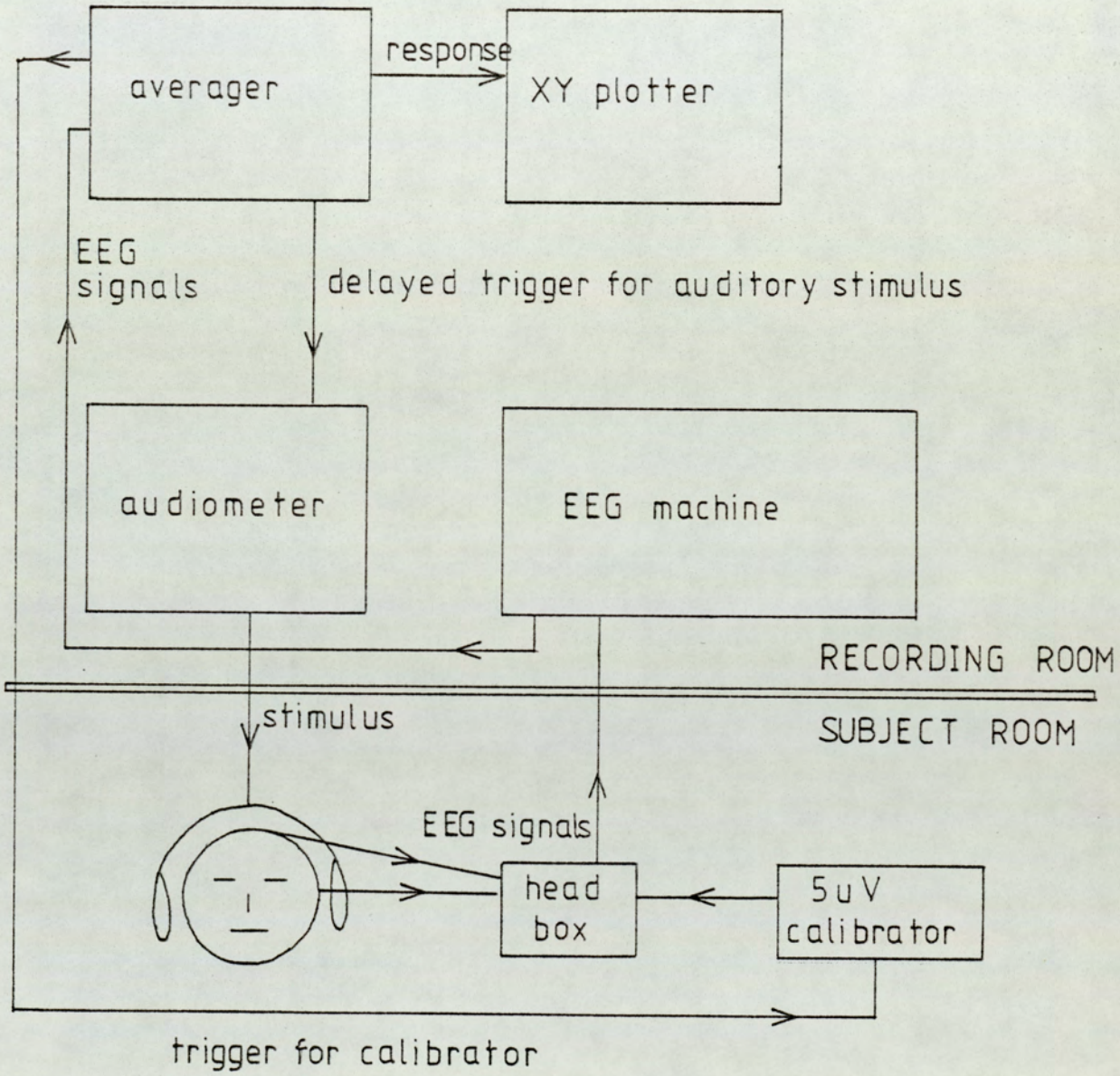


Fig. 5. 9.
Diagram of recording system for the slow vertex potential.

in Figure 5.9.

5.6.2. Results, Analysis and Discussion - for ease of comparison these have been divided into two main sections.

i) Normative Data

ii) Comparison of Subjective and Objective Hearing Thresholds.

All stimulus intensity levels are expressed in dBSL - that is relative to each subjects own sensation level or threshold of hearing.

5.6.2.1. Normative Data - the effects of stimulus intensity and frequency on the vertex response recorded in 26 normal young adults.

Results and Analysis

Measurement of the latencies and amplitudes of the components of the vertex potential were made from the permanent recordings of the X-Y Plotter. The latencies of components P_1, N_1, P_2 and N_2 and the peak-to-peak amplitudes of components P_1-N_1, N_1-P_2 and P_2-N_2 were measured. The amplitude measures were converted to microvolts by comparison with the standard 5uV. calibration pulse present on each individual evoked response recording.

a) The affects of stimulus intensity on the latencies of the components of the vertex potential.

The latencies of all the components P_1, N_1, P_2 and N_2 show a gradual increase with decreasing stimulus intensity. (Table 5.9. and Figures 5.10; 5.11 and 5.12). The absolute latency values of all components are comparable to those obtained in previous investigations (see Table 2.1.). The latency-intensity functions of response components P_1, N_1 and P_2 are fairly parallel showing a greater increase in latency at near threshold intensities. The N_2 component also increases in latency with decreasing stimulus intensity, but the exact form of this relationship tends to be obscured by the greater inter-subject variation in latency observed for this component.

The latency-intensity functions of the vertex response components show similar characteristics at stimulus frequencies of 250, 1000 and 4000Hz.

b) The affects of stimulus intensity on the amplitude of the vertex potential

The problems of amplitude measurement have been previously discussed (Chapter 3) and because of the difficulties of establishing a reliable baseline, peak-to-peak amplitude measures have been used of components P_1-N_1; N_1-P_2 and P_2-N_2. These peak-to-peak amplitude values were expressed firstly in terms of microvolts by comparison with the 5uV. calibration pulse and secondly, in an attempt to reduce the great inter subject variability in response amplitude, in terms of percent maximum amplitude over the three stimulus

FREQUENCY		4000 Hz				1000 Hz				250 Hz			
COMPONENTS		P1	N1	P2	N2	P1	N1	P2	N2	P1	N1	P2	N2
Intensity dBSL													
80	n	3	5	4	2	2	3	3	1				
	$\bar{x}$	30	102	173	272	42	98	161	255				
	SD	0	16	23	39	3	3	8					
70	n	7	9	9	8	6	8	6	6	4	7	7	7
	$\bar{x}$	34	101	176	259	32	103	188	268	40	102	176	293
	SD	16	9	30	36	26	35	46	20	11	9	17	21
60	n	8	12	13	10	8	11	10	8	4	5	4	2
	$\bar{x}$	49	109	177	277	37	99	166	291	49	104	161	325
	SD	13	13	21	22	13	12	14	41	13	14	20	35
50	n	12	18	18	12	13	18	18	14	6	13	13	10
	$\bar{x}$	51	110	182	284	34	98	179	282	56	116	182	299
	SD	17	17	24	57	12	13	32	33	25	11	22	28
40	n	7	17	16	8	11	17	18	14	7	11	10	8
	$\bar{x}$	56	128	202	301	46	112	187	271	53	120	187	274
	SD	15	20	38	50	13	14	30	84	16	19	24	33
30	n	16	21	20	13	10	21	20	16	5	15	14	11
	$\bar{x}$	57	129	191	276	45	113	198	297	58	136	186	303
	SD	16	20	24	36	20	16	31	50	16	29	44	34
20	n	11	20	18	12	11	23	23	13	9	19	17	11
	$\bar{x}$	74	139	209	332	65	125	203	314	60	129	209	294
	SD	12	15	39	59	8	20	34	51	22	40	35	32
10	n	16	25	19	10	11	21	19	13	6	16	13	11
	$\bar{x}$	62	142	220	317	62	139	225	320	79	152	228	319
	SD	19	17	46	51	21	28	30	57	20	20	39	47
0	n	10	14	11	5	5	15	12	4	6	13	11	7
	$\bar{x}$	113	190	285	354	99	160	239	326	94	200	258	359
	SD	20	28	59	61	33	22	38	77	48	38	59	65

$\bar{x}$ - ms.

TABLE 5.9. Mean Latencies and Standard Deviations of Components P1, N1, P2 and N2 of the Vertex Potential at Stimulus Intensities of 80 - 0 dBSL.

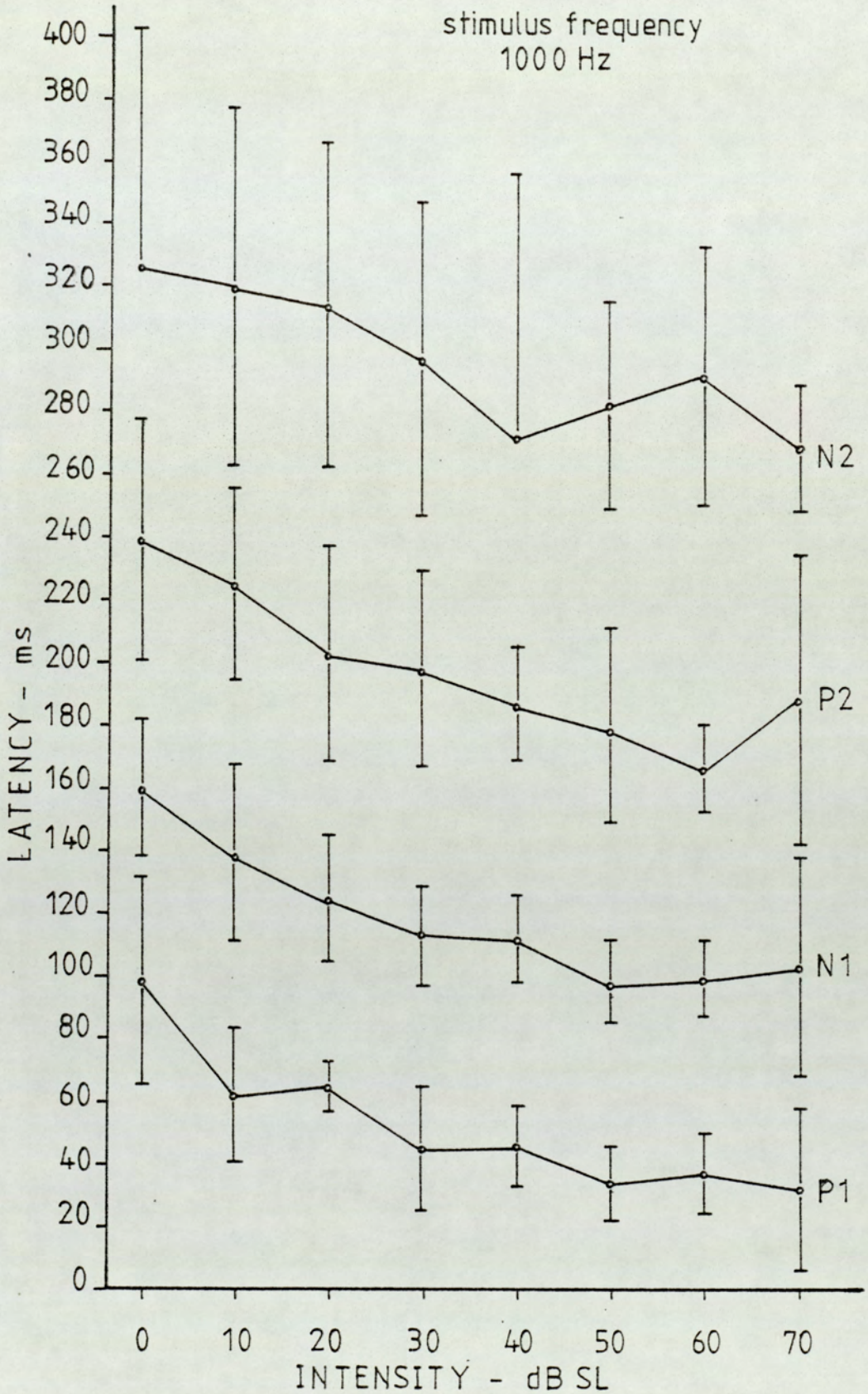


Fig 5.10.
Cortical Evoked Potential
Latency~intensity functions of components P1, N1, P2 and N2 at stimulus frequency of 1000Hz

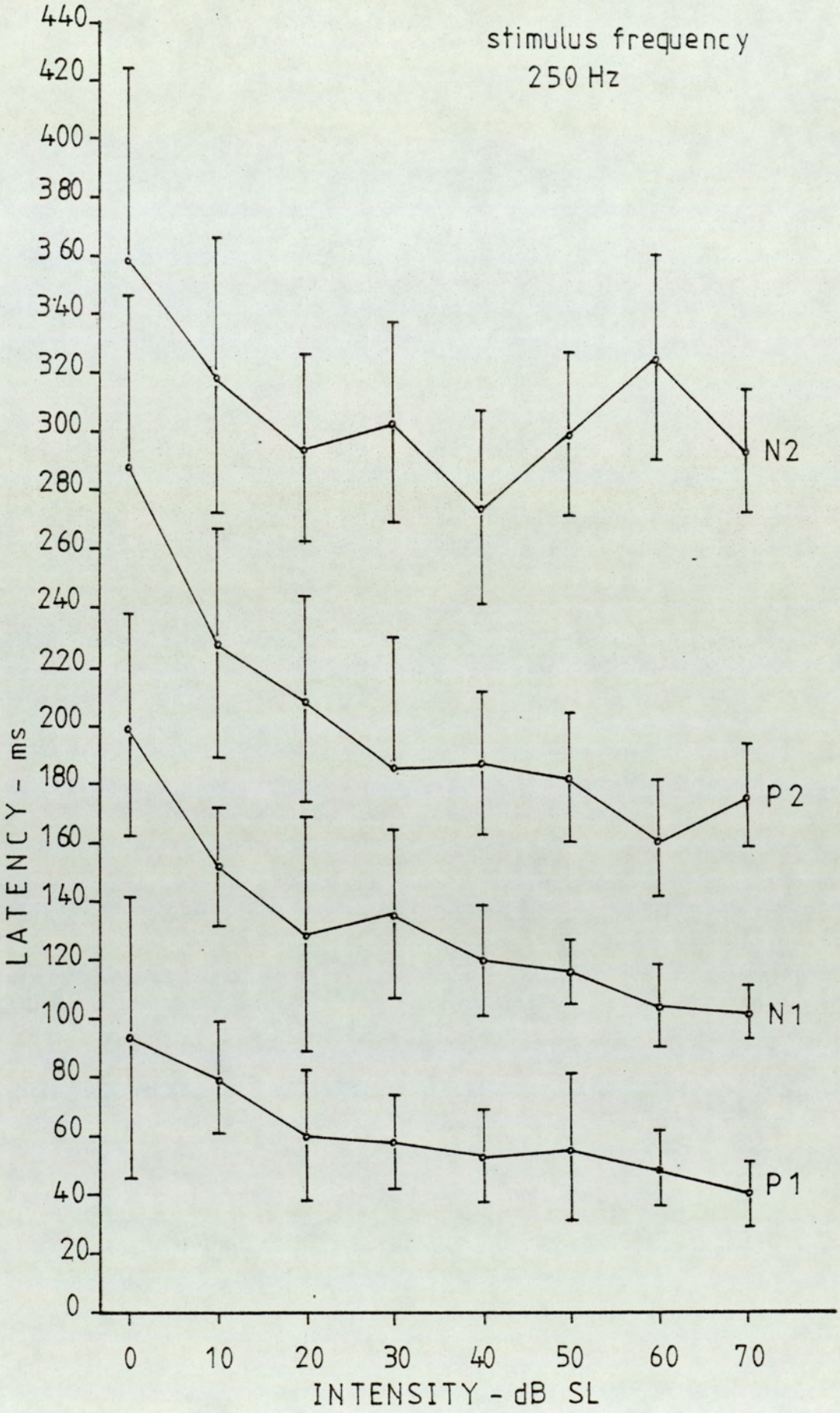


Fig. 5 11.
Latency~intensity functions of components P1,N1,P2 and N2 at a stimulus frequency of 250 Hz

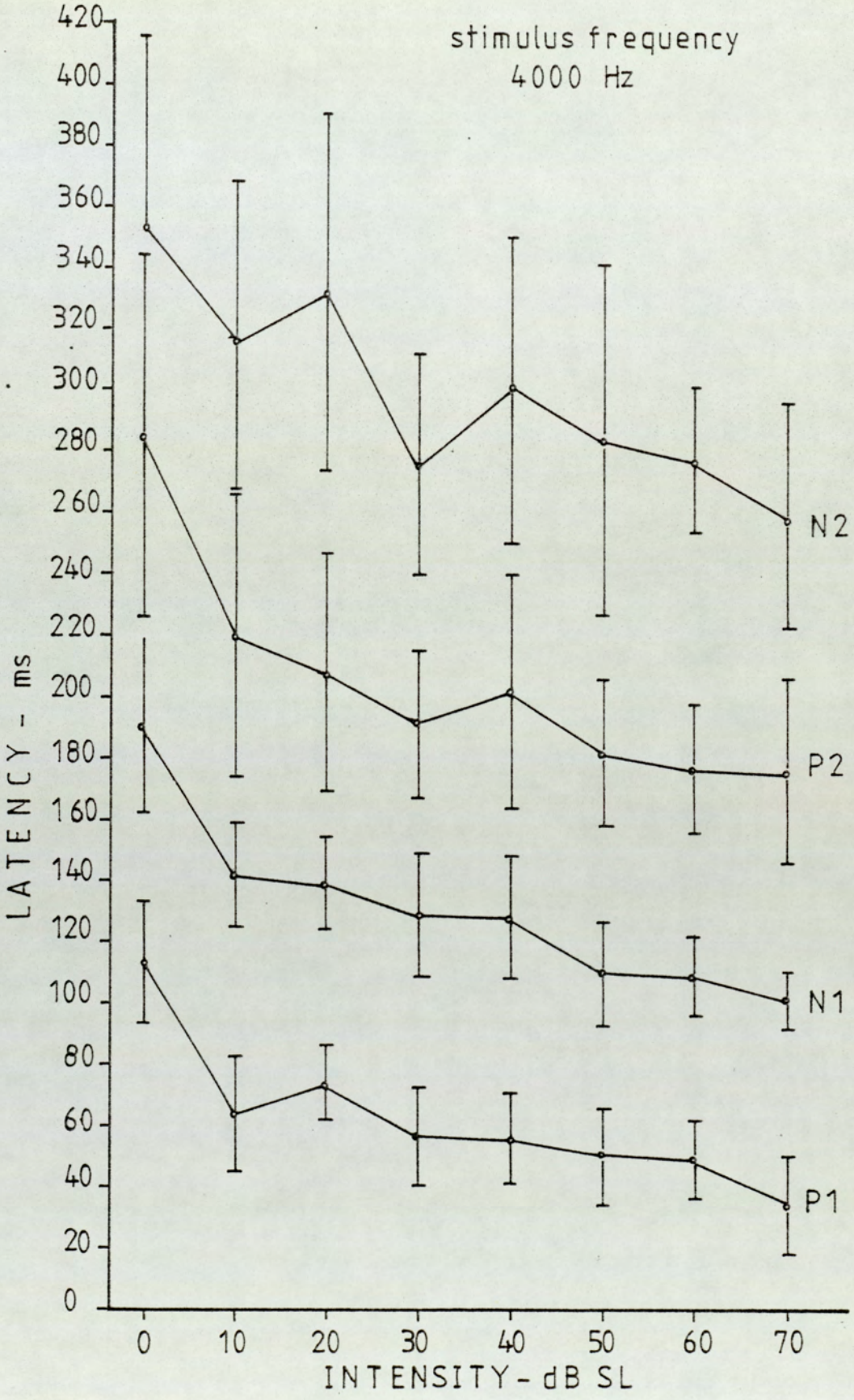


Fig. 5.12.
Latency–intensity functions of components P1, N1, P2 N2 at a stimulus frequency of 4000 Hz.

frequencies. The changes in amplitude with stimulus intensity expressed both in terms of microvolts and percent maximum amplitude are shown in Tables 5.10 and 5.11 and their amplitude-intensity functions in Figures 5.13 to 5.18.

The great variability in amplitudes of all the components across individuals in seen in the large values of the standard deviations in Tables 5.10 and 5.11. This inter-subject variability in response amplitude confirms the findings of most previous reports (Davis et al. 1966 and 1968). Examination of the amplitude-intensity functions expressed both in terms of microvolts and percent maximum amplitude shows that although response amplitude does increase with in-creasing stimulus intensity it does not appear to do so in a gradual uniform manner. This observation is probably a reflection of the considerable intra-subject variability in response amplitude.

c) The affects of stimulus frequency on the amplitude of the vertex response

In view of the considerable variability in response amplitude both within and across subjects, any observations regarding the affects of stimulus intensity on response amplitude may only be tentative. However, there is a tendancy of peak-to-peak amplitude measures expressed both in microvolts and percent maximum amplitude to be greater at a stimulus frequency of 250Hz and least at 4000Hz. These amplitude

STIMULUS FREQUENCY		4000 Hz			1000 Hz			250 Hz		
COMPONENTS		P1-N1	N1-P2	P2-N2	P1-N1	N1-P2	P2-N2	P1-N1	N1-P2	P2-N2
INTENSITY dB SL										
70	n	7	8	6	4	6	6	7	8	7
	x	18.9	18.4	10.7	12.6	20.2	21.2	27.9	27.6	18.7
	SD	7.4	7.3	3.5	6.7	16.7	8.0	10.3	9.9	4.8
60	n	7	9	5	8	9	7	2	3	2
	x	16.3	16.8	10.8	18.2	20.3	19.7	25.2	19.9	24.0
	SD	9.5	11.6	3.9	9.8	14.4	8.1	1.3	12.8	13.5
50	n	12	16	12	10	15	10	7	12	7
	x	9.6	10.8	9.6	16.9	16.7	15.6	22.6	23.7	18.8
	SD	5.7	6.9	7.4	9.1	11.0	9.2	11.2	17.2	12.1
40	n	9	13	7	11	18	11	7	9	8
	x	14.7	13.0	10.4	14.7	16.2	16.8	21.6	14.4	8.2
	SD	8.2	9.4	4.8	8.5	9.9	8.0	17.4	12.4	6.9
30	n	14	18	9	12	17	11	8	14	7
	x	11.9	10.1	8.5	16.9	17.2	13.1	20.4	19.2	14.3
	SD	6.1	7.6	5.2	14.9	16.8	10.8	11.5	12.9	6.3
20	n	10	15	7	13	21	8	11	18	14
	x	9.4	11.1	14.7	14.0	12.5	7.1	12.6	12.5	7.9
	SD	4.7	6.8	5.6	8.0	9.3	3.3	7.1	9.5	4.6
10	n	14	16	7	10	18	8	6	12	5
	x	11.3	10.6	7.8	12.1	10.7	10.0	13.7	11.3	11.0
	SD	5.4	7.7	3.9	14.5	11.4	7.5	8.9	9.1	1.5
0	n	4	4	1	3	12	2	1	5	2
	x	10.6	6.3	7.8	7.5	6.9	9.7	6.3	5.5	7.4
	SD	1.9	1.9		2.8	5.0	6.4		2.3	2.4

TABLE 5.10 Cortical Evoked Potentials.

The Effect of Stimulus Intensity on Peak to Peak Amplitudes of P1-N1; N1-P2 and P2-N2 Expressed in uVs.

STIMULUS FREQUENCY	4000 Hz			1000 Hz			250 Hz		
COMPONENTS	P1-N1	N1-P2	P2-N2	P1-N1	N1-P2	P2-N2	P1-N1	N2-P2	P2-N2
INTENSITY dBSL									
70 n	5	6	4	5	7	7	4	6	6
$\bar{x}$	60	58	39	66	69	73	77	85	69
SD	21	15	7	18	14	16	26	19	25
60 n	7	10	6	7	8	7	1	2	2
$\bar{x}$	54	58	49	66	71	69	88	93	100
SD	22	22	19	22	24	17			0
50 n	13	16	8	11	17	11	6	11	7
$\bar{x}$	50	47	48	63	74	71	71	70	56
SD	27	22	30	17	18	20	15	25	33
40 n	9	15	5	9	14	9	6	8	6
$\bar{x}$	60	49	39	79	82	84	89	83	57
SD	29	22	7	23	23	19	17	27	33
30 n	14	18	9	12	19	11	8	14	7
$\bar{x}$	59	52	51	65	68	60	68	67	47
SD	27	25	18	23	23	26	24	27	18
20 n	9	15	8	11	20	9	10	19	13
$\bar{x}$	46	54	47	63	54	66	71	55	49
SD	23	22	14	25	21	27	22	22	22
10 n	17	17	8	10	17	6	8	16	6
$\bar{x}$	50	44	45	59	54	59	68	42	27
SD	22	14	24	27	22	23	22	20	13
0 n	7	8	2	5	13	2	4	6	2
$\bar{x}$	53	41	48	45	35	46	38	45	55
SD	13	13	19	24	12	7	3	19	13

TABLE 5.11 Cortical Evoked Potentials.

The Effects of Intensity on Peak to Peak Amplitudes of P1-N1; N1-P2; P2-N2; expressed as Percentage Maximum Amplitude.

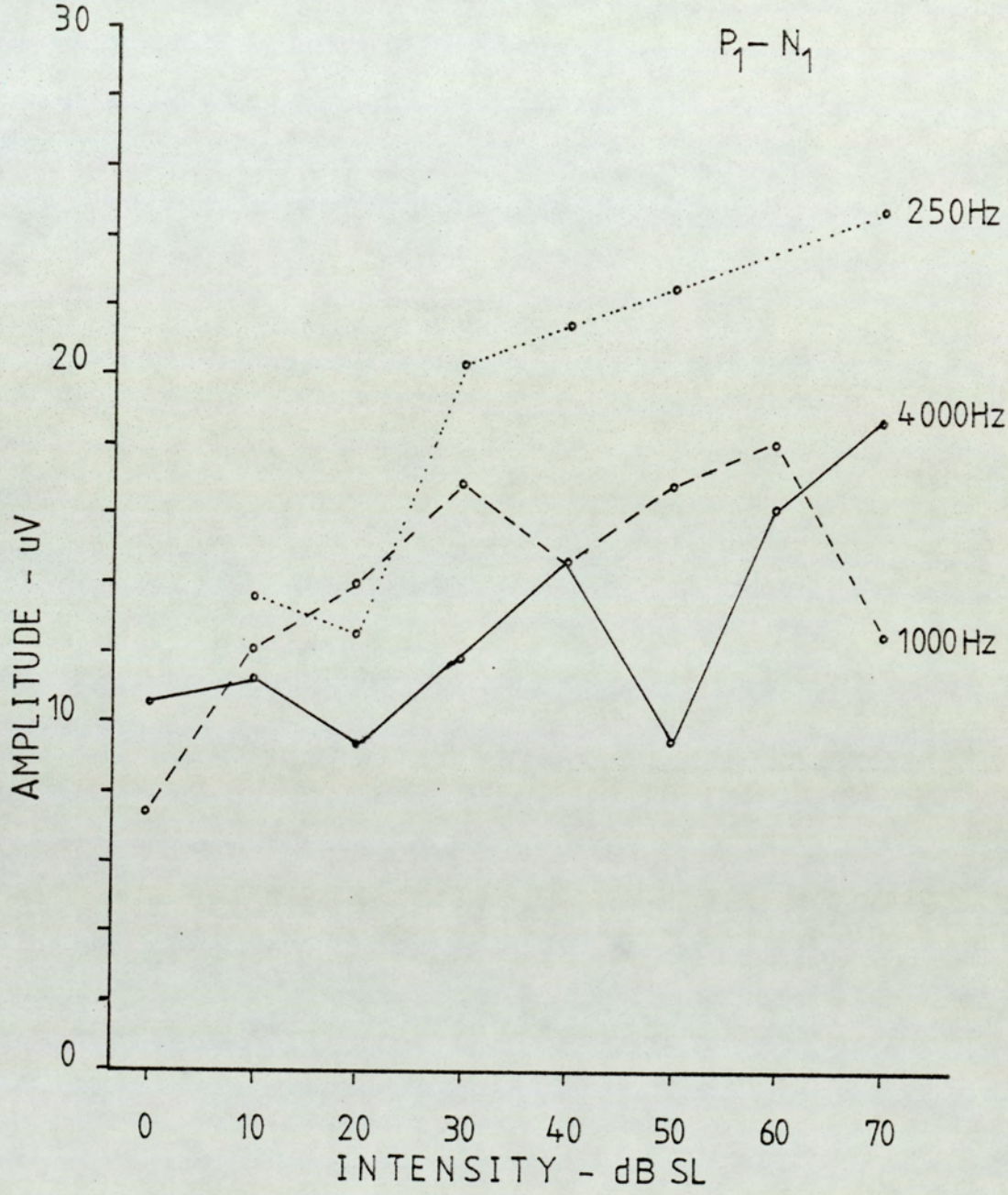


Fig.5.13.
Amplitude~intensity functions of the P1–N1 components at stimulus frequencies of 250 1000 and 4000 Hz.

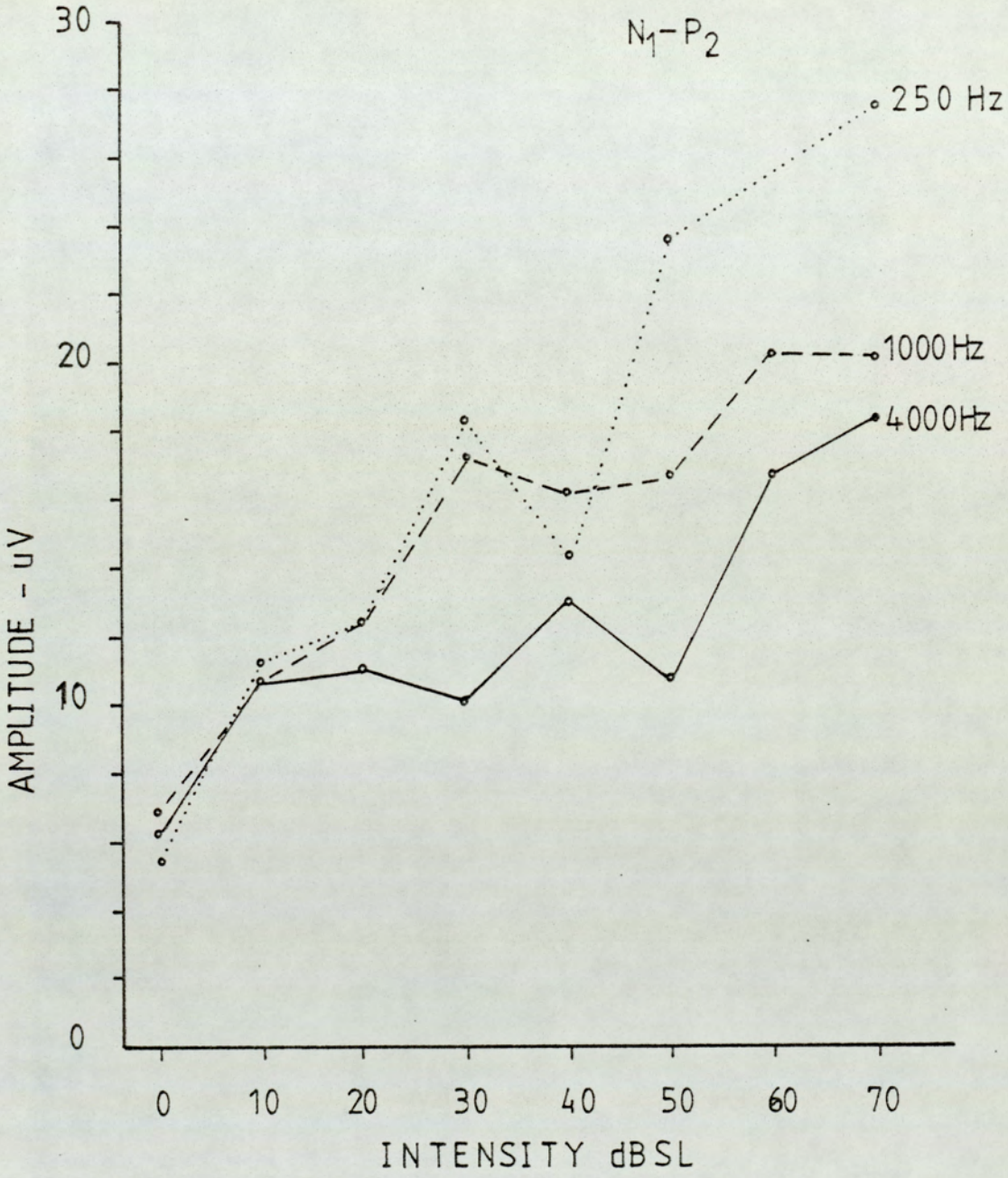


Fig. 5. 14.

Amplitude~intensity functions of N1-P2 components at stimulus frequencies of 250 1000 and 4000 Hz.

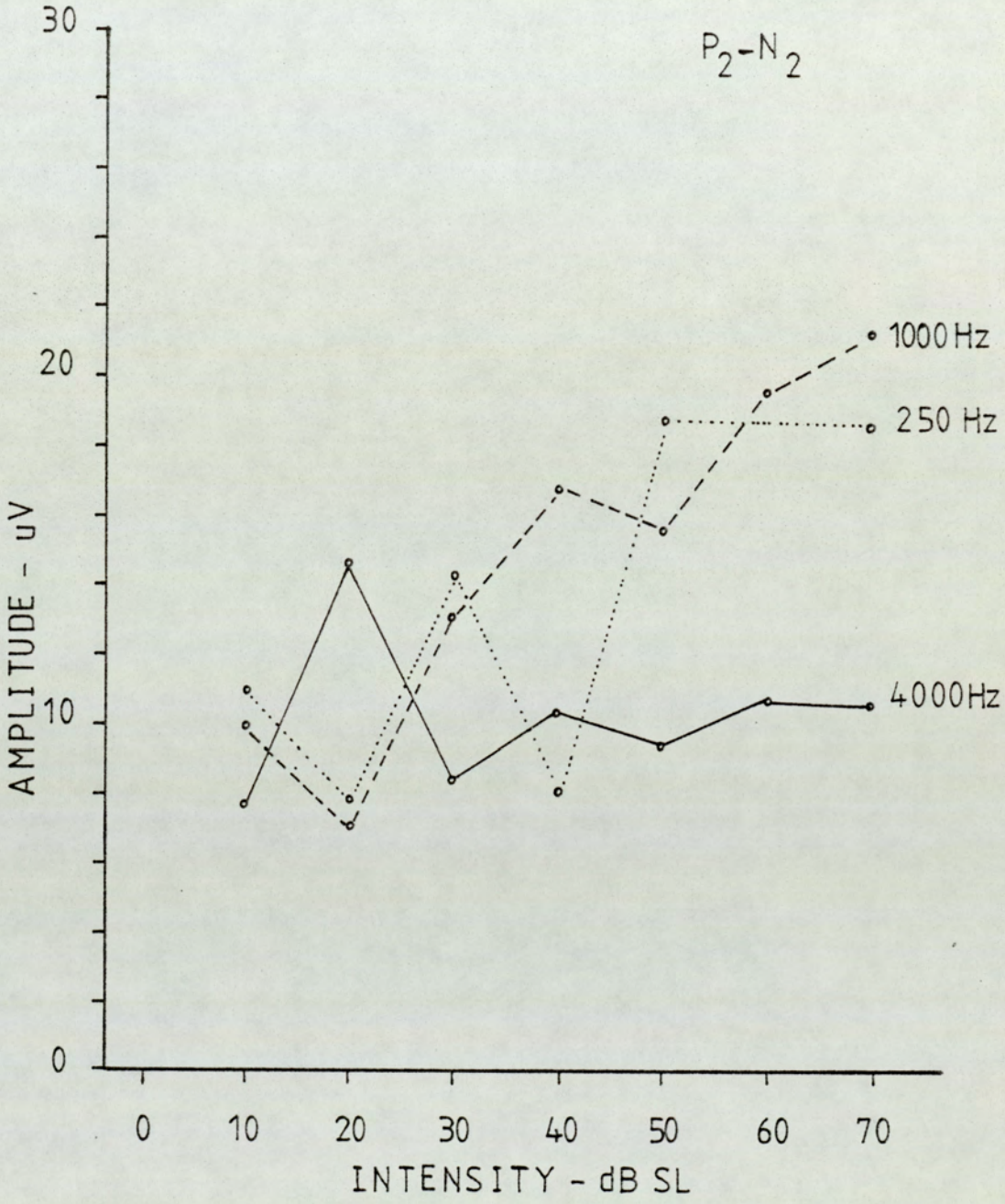


Fig. 5. 15.
Amplitude~intensity functions of components P2–N2 at stimulus frequencies of 250,1000 and 4000 Hz.

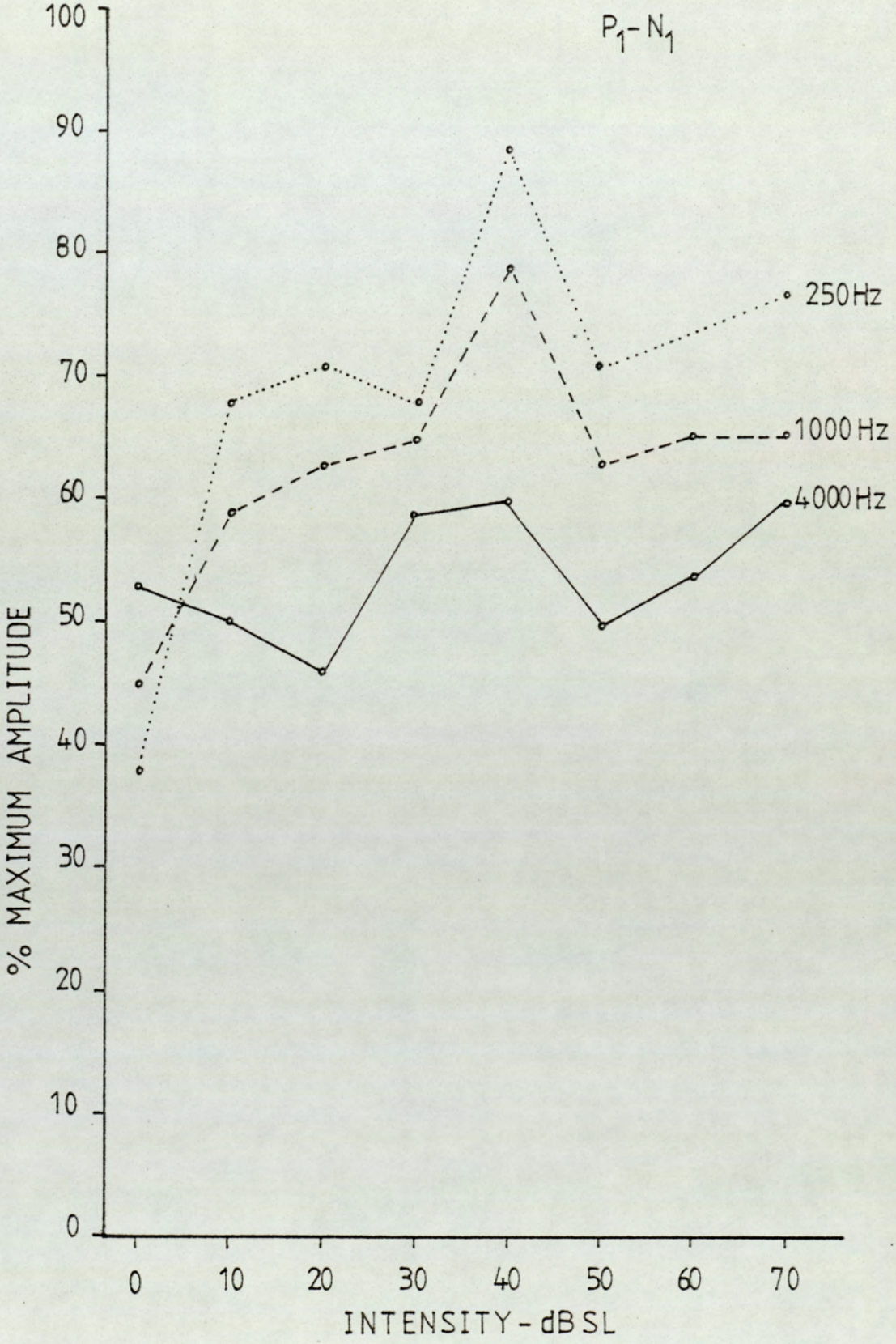


Fig. 5.16.
Amplitude intensity functions of P1–N1 components at stimulus frequencies of 250, 1000 and 4000 Hz.

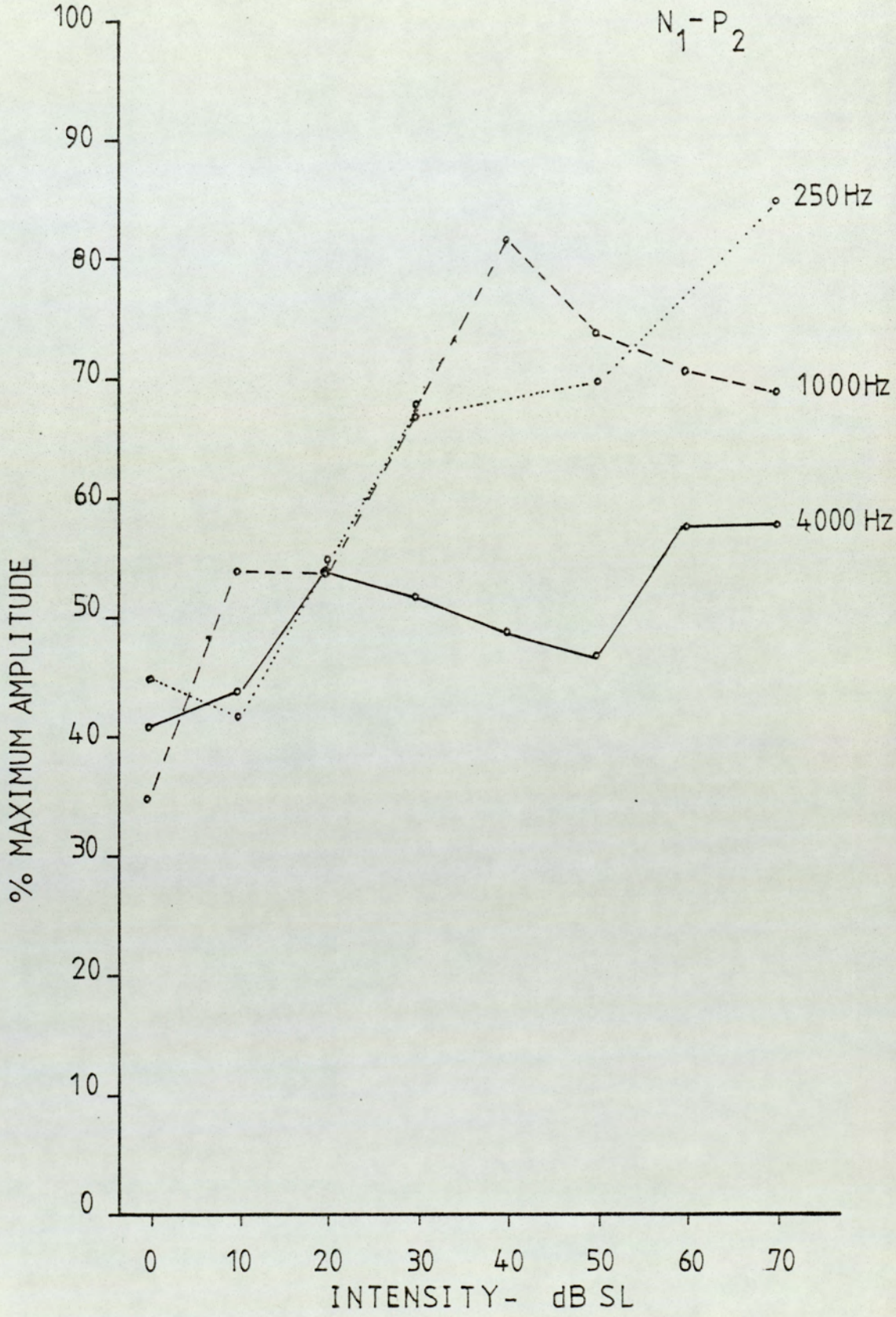


Fig. 5.17.
Amplitude intensity functions of components N1–P2 at stimulus frequencies of 250, 1000 and 4000 Hz.

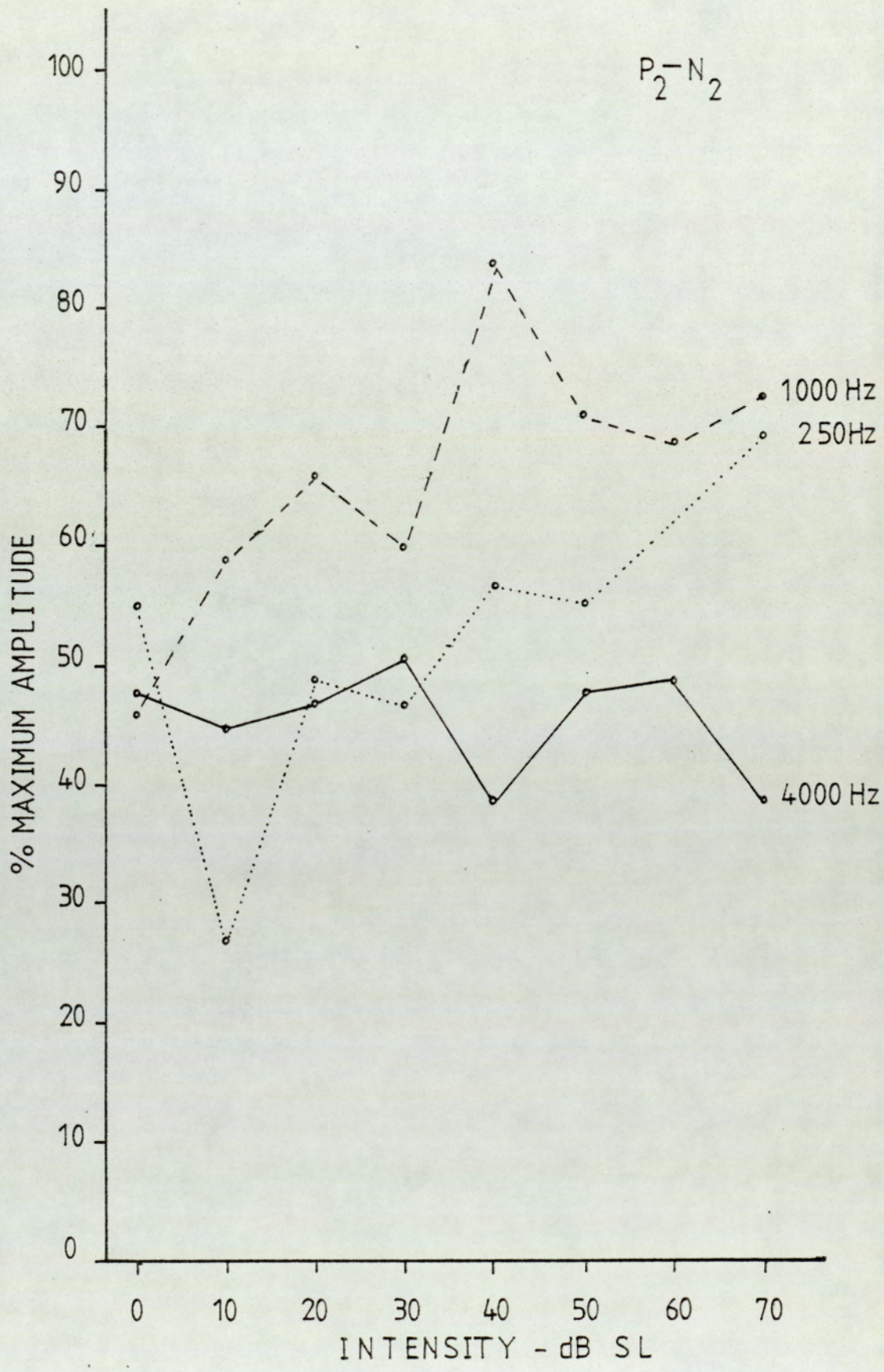


Fig. 5.18.
Amplitude intensity functions of P2-N2 components at stimulus frequencies of 250, 1000 and 4000Hz.

differences are more marked at higher sensation levels and result in steeper amplitude-intensity functions at frequencies of 250 and 1000Hz than for 4000Hz which (taking into the account the response variability) shows least variation with stimulus intensity.

In an attempt to clarify the effect of stimulus frequency on the amplitude of the vertex response components, the differences in percent maximum amplitude were measured between the three stimulus frequencies (Table 5.12). These are shown as a function of intensity in Figure 5.19. Again, there is considerable variation in these amplitude differences both across subjects and with stimulus intensity, but stimulus frequencies of 1000 and 250Hz appear to produce consistently larger amplitude responses than 4000Hz. The difference in response amplitude between 250 and 1000Hz appear to vary with the response component measured.

Discussion

The lengthening of response latencies with decreasing stimulus intensity confirm the findings of previous investigators (Davis et al. 1966 and Rapin et al. 1966). These changes in latency which are more marked at near threshold levels may be of value in the determination of objective threshold or at least provide an indication of when threshold is being approached. The similar latency-intensity functions observed at stimulus frequencies of 250, 1000 and 4000Hz indicates that this latency change

STIMULUS FREQUENCY	250 - 1000 Hz			1000 - 4000 Hz			250 - 4000 Hz		
COMPONENTS	P1-N1	N1-P2	P2-N2	P1-N1	N1-P2	P2-N2	P1-N1	N1-P2	P2-N2
INTENSITY dBSL									
70 n	3	6	6	3	3			2	
$\bar{x}$	-9	+15	+1	+6	0			+41	
SD	29	22	25	28	17			23	
60 n				4	5	4			
$\bar{x}$				-6	-15	-18			
SD				19	20	30			
50 n	4	7	4	6	10	6	3	6	2
$\bar{x}$	+16	+5	-38	+19	+40	+13	+22	+37	-16
SD	11	36	30	36	43	37	26	26	7.0
40 n	3	4	2	4	8	2	4	5	2
$\bar{x}$	+3	-17	-9	+37	+23	+30	+41	+15	-4
SD	50	46	25	53	33	10	23	39	21
30 n	7	9	4	11	14	5	7	16	2
$\bar{x}$	0	-12	-13	+2	+11	+15	-4	+7	+3
SD	35	39	38	16	17	14	46	45	24
20 n	7	14	8	4	14	5	4	9	6
$\bar{x}$	+1	+2	-5	+21	+2	+9	+27	+7	+5
SD	34	36	37	15	33	18	19	30	33
10 n	3	8	2	7	9	4	6	10	3
$\bar{x}$	-45	-6	-29	+23	+15	+17	+8	-7	-1
SD	12	20	3	29	26	17	26	11	9

TABLE 5.12 Differences in Percent Maximum Amplitude of Peak to Peak Amplitudes of P1-N1; N1-P2 and P2-N2 at Stimulus Frequencies of 250, 1000 and 4000Hz.

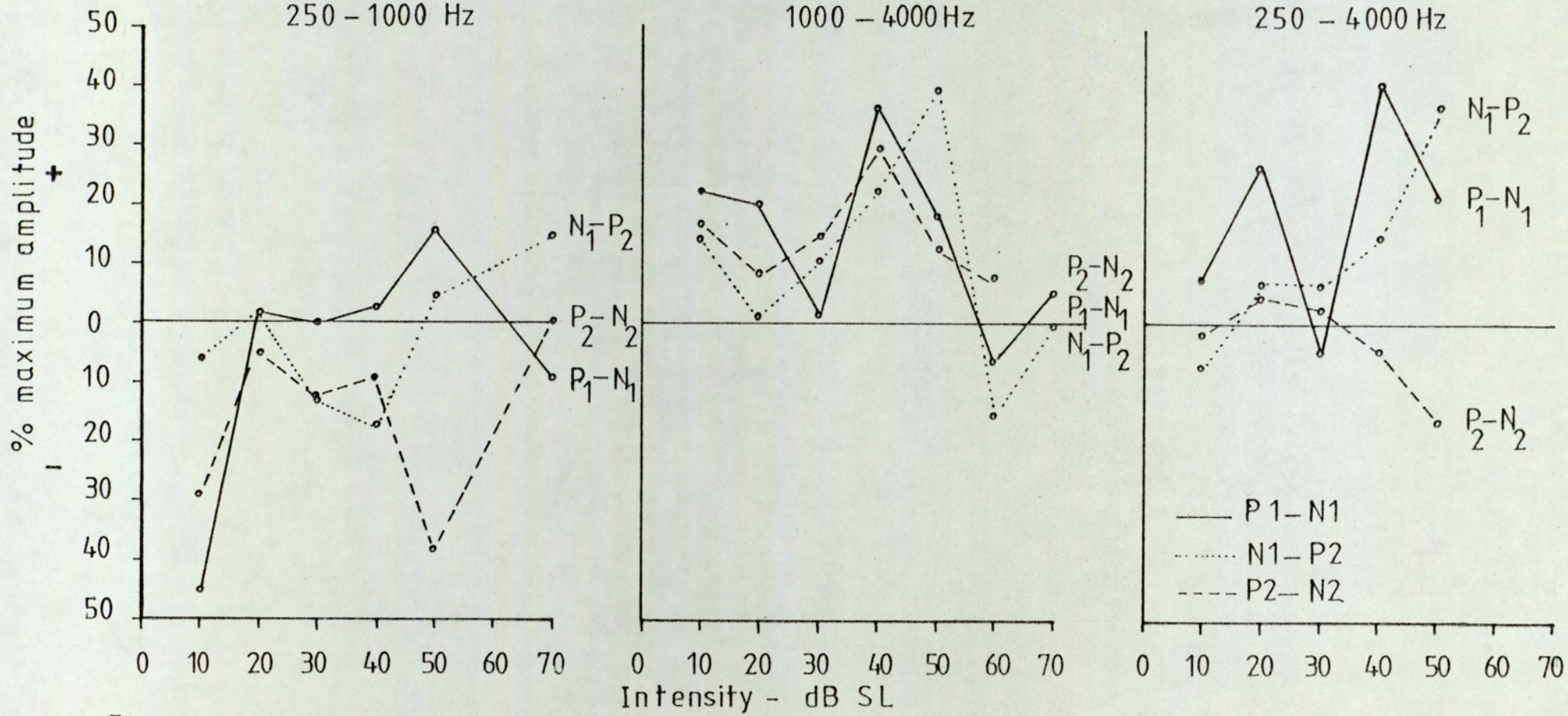


Fig. 5.19.
Differences in % maximum amplitude over stimulus frequencies of 250, 1000 and 4000 Hz.

with intensity may be applied in the establishment of objective threshold at all stimulus frequencies and does not necessitate the development of different latency-intensity criteria for each frequency.

However, when applying this criterion of more marked increases in response latency at near threshold intensities the reports of Knight et al.1968 and Uziel et al. 1978 should be borne in mind. They provide evidence that the amplitude intensity functions (and thus possibly the latency-intensity function) may be dependant on the type of hearing defect, that is, whether of conductive or sensori-neural origin. In the case of the latter, if recruitment is present both latency and amplitude-intensity functions may depart significantly from the norm.

The considerable inter-subject variab-ility in response latency of all components makes it impossible to deduce a direct estimate of the subjective hearing thresholds of a patient directly from the standard latency-intensity function obtained from a group of normal individuals. Even if inter-subject variability in latency of response was reduced the flatness of the latency-intensity function especially at higher sensation levels would also prevent an accurate assessment of hearing thresholds.

The amplitude data arising from this investigation sheds very little light on the relationship between response amplitude and stimulus intensity, other than to indicate that response amplitude increases with increasing stimulus

intensity at least at stimulus frequencies of 250 and 1000Hz. It confirms both the inter and intra-subject variability in amplitude reported by most previous investigators (Chapter 3). It also tentatively supports the observations of Antinoro and Skinner (1968) of a decrease in response amplitude and a less steep amplitude-intensity function with increasing stimulus frequency.

Since the decrease in response amplitude with decreasing stimulus intensity is an important criterion in the detection of threshold responses then this change in amplitude-intensity function with frequency may result in less reliable estimates of auditory evoked response thresholds at higher stimulus frequencies such as 4000Hz.

The method of data collection used in this experiment has no doubt contributed to some extent to the variability in response amplitude as a function of stimulus intensity. Ideally, each subject used in the study should be represented at each intensity level from 0-70dBSL, but as intensity was reduced in 20 or 10dB steps and then ultimately expressed in terms of sensation level, this did not occur. Thus, because of the considerable inter-subject variability in amplitude and the relatively small numbers of subjects investigated the failure for each subject to produce amplitude data at all sensation levels may effectively obscure any clear relationship of response amplitude with stimulus intensity.

Another factor which appears to contribute to the variability in response amplitude as a function of sensation level is the background EEG activity. Although the subjects remained fully alert throughout the investigation and no gross changes in EEG pattern occurred, the effects of background EEG activity on the amplitude of an added response can be seen by examination of the amplitude of the 5uV. calibration pulse. The amplitude of this signal varied considerably with each individual evoked response run, and on some occasions was not even detectable. Thus, if the evoked potential is also considered as an added response (although it may not be exactly reproducible in terms of amplitude and latency in response to each stimulus repetition) then it seems reasonable to assume that ongoing changes in background EEG activity will also considerably influence the resultant amplitude of the vertex potential and thus contribute to its variability.

5.6.2.2. Comparison of Subjective and Objective Auditory Thresholds.

Results and Analysis

Objective threshold was defined as the lowest stimulus intensity at which a vertex response could be detected (to within 10dB). The criteria available as an aid to the identification of objective threshold levels were described in Chapter 4 Section 4.3.5. The most useful of these criteria were found to be:-

a) the use of a response template so that the configuration of the vertex potential could be clearly established.

b) the observations of a reduction in response amplitude and lengthening in latency which are most apparent at or near threshold intensities.

c) the use of multichannel recording - if a response was present in both channels it reliability was increased.

d) the increase in the number of individual evoked responses obtained at each intensity at near threshold values.

e) Finally, it was extremely important to monitor the background EEG to assess its contribution to the reliability and detecting an evoked potential. Factors such as EMG artifact, movement artifact or alpha rhythm may effectively obscure evoked potentials to low intensity stimuli and so affect the difference between subjective and objective threshold estimates.

Objective response thresholds were determined on-line at the time of the investigation and later re-assessed off-time in greater detail. They were then compared where possible

with the subjective hearing thresholds measured under the same experimental conditions, otherwise with the most recent subjective audiogram available.

Group i) Normal Young Adults (n=23)

Subjective and objective hearing thresholds were compared in 23 normal young adults. Both subjective and objective thresholds and their difference are shown in Table 5.13. The difference in subjective and objective thresholds was calculated by subtracting the subjective threshold measure from the objective threshold measure. Thus, when the objective threshold was greater or less sensitive than subjective audiometry (which is usually the case) then the subjective and objective threshold difference was positive, and when the objective threshold was lower or more sensitive than subjective assessment then a negative difference was obtained. Such a negative difference is known as a false positive.

The mean value and standard deviation of the difference between subjective and objective thresholds was calculated for each of the three stimulus frequencies. These are shown in Table 5.14.

The distribution of subjective and objective threshold differences is seen in Figure 5.20. At all stimulus frequencies the distributions are narrow with the same subjective and objective thresholds in 81% at 250Hz; 70%

TABLE 5.13

Comparison of Subjective (S) and Objective (O) Hearing Thresholds in 23 Normal Adults.

STIMULUS FREQUENCY								
250Hz			1000Hz			4000Hz		
dBHL			dBHL			dBHL		
O	S	O-S	O	S	O-S	O	S	O-S
40	40	0	20	30	-10	5	10	-5
20	20	0	15	15	0	20	10	+10
20	5	+15	40	30	+10	10	10	0
20	20	0	10	10	0	10	0	+10
40	40	0	20	20	0	5	5	0
40	40	0	20	20	0	10	10	0
20	20	0	20	20	0	0	0	0
50	40	+10	20	20	0	5	5	0
-	-	-	20	20	0	-	-	-
50	40	+10	20	10	+10	5	10	-5
0	0	0	0	0	0	0	0	0
40	40	0	20	20	0	10	10	0
10	10	0	10	0	+10	0	0	0
20	10	+10	10	0	+10	10	10	0
10	10	0	20	10	+10	0	0	0
40	40	0	20	20	0	10	10	0
30	30	0	20	20	0	20	20	0
30	30	0	10	10	0	10	10	0
10	10	0	10	10	0	10	20	-10
-	-	-	10	10	0	0	0	0
20	20	0	20	20	0	20	10	+10
10	10	0	30	20	+10	0	10	-10
30	30	0	10	10	0	20	20	0

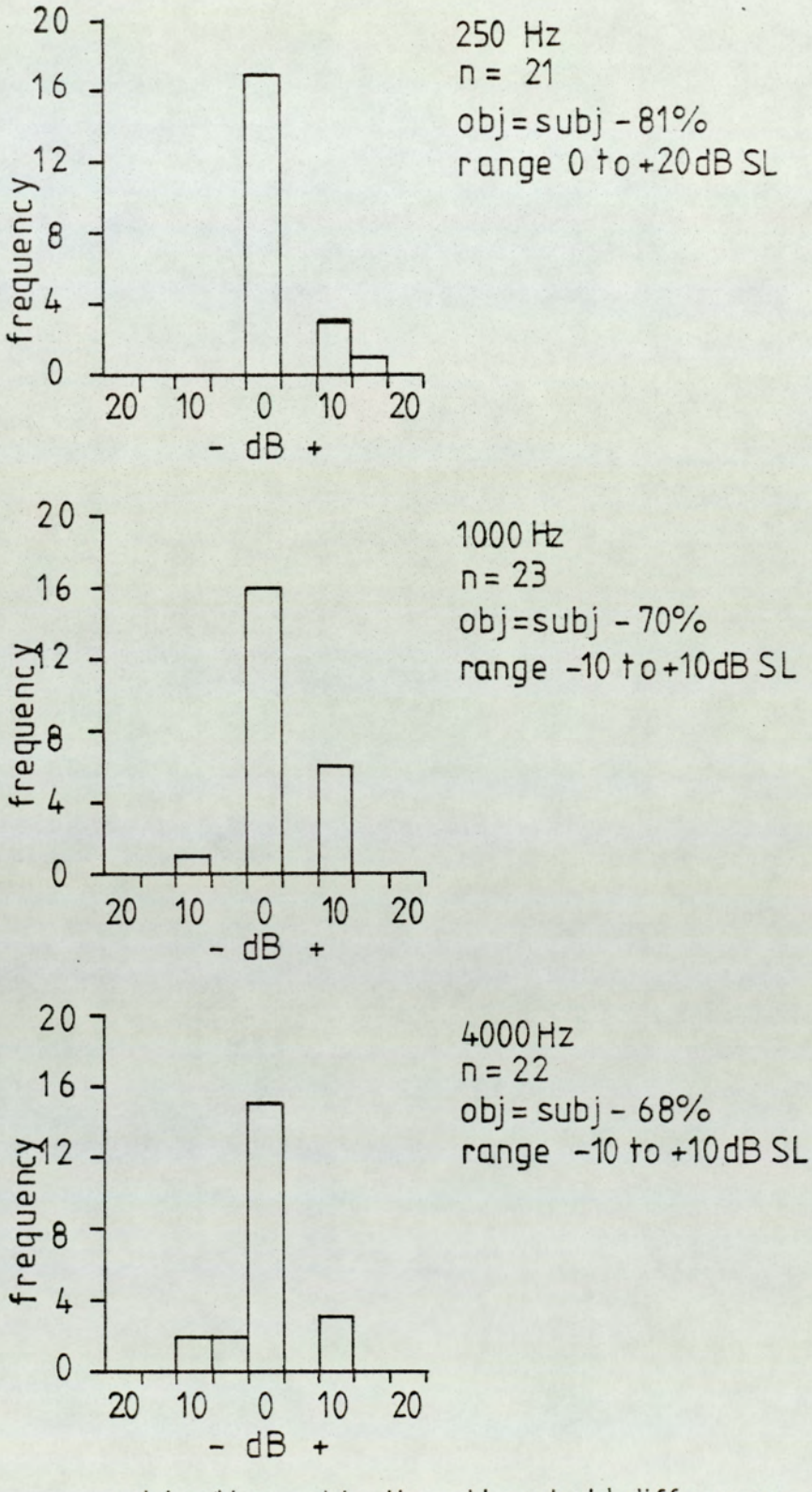


Fig. 5.20.

Frequency histogram of subjective and objective threshold differences in 23 normal adults at stimulus frequencies of 250, 1000 and 4000 Hz.
Vertical axis – number of subjects.
Horizontal axis – subjective objective threshold difference.
[+] objective less sensitive, [-] subjective less sensitive.

	Stimulus Frequency Hz		
	250	1000	4000
n	21	23	22
$\bar{X}$	2.14	2.17	0
S.D.	4.63	5.18	5.11

Table 5.14. Mean Values and Standard Deviations of Subjective and Objective Threshold Differences at Stimulus Frequencies 250Hz, 1000Hz and 4000Hz.

at 1000Hz and 68% at 4000Hz. The ranges of differences were 0 to +20dBSL; -10 to +10dBSL and -10 to +10dBSL respectively.

Group ii) Adults with Known Hearing Defects (n=22)

In this group of 22 adults there was sufficient time in most cases for objective thresholds to be measured independantly in both right and left ears. The subjective and objective thresholds and their difference are shown in Table 5.15 for both ears separately.

The main differences in subjective and objective thresholds and their standard deviations are illustrated in Table 5.15 for each ear separately and for both ears combined.

The distribution of subjective and objective threshold

TABLE 15. Comparison of Subjective (S) and Objective (O) Hearing Thresholds in 22 Adults with known Hearing Defects.

RIGHT EAR									LEFT EAR									
250Hz			1000Hz			4000Hz			250Hz			1000Hz			4000Hz			
dBHL			dBHL			dBHL			dBHL			dBHL			dBHL			
O	S	O-S	O	S	O-S	O	S	O-S	O	S	O-S	O	S	O-S	O	S	O-S	Subject
40	45	-5	40	35	+5	50	40	+10	50	65	-15	50	55	-5	70	70	0	H.J.
60	50	+10	70	60	+10	70	60	+10	30	25	+5	20	15	+5	30	15	+15	V.S.
50	55	-5	50	60	-10	40	60	-20	30	80	-50	↓	85	-	60	95	-35*	E.C.
30	30	0	30	30	0	40	40	0	30	25	+5	20	20	0	20	25	-5	D.G.
50	45	+5	40	30	+10	40	35	+5	50	95	-45	50	75	-25	80	90	-10	A.H.
90	80	+10	80	80	0	-	70	-	40	35	+5	30	30	0	40	40	0	E.W.
40	45	-5	40	35	+5	40	35	+5	50	50	0	40	25	+15	40	40	0	C.H.
20	20	0	20	15	+5	20	10	+10	-	-	-	-	-	-	-	-	-	T.K.
40	25	+15	30	15	+15	30	10	+20	60	40	+20	30	30	0	30	35	-5	C.W.
-	85	-	80	70	+10	-	↓	-	70	85	-15	50	45	+5	70		-*	E.J.
-	55	-	60	50	+10	50	40	+10	40	55	-15	30	40	-10	30	30	0+	L.D.
-	65	-	70	60	+10	50	65	-15	20	30	-10	20	20	0	10	20	-10	J.M.
50	40	+10	40	25	+15	30	15	+15	90	75	+15	70	60	+10	70	65	+5	A.K.
30	25	+5	30	20	+10	60	45	+15	20	30	-10	20	20	0	20	15	+5	D.M.
40	40	0	50	40	+10	30	20	+10	80	65	+15	80	70	+10	50	70	-20	P.B.
40	40	0	30	30	0	80	35	+45	-	80	-	80	70	+10	-	75	-	R.H.
10	30	-20	20	35	-15	20	30	-10	30	30	0	40	35	-5	40	45	-5*	K.F.
60	55	+5	50	55	-5	70	60	+10	-	70	-	-	55	-	-	80	-*	M.H.
40	50	-10	30	40	-10	50	45	+5	-	90	-	70	100	-30	-	110	-	R.G.
30	25	+5	30	25	+5	30	30	0	10	40	-30	30	30	0	30	30	0	T.H.
50	50	0	60	50	+10	40	40	0	40	30	+10	30	25	+5	10	40	-30 °	E.M.
30	25	+5	30	25	+5	20	20	0	40	60	-20	40	50	-10	40	40	0	W.M.

* persistent rhythmic alpha activity made objective threshold determination difficult.

\+ thresholds difficult to determine.

° tinnitus at 4000Hz in left ear.

	Ear Stimulated	Stimulus Frequency Hz		
		250	1000	4000
n	Right	19	22	20
$\bar{x}$		+1.31	+4.32	+6.25
S.D.		8.13	8.21	13.56
n	Left	18	19	17
$\bar{x}$		-6.94	-0.79	-5.59
S.D.		19.64	11.46	12.61
n	Combined	37	41	37
$\bar{x}$		-0.27	+1.95	+0.67
S.D.		15.25	10.05	13.85

Table 5.16. Mean values and standard deviations of subjective and objective threshold differences in 22 adults with known hearing defects.

differences for each ear is shown in Figure 5.21, and for both ears combined in Figure 5.22. The same subjective and objective thresholds were obtained in 19% at 250Hz, in 22% at 1000Hz and 27% at 4000Hz. 67% of objective thresholds were within 10dB of subjective assessment at 250Hz; 85% at 1000Hz and 73% at 4000Hz.

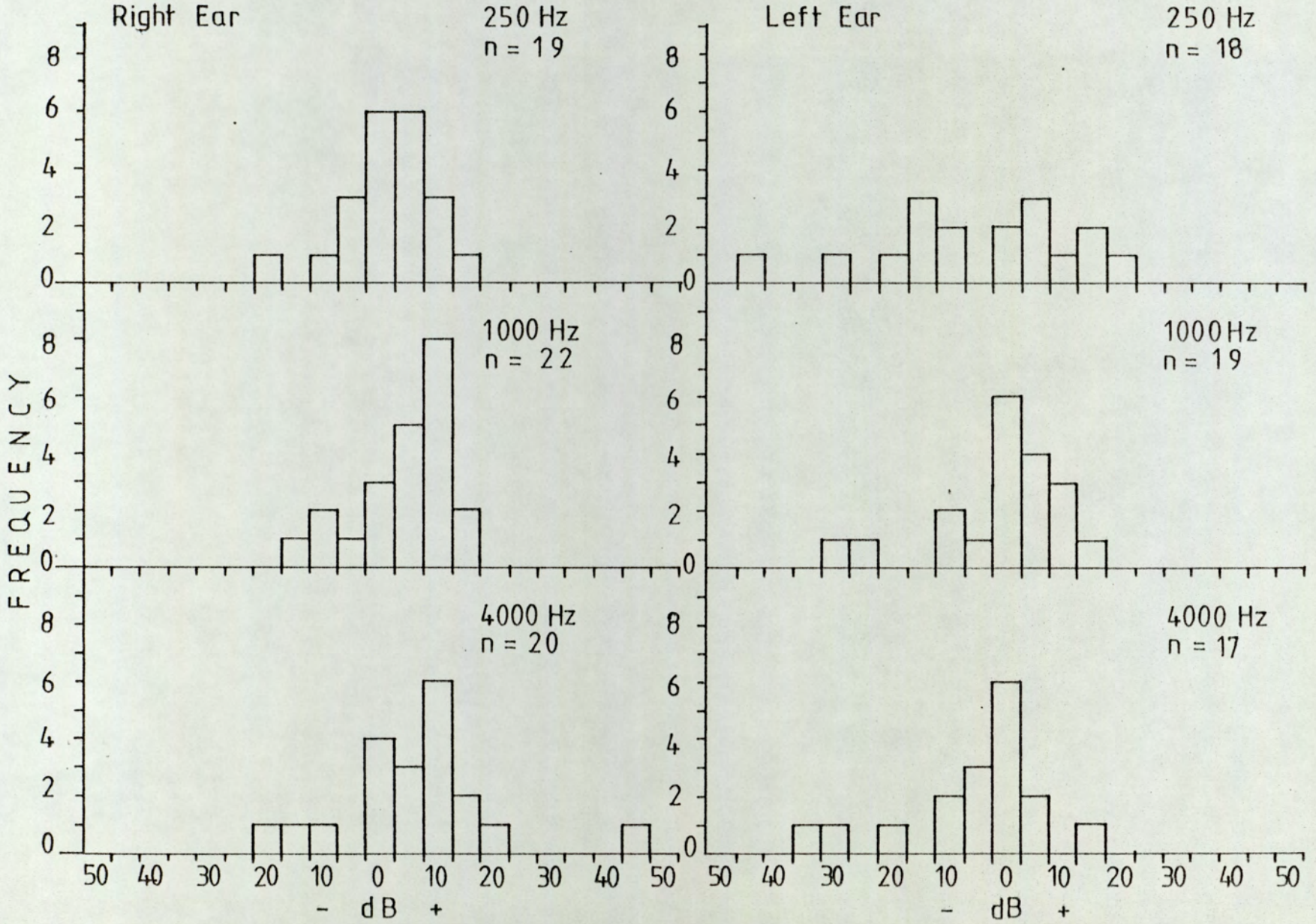


Fig. 5.21. subjective - objective threshold difference dB SL

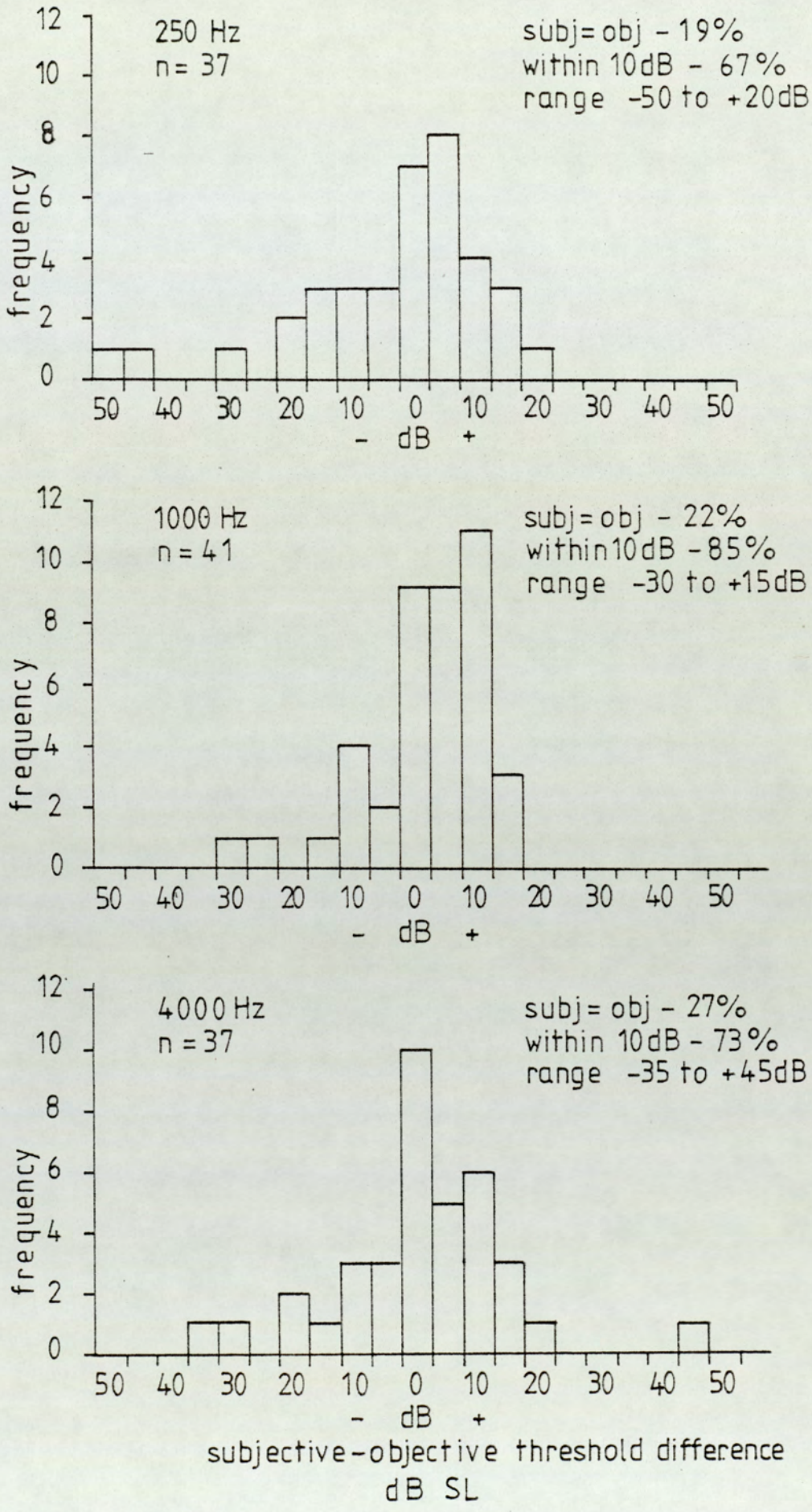


Fig 5. 22. (also 5.21.)
Distribution of subjective and objective threshold differences in 22 adults with known hearing defects.

Group iii) Children with Known Hearing Defects (n=20)

Objective thresholds were compared when possible with subjective threshold measured within the Unit, but when this was not possible (not all the children would co-operate) then objective thresholds were compared with the most recent subjective audiogram recorded either at the Children's Hospital or The Aural Clinic. In some children the most recent audiogram was obtained 1 to 4 years previous to the evoked response investigation. In these cases repeat subjective assessment was carried out at the Children's Hospital in those who were agreeable. The subjective and objective thresholds obtained and their differences are shown in Table 5.17 and the mean values and standard deviations of these differences in Table 5.18.

	Stimulus Frequency Hz		
	250	1000	4000
n	21	25	23
$\bar{x}$	+8.80	0	+1.30
S.D.	10.11	14.96	8.42

Table 5.18. Mean Values and Standard Deviations of Subjective and Objective Threshold Differences in 20 Children with Known Hearing Defects.

The distribution of subjective and objective threshold

STIMULUS FREQUENCY									
250 Hz			1000 Hz			4000 Hz			
O	S	O-S	O	S	O-S	O	S	O-S	
50	50	0	20	45	-25	20	15	+15	L.H.
50	45	+5	70	75	-5	60	75	-15	S.H.
50	35	+15	80	80	0	70	75	-5	D.J.
40	20	+20	70	80	-10	100	100	0	A.H.
-	-	-	30	20	+10	-	-	-	C.H.
50	50	0	50	40	+10	40	50	-10	K.C.
50	30	+20	60	90	-30	60	65	-5	B.A.
40	30	+10	30	25	+5	20	30	-10	B.A.
20	10	+10	30	20	+10	60	50	+10	A.R.
20	5	+15	30	10	+20	30	30	0	G.C.
90	85	+5	100	100	0	100	100	0	M.P.
70	45	+25	90	75	+15	60	55	+5	M.B.
-	60		70	65	+5	60	65	-5	M.B.
40	25	+15	60	35	+25	65	50	+10	A.B.
-	-	-	50	45	+5	-	-	-	A.B.
10	5	+5	10	10	0	60	50	+10	K.G.
40	45	-5	40	65	-25	70	65	+5	P.A.
-	45	-	50	65	-15	70	60	+10	P.A.
90	80	+10	90	80	+10	90	90	0	S.B.
90	70	+20	100	90	+10	100	100	0	S.B.
30	40	-10	50	80	-30	80	75	+5	M.D.
20	25	-5	20	20	0	30	10	+20	S.P.
50	30	+20	30	20	+10	30	40	-10	A.A.
30	15	+15	80	85	-5	100	100	0	J.H.
20	25	-5	80	75	+5	100	90	+10	A.S.

TABLE 5.17

Comparison of Subjective (S) and Objective (O) Hearing Thresholds in 20 Children with Known Hearing Defects.

differences is shown in Figure 5.23. The same subjective and objective thresholds were obtained in only 9% at 250Hz, in 16% at 1000Hz and in 26% at 4000Hz. At 250Hz, 57% of objective thresholds were within 10dB of subjective assessment, with 68% within 10dB at 1000Hz and 91% at 4000Hz.

Discussion

Comparative data from three experimental groups is presented in Figure 5.24 and Table 5.19. In the group of normal adults the same subjective and objective thresholds were recorded in 81% at 250Hz, 70% at 1000Hz and in 68% at 4000Hz. In comparison, the group of adults with known hearing losses showed a decrease in the number of subjects with the same subjective and objective thresholds with only 19% at 250Hz, 22% at 1000Hz and 27% at 4000Hz. In the majority of these subjects objective thresholds were within 10dB of subjective assessment (67% at 250Hz, 85% at 1000Hz and 73% at 4000Hz). The final group of children with known hearing defects were the most difficult to assess. The same subjective and objective thresholds were obtained in only 9% at 250Hz, in 16% at 1000Hz and in 26% at 4000Hz with 57% within 10dB at 250Hz, 68% at 1000Hz and 91% at 4000Hz.

Thus, the vertex potential provided the closest and most reliable measure of subjective hearing levels in the group of normal adults. In this group the distribution of

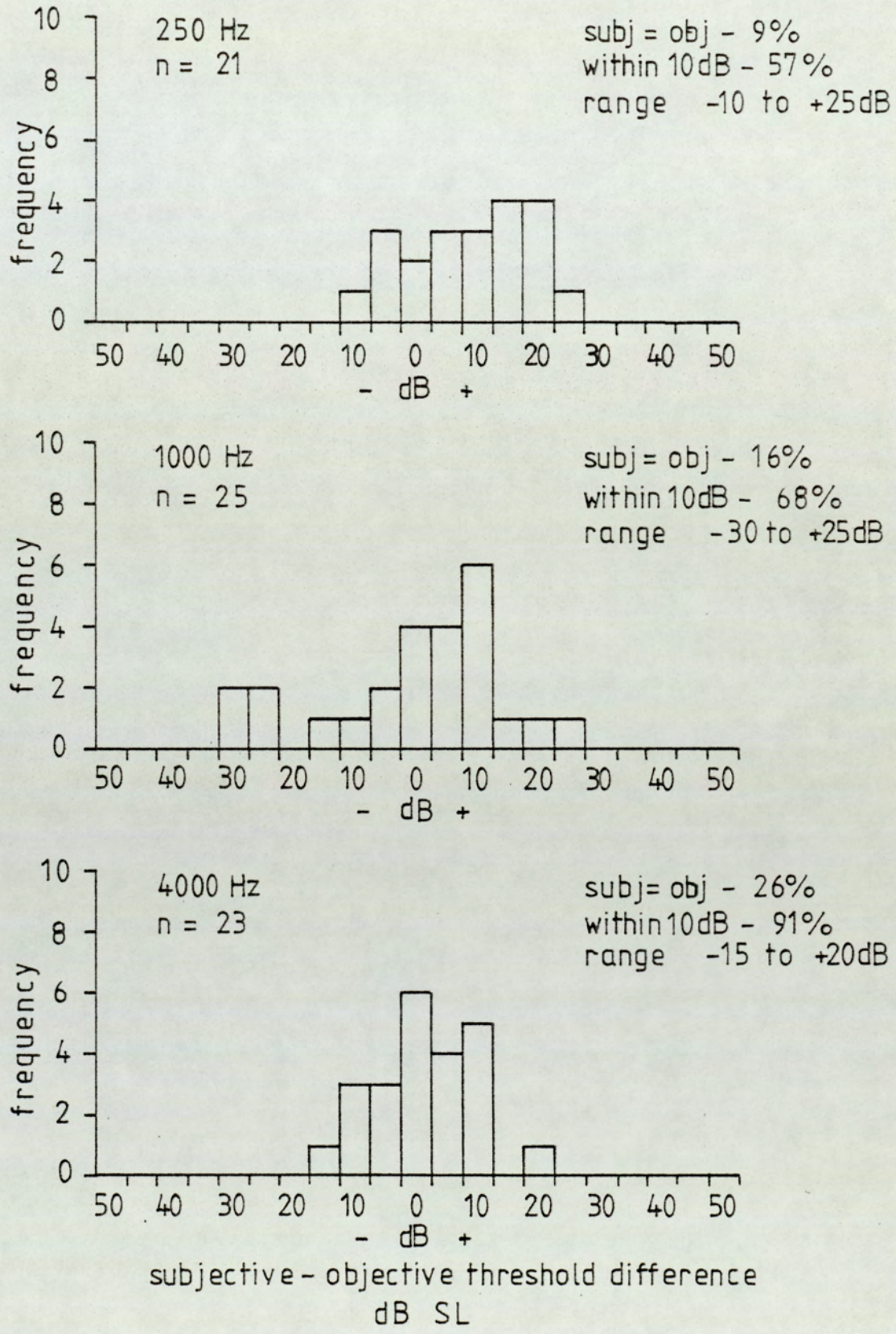


Fig. 5. 23.
Distributions of subjective and objective threshold differences in 23 children with known hearing defects.

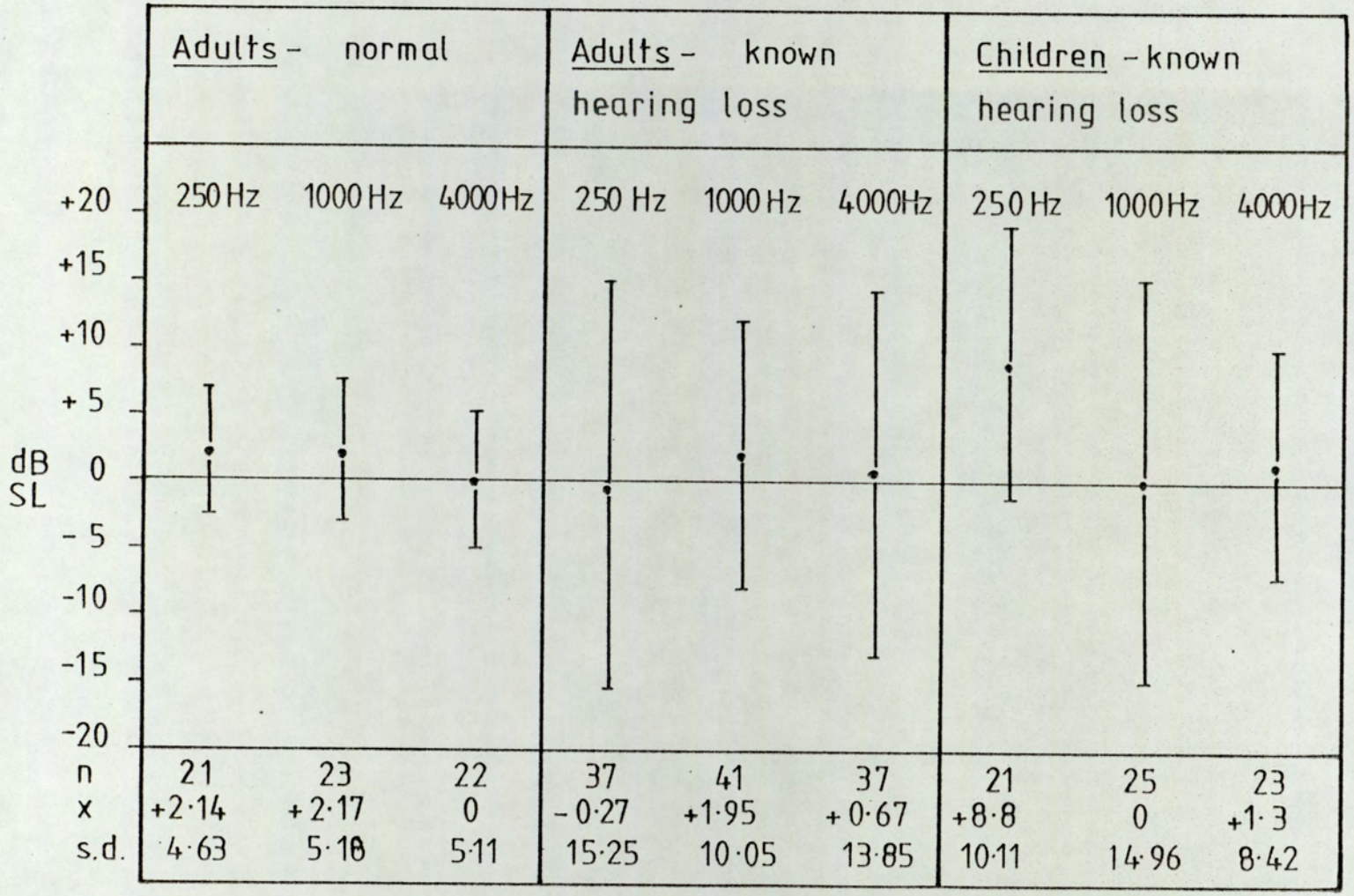


Fig. 5. 24.

Mean values and standard deviations of subjective and objective threshold differences.

GROUP	STIMULUS FREQUENCY Hz.	S = 0 %	WITHIN 10dB %	RANGE dBSL
Normal Adults	250	81	95	0 to +20
	1000	70	100	-10 to +10
	4000	68	100	-10 to +10
Adults - Known Defects	250	19	67	-50 to +20
	1000	22	85	-30 to +15
	4000	27	73	-35 to +45
Children - Known Defects	250	9	57	-10 to +25
	1000	16	68	-30 to +25
	4000	26	91	-15 to +20

TABLE 5.19

Summary of Results of Subjective and Objective Threshold Differences in Normal Adults and in Adults and Children with Known Hearing Defects.

subjective and objective threshold differences was narrow with a clear peak value at OdBSL (Figure 5.20.). The adult known hearing loss group produced a much wider distribution of subjective and objective threshold differences extending from -50 to +45dBSL.with peak differences occurring between 0 and +10dBSL (Figures 5.21 and 5.22.). The vertex potential was least efficient in the group of children where the distribution of subjective and objective threshold differences was again broad with no clear peak values (Figure 2.23).

The decrease in efficiency of the vertex potential in subjective assessment in the group of children as compared with the normal adult group was as expected, and may be attributed to several factors which will be discussed below. However, the fairly large differences observed between the normal and hearing loss adult groups with much greater variability in subjective and objective threshold differences in the latter group was not expected.

The difference in the two adult groups may be to a certain degree be magnified by the occurence of experimenter bias in the normal control group.

The expectation of normal hearing thresholds may often cause a doubtful response that occurs to a stimulus at or near normal hearing thresholds to be judged as positive. Whereas in the case of a suspected hearing loss, with

unknown subjective hearing thresholds, such a response would be more likely to be judged as absent in order to avoid the possibility of false positive responses, which would have more serious consequences in terms of subsequent patient management than the occurence of a false negative result.

Evidence of experimenter bias in their group of normal controls was presented by Beagley and Kellogg (1969).

There was no possibility of experimenter bias in the group of adult hearing defects as the evoked potentials were recorded and assessed without the knowledge of their subjective hearing levels. It is difficult to account for some of the wide discrepancies in subjective and objective assessment. In a number of these cases, however, it was possible to predict in which subjects such discrepancies would occur. The subjects in which it was difficult to establish satisfactory objective thresholds are shown in Table 5.15. In most of these cases the difficulties were due to large amounts of rhythmic background activity, usually alpha activity which was present even when the subject was fairly alert.

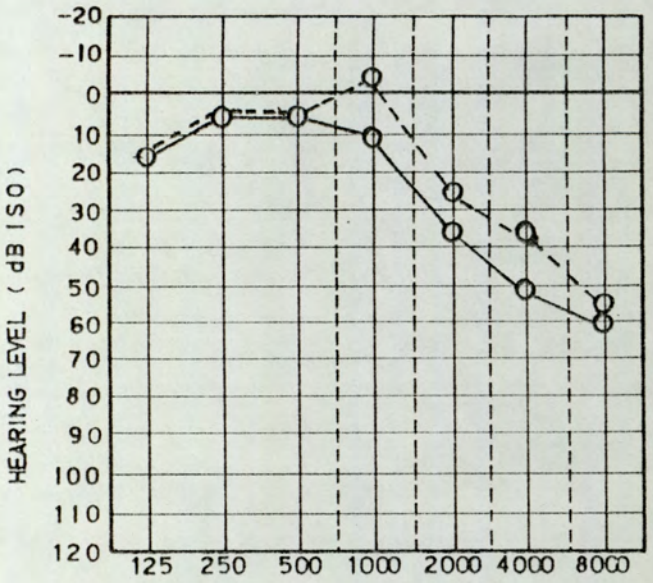
Although such activity does not interfere with the detection of the vertex potential at high stimulus intensities, it can seriously interfere with and obscure response detection at near threshold values where the signal:noise ratio is low.

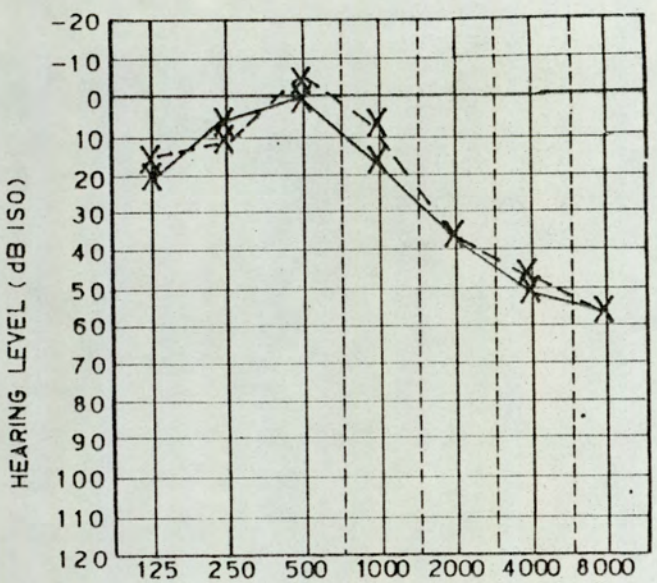
However, the cases were difficulty was experienced in establishing satisfactory objective threshold levels do not always result in the greatest discrepancies between subjective and objective assessment.

In the case of subject E.M. who reported tinnitus in the left ear at 4000Hz, the discrepancy of -30dBSL in subjective and objective assessment can be accounted for by the unreliability of subjective assessment at this frequency.

The greatest difficulty in establishing a reliable ob - jective assessment of hearing level was experienced in the group of young children where there was an increase not only in the discrepancy between subjective and ob- jective assessment, but also in the variability of this difference across the individual subjects. This increase in variability reduces the reliability with which an estimation of subjective hearing levels may be made from the objective results of evoked response audiometry. The decrease reliability of the vertex potential in the objective assessment of hearing in children may be attributed to several factors.

1) The greater inherent variability of the waveform of the vertex potential which occurs in children makes it more difficult to develop satisfactory response criteria and thus increases the possibility of both false positive and false negative results.





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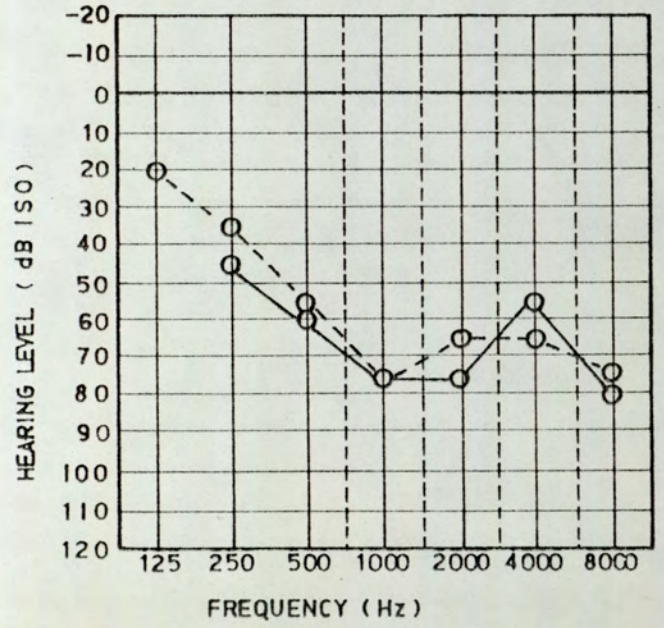

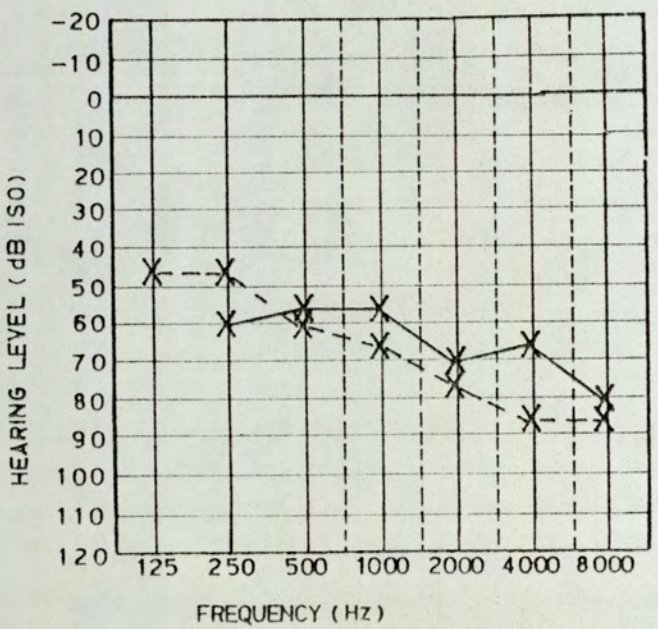

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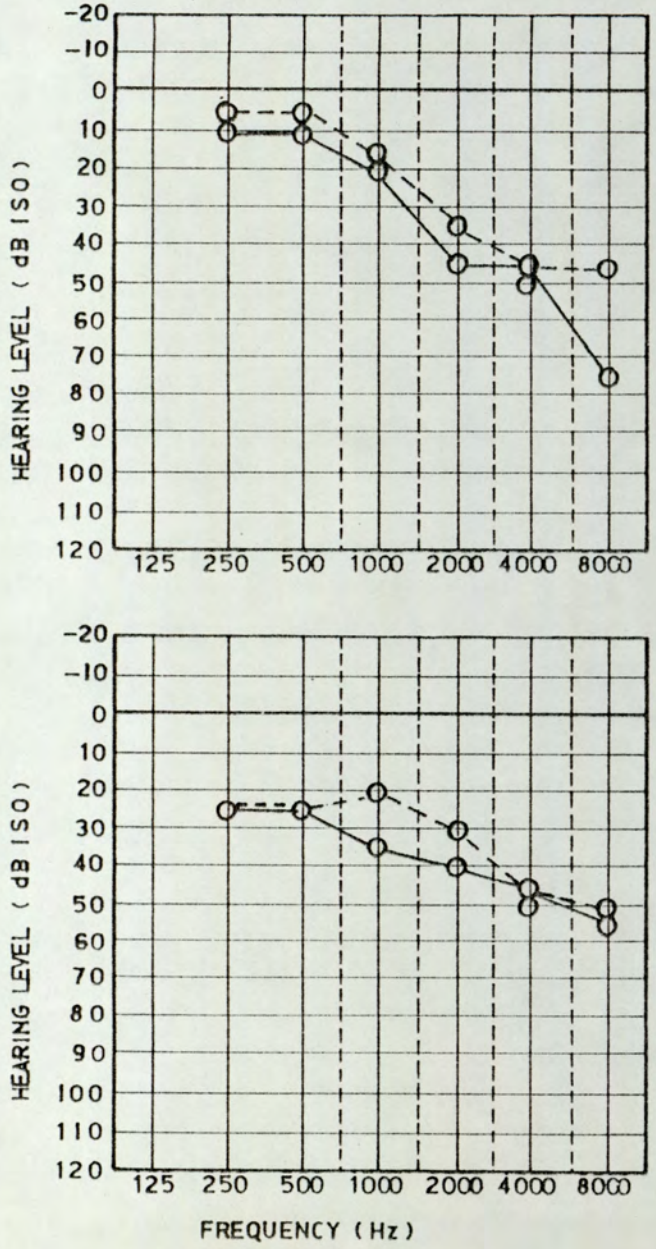
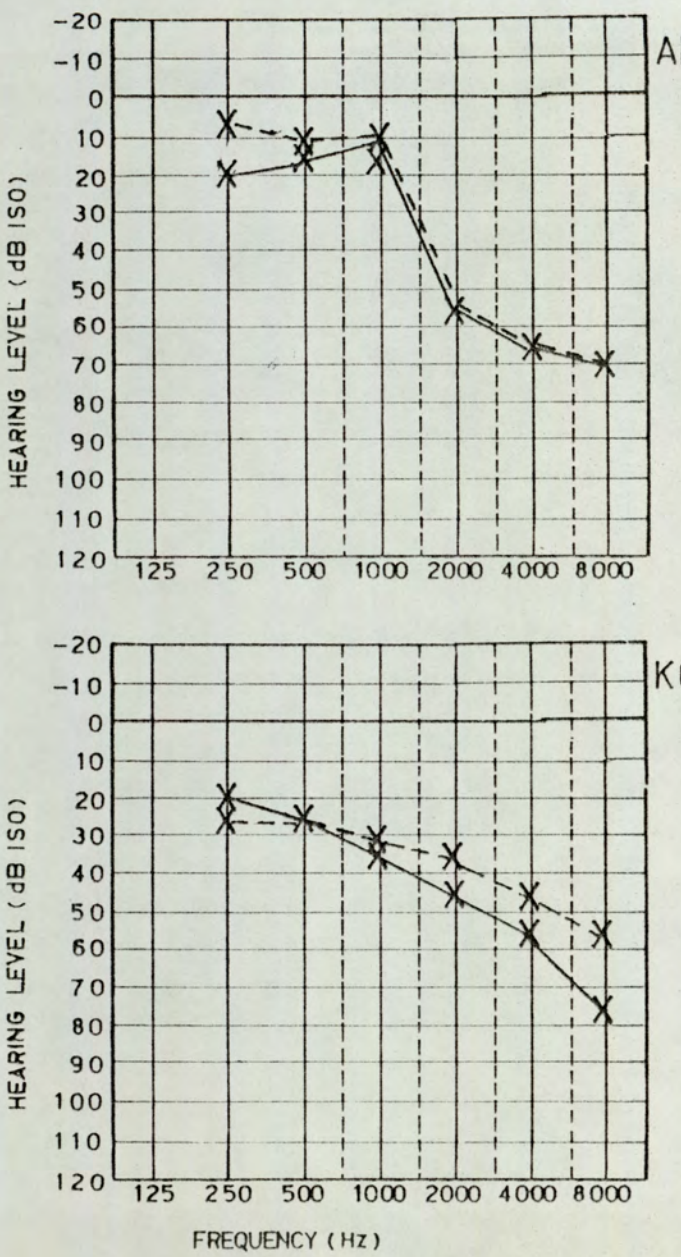
29. 3. 73. 1. 7. 74.

Fig 5 25
Comparison of
subjective audiograms





dates of audiograms

10. 4. 73.	1. 7. 74.
26. 3. 73.	30. 7. 74.

Fig. 5.26.
Comparison of subjective audiograms.

2) The amplitude of the background EEG in this age group is generally of higher amplitude, of slower frequencies and more rhythmic than in the adult. Such factors produce a decrease in the signal:noise ratio which may result in an increase in the discrepancy between subjective and objective assessment.

3) Children of this age are easily bored and distracted giving rise to problems of changes in attention and increases in EMG or movement artifact as the investigation proceeds. Such factors will also interfere with the detection of evoked response threshold levels.

4) Finally, the control measure used - the subjective audiogram - is also less reliable in children than in adults.

Examples of the results of pure-tone audiometry carried out on some of the children used in the study on two separate occasions separated by a few months interval are shown in Figures 5.25 and 5.26.

Other factors, not occurring in this group of children, are commonly encountered in routine clinical investigations: Many of the children who require evoked response audiometry are physically or mentally handicapped and often present with abnormal background EEG activity such as spike and wave

discharges or high amplitude slow activity. Such activity will decrease the signal:noise ratio and may distort or completely obscure the evoked potential.

Also the use of many barbiturates and tranquilisers may interfere with evoked response detection by the production of fast activity in the background EEG. A good example of such a drug is nitrazepam (Mogadon) which can produce continuous fast activity up to 50uV. in amplitude.

It is unfortunate that the vertex potential appears to be least reliable in the assessment of subjective hearing levels in young children as these provide the major portion of the clinical population referred for auditory assessment. However, even in young children the vertex potential can provide a fairly accurate and reliable assessment in the majority of cases and it is usually possible to predict in which cases its reliability will be reduced.

The assessment of hearing using evoked response audiometry can be broadly divided into two main areas:-

a) The measurement of objective threshold levels using the vertex potential

b) The assessment of the reliability of this objective measure and its relation to subjective hearing levels.

The initial part of the procedure - the measurement of objective threshold levels - can be facilitated by the use

of a response template and the gradual reduction of stimulus intensity with each successive averaging run. This enables the monitoring of progressive amplitude reduction and lengthening of response latencies as threshold intensities are approached. Without the use of this technique it is often extremely difficult to accurately identify the presence of evoked potentials to low intensity stimuli.

Such responses may be judged as absent when viewed in isolation, but are clearly present when compared with previous responses recorded to louder stimuli. The use of amplitude and voltage criteria in the identification of vertex responses (Osterhammel et al. 1973 and Mendel et al. 1975) is probably not justified, especially in children where the extreme variability in both latency and more especially amplitude would make it extremely difficult to develop criteria which could be applied universally to all children.

In assessing the reliability of the objective threshold obtained and its relationship to subjective hearing levels the following factors should be taken into account:-

a) Age
b) State of arousal - awake - asleep
c) Behavioural state - quiet and co-operative or noisy and restless
d) Possible EEG abnormality
e) Drugs

In cases where the adult or child is reasonably co-operative and alert, then the subjective-objective threshold differences obtained in the above studies may be assumed for the relevant age groups, but any of the above mentioned factors which cause a reduction in the signal:noise ratio will invariably decrease the reliability with which evoked response thresholds reflect subjective hearing levels.

CHAPTER 6

The Role of the Vertex Potential in the Measurement of Speech Perception and Hemispheric Specialisation of Function.

6.1. Problems Involved in the Measurement of Evoked Potential Correlates of Meaning

Normal hearing as described by Whetnall and Fry (1971) involves "the process of detection, recognition and interpretation of the meaning of sound". Although close correlations are obtained between thresholds of the vertex potential and pure-tone audiometry, the investigations reviewed in the previous Chapters indicate that the vertex potential produces only a measure of the initial stage of hearing - that is - in the detection of a response within the brain.

However, the fairly accurate localisation of linguistic processing to the dominant hemisphere (usually the left) had led to the search for neurophysiological correlates of this localisation using both spontaneous EEG and evoked potential measures.

Studies of the auditory evoked potential correlates of measuring can be sub-divided into two areas:-

1. Changes in the characteristics of the vertex potential which can be associated with verbal or linguistic processing.

2. The measurement of hemispheric asymmetries in the auditory evoked potential which may reflect the differential processing of linguistic and non-linguistic information. Many of the studies require the active co-operation and participation of the subject. The results of both types of investigation are controversial and when evaluated in the light of the normal response characteristics of the vertex potential are of doubtful significance.

In many cases response changes attributed to stimulus meaning or differential hemispheric processing may be explained by alternative factors. The physical characteristics of the stimulus material (primarily rise time and frequency) may considerably influence the latency and amplitude of the vertex potential. Since many of the investigations involve the active participation of the subjects in some form of discrimination task regarding the stimulus, selective attention may also play an important part in determining the characteristics of the auditory evoked response.

The measurement of evoked potential correlates of meaning are beset with a large number of problems:-

1. The requirement for averaging procedures of the repetition of the stimulus may interfere with the meaningfulness of the stimulus. The use of different stimulus words introduces the possibility of response variation due to changes in the physical characteristics of the stimulus.

2. The vertex potential is considered as an on-response to stimulus change which is usually completed by approximately 250 m.secs. If this is the case then it is difficult to explain how such a response can reflect the meaning of verbal material which may not be resolved until after this time interval.

More specifically in cases of hemispheric asymmetry:-

3. In many cases decisions regarding the dominant speech hemisphere are made on the basis of simple tests such as handedness which are poor and unreliable (Davis and Wada, 1974).

4. Since the source of the vertex potential is to a large extent unknown and the relative contributions of primary auditory cortex and association areas have still to be elucidated, the interpretation of any observed response asymmetries must be tentative

5. The recording derivations used in the measurement of response asymmetries are usually in temporal and parietal scalp areas where the responses are of considerably reduced amplitude in comparison with the vertex. In addition, such areas often show an increased amount of EMG activity in the spontaneous EEG. Both these factors will reduce the signal:noise ratio and thus increase the variability of the vertex potential and decrease the significance of any observed hemispheric asymmetries.

6. Localised changes in EEG amplitude or power are known to occur when tasks of different cognitive mode preferentially involve one hemisphere or other (Butler and Glass, 1974). Activation of the left hemisphere is primarily associated with tasks of an analytical and logical nature as seen in language and arithmetic process, while the right hemisphere is mainly concerned with tasks involving spatial relationships and musical functions. Any task involving the activation of a particular hemisphere usually results in the desynchronisation of alpha activity and a decrease in alpha amplitude or power within that hemisphere. Thus, it is possible that any hemispheric changes in the vertex potential may only reflect hemispheric processing indirectly through the decrease in background EEG amplitude and subsequent increase in signal:noise ratio producing an apparent increase in vertex response amplitude.

Evidence of this was presented by Gallin and Ellis (1975, 1977) where right and left hemisphere were differentially engaged by the use of spatial and verbal tasks. The change in the evoked response to flash stimuli presented during either task was found to parallel the changes in background alpha activity, with the EEG providing the most consistent measure of hemispheric function. Care should also be taken in hemispheric studies to control for the basic 'resting' state of hemispheric asymmetry in both the background EEG and the evoked potential.

7. When examining evoked potentials for evidence of asymmetry due to left hemisphere involvement in linguistic processing, it is also necessary to assess the contribution of the well known contralateral or ear effect if monaural stimulation is used. The crossing of a greater number of nerve fibres across the brainstem to the contralateral auditory cortex would be expected to produce a larger amplitude response in the hemisphere contralateral to the ear stimulated.

Using mastoid references, Muller and Stange (1971) reported significant differences in the amplitude-intensity functions of the vertex potential in vertex and ipsilateral and contralateral temporal derivations. Evidence of the greater number of contralateral fibres was indicated by the greater amplitude vertex potential reported by Andreassi, Simon, Friend and Grota (1975) in the hemisphere contralateral to stimulation when recordings were made from C_3 and C_4 with earlobe references.

Ruhm (1971)$_{\alpha}$using a click stimulus found evidence of both contralalateral and hemispheric affects. Recording responses from T_3 and T_4, he found consistently larger responses in the right hemisphere than the left hemisphere with left ear stimulation with a mean difference in response amplitude of 53%. Stimulation of the right ear produced no consistent hemispheric affects. He suggested that the differences in responses obtained from each ear may have resulted from the addition of hemispheric and contralateral effects in the

right hemisphere to left ear stimulation (he relates the processing of non-verbal, non-meaningful stimuli to the right hemisphere) whereas their opposing effects with right ear stimulation would tend to cancel any observed asymmetry.

6.2. The Vertex Potential - Correlates of Meaning

Comparisons of the vertex potentials recorded to sense and nonsence words of physically matched properties made by Roth, Kopell and Bertozzi (1970) revealed no obvious differences in response characteristics. The authors also looked at the responses to more meaningful words in the form of a sentence under conditions of attention and non-attention. Evoked potentials were recorded to a) the initial syllable of each sentence and b) the first syllable of each successive word in the sentences. They found no significant effects of attention, but the response amplitude of the evoked potential obtained in condition a) was approximately eight times larger than that in condition b). This difference was explained by the larger interstimulus interval preceding the initial syllable in the sentence as compared to subsequent syllables.

The evoked potentials to the words of a sentence were also examined by Feldman and Goldstein (1967) and Sharrard (1973). The earlier study found similar evoked potentials to words as tone pips and that the former were unaffected by changes in stimulus intensity. Sharrard attempted to

measure the total effect of meaning as reflected from the whole sentence. He did this, firstly by measuring the vertex potential obtained to the initial syllable of each word in a 64 word sentence and then by measuring the evoked potential to each individual word reversed with the initial sentence order preserved. The subtraction of this second response from the first he believed would reflect the evoked potential component related to meaning alone. A statistically larger amplitude evoked potential was produced to the meaningful stimuli as compared with the non-meaningful stimulus of the reversed message. However, rather than attributing these response differences to stimulus meaning, it is much more likely that they arise from the differences in the physical characteristics of the stimuli. When the word stimuli are reversed, the considerably longer rise times would produce poorer neural synchronisation and thus explain the reduced amplitude. The method used in the production of the stimulus material also introduced a variable time delay between the trigger stimulus for the averaging procedure and the onset of the word stimulus which was dependant on the experimenters reaction time.

Dorman (1974) presented evidence of vertex potential changes in the perception of different stop consonants. Three synthetically generated stop consonants which differed solely in their voice onset times (VOT - the delay between the initial sound produced by the release of the lips and the subsequent sound produced by vibration of the vocal

cords) of 0,20 and 40 m.secs. were used in a discrimination task. The consonants with VOT's of 0 and 20 m.secs. were both perceived as the phoneme/ba/ (discrimination between the two stimuli is no better than chance) and that with the VOT of 40 m.secs. was perceived distinctively as /pa/. The discrimination task was to detect the occurence of either the 20 m.secs. VOT phoneme (within phoneme category shift) or the 40 m.secs. VOT phoneme (across category shift) from amidst a sequence of standard (0 VOT) stimuli. Different evoked potentials were obtained in across and within category shifts. In the across category shift the amplitude of evoked potentials to both stimuli were greater than to the standard stimuli when presented alone. This amplitude increase was more marked for the infrequent stimulus /pa/. The within category stimulus shift produced no change in response amplitudes of either stimulus, and both were of the same amplitude as the standard stimulus. Dorman concluded from these findings that the discrimination of different phonemic categories was reflected in the amplitude of the evoked potential. However, an alternative explanation exists based on the effects of selective attention which is reported to increase both vertex potential and P300 response amplitude. Selective attention could only operate in the across category shift as in the case of the within category shift the subjects were unable to discriminate between the two stimuli used.

Finally, reports by Young and Horner (1971) and Pemberton (1973) suggest that the vertex potential may reflect

inhibitory processes occurring in response to socially unacceptable word stimuli. The former study compared vertex potentials obtained to 50 emotional and 50 non-emotional verbal stimuli. These, however, were poorly controlled in terms of both their physical characteristics and in the emotional response they produced. Attempts to control for the physical characteristics of the words were made by Pemberton (1973), he also monitored the emotionality of each word in terms of the galvanic skin response and Osgood's semantic differential. Both authors report a reduction in response amplitude to the affective as compared to neutral words. These findings would be consistent with the operation of inhibitory processes to socially unacceptable words.

Thus, at present there is no clear evidence that the linguistic processing of verbal information is reflected in the vertex potential. The results obtained in most of the previous studies can be more plausibly explained on the basis of changes in stimulus parameters or in selective attention, both of which produce well documented affects of the vertex potential (Chapter 3).

6.3. The Vertex Potential - Correlates of Hemispheric Function.

Evidence of vertex potential sensitivity to hemispheric specialisation was indicated in the results of Morrell and Salamy (1971) where the response amplitude to a series of

nonsense words was considerably greater in the left hemisphere in frontal, rolandic and tempero-parietal derivations in seven right handed subjects. The greatest differences of the order of 40% were observed in temporo-parietal derivations. The authors, however, failed to obtain control data for non verbal stimuli to provide a baseline or comparison for these results and thus it is possible that the asymmetries may have existed irrespective of the nature of the stimulus.

Interhemispheric asymmetries to both speech and sound effect stimuli were found by Matsumiya, Tagliasco, Lombroso and Goodglass (1972). The maximum asymmetry occurred at a post-stimulus latency of 100 m.secs. The authors attributed this asymmetry to the meaningfulness or relevance attached to the stimulus rather than the verbal or non-verbal nature as the asymmetries observed for both verbal and non-verbal stimuli were more marked when a greater relevance was attached to the same stimuli with more difficult or demanding discrimination tasks. Wood, Goff and Day (1971) concluded from their findings that hemispheric differences in the vertex potential depended on whether a decision regarding the stimulus was of a linguistic or non-linguistic nature. The stimuli for the linguistic discrimination task differed only in the voice stop consonants and were perceived as /ba/ and /da/, while the stimuli for the non linguistic discrimination task differed in fundamental frequency of the phoneme/ba/ producing /ba/-low and /ba/-high.

Vertex potentials were recorded from T_3 and C_3 and T_4 and C_4 with ear reference electrodes. Their results indicated identical right hemisphere responses in both discrimination tasks, but a significant difference in left hemisphere responses was indicated as measured by the Wilcoxon matched pairs test of significance. However, examination of Figure 6.1. indicates only a slight change in the waveform of the left hemisphere response, and in view of the normal variability of the vertex potential even in identical experimental conditions, it is difficult to accept the significance of this difference and hence the validity of the statistical measure employed.

Later measures of evoked potential asymmetries with hemispheric function have failed to produce such apparently significant results. Friedman, Simson, Ritter and Rapin, (1975) using 5 different speech stimuli and 5 speech noises in conditions of attention and non-attention found no consistent hemispheric differences in either the vertex potential or the P300 component recording from temporo-parietal areas. The only effects observed were of directed attention which produced an increase in the amplitude of the P300 component to both sounds and words. In the light of their results the authors reassessed the existing literature and were critical of the lack of control conditions and the inappropriate use of bipolar recording derivations. They also questioned the use of various statistical methods of significance assessment citing the work of Wood et al. 1971.

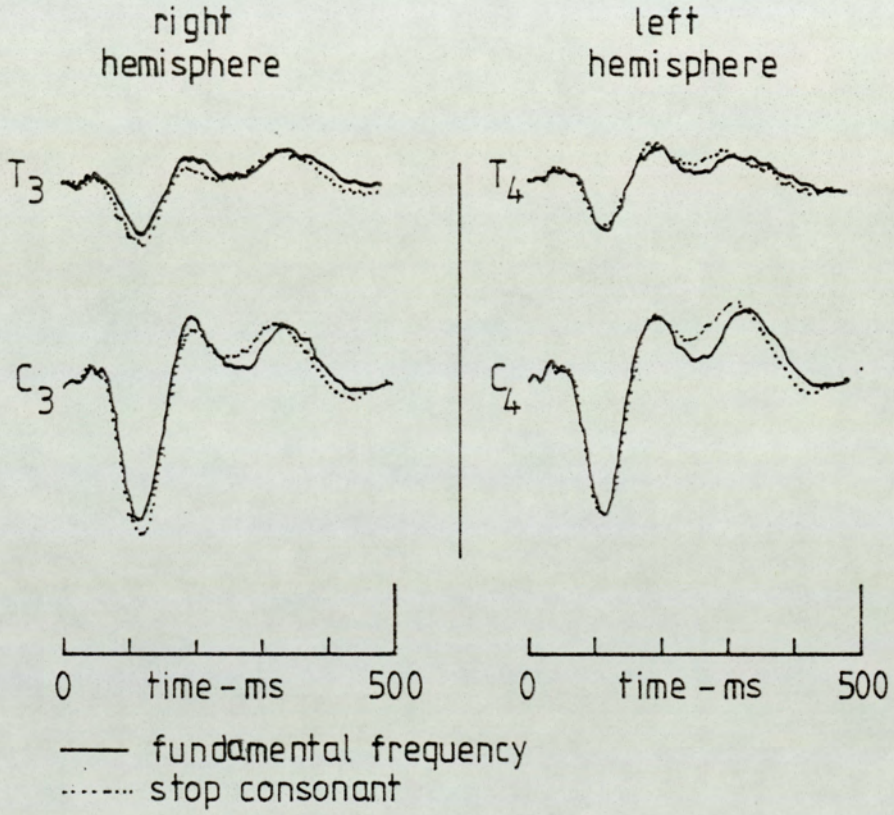


Fig. 6.1.
Hemispheric differences in the vertex potential during linguistic and non-linguistic discrimination tasks. [Wood et al, 1971]

The inconsistencies of their findings were supported by Galambos, Benson, Smith, Schulman-Galambos and Osier (1975), when recording responses to speech syllables and pure tone stimuli from parietal association areas with joint mastoid references. The subjects were required to detect an infrequent stimulus from a train of frequent stimuli in lists of either speech or tone stimuli. No overt response was required. The responses to both words and tones were similar except that the P300 was of longer latency for word stimuli, and increased with attention for both stimuli. No significant differences were detected in hemispheric responses.

Tanguay, Taub, Doubleday and Clarkson (1977) could find no clear hemispheric effects in the vertex response to the three consonant-vowel stimuli, /ba/, /da/, and /ga/. They did, however, observe a marked ear or contralateral effect where responses were consistently larger in the hemisphere contralateral to the ear stimulated.

Later studies by Brown, Marsh and Smith, 1973; Marsh and Brown, 1977; Teyler, Roemer, Harrison and Thompson 1973; Roemer and Teyler 1977, are more controversial in terms of the measures of evoked response asymmetries used and their relationship to cerebral functioning.

Brown et al. (1973) and Marsh and Brown (1977) reported hemispheric differences in the evoked potential obtained to the same physical word stimulus depending on its perception as either a verb or a noun within the context of

a sentence. Correlations between the evoked potentials obtained in different stimulus conditions were made for each recording site (scalp areas overlying Brocas and Wernicke's areas on the left and analogous areas on the right referred to joint ear electrodes). The lower correlations observed between evoked potential waveforms to noun and verb forms of the stimulus that were observed in the left hemisphere were interpreted as evidence of a difference in responses in the two conditions which changed as a function of meaning. However, it seems a little premature to conclude that a decrease in correlation score automatically reflects the change in response meaning.

Similar techniques were used by Tyler et al. 1973 and Roemer et al. 1977. They attempted to measure hemispheric differences to the same stimulus either perceived as a noun or vowel. Recordings were made from C_3 and C_4 and referred to joint mastoids. Prior to each stimulus presentation the subject was instructed as to whether to think of the stimulus as a noun or verb. Each stimulus presentation was followed by a 1-5 second pause when the subject heard a click stimulus which acted as a trigger for the average response and for the verbal response of the subject who repeated the stimulus word thinking of it as either a noun or verb, as previously instructed. The evoked potentials to all stimuli were larger in the left hemisphere, and hemispheric amplitude, latency and waveform differences resulted from the perception of noun and verbal forms of the stimulus. They conclude that their experimental procedure allows the analysis of the effect of meaning on the auditory evoked potential.

However, it is somewhat difficult to draw any clear conclusions from their data as:-

1) They appear to be measuring the hemispheric differences in the evoked potential to a click stimulus while the subject pronounces the stimulus word and thinks of it in verb or noun form. They provide no control data of responses to clicks alone.

2) The production of speech will produce EMG artifact within the spontaneous EEG which may modify the response.

3) The response may be influenced by additional potentials which are related to speech production and tongue movements, many of which are reported to produce laterality or hemispheric effects. (Grözinger, Kornhuber and Kriebel, 1977; Szirtes and Vaughan, 1977). In addition, the expectation of a click stimulus following the stimulus word will also generate a CNV (Low and Fox, 1977).

Finally, functioning of the right hemisphere was investigated by Taub, Tanguay, Doubleday, Clarkson and Remington 1976, using musical cord stimuli. Recording from rolandic and Wernickes areas they found consistently larger amplitude responses in the right hemisphere in the area analogous to Wernickes area which would be consistent with right

hemisphere activation. The greater hemispheric differences observed with left ear stimulation were explained by the additive effects of contralalateral and hemispheric factors.

To summarise, studies of both the vertex potential and hemispheric asymmetries in the vertex potential provide no clear evidence of the processing of linguistic information at a meaningful level or of preferential activation of the left hemisphere during linguistic processes. Such measures of meaning may be better reflected in the later cortical component, the P300.

It is possible that in carefully controlled laboratory experiments with the active co-operation of subjects, that evoked potential studies may reflect some degree of hemisphere function, but such tests would be impossible in a clinical population.

6.4. Experimental Section

Although a number of the previously reviewed studies have presented evidence of correlations between the latency and amplitude characteristics of the vertex potential and the verbal or linguistic processing of stimulus information, such studies have inevitably required the active participation of the subject. This usually takes the form of some mental discrimination regarding the nature of the stimulus, which may or may not involve a motor response.

Using such methods, it is not always possible to decide whether changes in the vertex potential directly reflect differences in the linguistic nature of the stimulus or whether they arise indirectly through subjective changes in attention or from contamination with motor potentials associated with the response made. In addition, such investigations are not applicable to the majority of patients referred for evoked response audiometry as the usual reason for their referral is an unwillingness or inability to co-operate with subjective assessment procedures.

This study has been designed with this particular patient population in mind. Changes in the characteristics of the vertex potential are measured in response to linguistic and non-linguistic stimuli using the same recording procedures as described in Section 5.6.1. for audiological assessment which do not require the active participation of the subject. The stimulus material has been chosen in

an attempt to control for the physical characteristics of the stimulus and isolate these factors from the meaninfulness of the stimulus.

6.4.1. Method

Equipment

The recording equipment was identical to that described in Section 5.6.1. and consisted of:-

8 channel SLE EEG Machine
The Computer of Average Transients (CAT 400C, TMC)
X-Y Plotter
5uV. Calibration Box
Peters Audiometer

The stimulus material consisted of words in pairs or groups of three which were chosen with the aid of a phonetic lexion to be as closely matched as possible in their physical characteristics within each group. This was done by holding the initial phoneme of each word in the group constant and changing the second phoneme to alter the meaning. The first phoneme alone was also used as a stimulus for comparison with the whole word response. The groups of stimulus words and phonemes are shown overleaf in Table 6.1.

Stimulus	Meaningful	Less Meaningful	Phoneme
Group 1	dog	deg	d
	dig		
Group 2	kid	ked	k
Group 3	late	lat	l
Group 4	bike	bok	b

Table 6.1. Stimulus Material

It seemed reasonable to assume that any changes occurring in evoked potential characteristics within each stimulus group (where physical characteristics were held as constant as possible) would reflect changes in the degree of meaningfulness of the stimulus. Any across group changes in the evoked potential would reflect both changes in meaning and the physical characteristics of the stimulus. Finally, the comparison of within group word and phoneme responses would enable an assessment of the contribution of the later parts of the stimulus word to the evoked potential and similarities in responses to both words and phonemes would provide evidence to support the on-response nature of the vertex potential.

The stimulus material was prepared as follows:-

Each spoken word was initially recorded on one channel of a stereo tape recorder and then recorded from this channel to the second channel. This was carried out in order to introduce a slight time delay between the onset of both

words. The word from the first channel was then fed into a pulse generator and the rising edge converted into a trigger pulse which replaced the word on channel one. The net result was a trigger pulse on channel one of the tape recorder which would be used to trigger the averaging computer. The stimulus word occurred on the second channel and the time delay between trigger pulse and word stimulus allowed the introduction of the 5uV. calibration into the recording system without interference with the evoked potential to the stimulus word.

Each stimulus recording was made into a tape loop of approximately 3 second duration and then transferred to a continuous tape when 100 stimulus presentations were recorded. Previously, stimuli had been used in the form of tape loops during the evoked response investigations, their continuous use, however, rapidly produced wear and tear on the magnetic tape.

Procedure.

The subjects were 20 normally hearing young volunteers selected from the University population. Each subject was seated in a sound-damped room. Electrical activity was recorded from silver/silver chloride disc electrodes. The active recording electrode was placed at the vertex (C_Z) and referred to mastoid electrodes. All electrode resistances were below 5K ohms. The EEG activity was monitored on an 8 channel SLE EEG machine with band-pass

filters of 0.5 to 25Hz, and the evoked responses recorded on a computer of average transients (CAT 400C, TMC). The analysis time was 1000 m.secs. and each response consisted of 50 sweeps. The trigger pulse on channel 1 of the tape recorder was used to initiate the analysis sweep of the averager and also to trigger the 5uV. calibration signal which was induced at the head box on the vertex electrode. The stimuli were relayed to each subject via the Peters Audiometer and TDH 39 headphones. Each stimulus was presented monaurally at an intensity of 70dBHL. The stimuli consisted of the 13 words and phonemes shown in Table 6.1. and also the standard 1000Hz tone stimulus which was used for comparison. The stimuli were presented in random order, but in most cases because of time limitations it was not possible to present all stimuli in each investigation. The subjects were asked to listen to the stimuli, but were not required to make any form of response.

6.4.2. Results and Analysis

In order to measure the latencies of the components of the response to linguistic stimuli, it was necessary to measure the time delay between the trigger pulse for the averager and the occurence of the stimulus word. Both were displayed on a storage oscilloscope and the latency of onset of each word stimulus measured from a permanent photographic record.

The latencies of the response components P_1, N_1, P_2 and N_2 and the peak to peak amplitude of N_1-P_2 components

were measured for each stimulus. The mean values and standard deviations are shown in Tables 6.2. and 6.3. and in Figures 6.2., 6.3. and 6.4. The amplitude of the N_1-P_2 components is expressed both in microvolts and in % maximum amplitude over all stimulus conditions.

The latencies of the P_1 component appear to show the least variation across the different linguistic stimuli. The variance both within and across each stimulus condition increases with component from P_1 to N_1 to P_2 to N_2. The latencies of response components to the group 3 stimuli ('l' group) tend to be slightly longer and to the 1000Hz tone slightly shorter than the responses to the remaining stimuli.

The amplitude data shows great inter-individual variation which makes interpretation difficult. However, there appears to be a trend of consistently larger amplitude responses to the stimuli in group 1 ('d' group) and consistently smaller responses to group 2 ('k' group). The amplitudes of responses in groups 3 and 4 ('b' and 'l' groups) show considerable within group variability. The response to the tone stimulus was generally of lower amplitude than to the word stimuli.

A one-way analysis of variance was carried out to test for homogeneity between stimulus groups for the latencies of P_1, N_1, P_2 and N_2 components and for N_1-P_2 amplitude. The results are shown in Tables 6.4. and 6.5. The latencies

WORD	LATENCY OF COMPONENTS - MS											
	P_1			N_1			P_2			N_2		
	n	$\bar{x}$	sd	n	$\bar{x}$	sd	n	$\bar{x}$	sd	n	$\bar{x}$	sd
DIG	17	59.0	9.26	18	123.7	14.86	18	213.3	21.75	13	298.6	45.64
DEG	17	57.1	16.39	19	127.4	15.97	19	218.2	23.60	12	310.8	32.36
DOG	18	62.6	12.23	19	132.6	14.69	19	227.5	23.39	14	321.5	24.94
D	12	63.5	9.87	13	132.9	6.75	13	219.6	22.30	11	317.0	23.24
KID	12	59.5	13.17	15	121.4	14.48	14	223.4	45.24	5	325.0	68.38
KED	9	60.6	15.19	14	119.7	14.98	14	216.5	35.01	8	339.4	62.86
K	11	65.0	10.73	12	130.5	14.82	12	227.6	24.09	6	327.0	47.03
BIKE	16	60.5	11.88	16	130.3	12.63	16	212.9	14.04	13	306.8	27.77
BOX	13	66.8	11.12	15	130.2	15.12	15	212.6	21.29	8	319.6	32.48
B	11	61.1	20.72	13	121.1	29.88	13	216.8	18.71	10	296.9	25.25
LATE	13	76.5	14.05	14	154.1	11.64	14	241.9	27.82	14	351.0	75.07
LAT	11	81.2	15.12	13	148.8	13.93	12	244.3	40.01	5	329.2	50.53
L	11	64.3	16.97	12	137.8	14.47	12	219.5	17.70	8	319.5	31.81
TONE	8	58.1	9.20	13	109.9	13.25	14	188.1	26.03	5	264.4	48.52

Table 6.2. The mean values and standard deviations of response components to linguistic stimuli.

STIMULUS	Amplitude N_1 - P_2uV.			Amplitude N - P_2%		
	n	$\bar{x}$	sd	n	$\bar{x}$	sd
DIG	18	20. 6	7.89	18	72. 7	23.46
DEG	19	20. 9	11.56	19	67. 7	19.81
DOG	19	22. 4	12.49	19	71. 8	26.12
D	13	18. 9	9.03	13	66. 3	23.18
KID	14	14. 9	6.76	14	53. 5	16.73
KED	14	12. 9	3.38	14	51. 3	23.61
K	12	12. 8	8.17	12	46. 9	18.02
BIKE	16	21. 5	12.89	16	71. 2	22.45
BOX	15	15. 0	6.34	15	55. 7	20.32
B	13	18. 9	5.10	13	69. 5	17.10
LATE	14	10. 8	3.67	14	42. 3	18. 9
LAT	13	14. 5	5.18	13	56. 9	24. 7
L	11	12.03	4.89	11	43.27	10.84
TONE	14	11. 9	5.85	14	44. 0	24.28

Table 6.3. Mean values and standard deviations of N_1-P_2 amplitude expressed in both microvolts and % maximum amplitude in response to linguistic stimuli.

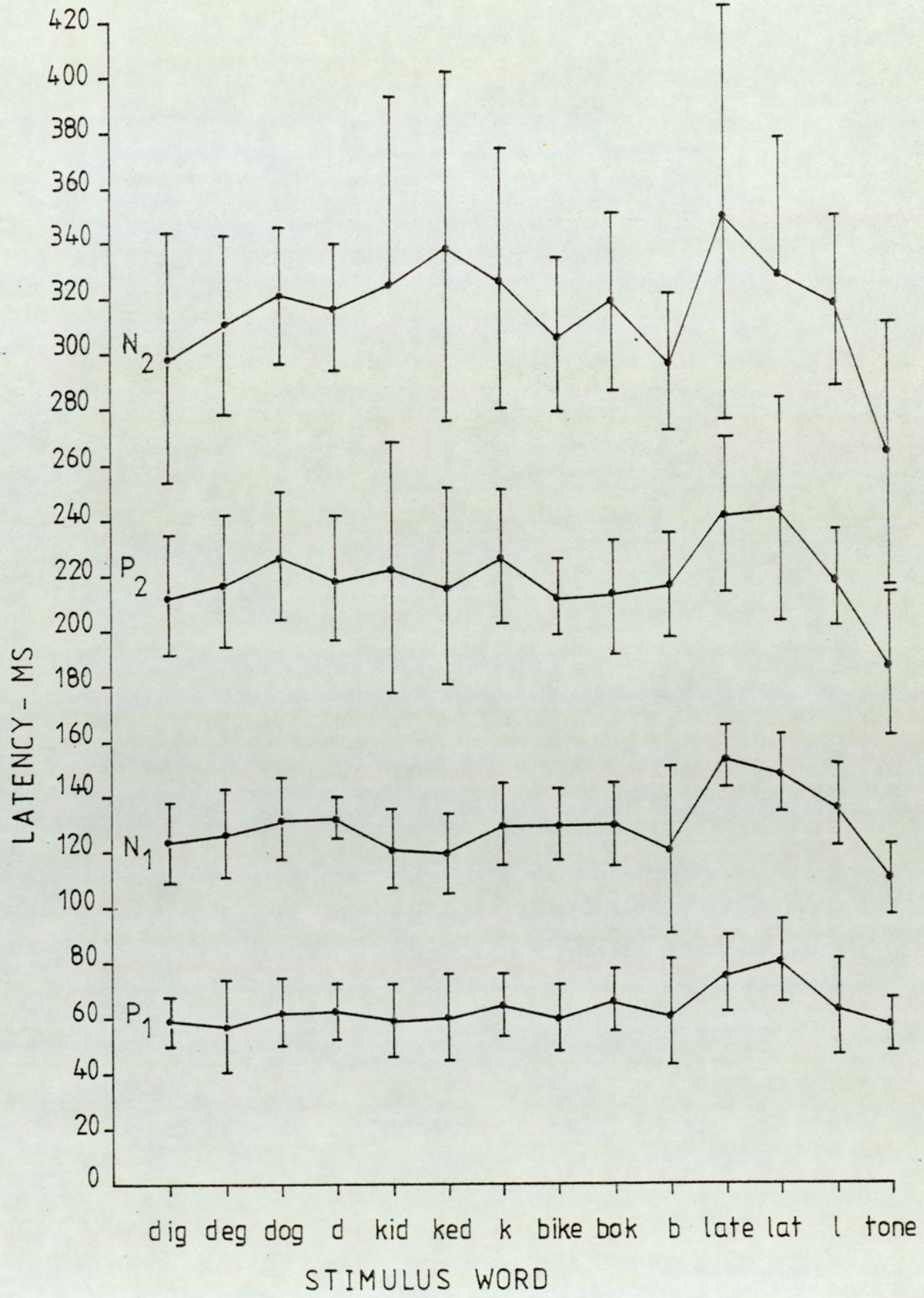


Fig 6.2.
Mean values and standard deviations of P1, N1, P2 and N2 components in response to verbal stimuli.

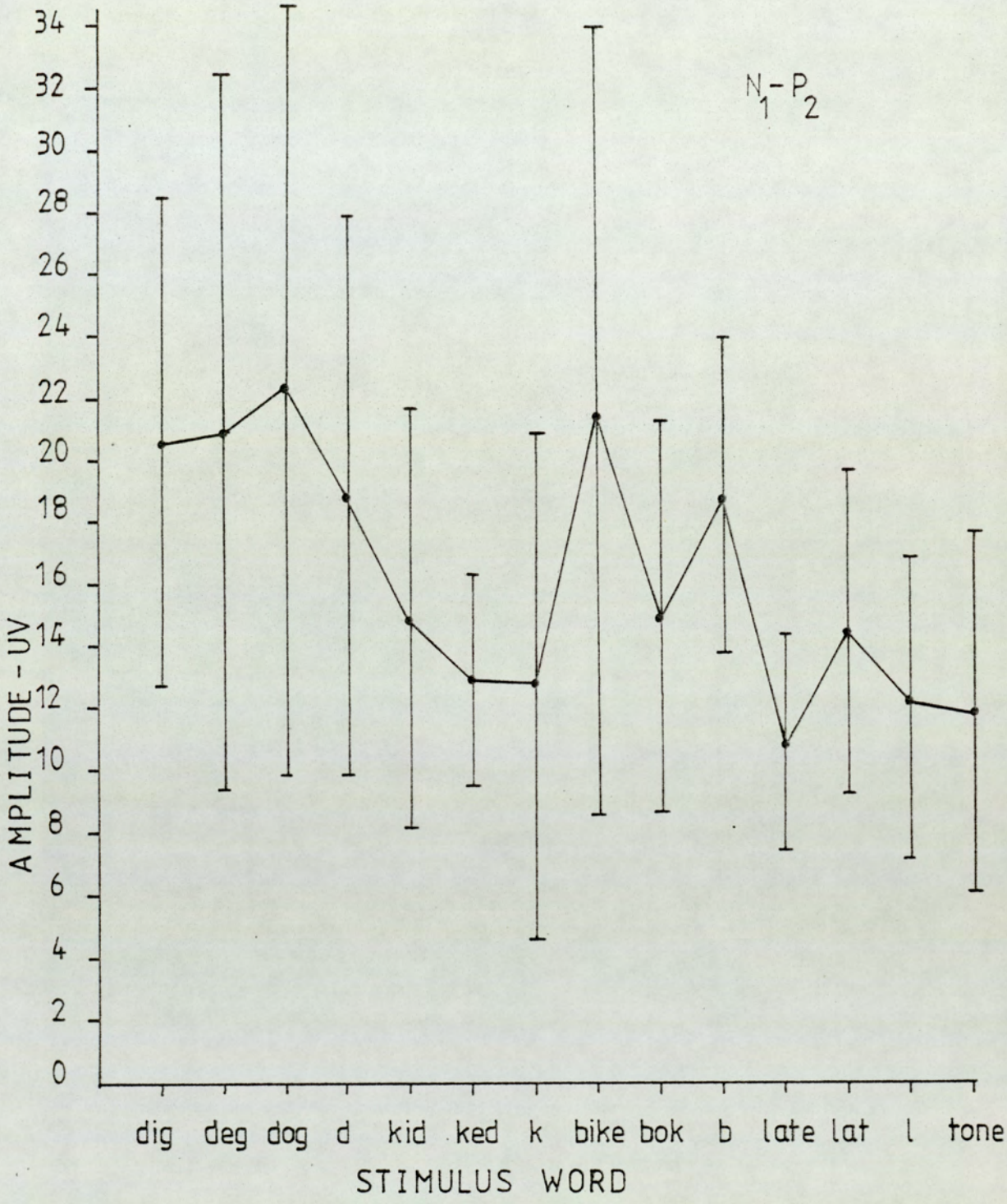


Fig. 6.3.
Mean values and standard deviations of N1–P2 amplitude in response to verbal stimuli expressed in microvolts.

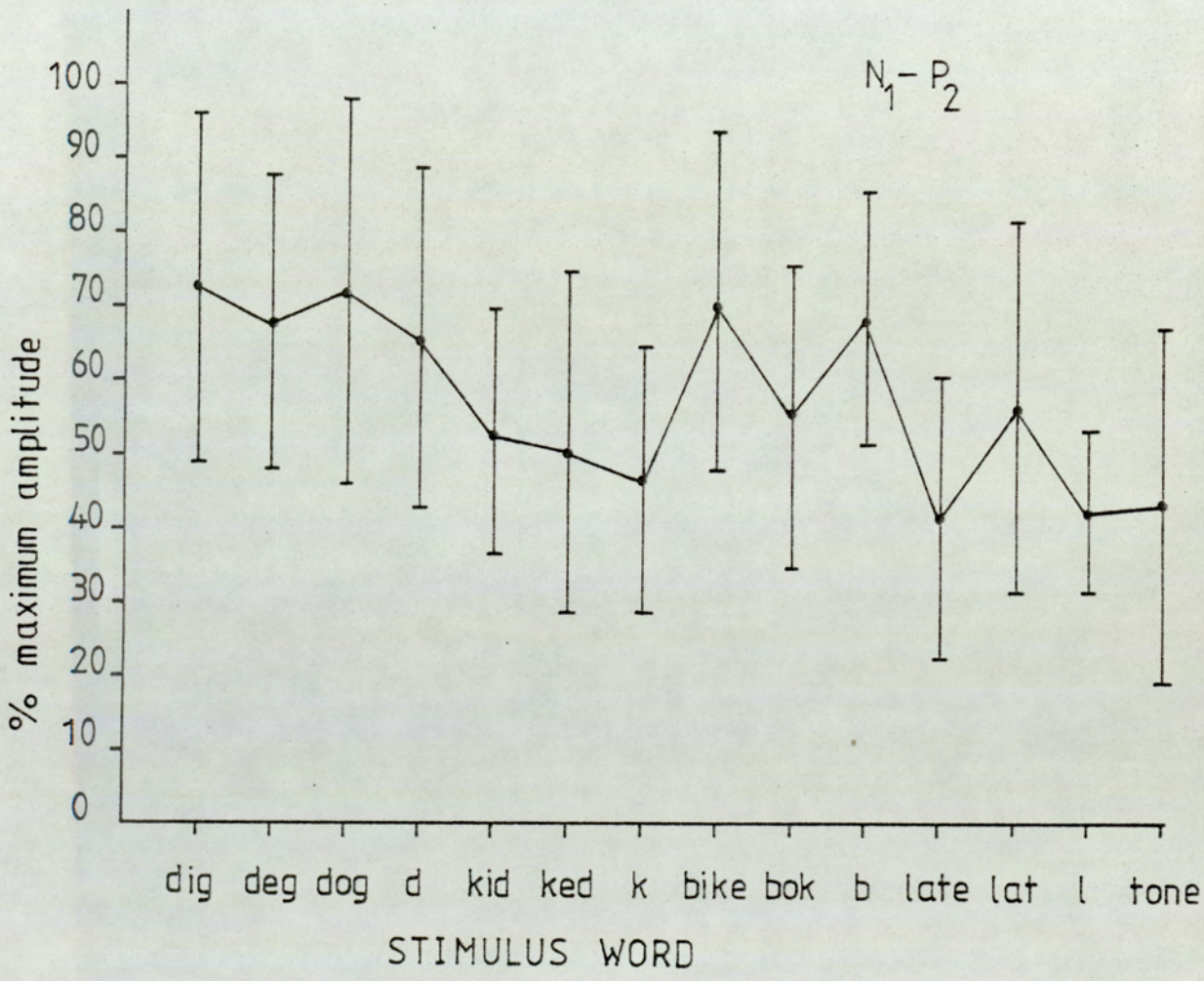


Fig. 6.4.
Mean values and standard deviations of N1–P2 amplitude in response to verbal stimuli–% maximum amplitude.

of components P_1, N_1, and P2 and N_1-P_2 amplitude show a difference in homogeneity between samples which is significant at the 1% level. Further analysis was carried out on the between sample differences by the calculation of the standard error of the difference between sample means. The significance of the calculated t values are shown in Tables 6.6. to 6.9. for components P_1, N_1 and P_2 and N_1-P_2 amplitude.

P_1 - The latencies of the P1 component in response to stimuli 'late' and 'lat' only, are consistently different from the remaining stimuli. Using the students 't' test this difference is significant at the 1% level. No other consistent differences were observed in the latencies of P_1.

N_1 - As with the P_1 component the latencies of N_1 in response to the stimuli 'late' and 'lat' are consistently different (of longer latency) from the latencies of the remaining stimuli. The latency of the response to 1000Hz tone also differed from most other stimuli (shorter latency) at the 1% level.

P_2 - Differences in the latencies of the response to stimuli 'late' and 'lat' show less consistent differences from the remaining stimuli whereas consistent differences at the 1% level of significance are still recorded for the tone stimulus.

Variance	Sum of Squares of Deviation	Degrees of Freedom	Variance Mean Square	Variance Ratio
P_1 Latency				
Between Sample	7582	13	583	
Within Sample	30238	165	183	3.182
Total	37820	178		
			Significant at the 1% level	
N_1 Latency				
Between Sample	23263	13	1789	
Within Sample	45878	192	239	7.489
Total	69141	205		
			Significant at the 1% level	
P_2 Latency				
Between Sample	32834	13	2526	
Within Sample	136277	191	713	3.539
Total	169113	204		
			Significant at the 1% level	
N_2 Latency				
Between Sample	39470	13	3036	
Within Sample	355071	108	3288	0.9234
Total	394541	121		
			Not Significant	

Table 6.4. Results of analysis of Variance on Latencies of components P_1, N_1, P_2 and N_2 of the vertex potential.

Variance	Sum of Squares of Deviations	Degrees of Freedom	Variance Mean Square	Variance Ratio
Amplitude N_1-P_2uV.				
Between Sample	3284	13	253	
Within Sample	13293	191	69	3.629
Total	16577	204		
			Significant at the 1% level	
N_1-P_2%				
Between Sample	25387	13	1953	
Withih Sample	87322	191	457	4.27
Total	112699	204		
			Significant at the 1% level	

Table 6.5. Results of analysis of variance of the amplitude of N_1-P_2 components of the vertex potential

$N_1 - P_2$ - Although the amplitude of N_1-P_2 components expressed both in microvolts and % maximum amplitude show significant differences in homogeneity at the 1% level, further analysis failed to reveal any consistent pattern of amplitude variation within each stimulus group. The greatest and most consistent amplitude differences were observed between Group 1 ('d' group) and Group 2 ('k' group), the latter showing a significantly smaller response amplitude at the 1% level. The 'd' group of stimuli also showed consistently larger amplitude responses than the tone stimulus and most of the 'l' group stimuli. No consistent differences were observed between the amplitudes of responses in the 'b' and 'd' groups.

6.4.3. Discussion

Since Tables 6.6. and 6.9. compare the differences between 91 pairs of means, then stricter levels of significance should be applied than at 5% or 1% levels as in both cases it is probable that some significant differences may have arisen purely by chance. Thus, although the levels of significance shown in the tables may not represent the true situation, they serve to indicate where the greatest differences occur both within and across stimulus groups and also the consistency of these differences.

Both visual analysis and the analyses of variance fail to show any clear electrophysiological correlates of stimulus meaning reflected in either the latency or amplitude of the vertex potential. This may be inferred from the similarity in responses within each stimulus group where both latency and amplitude characteristics of responses to meaningful and less-meaningful words and the initial phoneme show no significant differences. The more consistent and apparently significant differences recorded in response amplitude and latency across some of the stimulus groups would suggest that such changes resulted primarily from changes in the physical characteristics of the stimulus words, and more specifically the initial phonemes rather than from a change in the meaning of the stimulus.

Finally, the similarity of responses to within group words and their initial phoneme would suggest that the characteristics of the vertex potential are determined by the initial part of the stimulus. Thus, under the above experimental conditions, the present findings would not support the use of the vertex potential as a measure of stimulus meaning. They would, however, support the description of the vertex potential as an on-response to change in stimulation, whose amplitude and latency characteristics are primarily determined by the physical characteristics of the initial part of the stimulus (rise time and frequency).

These findings do not oppose or negate previous investigations which present positive evidence for the reflection of verbal or linguistic processing in the vertex response. They do, however, suggest that in such investigations where the subject is required to make a discrimination and verbal or motor response regarding the stimulus, that differences in the vertex potential may arise through the action of other factors such as changes in attention or by the presence of other motor potentials associated with the response required.

Thus at present, although the vertex potential may reflect aspects of the linguistic processing of verbal material in subjects who are able to actively participate in the experimental procedure, its failure to do so without this active participation make its application to a clinical population, who are unwilling or unable to co-operate, both unsuitable and inappropriate.

In conclusion, it appears that the vertex potential alone fails to meet the criteria of Whetnall and Fry for the measurement of hearing, but according to their definition only reflects the initial stage of the process of hearing, that is, the registration of the response in the cortex.

The method of evoked potential recording presents a number of problems to investigators which attempt to measure correlates of stimulus meaning. A major drawback is the requirement of stimulus meaning. This raises the question of how meaningful a stimulus is when repeated approximately

50 times in rapid succession. The use of whole sentences would be more likely to provide meaningful stimulus material, but the difficulty in controlling for the physical characteristics of the different stimuli make this method only really applicable to the studies of hemispheric asymmetries.

Finally, even in the case of short stimulus words used in this study (300-400 m.secs. duration) the major portion of the evoked potential is completed before the termination of the word and possibly before the extraction of its meaning and thus would be unlikely to reflect this meaning.

The use of the P300 and CNV offer greater prospects than the use of the vertex potential in the measurement of stimulus meaning or comprehension, but both again require the co-operation of the subject and so would again be inappropriate to the large majority of patients requiring evoked response audiometry.

P_1

	dig	deg	dog	d	kid	ked	k	bike	bok	b	late	lat	l	tone
dig		NS	NS	NS	NS	NS	NS	NS	NS	NS	**	**	NS	NS
deg			NS	NS	NS	NS	NS	NS	NS	NS	**	**	NS	NS
dog				NS	NS	NS	NS	NS	NS	NS	**	**	NS	NS
d					NS	NS	NS	NS	NS	NS	**	**	NS	NS
kid						NS	NS	NS	NS	NS	**	**	NS	NS
ked							NS	NS	NS	NS	**	**	NS	NS
k								NS	NS	NS	*	**	NS	NS
bike									NS	NS	**	**	NS	NS
bok										NS	NS	**	NS	NS
b											**	**	NS	NS
late												NS	*	**
lat													**	**
l														NS
tone														

* 5% significance
** 1% significance
NS not significant

Table 6.6.

Significance values for differences between means using Students t values.

N_1

	dig	deg	dog	d	kid	ked	k	bike	bok	b	late	lat	l	tone
dig		NS	**	NS	NS	NS	NS	NS	NS	NS	**	**	*	*
deg			NS	NS	NS	NS	NS	NS	NS	NS	**	**	*	**
dog				NS	*	*	NS	NS	NS	NS	**	**	NS	**
d					*	*	NS	NS	NS	NS	**	*	NS	**
kid						NS	NS	NS	NS	NS	**	**	*	*
ked							NS	NS	NS	NS	**	**	**	NS
k								NS	NS	NS	**	**	NS	**
bike									NS	NS	**	**	NS	**
bok										NS	**	**	NS	**
b											**	**	**	NS
late												NS	**	**
lat													**	**
l														**
tone														

* 5% significance
** 1% significance
NS not significant

Table. 6. 7.

Significance levels for the differences between means using Students t values.

P_2

	dig	deg	dog	d	kid	ked	k	bike	bok	b	late	lat	l	tone
dig		NS	*	NS	NS	NS	NS	NS	NS	NS	**	**	NS	**
deg			NS	NS	NS	NS	NS	NS	NS	NS	*	*	NS	**
dog				NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**
d					NS	NS	NS	NS	NS	NS	*	*	NS	**
kid						NS	NS	NS	NS	NS	NS	*	NS	**
ked							NS	NS	NS	NS	*	**	NS	**
k								NS	NS	NS	NS	NS	NS	**
bike									NS	NS	**	*	NS	*
bok										NS	**	*	NS	*
b											*	*	NS	**
late												NS	NS	**
lat													NS	**
l														**
tone														

* 5% significance
** 1% significance
NS not significant

Table. 6. 8.
Significance levels for the differences between means using Students t values.

$N_1 - P_2$

	dig	deg	dog	d	kid	ked	k	bike	bok	b	late	lat	l	tone
dig		NS	NS	NS	NS	**	*	NS	NS	NS	**	NS	**	**
deg			NS	NS	*	**	**	NS	NS	NS	**	NS	**	**
dog				NS	*	**	**	NS	*	NS	**	*	**	**
d					NS	NS	NS	NS	NS	NS	*	NS	*	*
kid						NS	NS	*	NS	NS	NS	NS	NS	NS
ked							NS	**	NS	NS	NS	NS	NS	NS
k								**	NS	NS	NS	NS	NS	NS
bike									*	NS	**	*	**	**
bok										NS	NS	NS	NS	NS
b											NS	NS	*	*
late												NS	NS	NS
lat													NS	NS
l														NS
tone														

* 5% significance
** 1% significance
NS not significant

Table. 6. 9.

Significance levels for the differences between means using Students t values.

CHAPTER 7

7.1. Classification and Distribution of Myogenic Potentials

The myogenic potentials lie within Picton's classification of middle latency components of 8-50 m.secs. (1974). They not only show a wide distribution over scalp and neck musculature, but may also be elicited from muscles of the arms and legs (Bickford et al. 1964; Cody et al. 1964 and Borsanyi and Blanchard 1964).

Widespread activation of scalp musculature is reported in response to abrupt auditory stimulation. Click stimuli and bursts of white noise or pure tones have all been found to elicit these responses (Picton et al. 1974 and Streletz et al. 1977). Four distinct myogenic responses may be discerned from the scalp:-

i) The Neck Muscle or Inion Response - probably arising from the cervical musculature. This was the original Sonometer Response to be recorded by Bickford in 1964. The response consists of a series of negative and positive components occurring between 12-40 m.secs. (Table 7.1.).

ii) The Post-Auricular Muscle Response arising from a restricted scalp area behind the ears in the region of the post auricular muscle (Table 7.2.)

Author	Latency of Components - m.s.				Nature	Origin
	N	P	N	P		
Streletz 1977	14.8	18-20	28-32	36-42	Myogenic	Vestibular
Picton 1974	11.8 ± 0.2	16.8 ± 2.4	24.6 ± 1.3	38.8 ± 0.5		

Table 7.1. Components of the Inion Response

Author	Latency of Components m.s.		Nature	Origin
	N	P		
Streletz 1977	11-14	15-20	Myogenic	Cochlear
Picton 1974	11.8±0.8	16.4±0.7		

Table 7.2. The Components of the post-auricular muscle response.

iii) The Temporalis Muscle Response which is recordable from central and temporal scalp regions. Potentials from these regions may consist of a mixture of myogenic and early cortical neurogenic response components. (Table 7.3.).

Author	Latency - m.s.		Nature	Origin
	N	P		
Streletz 1977	15-20		Myogenic	Vestibular
Picton 1964	17.2±1.9	22.8±2.8		

Table 7.3. The components of the Temporalis Muscle Response.

iv) The Frontalis Muscle Response (Table 7.4.).

Author	Latency - m.s.		Nature	Origin
	N	P		
Streletz 1977	14-18	22-36	Myogenic	
Picton 1964		30 m.s.		

Table 7.4. The components of the Frontalis Muscle Response.

Streletz found that amplitudes of all these responses were greatly enhanced by increases in the degree of resting muscle tone in the particular muscle groups. An example of this was presented by Picton (Figure 7.1.) where activity in the individual muscle groups was enhanced by appropriate movement of the head and jaw.

Responses from the body musculature have also been recorded. The latencies of these responses are longer and of the order of 25-30 m.secs. from the arms and 50-60 m.secs. from the legs. (Borsanyi et al.1964; Cody et al.1964 and Bickford et al. 1964).

7.2. The Inion Response

Following the initial discovery of evoked potentials to

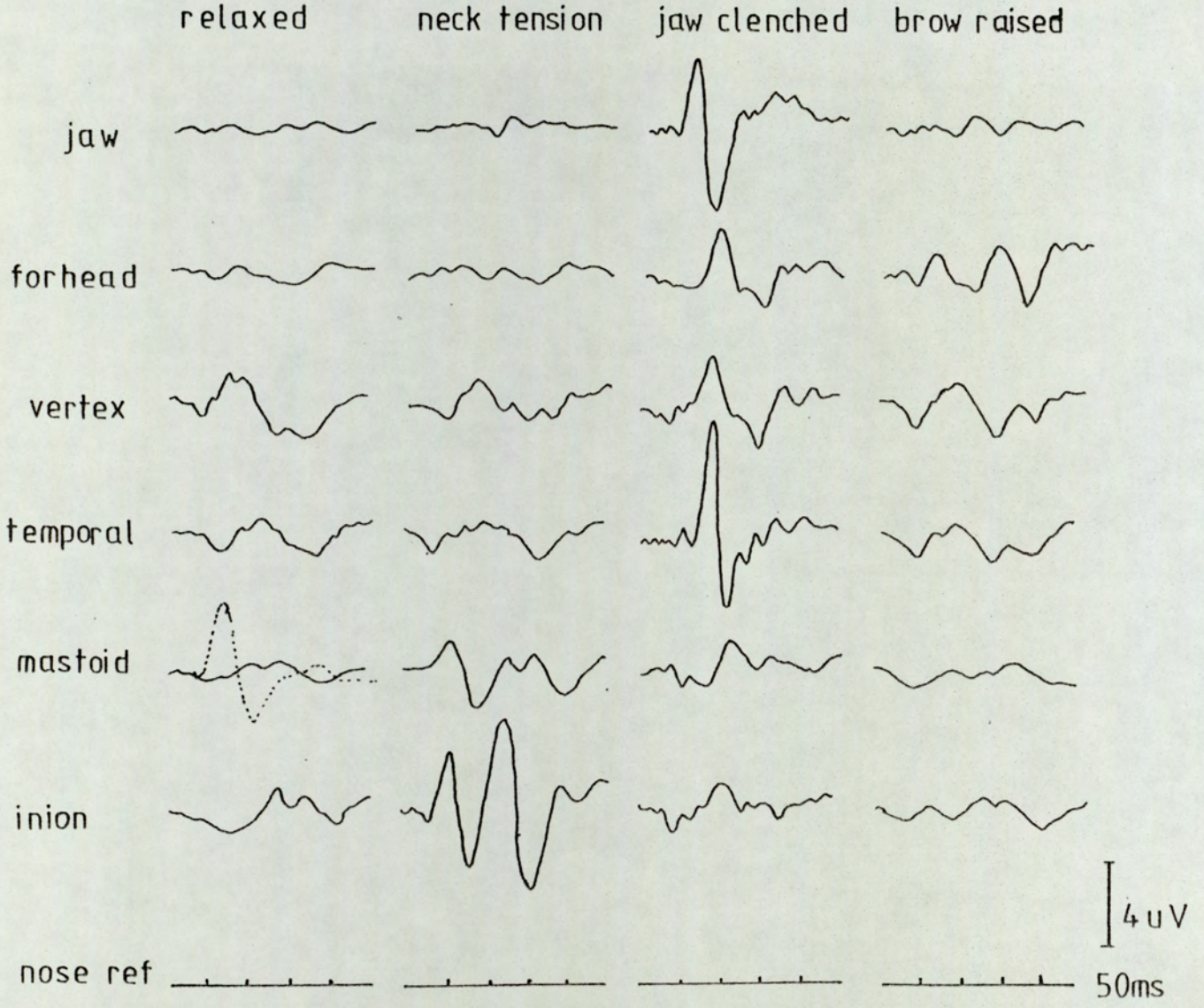


Fig 7. 1.
Distribution of scalp muscle reflexes elicited to 90dB SL clicks. [Picton et al.] 1974

sound stimulation within the spontaneous EEG by Davis (1939), the first auditory evoked potentials obtained by averaging techniques were reported by Geisler et al.(1958). These potentials occurred with latencies of 20-30 m.secs. and were maximal in the region of the inion. He concluded that these responses were of cortical origin on the basis of their consistency within each subject; their wide scalp distribution; their onset latencies which were comparable with those of somatosensory and visual evoked potentials and their similarity to animal responses.

However, other characteristics of these early potentials such as, their unusual location in the region of the inion for responses from the auditory system; their enhancement with increased muscle tone and reduction or disappearance on relaxation; and their requirement of high intensity abrupt stimulation led Bickford (1964) to suspect their possible myogenic origin. He studied the inion response in 30 normally hearing individuals (3-52 years) and in 4 patients with audio-vestibular lesions. The response to high intensity clicks consisted of several components, the most consistent being negatives at 12 and 26 m.secs. which were sometimes followed by 2 further negative potentials at 51 and 75 m.secs. All components were enhanced by an increase in tension of the neck muscles which was produced by forward flexion of the head and reduced or abolished by relaxation of the same muscles. Relaxation was produced either physically by pressure on the forehead or metabolically by the administration of curare. Initially, Bickford

proposed a short reflex arc of 2-3 neurons of possible cochlear origin to account for the inion response, but further studies on patients with audio-vestibular dysfunction revealed that this response was mediated through vestibular rather than cochlea mechanisms. The use of vestibular mechanisms and the spinal-vestbular pathways would explain the well developed inion response and also the responses from body and limb musculature.

Bickford gave the general name of Sonometer Responses to these widespread myogenic potentials. His findings were corroborated by Cody et al. (1964) and by Borsanyi et al. (1964). The latter authors reporting response components at 16, 25 and 35 m.secs. found that the amplitude of the responses was directly proportional to the amount of tension or stretch applied to the neck muscles, but once this tension was held constant then response amplitude increased with intensity. While Bickford and Cody who could only elicit the inion response at high stimulus intensities, Borsanyi reported it to be present to 20dBSL.

The almost certain vestibular origin of the inion response automatically excludes it as a clinical test of auditory function.

7.3. The Post-Auricular Myogenic Potential

This response was first discovered by Kiang et al. (1963) in a fairly localised area in the post-auricular region. It is believed to result from reflex activity initiated

in the cochlea and mediated by brainstem auditory nuclei and the post-auricular branch of the facial nerve.

7.3.1. Distribution and Configuration

First recorded by Kiang et al. (1963) from both needle and wick electrodes in the post-auricular region, this response consists of a negative component at 11 m.secs. and a positive component at 18 m.secs. The waveform and latency of this response were found to vary considerably with electrode location and type of recording electrode. Increases in distance from the post-auricular region caused rapid decrements in response amplitude and lengthening of latencies. The restriction of this response to the post-auricular region was confirmed by Jacobson, Lambert and Bickford (1964) and by Yoshie and Okudaira (1969).

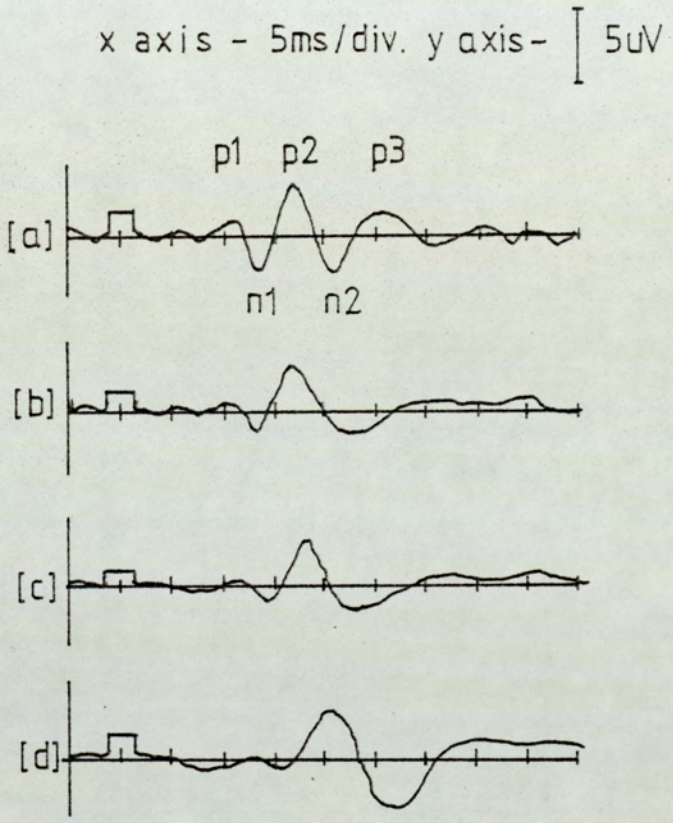
The differences in the components present and their latencies recorded between the various studies may be accounted for to some degree by differences in type of electrode, location of electrode, stimulus and recording techniques (Table 7.5.).

There is general agreement that the most prominent and stable components are the negative-positive complex, occurring between 11-20 m.secs. Thornton (1975)c attributes these differences in waveform in man to the differences in bandpass filters and more specifically to the high frequency cut-off points used in the different experimental conditions.

Latencies of Components Present - m.s.							Author
P	N	P	N	P	N	P	
	11	18					Kiang et al.1963
	16			24	36	45	Lowell 1965
	12	18	25				Yoshi et al. 1969
	11.8	16.4					Picton et al. 1974
	14			25			Douek et al. 1973
10	12	15	19.5	24			Thornton 1975

Table 7.5. Summary of reported response components of the Post-auricular Myogenic Potential and their variation in latency.

Using a wide band-pass of 1-4000Hz. he obtained 5 individual response components (Table 7.5.). The effects of different high frequency cut-off points (500, 200 and 100 Hz) on this waveform is illustrated in Figure 7.2. and Thornton concludes that N_1 (12 m.secs.) and P_3 (24 m.secs.) can be recorded at all bandwidths used while the presence of the other components appears to be dependant on the use of greater high frequency cut-off filters. Spectral analysis of the wide bandpass response revealed that the minimum of 100-1600Hz bandpass filters were necessary to record all components without distortion. Thornton presents the post-auricular response data obtained by other authors in support of these observations (Table 7.6.).



[a] high frequency filter - 4 kc/sec

[b] - 500c/sec

[c] - 200c/sec

[d] - 100 c/sec

Fig. 7.2.
The effects of system bandwidth on the post-auricular myogenic potential. [Thornton. 1975c]

Author	Stimulus dB	High Freq. limit c/s	Latency - m.s.				
			P1	N1	P2	N2	P3
Mendel & Goldstein 1969	50	100		13			22
Douek et al. 1973	70	200		14			25
Yoshie & Okudaira 1969	80	500		12	16	21	
Picton et al. 1974	60	2500	9	12	16	25	36
Thornton 1975	80	4000	10	12	15	19.5	24

Table 7.6. Latencies of the Post-Auricular Myogenic Potential Components with different band-pass high frequency limits (Thornton,1975).

However, of these data, the findings of Mendel and Goldstein (1969) refer to middle latency components not of myogenic origin, but to those of cortical origin recorded maximally in the region of the vertex. Similarly the results of Picton et al.(1974) include both myogenic and early cortical components. The post-auricular myogenic response recorded by Picton and shown in Table 7.5. consists of only two components in spite of high frequency cut-off filters of 2500Hz. The data of both Mendel et al. and Picton et al. are represented in a summary table of middle latency components by Picton (1974) and the components are described in terms of positivity and negativity at the vertex, whereas Thornton (1975) describes these same components in terms of positivity and negativity in the post-auricular region. The result of this is that Picton's middle latency components consisting of No at 8.9 m.secs. and Po at 12 m.secs., Na at 16 m.secs.

Pa at 25 m.secs. and Nb at 36 m.secs. become in Thornton's paper P_1 at 9 m.secs., N_1 at 12 m.secs., P_2 at 25 m.secs., N_2 at 25 m.secs. and P_3 at 36 m.secs.

As the recording of the middle latency components of neurogenic and myogenic origin require different experimental procedures and subjective states, it is not really valid to compare the effects of Bandwidth using two essentially different recording procedures. It is also possible that Thornton's data contains a mixture of myogenic and neurogenic components which would explain the greater number of components reported.

7.3.2. Effects of Stimulus Parameters

As with the vertex potential, the post-auricular myogenic potential has been found to vary considerably in amplitude, latency and configuration with variation in stimulus parameters.

Post-auricular myogenic activity may be elicited by stimulation with any abrupt signal with a short rise time such as a click, or tone burst or white noise.

i) Stimulus Intensity

Increases in stimulus intensity generally result in increases in response amplitude and decreases in response latency (Kiang et al. 1963; Gibson, 1978; Lowell, 1965).

Jacobson et al. (1964) and Yoshie et al. (1969) found that the increase in response amplitude was more marked at higher intensities of 50-60dBSL (Figure 7.3.).

Latency decreases of 3-5 m.secs. were reported by Yoshie et al. (1969) in responses from threshold intensities compared to 100dBSL., these effects were more pronounced near threshold.

ii) Inter-Stimulus Interval

Post-auricular myogenic potentials were recorded up to stimulus rates of 100-200 per second by Kiang et al. (1963), but these responses were complicated by superimposition. Yoshie et al. (1969) suggested a stimulus rate of 10 per second which produced a 90% recovery of maximum amplitude, whereas a rate of 50 per second only resulted in a 20% amplitude recovery (Figure 7.4.).

7.3.3. Affects of Subjective Parameters

The waveform, latency and especially amplitude of the post-auricular myogenic potential are extremely variable both across and within subjects. Several subjective and physiological factors may contribute to this variability.

i) Muscle Tension

The enhancement of response amplitude with increases in muscle tension have been reported by Kiang et al. 1963;

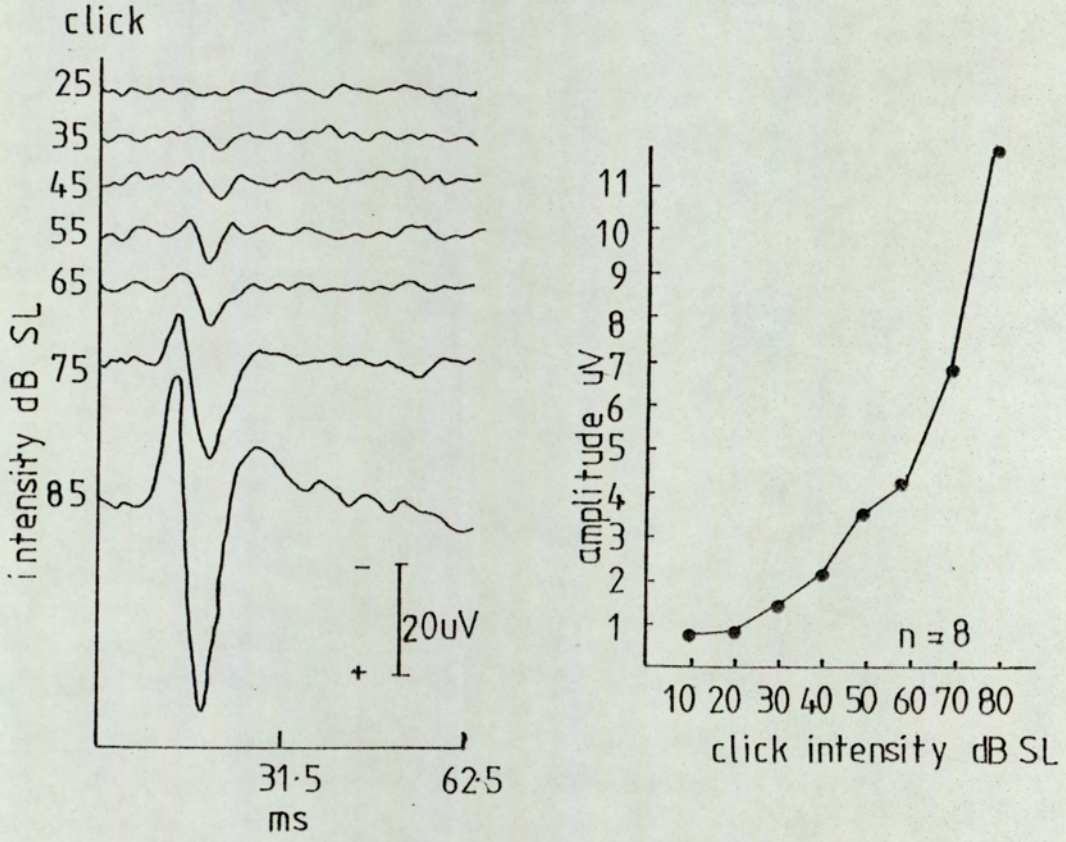


Fig 7.3.

The effects of intensity on the amplitude of the post-auricular myogenic potential. [Yoshie 1969]

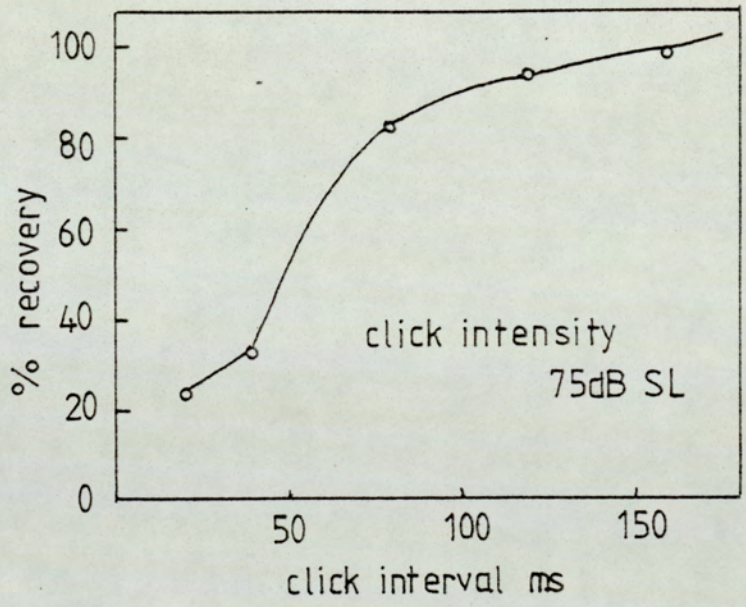


Fig 7.4.
Amplitude recovery curve (n = 3)
% recovery is the ratio of the amplitude of the second response to that of the first. [Yoshie et al.1969]

Jacobson, Cody, Lambert and Bickford 1964 and Yoshie et al. 1969. Increased muscle tone was effected by forward flexion of the head or by movement of the head to the right or left (Figure 7.5.).

Jacobson, et al. (1964) found a seven-fold increase in amplitude in a subject who could voluntarily contract his post-auricular muscles and thus move his ears. The post-auricular responses were decreased or abolished by relaxation produced either by bending the head backwards or by procaine block to the post-auricular branch of the facial nerve. Variability of amplitude across subjects was great, especially at high stimulus intensities. Yoshie et al. (1969) found variations in amplitude from 5-100uV. at 90dBSL and 1-5uV. at 30dBSL. The response was abolished or diminished during sleep (Streletz et al. 1977).

In contrast, Picton et al. (1974) found no relation between response amplitude and either the degree of resting muscle tone or head position in 22 normal adults, although he did find the response highly variable.

ii) Habituation

No evidence of habituation or fatigue in response amplitude over time was found by Jacobson et al. (1964), whereas Kiang et al. (1963) presented clear evidence of habituation over a 12 minute testing session (Figure 7.6.)

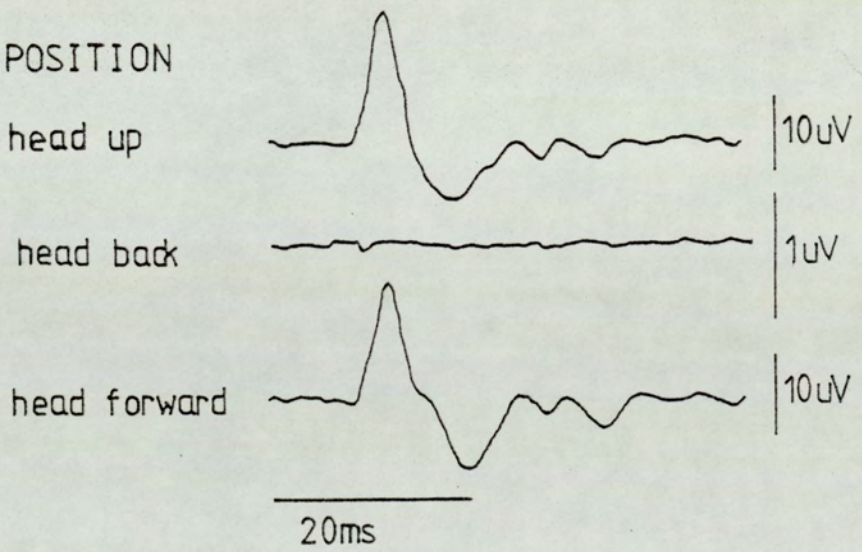


Fig. 7.5.

The effects of head position and muscle tension on the post-auricular myogenic potential.[Kiang 1963]

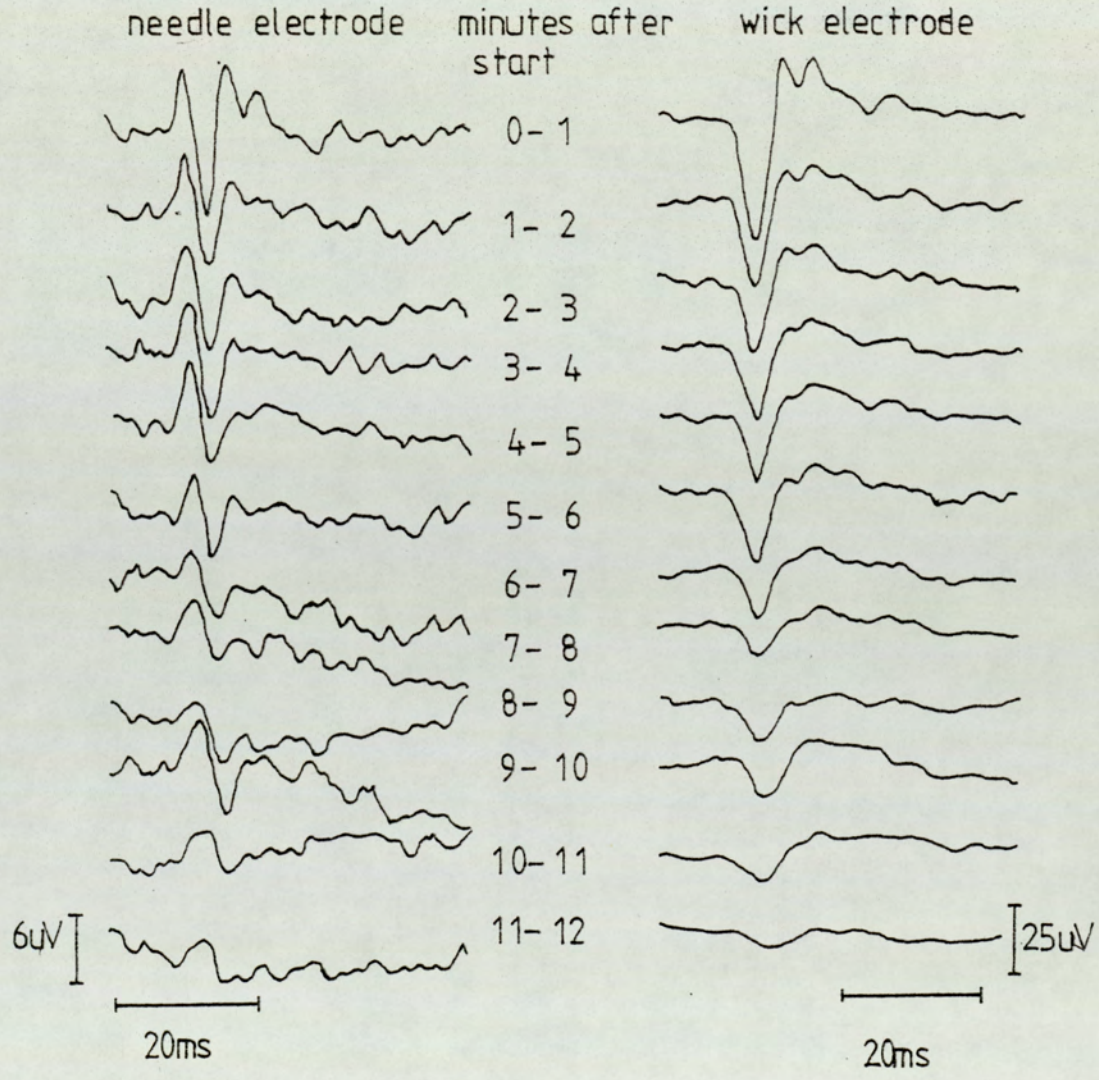


Fig. 7.6.

Averaged post-auricular responses as a function of time after the start of stimulation from both needle and wick electrodes. [Kiang, 1963]

with a decrease in amplitude of successive response as a function of time.

7.3.4. The Nature and Origin of the Post-Auricular Potential

Observations of the restricted location of the post-auricular response and its dependancy on muscle tension led Kiang et al. (1963) to suggest that it resulted from bilateral activation of neck or ear muscles.

Subsequent investigations have supported these findings (Jacobson 1964). On the basis of its sensitivity to low intensity stimuli and its dependancy on intact cochlea rather than vestibular mechanisms, Yoshie (1969) has suggested that it is mediated through the cochlear, and brainstem auditory nuclei and thus may have possible application in audiological assessment. Gibson (1978) suggests the following pathway for the mediation of the post-auricular myogenic response.

a) Spiral glanglion of cochlea
b) Ventral Cochlea Nucleus
c) Superior Olive Complex
d) Lateral Lemniscus
d) Reticular Formation or Inferior Colliculus
d) Post-auricular branch of facial nerve

At this stage mention should also be made of possible cortical neurogenic evoked potentials which may also be

elicited in the same latency range as the myogenic potentials. Mast (1963, 1965) and Goldstein (1965) are not convinced of the pure myogenic nature of the post-auricular response.

Mast was able to detect responses in the vertex and parietal areas which were unaffected by muscle tension, were stable over time and detected to near threshold stimulus intensities. He suggested that such possible neurogenic potentials may contribute to some degree to the myogenic potentials. Clear evidence of the neurogenic nature of these early vertex components was obtained by Ruhm, Walker and Flannigan 1967 by comparison of subdural and scalp response recordings at the vertex. The characteristic response reported by Goldstein and Rodman (1967) and Mendel and Goldstein (1969) consisted of the following components - Po at 13 m.secs., Na at 22 m.secs., Pa at 34 m.secs., Nb at 44 m.secs. The response was maximal at the vertex and stable over time and with sleep and arousal.

Thus, it is possible that post-auricular potential recordings may contain some degree of contamination from early neurogenic components arising from reference scalp electrodes, but these do not usually present a problem as they are of much smaller amplitude (0.5-3uV.) than the post-auricular response.

However, the selective recording of the early cortical neurogenic potentials certainly does present problems in avoiding their contamination by higher amplitude myogenic

potentials from various areas of scalp musculature.

7.3.5. The Clinical Application of the Post-Auricular Myogenic Potential

The necessary pre-requisites for an objective measure of auditory function are that the response must be stable and consistent both across and within individuals and provide a close approximation to subjective hearing levels. Examination of the current literature demonstrates that there is some controversy as to whether the post-auricular myogenic potential accurately meets these requirements.

Variability in response amplitude and in presence and absence, chiefly on account of resting muscle tone, may make it unreliable. Picton et al. (1974) could only detect the presence of the post-auricular response in 50% of 22 normal subjects. On account of the variability of the myogenic potential, Lowell (1965) prefers the use of the vertex potential in auditory assessment. Dus and Wilson (1975) found that the post-auricular responses were inconsistent even with the manipulation of background muscle tension. Bilateral post-auricular responses were recorded in 37 adults and 8 children with normal hearing. The alternation of stimuli to each ear and the bilateral recordings resulted in 4 separate responses in each of the following conditions:-

a) Relaxed - head upright

b) Smiling

c) Forward Flexion of the Neck

Since no significant differences were observed in ipsa-lateral and contralateral recordings, both were combined and out of 180 possible responses only 71 produced a post-auricular response in the relaxed state. Although the number of responses increased with increases in muscle tension (conditions band c) still only 89% of responses were present (see Table 7.7.).

Condition	N	Total Responses Possible	Responses Present
Rest	45	180	71
Smiling	45	180	128
Flexion	45	180	128

Table 7.7. Total number of responses present with variation in muscle tesnion (Dus and Wilson 1975).

Thus, the authors stress that absence of a response in a clinical situation does not necessarily imply the presence of abnormality in the reflex system generating the response.

Similar findings were presented by Bochenek and Bochenek (1975) who obtained only an 80% occurence of the post-auricular response in normal individuals and in patients with audiometric lesions. In addition, in the cases where a response was present there was great variation in its relationship to subjective hearing threshold and the

discrepancy varied from O-50dB SL.

A number of other investigators present favourable evidence for the use of the post-auricular response in audiological assessment. Jacobson et al. (1964) and Yoshie et al. (1969) both report consistent responses and close correlation between post-auricular myogenic thresholds and subjective hearing levels and suggest its use not only in auditory assessment, but also in oto-neurological diagnosis. Yoshie et al.(1969) reported responses to be consistently present to within O-20dBSL in normals irrespective of muscle tension, but absent at 100dB in patients with sensori-neural hearing losses.

Douek et al. (1973 and 1974) also report favourably on the post-auricular response on the basis that it is simple to carry out, painless and requires no sedation and provides a good measure of auditory function. Whereas the vertex potential is time consuming and often seriously interfered with by movement artifact, and the electrocochleogram requires anaesthesia and perforation of the eardrum and thus cannot be used as a routine technique. They find that the reliability of post-auricular recordings are increased by simultaneous ipsalateral and contralateral recording from both stimulated and non-stimulated mastoids. When a response, if not represent in one recording derivation, is likely to be present in the other. They reported good correlations between post-auricular and clinical findings in younger children, and older children and adults close correlations with subjective audiograms. Responses

recorded to the level of 40dB were considered as normal as there was a fairly high background noise level in their testing conditions. They conclude not by proposing the post-auricular myogenic potential as a replacement for the vertex potential, but rather as a rapid routine screening technique which may indicate the need for further investigations.

Finally, Thornton (1976), in spite of its variability, also finds close correlation of the post-auricular potential with subjective hearing levels with a mean difference of 10dBSL$\pm$7dB in 18 normal young adults.

The general conclusion reached by Davis (1973 and 1976) was that myogenic potentials were not reliable or consistent enough to provide a measure of auditory acuity, but may provide evidence regarding the itegrity of brainstem reflexes. This opinion was re-iterated by Gibson (1978) who suggests that the post-auricular myogenic potential may provide only an approximate measure of hearing, but that its application to neuro-otological diagnosis is doubtful.

Douek et al. (1974) also attempt to use the post-auricular myogenic potential in the detection and localisation of lesions of the brainstem. This technique is based on the bilateral nature of the post-auricular response and they hypothesised that any lesion of the brainstem would distort the passage of this reflex across the brainstem producing

an abnormal or absent contralateral response. 12 normally hearing subjects and 22 cases of cochlear pathology were used as controls and bilateral responses were obtained in all cases. However, abnormalities in the post-auricular response and its cross-over were reported in 7 cases of proven and possible brainstem disorders. The two proven cases were an astrocytoma of the right cerebellopontine angle where no response was recorded from the right ear, and a normal response with no cross-over from the left ear. The second case was a calcified lesion of the posterior fossa where the right ear produced an abnormality with no cross-over, with a normal response from the left ear. The remaining 5 patients had possible brainstem disorders, most arising from diffuse carcinoma.

However, the authors give no clear indication of the definition of an abnormal response, as regards the consistency of the cross-over of the response, in the same paper when discussing the application of the post-auricular response to the measurement of hearing acuity they advocate bilateral recording on the basis that if the response is absent in one derivation, it will probably be present in the other. If this is the case, then the absence of cross-over of the post-auricular response across the brainstem does not appear to be a valid or reliable measure of brainstem disfunction. This technique is also complicated by the presence of hearing loss in some of the patients and while the recording of the brainstem auditory evoked potentials offers no adequate method of separation of the effects of possible

peripheral and central contributions to this hearing loss. The authors themselves also conclude that it is impossible to draw any firm conclusions from their data.

7.4. Summary

Examination of the literature indicates that although the post-auricular myogenic potential is of cochlea origin and thus provides a reflection of auditory function, its extreme variability in both presence and absence and laterality preclude it from a reliable measure in the assessment of either audiological or neurlogical function.

Its dependance and enhancement by increased muscle tone would support its application as a rapid screening technique in infants and young children where resting muscle tone is usually high. However, since the post-auricular response is best elicited in response to click stimulation, the information provided would be limited to high frequencies of approximately 2000Hz and above and thus only reflect neural activity in the basal turn of the cochlea.

In all investigations reported, the post-auricular myogenic potential does not appear to produce false positive results, that is, the diagnosis of normal hearing when a hearing loss exists. The converse, however, is certainly not true and in view of its variability and often complete disappearance with relaxation, the absence of the post-

auricular response cannot be taken as definitive evidence of a hearing loss. Since this response occurs at the level of the brainstem, it provides no information regarding the possibility of lesions at higher levels of the auditory system.

Similarly, in the case of possible brainstem lesions, the presence of a bilateral response can indicate the integrity of the reflex arc mediating this response within the brainstem, but the absence of a bilateral response cannot be taken as definitive evidence of a brainstem lesion.

7.5. Experimental Section

Two separate investigations were carried out on the post-auricular myogenic potential. The initial study on a group of 30 normal young adults was designed to investigate the effects of changes in the degree of resting muscle tone in the post-auricular muscle on:-

a) subjective and objective threshold differences
b) the occurence of the response in ipsilateral and contralateral mastoid recording derivations.

In the second experiment, the post-auricular myogenic potential was recorded simultaneously with the brainstem evoked potentials in 25 normal young adults. In this case the behavioural state of each subject was held constant and the effects of stimulus intensity on the latency, amplitude and occurence of the post-auricular response in ipsilateral and contralateral mastoid derivations were measured in the relaxed state. The subjective and objective threshold differences measured in both experiments were compared.

7.5.1. Method

Experiment 1

Equipment

The post-auricular myogenic potentials were recorded in

response to a 0.1 m.sec. click stimulus of alternating polarity which was relayed monaurally to the subject through TDH-39 headphones. Stimulus intensity was calibrated by a Breul and Kjaer sound level meter with artificial ear attachment.

The electrical activity recorded from the scalp was amplified and monitored by an 8 channel SLE EEG machine in which the pre-amplifiers of the selected channels had been modified to give a band-pass of 5-1000Hz. The averaged post-auricular myogenic potentials were recorded by a computer of Average Transients (400C TMC) (and a permanent record of each response was obtained directly from an X-Y Plotter) from which all subsequent measurements were made.

Procedure

A total of 30 normal young adult subjects between the ages of 17 to 25 years were investigated. Each subject was seated in a sound-damped room and given reading material to keep his level of attention reasonably constant through the procedure. The post-auricular responses were recorded from silver/silver chloride disc electrodes attached to both ipsilateral and contralateral mastoids by adhesive discs and blenderm tape. References and earth electrodes were glued to the scalp with collodion at vertex (C_z) and P_z derivations respectively. All electrode resistances were below 5Kohms. The electrical activity recorded between

ipsilateral mastoid to vertex and contralateral mastoid to vertex derivations was monitored on 2 channels of the SLE EEG machine and relayed to the CAT set up for 2 channel averaging (providing 200 data stores per channel). Each average consisted of 300 individual sweeps each with an analysis time of 31.5 m.secs. The click stimulus was relayed to the subject monaurally through TDH-39 headphones and the activity from ipsilateral and contralateral mastoids recorded. The onset of each sweep of the averager was triggered externally, simultaneously with the onset of the click stimulus. The post-auricular responses were initially recorded at a stimulus intensity of 90dBA . The intensity was then reduced in each successive average by 10dB until the objective threshold was ascertained and the response no longer detectable. The affects of resting muscle tone on the occurence of the post-auricular response was also investgated by voluntary manipulation of the subjects resting muscle tone, either by forward flexion of the head or by general random movements of the head. This latter condition would simulate the behaviour of restless young children which was often encountered in clinical testing situations.

Experiment 2

In this second experiment, post-auricular myogenic potentials were recorded simultaneously with brainstem evoked potentials from ipsilateral and contralateral mastoid derivations in 25 normal young adults. The subjects, equipment and recording procedure are identical to those for recording the brainstem evoked potentials which are described in Chapter 8.

The essential differences in this and the previous study are -

a) the use of band-pass filters of 5-4000Hz instead of 5-1000Hz to enable simultaneous recording of the brainstem potentials

b) the potentials were recorded on a Data Lab 1000 instead of the CAT. The sweep time used was reduced to 20 m.secs. and the number of sweeps increased from 300 to 2048 to record the smaller amplitude brainstem responses

c) the responses of this second study were again recorded on an X-Y Plotter, but all amplitude and latency measurements made directly from the cursor facility of the Microprocessor

d) the behavioural state of the subject was maintained relatively constant throughout the recording procedure. This enabled the effects of stimulus intensity on the amplitude and latency of the post-auricular response to be measured and also, by comparison with the previous study, the effects of changes in resting muscle tone on the difference obtained between subjective and objective threshold measurements.

7.5.2. Results and Analysis

Experiment 1

The affects of stimulus intensity on the amplitude and latency of the post-auricular response were not measured in this study as the voluntary control of resting muscle tone was found to produce marked changes in both response parameters which tended to obscure the effects of stimulus intensity. In general, response latency was reduced and response amplitude increased by increases in resting muscle tone in the post- auricular region. An example of the effects of increased muscle tone as measured in the resting EEG record on the amplitude of the post-auricular muscle response is shown in Figure 7.7. The results obtained in this study may be summarised as follows:-

1. The post- auricular myogenic potential was not consistently recorded in all subjects from either ipsilateral or contralateral mastoid derivations or from both in the relaxed state. At the maximum stimulus intensity level used the response was present only in 83% of the subjects (25/30). However, when resting muscle tone was increased, the response was recordable in all subjects.

2. In 80% of subjects (24/30) the response was consistently bilateral and recorded from both ipsilateral and contralateral mastoid derivations. There was often a

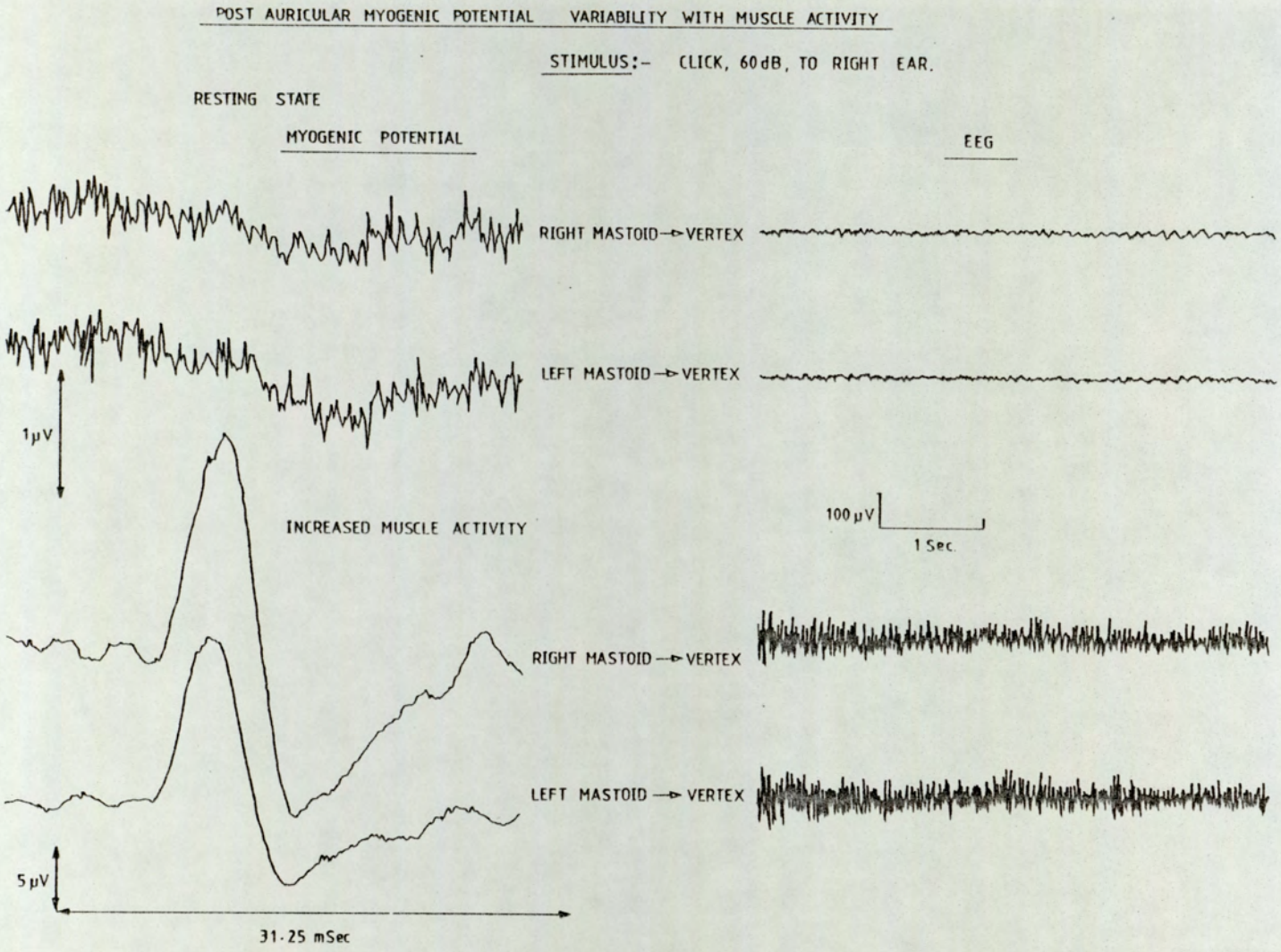


Fig. 7.7. The effects of changes in resting muscle tone on the amplitude of the post-auricular myogenic potential.

considerable amplitude difference between ipsilateral and contralateral responses which appeared to be related to the degree of resting muscle tone in each recording derivation rather than to the ear stimulated. In the remaining 20% of subjects (6/20) the responses were either ipsilateral or contralateral with no clear bilateral responses recordable (Figure 7.8.).

3) The relationship between subjective and objective hearing thresholds was measured in 23 subjects where muscle tone had been enhanced by voluntary co-operation. The mean difference in thresholds was +13.9dB with a standard deviation of ± 7.53dBSL. The range of subjective and objective threshold differences was +5dB to +30dBSL.

Experiment 2

1) The Effect of Stimulus Intensity on the Latency of the Post-Auricular Myogenic Potential

Latency measurements were made only on the major mastoid negative component of the myogenic potential. The values obtained from both ipsilateral and contralateral mastoid derivations are shown in Table 7.8. and the latency intensity functions shown in Figure 7.9. It can be seen that the variability in response latency across subjects is reasonably large even when muscle tone is held relatively constant.

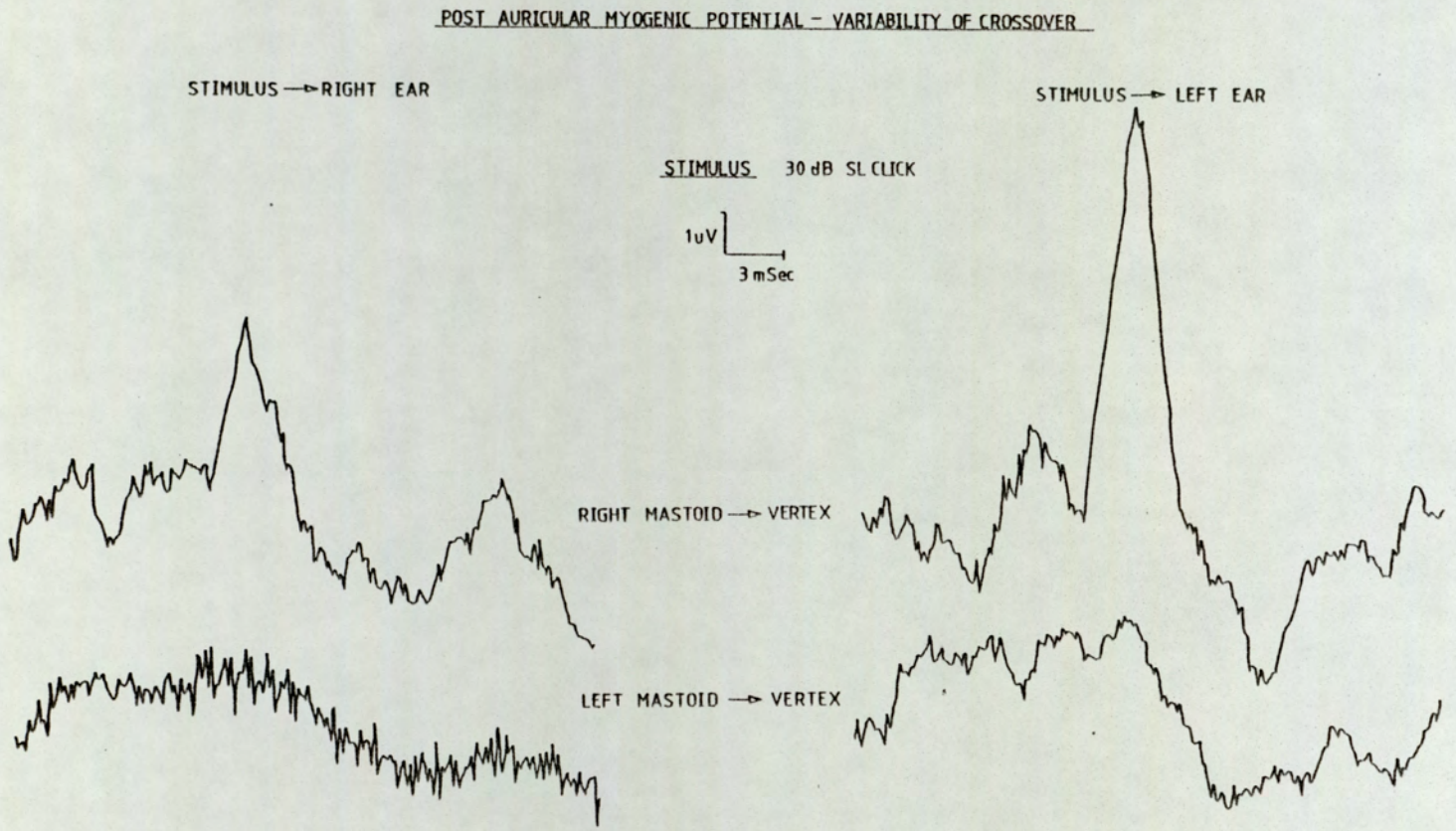


Fig. 7. 8. The variability in cross-over of the post-auricular myogenic potential.

INTENSITY dBSL		IPSILATERAL MASTOID - VERTEX			CONTRALATERAL MASTOID - VERTEX			TOTAL % Occ.
		Latency ms	Amplitude uV	% Occ.	Latency ms	Amplitude uV	% Occ.	
90	n	3	3	3/3	3	3	3/3	3/3
	x̄	12.856	3.889	100	11.304	8.199	100	100
	SD	0.999	5.158		0.559	11.651		
80	n	11	11	12/14	12	11	12/14	13/14
	x̄	12.228	42.972	86	12.372	27.744	86	93
	SD	1.457	47.275		0.848	45.760		
70	n	17	15	18/23	17	12	19/23	21/23
	x̄	12.281	17.408	78	12.189	23.499	83	91
	SD	1.296	21.675		1.329	32.205		
60	n	16	16	18/25	14	14	18/25	21/25
	x̄	12.270	11.720	72	12.227	19.764	72	84
	SD	0.778	19.436		0.931	41.318		
50	n	15	15	19/25	13	13	16/25	22/25
	x̄	12.232	7.785	76	12.335	15.305	64	88
	SD	1.512	6.606		0.756	32.591		
40	n	17	17	21/25	12	12	15/25	23/25
	x̄	12.056	5.499	84	12.464	16.853	60	92
	SD	0.743	6.835		0.711	86,756		
30	n	11	11	16/25	10	11	15/25	20/25
	x̄	12.339	8.728	64	12.528	17.320	60	80
	SD	0.863	9.419		0.898	40.429		
20	n	11	9	14/25	9	7	13/25	19/25
	x̄	13.308	2.775	56	13.038	13.443	52	76
	SD	0.863	2.262		1.772	24.070		
10	n	7	6	10/25	6	5	9/25	13/25
	x̄	13.711	3.662	40	13.245	10.645	36	52
	SD	1.422	2.731		1.182	18.086		
0	n	3	3	6/25	3	3	4/25	7/25
	x̄	13.794	3.215	24	13.996	1.281	16	28
	SD	1.235	1.996		1.228	0.090		

TABLE 7.8 Variation in Latency, Amplitude and Occurrence of the Post-Auricular Myogenic Potential Recorded from Ipsilateral and Contralateral Mastoids with Changes in Stimulus and Intensity.

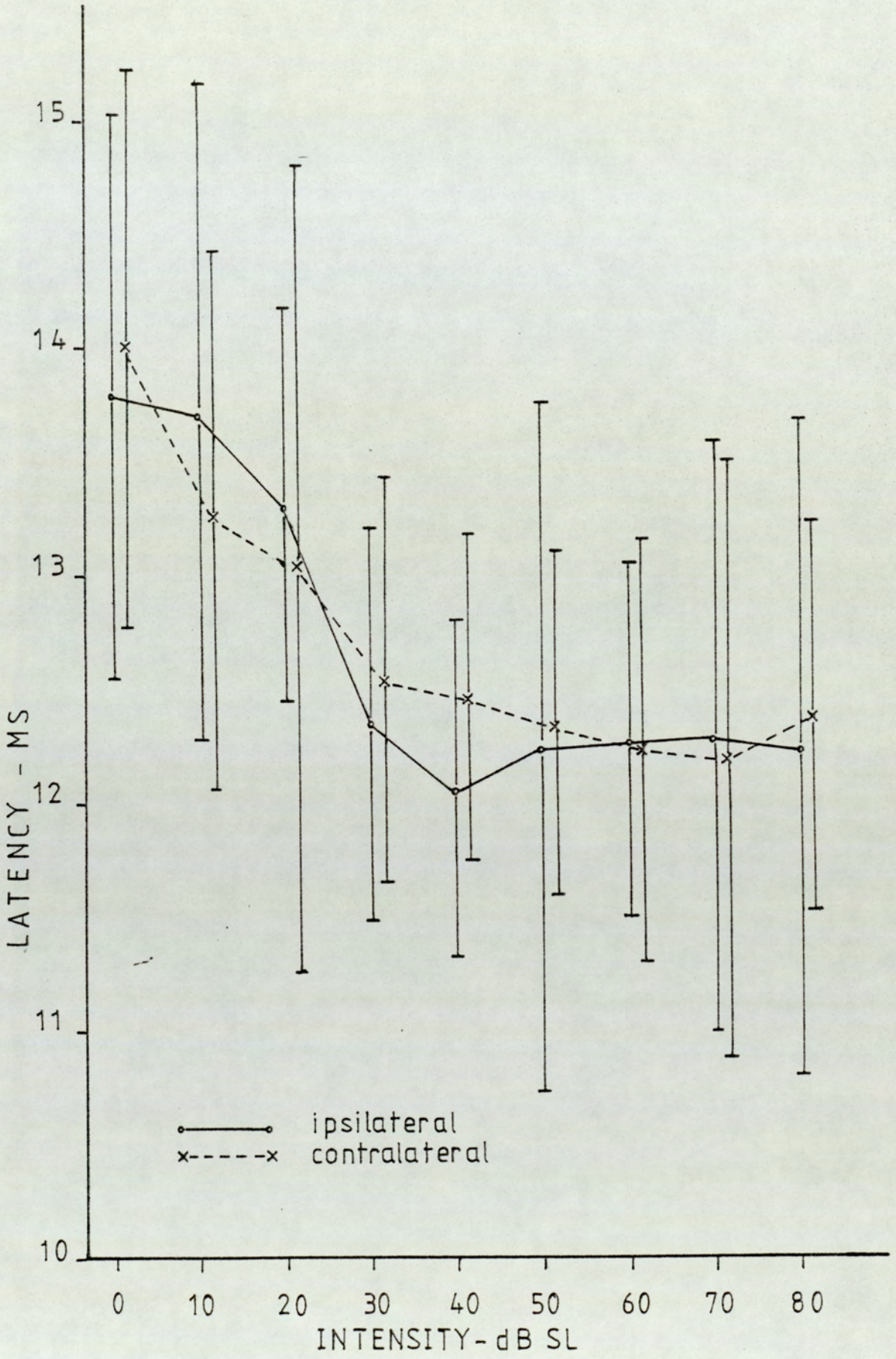


Fig. 7. 9.
Latency~intensity functions of the post-auricular myogenic potential recorded from ipsilateral and contralateral mastoids.

The response latency shows an increase with decreasing stimulus intensity which is more marked at lower sensation levels of 30dB and below. Above this level the latencies of the ipsilateral myogenic responses appear relatively independant of intensity. The variability in latency of response as reflected in the standard deviation remains constant over all intensities.

2) The Effect of Stimulus Intensity on the Amplitude of the Post-Auricular Myogenic Potential (n=25)

Peak to peak amplitude measures of the post-auricular potential were calculated from the major mastoid negative component to the following positive component. The amplitude values obtained from the microprocessor were converted to microvolts by comparison with a 5uV.calibration pulse.

The amplitudes of the post-auricular myogenic potentials show great variability across subjects at all intensities, (Table 7.9.) and only the mean amplitude values are shown in the amplitude-intensity functions of ipsilateral and contralateral responses in Figure 7.10. The amplitudes of both ipsilateral and contralateral responses increase with intensity and these increases are most marked at higher sensation levels.

Intensity dB SL	% Bilateral	% Ipsilateral	% Contralateral	% No Response
80	11/14 78	1/14 7	1/14 7	1/14 7
70	16/23 69	2/23 9	3/23 13	2/3 9
60	15/23 65	3/23 13	3/23 13	2/23 9
50	13/25 52	6/25 24	3/25 12	3/25 12
40	13/25 52	8/25 32	2/25 8	2/25 8
30	11/25 44	5/25 20	4/25 16	5/25 20
20	8/25 32	6/25 24	5/25 20	6/25 24
10	7/25 28	3/25 12	2/25 8	13/25 52
0	3/25 12	3/25 12	1/25 4	18/25 72

Table 7.9. Percentage of Bilateral, Ipsilateral and Contralateral Post-Auricular Responses over Intensities of 80-0dBSL.

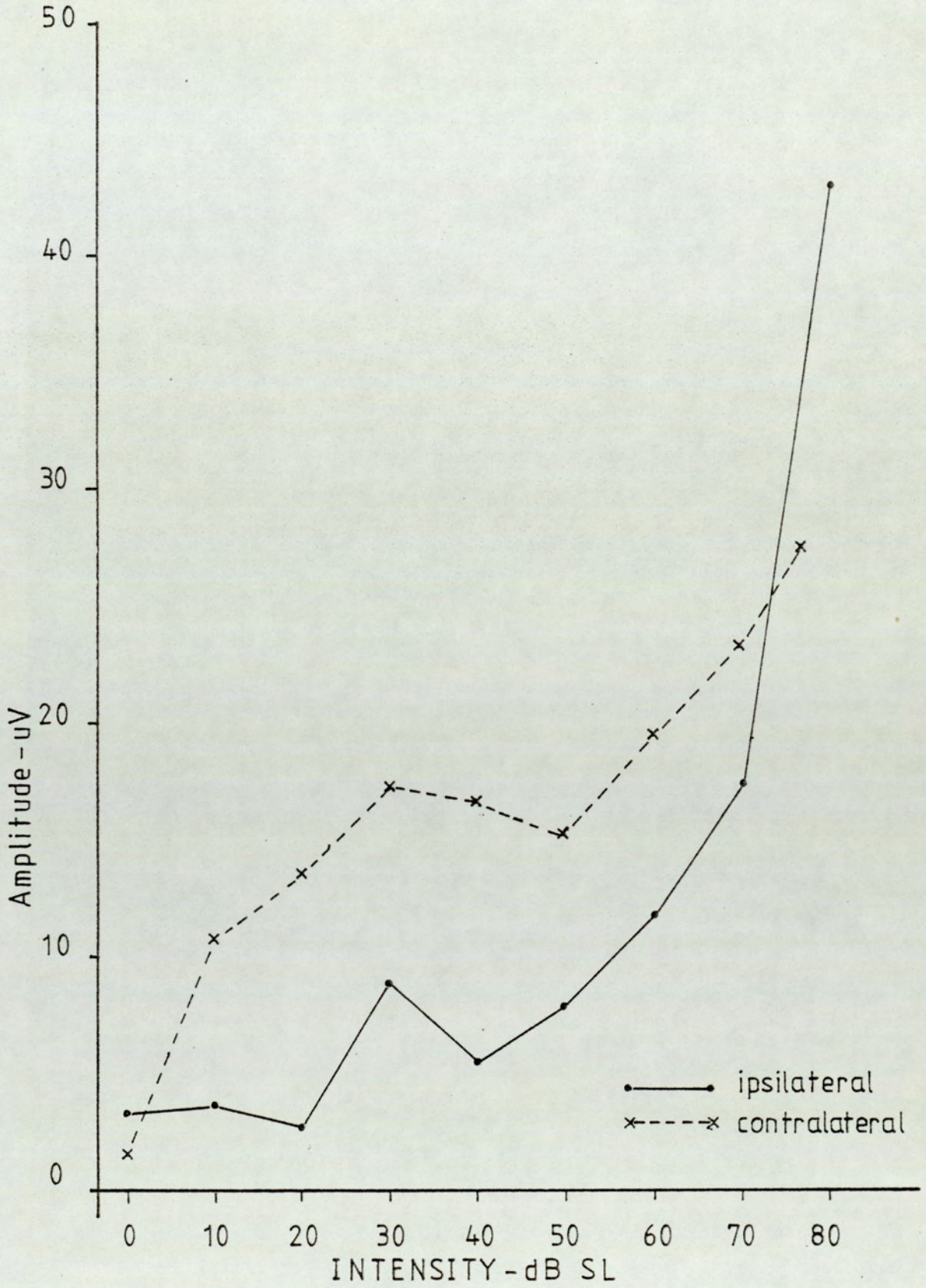


Fig. 7. 10.
Amplitude-intensity functions of the post-auricular myogenic potential recorded from ipsilateral and contralateral mastoids

3) The Relationship of Objective Threshold of the Post-Auricular Response to Subjective Hearing Threshold (n=25)

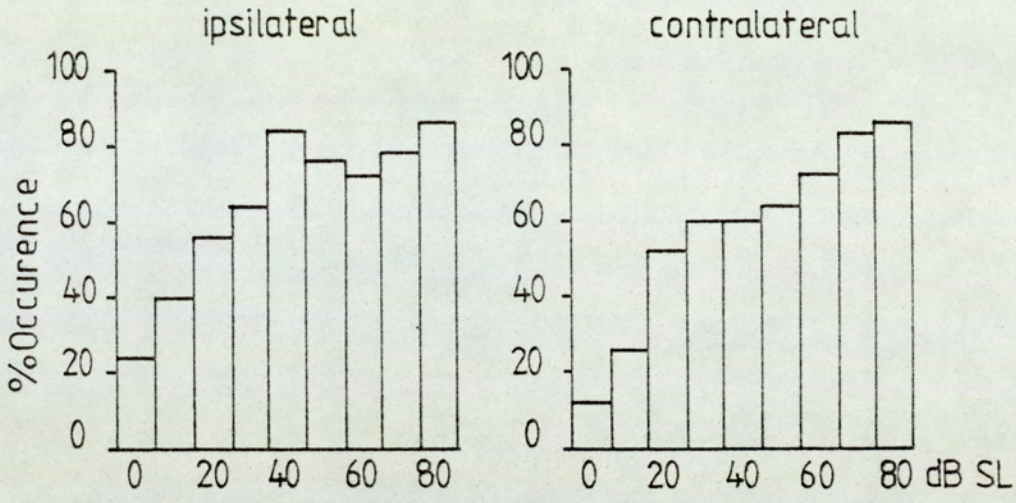
The affects of intensity on the combined percentage occurence of ipsilateral and contralateral responses is shown in Figure 7.11. Even in the fairly relaxed subjective conditions of this experiment when muscle tone was not voluntarily increased, the post-auricular response is present in the majority of subjects to the level of 20dBSL when it is detected in 76% of the individuals, whereas at 10dBSL this falls rapidly to 52%.

The comparison of subjective and objective thresholds produces a mean difference of +18dBSL with a standard deviation of ± 13.5dB. The distribution of these differences shown in Figure 7.12 is broad with a range from 0 to +55dBSL.

4) Differences between the Characteristics of Ipsilateral and Contralateral Recordings of the Post-Auricular Myogenic Potential (n=25).

Differences in ipsilateral and contralateral responses in terms of latency, amplitude and percentage occurence are shown in Table 7.9.

The comparison of ipsilateral and contralateral latency measurements show little difference in either mean values or variability of the two responses (Figure 7.9.).



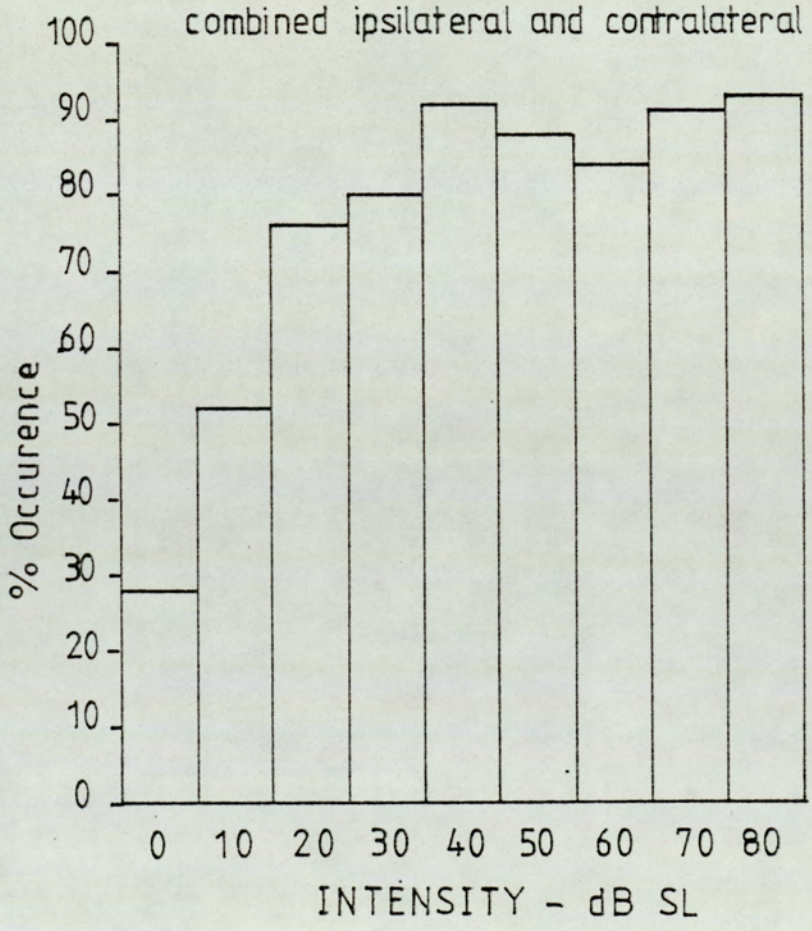


Fig.7.11.

The percentage occurrence of a) ipsilateral b) contralateral and c) combined ipsilateral and contralateral responses.

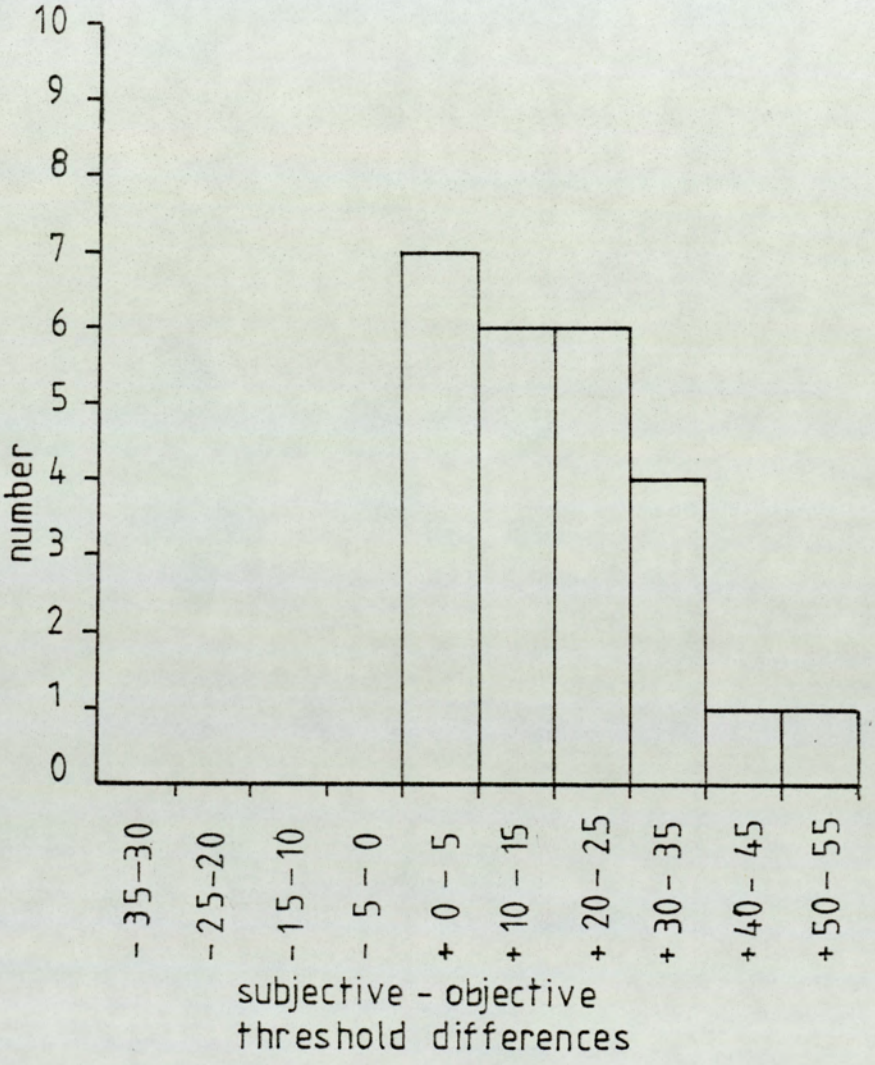


Fig. 7. 12.

Distribution of subjective and objective threshold differences using the post-auricular myogenic potential.

Response amplitudes, however, appear consistently larger in contralateral derivations over intensities from 0-70dBSL. Table 7.8. also indicates that variability in response amplitude is also greater in contralateral derivations.

Comparison of the occurence of contralateral and ipsilateral responses averaged over all subjects indicates that at all sensation levels responses are detected either bilaterally or more consistently in ipsilateral recording derivations (Table 7.9. and Figure 7.10). However, even at the higher sensation levels responses are not consistently present in all subjects either bilaterally or unilaterally.

7.5.3. Discussion

The post-auricular myogenic potential has mainly been used as an objective measure in the assessment of hearing thresholds, but Douek et al. (1973) have also suggested its use in the detection of brainstem lesions which may disrupt the cross-over and bilateral representation of this response.

Audiological Assessment

The differences obtained between subjective and objective thresholds obtained with different degrees in resting muscle tone are shown in Table 7.10.

This data suggests that increases in resting muscle tone

Number	Subjective-Objective Threshold Difference dBSL			Condition
n	Mean	Standard Deviation	Range	
23	+13.9	± 7.53dB	+5 — +130	Increased muscle ton
25	+18.0	±13. 5dB	0 — + 55	Relaxation

Table 7.10. The effects of changes in muscle tone on the difference in subjective and objective response threshold.

result in a closer relationship between subjective and objective threshold measurements and also in a decrease in variability and range of these differences. However, in both experimental conditions the mean differences and variability in subjective and objective thresholds are sufficiently small to support the use of the post-auricular myogenic potential, at least, as a rapid screening test for possible hearing disorders (Douek et al. 1973). The increase in reliability of the test with increased muscle activity is often a severe problem which seriously interferes with the recording and detection of the slow vertex potential response and also of the brain stem potentials.

Comparison of the percentages of responses present bilaterally, ipsilaterally and contralaterally justifies the use of simultaneous monitoring of ipsilateral and contralateral activity. Table 7.9. shows that a small but consistent number of responses are present in contralateral

derivations only; these would not have been detected with ipsilateral recordings alone. Thus, as suggested above, the presence of a post-auricular response may play an important part in the exclusion of hearing losses in young children but, owing to the extreme variability of the response, its absence may not be taken as definite evidence of a hearing loss, but may indicate the need for further investigations.

Neurological Assessment

The results of this study would not support the application of the post-auricular myogenic response in neurological assessment. Although a post-auricular response was detected in all subjects with voluntary increases in muscle tone (experiment 1), it was not consistently recorded in both post-auricular regions in all subjects. The response was sometimes present only in ipsilateral derivations and on other occasions only in contralateral derivations. In addition, both the latency and amplitude of the post-auricular response appeared to be dependant on resting muscle tone as well as stimulus intensity. Thus, although brainstem lesions may result in abnormalities in the post-auricular response in terms of both cross-over, and response latency and amplitude (Douek et al. 1973), such occurences may also be observed amongst the normal population. This would indicate the unreliability of the post-auricular response in the detection of brainstem lesions in terms of the production of false positive diagnoses.

CHAPTER 8

The Electrocochleogram and Brainstem Auditory Evoked Potentials.

8.1. Recording Techniques

Early attempts to record and measure cochlear and auditory nerve activity in man met with very little success. The application of such recording techniques was also extremely limited as the placement of the active recording electrode on the round window of the cochlear could only be carried out during surgical procedures.

The development of both averaging computers and low noise amplification systems have made it no longer necessary to place the active recording electrode so near the cochlea and in the 1960's several alternative less traumatic recording techniques were developed almost simultaneously. They enabled the recording of both the cochlear microphonic and the 8th nerve action potential, using relatively harmless techniques which could be carried out without complicated surgical procedures.

Recording techniques differed mainly in their placement of active recording electrodes. Three basic categories exist:-

i) Recordings from a transtympanic electrode

ii) Recordings from an electrode in the wall of the external auditory nucleus

iii) Recordings from scalp and earlobe electrodes.

8.1.1. Transtympanic Electrocochleography

The activity of the auditory nerve was monitored by Aran and Portman (1967) and Portman and Aran (1971) using a fine rigid steel electrode which was passed through the tympanic membrane to rest directly on the promontory near the round window of the cochlea. They named the auditory nerve response, so recorded, the electrocochleogram and defined it thus "as a test which notes, records and measures the averaged electrical responses which are set up between the bony promontory of the cochlea and the lobe of the ear in response to a very short acoustic stimuli of alternating positive and negative phase". The proximity of the recording electrode to the cochlea results in a marked enhancement of the signal:noise ratio and the production of a large clear response of amplitude of 20-40uV. The advantages of this technique are that it enables responses to be detected close to subjective hearing levels and thus provides a reliable measure of hearing acuity at the peripheral level. In addition, the shape of the response and the characteristics of both latency and amplitude - intensity functions allow the differentiation of conductive and sensori-neural deafness and also help in the diagnosis of possible 8th nerve neuromas and other neurological disturbances.

The disadvantages of this technique are that it requires performation of the eardrum which involves some slight element of risk and in addition the greater risk of general

anaesthesia in children under the age of 8 years. These factors automatically preclude this recording technique for use as a routine test in an electrophysiological laboratory as the presence of trained medical staff is required for both anaesthesia and electrode placement.

8.1.2. Recordings from the External Auditory Meatus

This technique was first developed by Yoshie, Ohashi and Suzuki in 1967, when following local anaesthesia, a hypodermic needle was inserted into the posterior wall of the external meatus to within a distance of approximately 5mm. from the annulus tympanicus. This active recording electrode was referred to an electrode on the earlobe. The response recorded to high intensity clicks (80dBSL) consisted of three negative components:- N_1, N_2 and N_3, the latencies of which were 2.1 m.secs., 3.1 m.secs. and 4.3 m.secs. respectively (calculated from arrival time of stimulus at the tympanic membrane).

The N_1 was the largest response component and on the basis of similarities with animal recordings directly from the round window was assumed to represent the activation of the auditory nerve. Similar recording procedures were carried out by Coats and Dickey (1970) who obtained action potentials of 1-4uV. amplitude in 6 normal subjects and by Salomon and Elberling (1971). The latter authors confirmed the major N_1 component present in all their subjects (n=17) to a rarefaction click with clear N_2 components in 16 and

N_3 components in 12 subjects (Figure 8.1.). They suggest the brainstem rather than the auditory nerve as a possible source of the N_2 and N_3 components.

8.1.3. Recordings from Scalp and Earlobe Electrodes

Sohmer and Feinmesser (1967) first recorded the action potential from the auditory nerve in response to a click stimulus from an electrode placed on the earlobe and referred to the vertex. Such an electrode placement is relatively distant from the source of the response and to overcome the resulting decrease in signal:noise ratio it is necessary to average around 2000 individual responses to obtain a resultant response of approximately 0.5uV. amplitude. This compares poorly with the 500 responses averages from meatal wall recording and subsequent amplitude of 1-4uV. However, the most important characteristic of this recording technique is that not only did the authors record the activity of the auditory nerve, but in total a series of 5 consistent earlobe-negative waves were detected within 8 m.secs. of stimulus onset. Early speculation as to the possible brainstem origin of these later components has now been confirmed by both studies in animals and man (see Section 8.2.).

This recording technique using scalp electrodes, although producing exceedingly small response amplitudes, has the advantage of being completely non-insultive and provides information regarding the integrity of the brainstem as well as the auditory nerve.

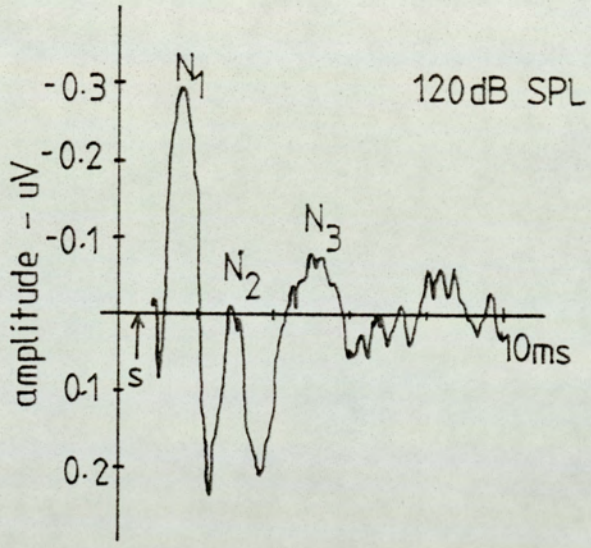


Fig.8.1.
The electrocochleogram recorded to a click stimulus from an electrode in the external auditory meatus.
[Salomon and Elberling, 1971]

Similar findings were reported in later studies by Terkildsen, Osterhammel and Huis In't Veld (1973) and Thornton (1975)a using the mastoid as the active recording electrode rather than the earlobe.

Terkildsen et al. (1973) obtained consistent electrocochleogram and brainstem potentials in response to a 4000Hz tone pip in 10 subjects (20-37 years) (Figure 8.2.). He demonstrated how the removal of interfering effects of the cochlear microphonic could be obtained by the addition of stimuli of alternating polarity. Since the cochlear microphonic follows exactly the waveform of the stimulus, then the addition of responses to stimuli of alternating polarity effectively removes the cochlear microphonic with minimal effects on the response latency of the brainstem components, where the shift of the stimulus by ½ a cycle does not appear significant with a high frequency stimulus. Alternatively, if the cochlear microphonic is to be viewed the subtraction of the responses of alternate polarity will cancel the neural response and enhance the microphonic (Figure 8.2.).

8.2. Configuration and Nomenclature of the Brainstem Auditory Evoked Potentials

Two main methods of classification have resulted from the early work of Jewett (1970) and of Sohmer and Feinmesser (1967). A series of 7 distinct vertex positive components were recorded by Jewett and Williston (1971) in response to

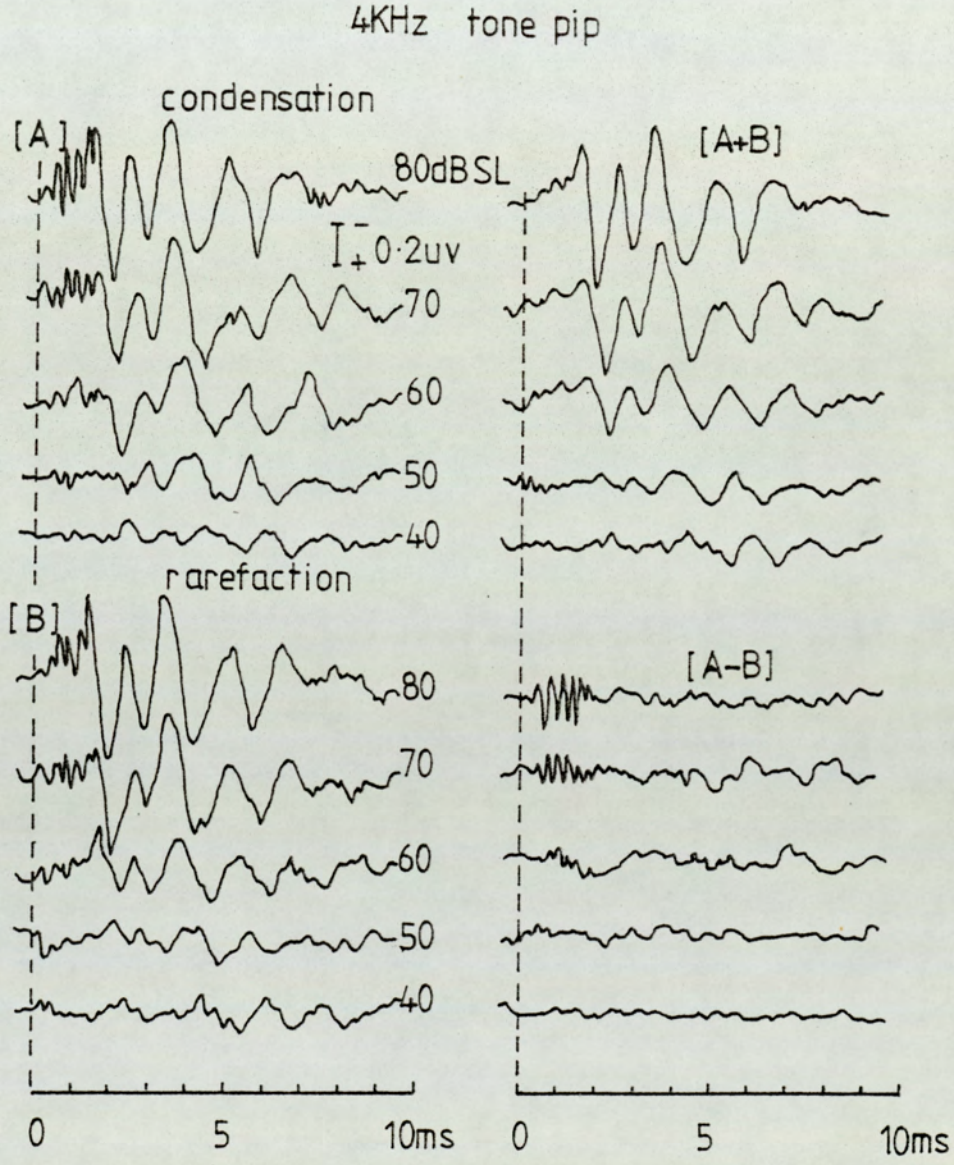


Fig. 8.2.

The recording of brain stem potentials and cochlear microphonic by alternation of stimulus polarity.

[Terkildsen et al. 1973]

binaural click stimulation from an active electrode at the vertex and reference electrode on the right earlobe. They labelled these components with the roman numerals 1 to V11 respectively. Both the amplitudes and more especially the latencies of these individual components were remarkably stable within and across subjects and with time. Wave 1 was found to vary in amplitude from 0.09 - 0.5uV. and wave V from 0.6 - 1.4uV. and the latencies of these components were 1.4-1.8 m.secs. and 4.6-5.1 m.secs. respectively (calculated from time of arrival of a 60-75dBSL click stimulus at the tympanic membrane). Wave 11 was usually present, but of smaller amplitude than wave 1 while wave 111 was clearly detectable. Wave 1V was inconsistent and when present only occurred as a small shoulder on the rising edge of component V. This latter component, usually known as Jewett's Wave V, was the largest and most consistant of all the components present (Figure 8.3.). The later V1 and V11 waves were not always detectable. In addition to the inter and intra subject stability of these components Jewett also found them resistant to the affects of sleep and attention. Jewett's classification system has been adopted by many investigators (Picton et al. 1974; Starr and and Achor, 1975 and Stockard and Rossiter 1977) while others use the system derived from the early work of Sohmer and Feinmesser (1967) who described the brainstem potentials in terms of negativity at the mastoid or earlobe with a reference electrode at the vertex. The 5 mastoid/earlobe negative components of Sohmer and Feinmesser were labelled

N_1 to N_5 respectively (Figure 8.3.). However, confusion between these two systems often arises as Sohmer does not include the variable wave 1V of Jewett's classification and hence Jewett's wave V is the N_4 component of Sohmer and Feinmesser. However, when both waves 1V and V are present they are denoted according to Sohmer's classification as components N_{4a} and N_{4b} respectively. Confusion also arises from a) the use of alternative conventions of representing positivity as upwards or downwards combined with b) the classification of the brainstem potentials as either vertex positive or mastoid negative. Thus, all conventions should be clearly stated.

The general findings of ensuing studies are in complete agreement with the early work of Jewett and Williston (1971) regarding the stability of these brainstem potentials especially of component 1, 111 and V (N_1, N_2 and N_4).

Summaries of the latency and amplitude characteristics of the brainstem potentials in both children and adults are presented in Tables 8.1; 8.2. and 8.3. The differences observed across investigators, especially in terms of response latency, may be partially explained by the use of different experimetal procedures. Such factors usually affect the latency of only wave 1 directly and hence passively affect the latencies of the later components. The affects of the different experimental procedures may be eliminated by the calculation of central transmission

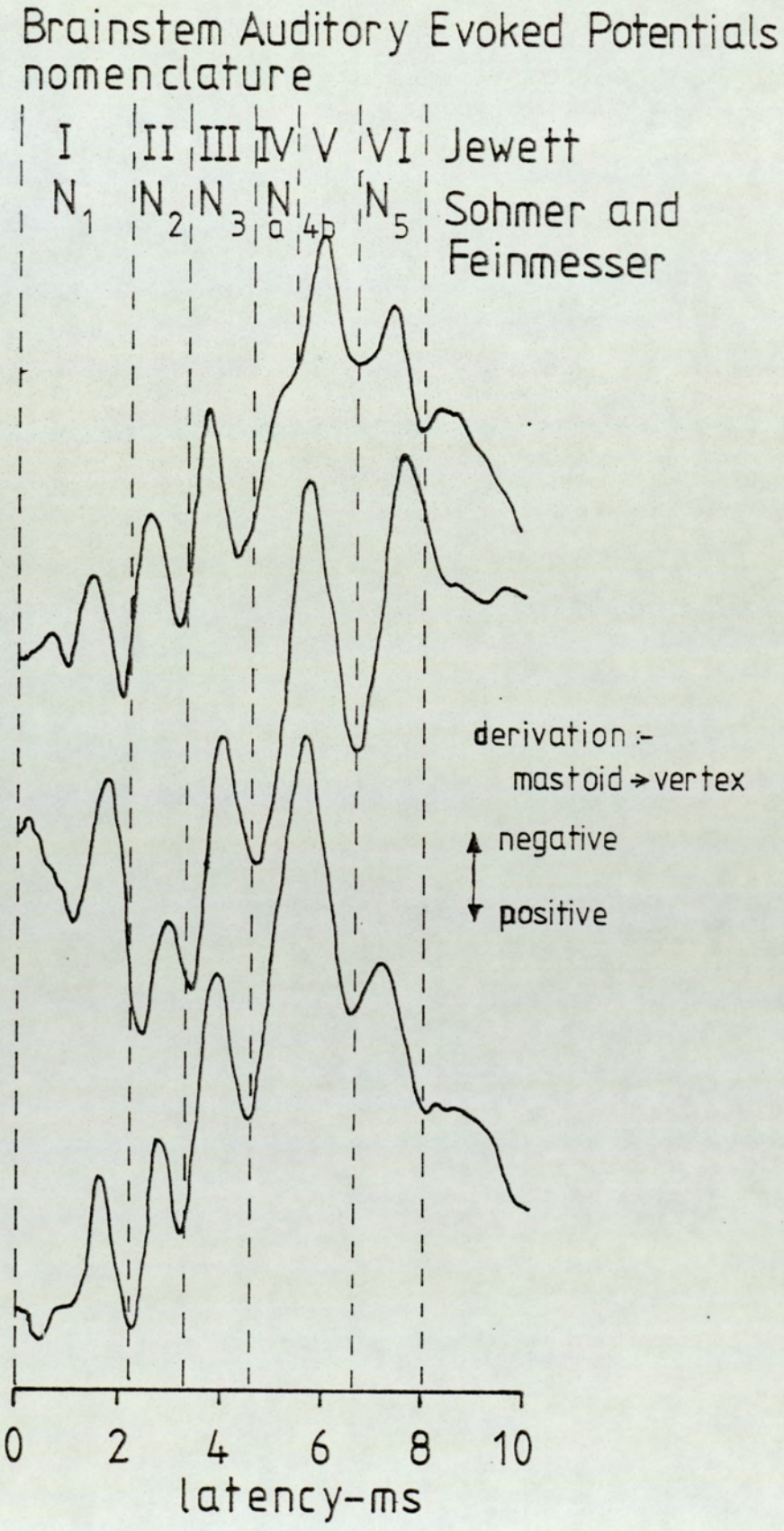


Fig. 8.3.

Configuration and nomenclature of brain stem auditory evoked potentials.

Author	n	Electrode Position	Click Stimulus Intensity	1 N1	11 N2	111 N3	1V $N4_a$	V $N4_b$	V1 N5	V11 N6
Pratt and Sohmer 1977	22	EL-V	75dBSL	1. 5	2.55	3.64		5.63	7.17	
			70dBSL	1.40	2.60	3.67		5.69	7.31	
			65dBSL	1.53	2.67	3.75		5.73	7.46	
			60dBSL	1.61	2.77	3.81		5.81	7.49	
Picton et al. 1974	20	V-M	60dBSL	1. 5	2. 6	3. 8	5. 0	5. 8	7. 4	
Starr and Achor 1975	6	V-M	75dBSL	1. 4	2. 6	3. 7	4. 6	5. 4	6. 9	
			65dBSL	1. 6	2. 8	3. 8	4. 8	5. 5	7. 1	
			55dBSL	1. 8	3. 0	3. 9	5. 0	5. 8	7. 5	
			S.D.	[0. 1 — 0. 3] m.secs.						
Stockard and Rossiter 1977	29	V-M	60dBSL	1. 9	3. 0	4. 1	5. 2	5. 9	7. 6	9. 2
			S. D.	0. 3	0. 3	0. 3	0. 2	0. 3	0. 3	0. 3

E-L Earlobe; M - Mastoid; V - Vertex

Table 8.1. Summary of brainstem evoked potentials in adults. Latencies of components. (continued next page)

Author	n	Electrode Position	Click Stimulus Intensity	1 N1	11 N2	11 N3	1V $N4_a$	V $N4_b$	V1 N5	V11 N6
Gilroy and Lynn 1978	15	V-M	75dBHL	1.55	2.67	3.60	4.69	5.40	7.03	8.66
			S.D.	0.09	0.16	0.19	0.25	0.14	0.16	0.29
Robinson and Rudge 1977	45	V-M	95.7dBL	2.00	3.24	4.11	5.20	6.00	7.41	9.45
			S.D.	0.18	0.21	0.19	0.24	0.24	0.40	0.60
Salamy and McKean 1976	13	V-M	55dBSL	1.57	2.73	3.64	4.82	5.55	6.89	
			S.D.	0.14	0.19	0.24	0.23	0.26	0.23	
Sohmer and Student 1978	18	EL-V	75dBHL	1.341	2.416	3.379		5.159	6.679	
			S.D.	0.104	0.146	0.189		0.285	0.306	
Rowe 1978	25	V-M 17-33yrs.	60dBSL	1.87	2.88	3.83	5.06	5.82	7.37	9.05
			S.D.	0.18	0. 2	0. 2	0.23	0.25	0.46	0.47
	25	V-M 51-74yrs.	60dBSL	2.17	3.36	4.35	5.43	6.16	7.95	9.30
			S.D.	0.27	0.31	0.26	0.34	0.26	0.38	0.51
Amadeo and Shagass 1973	4	V-M	105dBSL	1.61	2.80	3.71		5.56		
				0.24	0.31	0.87		0.42		

EL - Earlobe; M - Mastoid; V-Vertex

Table 8.1. (continued)

The Latencies of the Brainstem Evoked Potentials during Infancy.

Author	n	Age	Electrode Position	Click Stimulus Intensity	1 N1	11 N2	111 N3	1V $N4_a$	V $N4_b$	V1 N5
Schulman-Galambos and Galambos 1975	6	34-35wks.	V-M	60dBHL					8.57	
	6	36-37wks.							8.06	
	6	38-39wks.							7.87	
	6	40-42wks.							7.30	
Salamy and McKean 1976	90	Newborn	V-M	55dBSL	2.12	3.27	4.89	5.96	7.06	8.42
	21	6 wks.			1.82	2.75	4.37	5.65	6.64	7.98
	22	3 mnths.			1.82	2.79	4.15	5.43	6.40	1.56
	14	14 mnths.			1.74	2.88	4.16	5.31	6.34	7.48
	10	1 year			1.71	2.82	3.92	5.09	5.93	7.14

Table 8.2.

Author	n	Electrode Position	Click Stimulus Intensity	1 N1	11 N2	111 N3	1V $N4_a$	V $N4_b$	V1 N5	V11 N6
Pratt and Sohmer 1977	22	EL-V	75dBHL	0.32	0.26	0.23		0.17	0.12	
			70dBHL	0.30	0.23	0.24		0.17	0.11	
			65dBHL	0.27	0.22	0.20		0.18	0.09	
			60dBHL	0.20	0.15	0.16		0.15	0.08	
Starr and Achor 1975	10	V-M	65dBSL	0.28	0.16	0.26	0.11	0.30	0.16	
			S.D.	0.08	0.09	0.07	0.10	0.06	0.06	
Robinson and Rudge 1977	45	V-M	95.7dBC	0.119	0.177	0.264		0.993		
			S.D.	0. 69	0.209	0.184		0.230		
Amadeo and Shagass 1973	4	V-M	105dBSPL	0. 44	0. 49	0. 77		1. 66		
			S.D.	0. 03	0. 11	0. 26		0. 41		

Table 8.3.
Summary of amplitude data of the brainstem evoked potentials in the adult-expressed in micro-volts.

times of the latencies between peaks 1-V, 1-111 and 111-V all of which are independant of the absolute latency of wave 1. Experimental procedures which may influence response characteristics include electrode placement; stimulus characteristics; the reference point for calculation of response latency; and the band-pass filters used, these vary from 250-5000Hz (Sohmer and Feinmesser), 100-3000Hz (Thornton, Starr and Achor; Schulman-Galambos and Galambos) and 0.800Hz to 2500Hz by Robinson and Rudge.

8.3. Location of Response Generators

By the nature of the studies carried out much of the work in support of the brainstem origin of these early scalp recorded potentials have resulted from work on animals with supporting data from clinical and topographical studies in man. The areas of research may be divided into three categores:-

i) Depth Recording and Lesion Studies in Animals

ii) Clinical Studies in Man.

iii) Topographical Studies in Animals and Man.

8.3.1. Depth Recording and Lesion Studies in Animals

Depth recordings were carried out by Jewett (1970) in 18

anaesthetised cats. Responses from permanently implanted electrodes on or near the round window of the cochlea and in the non-auditory structure of the caudate nucleus were compared with responses recorded from the brainstem auditory nuclei. In 10 of these animals 4 clear positive peaks were detected in the caudate nucleus in response to click stimulation. The sources of the positive waves recorded in the caudate nucleus was indicated by an increase in amplitude or a change in phase of the signal when the brainstem recording electrode located its source. On this basis, P_1 (of the caudate nucleus) was found to correspond to the N_1 component of the electrocochleogram present in round window electrode recordings and detected only on the side ipsilateral to stimulation. The origin of P_2 (from the caudate nucleus) was found to be within the ipsilateral cochlear nucleus when the recording electrode produced either an increase in response amplitude, or a negative or triphasic component. Jewett also recorded slower later components arising from the cochlear nucleus which may contribute to the fast responses of the later brain nuclei. Terkildsen et al. (1973) had suggested that these later peaks (N_2 and N_3) may arise in part through the double firing of the auditory nerve, but Jewett (1974) concluded this to be unlikely on account of their different spatial distributions over the scalp. (see Section 8.3.3.). The P_3 component (of the caudate nucleus) corresponded to a large inverted signal in or

anterior to both ipsilateral and contralateral superior olive complexes and P_4 showed a large increase in response amplitude within or below both ipsilateral and contralateral inferior colliculi. These findings appear to confirm the brainstem origin of these early responses with the responses of the auditory nerve and cochlear nucleus present only in ipsilateral structures while the later components show bilateral representation. However, the idea that each component reflects the successive activation of ascending brainstem nuclei should be viewed with some caution as Jewett's results indicate the probability that at least the later responses reflect a composite of activities with contributions from slow components of the earlier responses together with their own fast responses. Similar conclusions regarding the location of the generators of the brainstem auditory evoked potentials were reached by Lev and Sohmer (1972).

External brainstem auditory potentials were recorded from earlobe-vertex derivations in 10 humans and from electrodes on the pinna, nose and vertex in 24 cats and compared with the depth electrode recordings in these animals. The external electrodes in both man and cat produced 5 distinct earlobe negative waves of similar waveform, latency and amplitude from which the authors concluded their similar sites of origin

in both species. In comparison with the depth recording electrodes wave 1 at the pinna corresponded to activity of the auditory nerve; wave 2 to activity within or near the cochlear nucleus with possible contributions from the N_2 component of the electrocochleogram; wave 3 correspon ded to activity in the lateral superior olive complex and waves 4 and 5 to the inferior colliculus. They concluded that the increased complexity of the responses recorded in the higher brainstem nuclei of the superior olive and inferior colliculus may reflect contributions from more than one group of nuclei.

Progressive lesion studies of the brainstem in cats by Buchwald and Huang (1975) confirmed these findings, but in addition suggested the differential origins of waves 4 and 5 with wave 4 arising from the ventral nucleus of the lateral lemniscus and pre-olivory region and wave 5 from the inferior colliculus.

Further studies by Huang and Buchwald (1978) into the effects of stimulus rate and intensity on the brainstem auditory responses led them to suggest that these resulted from the activation of a successive chain of simple synaptic connections with no great alteration of the neural pattern between each nuclei.They concluded this from the parallel nature of the amplitude and latency intensity functions of all the brainstem response components where the later components passively reflected the changes in the initial component. However, as will

be seen in section 8.4. parallel input-output amplitude and latency functions have not been found by all investigators.

8.3.2. Clinical Studies in Man

The study of the brainstem auditory evoked potentials in man in cases where clinical pathology of the brainstem is established has added support to the proposed brainstem locations indicated in the depth recording and lesion studies in animals.

A total of 100 infants and children with suspected brain lesions were reviewed by Sohmer and Feinmesser (1974). In cases where clinical observations pointed to cerebral and cerebellar damage with no involvement of the brainstem, all 5 earlobe negative brainstem potentials were clearly recorded. In the remaining patients where a brainstem lesion was clearly identified they found that in cases where a tumour resulted in pressure at the junction of the auditory nerve with the brainstem (ie acoustic neuroma, petrous bone meningioma), in general, only the N_1 component was clearly recordable while with more central brainstem lesions the later components were specifically affected.

Starr and Hamilton (1976) reported up to seven brainstem potentials in normal individuals using vertex to mastoid recording derivations (refer to waves as vertex positive components). By comparing their normal data with pathological conditions involving:-

i) extramedullary lesions of the cerebro-pontine angle i.e. acoustic neuroma, meningioma.

ii) focal brainstem lesions

iii) widespread brainstem lesions due to tumour or infarction

iv) widespread brainstem lesions due to anoxia

They concluded that the activity of components 1V-V11 was dependant on midbrain activity, and with widespread brain damage as occurs in condition iii) and iv) above, often only brainstem component 1 was evident. The earlier components 11 and 111 appeared to be dependant on the integrity of the lower regions of the brainstem more specifically the cochlear nucleus and superior olive complex.

More extensive studies were carried out by Stockard and Rossiter (1977) who correlated the occurence of the brain-stem potentials with known brainstem lesions (confirmed radiologically or at post-mortem) in 100 patients. Their findings were similar to those of Starr et al. (1976) where wave 1 was attributed to acoustic nerve activity, wave 11 from activity within the region of the pontomedullary junction; wave 111 from the caudal pons; wave 1V from the rostral pons and midbrain, wave V from the midbrain. They also provided some evidence for the origin of waves V1 and V11 in the thalamus and auditory radiation respectively,

but since these later waves were quite variable in normal individuals the significance of their abnormality in clinical cases must be doubtful.

Although these clinical studies do not specify the neural generators of the brainstem potentials, they demonstrate clearly that the different components are dependant on the integrity of fairly specific areas of the brainstem for their occurence and thus indirectly support the anotomical sources suggested in the animal studies. Stockard and Rossiter (1977) also find that their observations of the separation of the IV and V components in cases of demyelination support the separate origin of these components within the lateral lemniscus and inferior colliculus as suggested by the lesion studies of Huang and Buchwald (1975) and not the single origin within the region of the inferior colliculus as indicated in depth recording studies (Jewett, 1970; Lev and Sohmer, 1972).

8.3.3. Topographical Studies of the Brainstem Auditory Evoked Potentials.

Although it can be seen from Sections 8.3.1. and 8.3.2. that the sources and locations of the brainstem potentials are fairly well established, there still remains a good deal of controversy concerning the distribution of these components over the scalp, and the choice of so called active and reference electrode recording sites. Jewett classifies the brainstem responses with roman numerals (as described in Section 8.2.) and describes them as

vertex positive components, while Sohmer and Feinmesser, and Thornton refer to the same components as mastoid/ earlobe negative. However, in the ensuing discussion it will become fairly obvious that both mastoid/earlobe and vertex or scalp recording sites are active in terms of detecting the potentials of the brainstem components. Although differences of opinion still exist in the relative contributions of mastoid and vertex derivations to the resultant potentials, there is general agreement that the most favourable results are obtained with differential mastoid/earlobe to vertex derivations. It is of considerable importance to determine the relative contributions of both recording positions to the resultant brainstem potentials if the response is to be considered to reflect primarily the activity of the ipsilateral brainstem (see Section 8.7.2.). In such a case contributions from the vertex electrode would almost certainly reflect the sum of both right and left brainstem pathways, whereas mastoid contributions may reflect ipsilateral activity.

The concepts of near field and far field recording of auditory evoked potentials with scalp electrodes was introduced by Jewett and Williston in 1971. Near field potentials may be illustrated by the cortical visual and somatosensory evoked potentials and the post-auricular myogenic potentials where the recording electrodes are relatively close to the source of the signal. In such cases the configuration and amplitude of the response recorded is changed significantly with small changes in positions of the recording electrodes, and the responses show a

characteristic and fairly localised scalp distribution. However, in the case of far field recordings all the scalp electrodes are relatively distant from the source of the signal and in this case all recording sites should produce a similar response which shows no clear evidence of a localised distribution. Jewett described the brainstem auditory potentials as far field evoked potentials and reported the presence of seven distinct components recorded from both vertex region and mastoid region. He stated that the observation of seven vertex positive waves was consistent with the hypothesis that potentials when moving towards an electrode (vertex) in far field recording were seen as positive, but also on this basis he suggested that there should also be scalp locations where the same potentials are seen as negative.

To further this idea, Plantz, Williston and Jewett (1974) carried out extensive studies on the distribution of the brainstem auditory potentials over the scalps of anaesthetised cats and rabbits.

They found although brainstem potentials could be detected from widespread areas over both the scalp and the body, that each individual component showed a different spatial distribution over the scalp. This finding alone provides support for the separate sources and different locations of the individual brainstem components. The choice of different recording and reference sites was found to markedly influence the resulting response.

In some scalp areas they found either small shifts in the latencies of some of the response components or a phase inversion of the components so that the positive vertex peaks occurred as negative components. Such a phase inversion took place at the pinna (with reference to the neck) where waves 1 and 11 were seen as negative with concurrent positivity at the vertex. Such a finding is in keeping with their earlier proposal in 1971. The comparison of brainstem potentials recorded from vertex to neck and pinna to neck derivations in the cat is seen in Figure 8.4. where the result of differential recordings between pinna and vertex is an enhancement of the earlier components with little loss of amplitude of the later components. Jewett concluded that describing the brainstem potentials in terms of vertex positivity was purely arbitrary and as both mastoid and vertex sites were active and he suggested that each component should be labelled in terms of Roman numerals only without specification of polarity, as components could be described as either vertex positive or mastoid negative.

These findings are in keeping with the hypothesis of Sohmer and Feinmesser (1976) that if the action is considered as a dipole travelling up the auditory pathways of the brainstem, it will be detected as a positive component by the electrode it is moving towards and as a negative component by the electrode it is moving away from. This would explain the greater negativity of the early brainstem components at the mastoid where the action potential would be moving away from the madtoid in a normal direction, and the greater

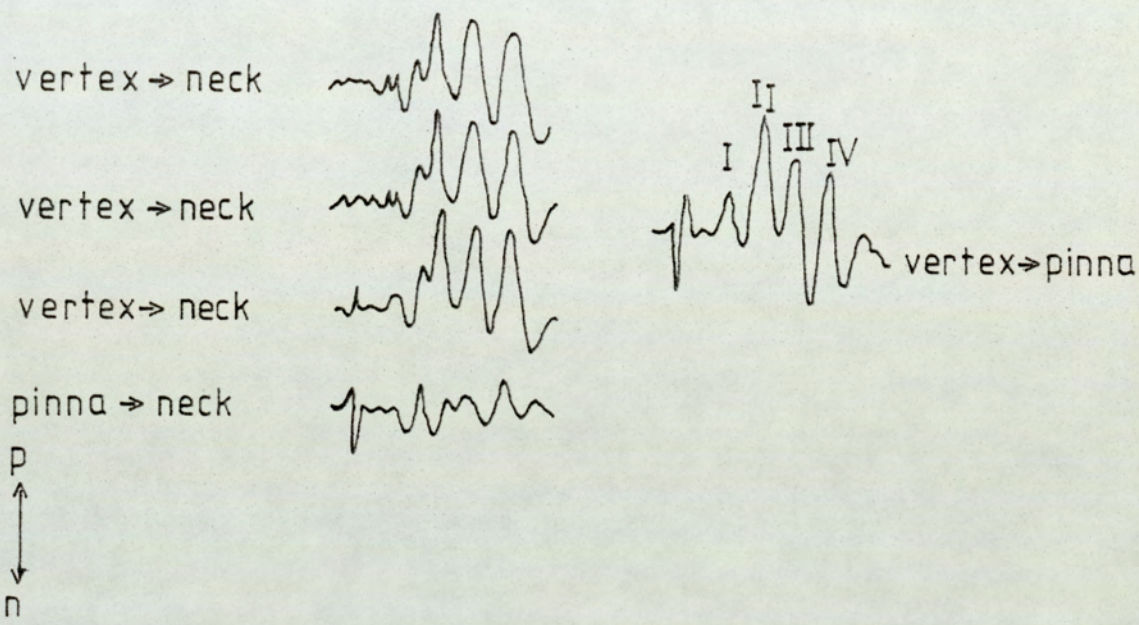


Fig. 8.4.
Brainstem responses in the cat recorded from vertex and pinna electrodes referred to a neck electrode.
[Jewett and Williston, 1971]

positivity of the later components at the vertex where the action potential would be approaching normal to this electrode.

Terkildsen et al. (1973) also report a phase inversion of brainstem potentials when recording components derived from ipsi and contralateral mastoids both referred to the tip of the nose. In the ipsilateral recording 5 mastoid negative waves were recorded while in the contralateral mastoid wave 1 was absent and subsequent waves from 2 m.secs. onwards were of opposite polarity. He advocates the use of differential mastoid recordings for the enhancement of all the brainstem components and suggests two alternative explanations for these findings. Firstly, waves 1 to 5 could be present in both mastoids, but occur with opposite polarity in the contralateral mastoid or alternatively they could arise solely from the ipsilateral auditory nuclei and the movement away from ipsilateral mastoid and towards the contralateral mastoid results in the polarity difference.

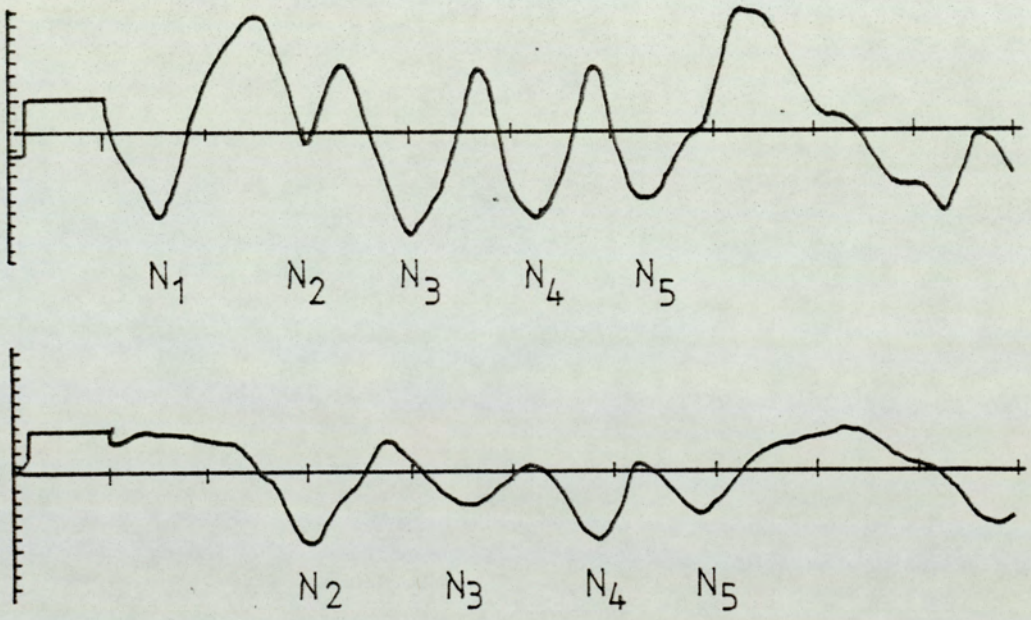
However, if this is the case one would expect only a polarity inversion of the earlier components when comparing ipsilateral and contralateral mastoid references as in the case of the later components the action potential will be moving away (although not normal to) from both mastoids and so they should both reflect the same polarity.

Such an occurence was confirmed by Picton (1974) who found that only the earlier brainstem components occurring between 2-4 m.secs. were of opposite polarity in the contralateral mastoid.

Ipsilateral and contralateral mastoid recordings were thoroughly investigated by Thornton (1975)b in 6 normally hearing adults. In all cases components N_1 to N_5 (negative at mastoids) were present in ipsilateral recordings. The ipsilateral recordings were of greater amplitude and showed less variability than the contralateral components. Although the components did not show the exact phase inversion of Terkilsden, latency differences existed which for components N_2 and N_3 approximated reasonably closely to a phase inversion (Figure 8.5.), but in N_4 and N_5 were of the same negative polarity.

The question raised by Thornton regarding the degree to which activity recorded from the ipsilateral mastoid reflects activity of the brainstem that side has possible important clinical implications which are discussed in Section 8.7.2. He takes support for this idea from the marked amplitude difference in ips lateral and contralateral recordings which would not be expected in the case of true far field evoked potentials.

Plantz et al. (1974) findings also partially support the reflection of ipsilateral brainstem activity at least for the earlier brainstem components. When recording from ipsilateral and contralateral ears to vertex locations waves 1 and 11 were more clearly located in the mastoid ipsilateral to stimulation while components 111 and 1V were more clearly seen at the vertex and here probably represent bilateral activity.



normal brainstem reponses
x axis 1·5ms/div. y axis 22nv/div
upper trace ipsilateral record
lower trace contralateral record

Fig. 8.5.
Brain stem evoked potentials recorded from ipsilateral and contralateral mastoids.
[Thornton, 1975]

Scalp distribution studies have been carried out in man by Streletz et al. (1977) and Picton et al. (1974) using a noncephalic reference. Streletz finds components 11-1V show a wide distribution over scalp, ear, nose and mastoid regions, but in all derivations the components are seen as positive waves which are most prominent at the vertex. Only wave 1 was detectable as a negative component at the ipsilateral mastoid. Picton's data (1974) also confirms the presence of a negative component in the ipsalateral mastoid and also as previously mentioned the polarity inversion of components between 2-4 m.secs. in the contralateral mastoid. Picton suggests that the polarity inversion between the mastoids would be consistent with horizontally orientated dipole generators within the areas of the cochlear nucleus and superior olive while the later vertex maximal components would represent the upward movement of the nerve impulse in the lateral leminscus or inferior colliculus. He stresses the complexity of such problems which are further complicated by the lack of homogeniety of the surrounding brain structure and also by the possibility of simultaneously active generators sites where each component may reflect a composite response of several contributory sources. Such sources may also arise from both sides of the brainstem, especially for the later components.

To summarise therefore, both lesion and depth recording studies in animals offer fairly unanimous agreement on the sources or generators of the brainstem potentials which appear to represent the successive activation of the brain-

stem auditory nuclei, with the proviso that later response components may also reflect slow activity arising from the previous responses.

The similarities between the characteristics of animal and human brainstem potentials, together with the clinical findings in man would indicate similar generator sites in both species.

Topographical studies show marked changes in response configuration with the location of the recording electrode with an inversion of the polarity of the earlier components in the region of the mastoid as compared to responses recorded at the vertex. This observation is consistent with the behaviour of the passage of a dipole in a conducting medium when the action potential is reflected as positive by the electrode it is moving towards and as a negative by the electrode it is moving away from.

8.4. The Effects of Stimulus Parameters

8.4.1. Stimulus Frequency

The recording of the brainstem auditory evoked potentials requires the maximal possible synchronisation of the individual neural responses within the auditory nerve. Such synchronisation is best produced by a click stimulus (Davis, 1976b and Galambos and Hecox, 1977). This unfortunately does not afford the brainstem auditory potentials the frequency specificity of the slow vertex potential. The response is

an on-response reflecting activity primarily in the basal turn of the cochlear and thus in terms of frequency of 2000Hz and above.

A number of problems arise when recording brainstem auditory potentials to low frequency stimulation. Firstly, neural synchronisation is poor with low frequency stimuli and secondly, even with intensities as low as 30dBSL low frequency stimuli produces activation of both basal and apical turns of the cochlea. Since there is a time difference in basal and apical response due to the time taken for the travelling wave to move down the cochlea, both responses are not synchronous and may interfere with each other. In addition, if the stimulus polarity is alternated to remove the cochlear microphonic, the stimulus onset is effectively shifted by half a cycle which at low frequencies will produce a significant shift in the latencies of the brainstem potentials (Davis and Hirsch, 1976).

Attempts have been made to determine the contribution of the apical turn of the cochlea to the neural response of the electrocochleogram (Elberling, 1974) and of the brainstem auditory potentials (Davis and Hirsch, 1976 and Don and Eggermont, 1978) by the use of high frequency masking techniques. The use of different high frequency masking bands enables the production of derived action potentials of brainstem potentials which reflect the neural activity arising from localised regions of the basilar membrane.

Brainstem auditory potentials have also been successfully

recorded to tone pips of 2,400 and 4,800Hz (Davis and Hirsch, 1976 and Terkildsen et al. 1973)
where the shift in response latency with alternation of stimulus polarity is negligible, and also to white noise bursts of frequencies 20-20,000Hz (Hecox, Galambos and Squires, 1976).

8.4.2. Stimulus Intensity

The electrocochleogram and brainstem potentials show the increases in amplitudes and decreases in latencies with increasing stimulus intensities which are characteristic of most auditory evoked potentials.

i) The Electrocochleogram - as recorded by external meatal electrodes.

Most investigations into the affects of stimulus intensity are restricted to the N_1 component of the electrocochleogram as the N_2 and N_3 components are only present at relatively high stimulus intensities.

Decreases in response latency were reported by Yoshie, Ohashi and Suzuki, (1967) and Yoshie (1968) with increases in stimulus intensity with a latency of 1.2 m.secs. at 90dBSL and 4.1 m.secs. at 10dBSL. Their amplitude-intensity functions produced clear evidence of 2 distinct response components with a slow initial rise in amplitude from threshold to 50-60dBSL and then a more rapid rise to 80-85dBSL.

This was often followed by a flattening off at 90-100dBSL (Figure 8.6.). These different response curves were denoted as L(low) and H(high) curves respectively. Coats and Dickey (1970) reported a maximum response amplitude of 1-4uV., but found no clear indication of L and H response curves, whereas Salomon and Elberling (1971) presented clear evidence of both L and H response curves in both amplitude and latency intensity functions.

Davis (1976)b suggested that the L and H response curves represented,

i) a low threshold response detected at near threshold intensities at relatively longer latencies which slowly increases in amplitude to approximately 50dBSL when

ii) a short latency higher threshold component appears which grows rapidly in amplitude with increasing intensity, but remains of relatively constant latency at approximately 1.3 m.secs.

The most popular explanation for this phenomena is that the L and H response curves result from the activity of two distinct groups of sensory receptors within the cochlea. The low amplitude L curve is associated with activity of the more sensitive outer hair cells of the organ of Corti and the H curve with the smaller population of less sensitive inner hair cells. Support for this idea is taken from the observation that recruitment which results from selective damage of the outer hair cells is often accompanied by

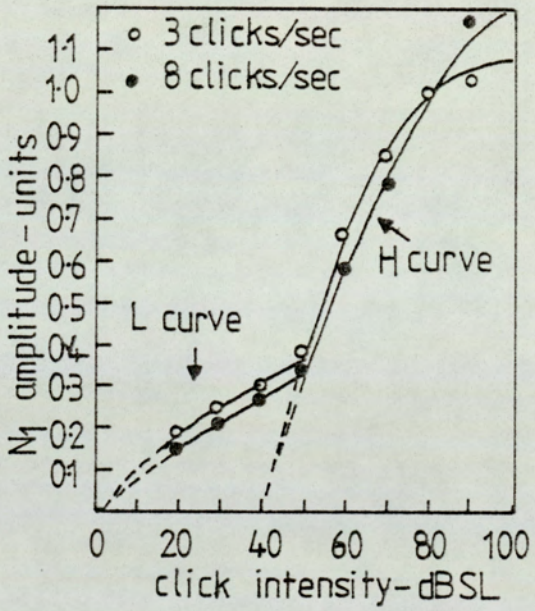


Fig. 8. 6.

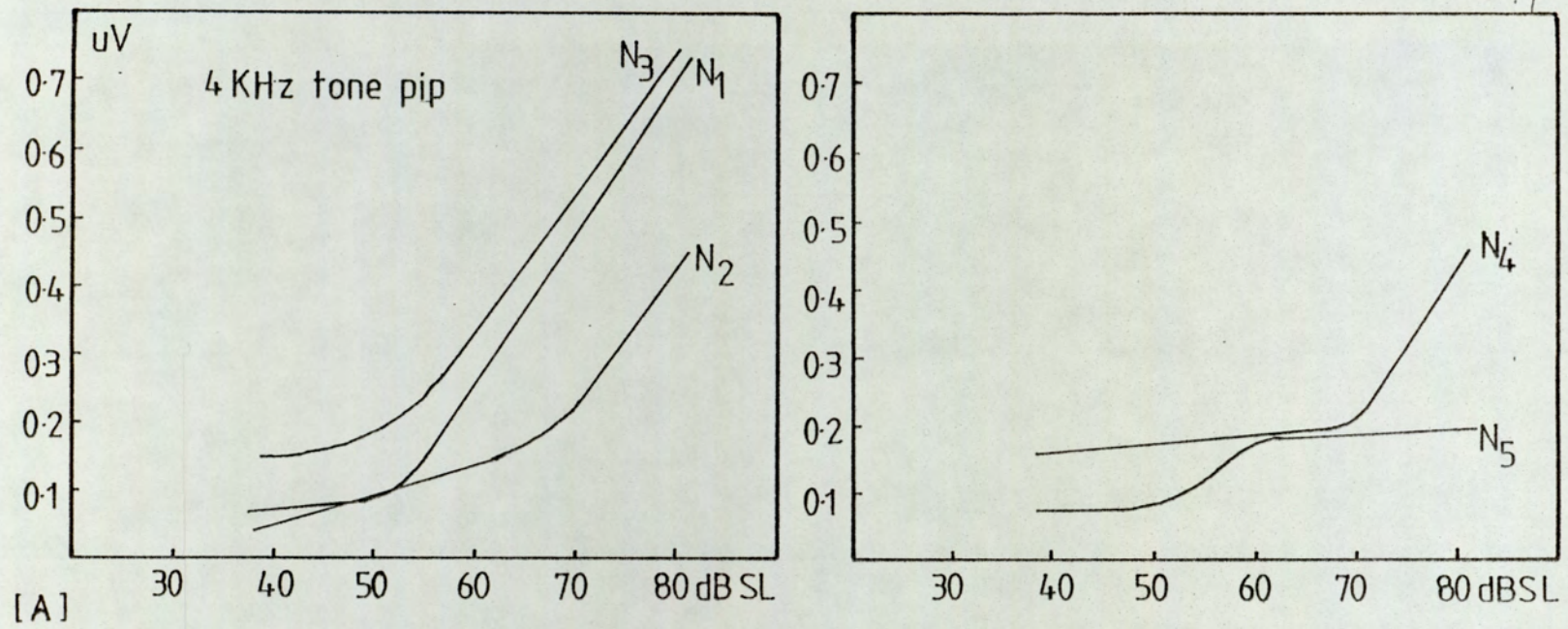
Demonstration of L and H response components in the amplitude-intensity function recorded from ear canal electrodes. [Yoshie, 1968]

the loss of the L curve from the amplitude-intensity function.

ii) Brainstem Auditory Evoked Potentials.

Alternative methods of amplitude measurement were investigated by Thornton (1975)b. These included peak-baseline and peak-peak amplitude measured between each mastoid negative component and either the preceding or succeeding positive component. He suggested the use of peak-peak measures as these produced the least variability and also a linear increase in amplitude with intensity. If amplitude was measured from each negative component to the following positive component, then all peaks including N_1 could be assessed.

Increases in amplitude of all waves from 1-V11 with increasing intensity were reported by Jewett and Williston (1971), but they found considerable variability in absolute amplitude between subjects. Evidence of L and H response curves in amplitude-intensity function of all components except N_5 was found by Terkildsen et al. (1973) (Figure 8.7.), but only of component wave 1 by Starr and Achor (1975) with a change over point at approximately 55dBSL. The change from L to H curves of the brainstem potentials was found to occur at a different intensity for each component by Terkildsen. Starr and Achor (1975) found that although amplitude varied considerably across subjects, a consistent feature was the amplitude ratio of the 1V/V and 1 waves which was always greater than 1 with binaural stimulation



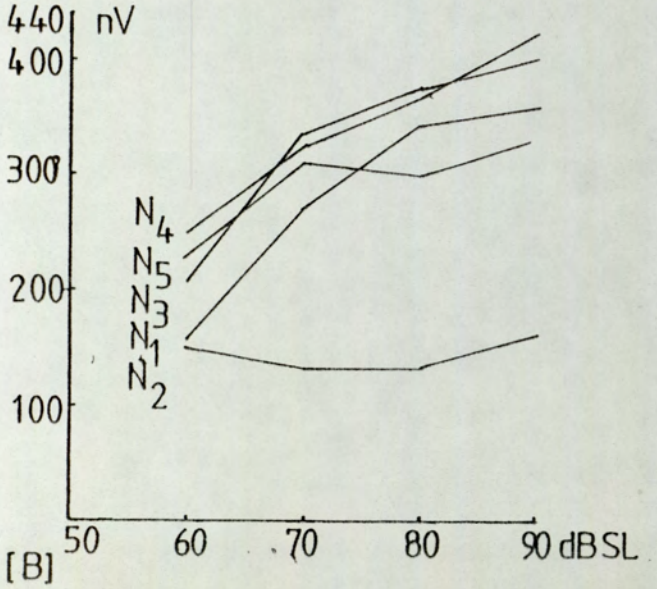


Fig. 8.7.

Comparison of amplitude-intensity functions of brainstem potentials obtained by Terkildsen et al (1973) and Thornton (1975)

at intensities of 5-75dBSL and with monaural stimulation from intensities of 5-55dBSL. Both investigators report report linear increases in the latencies of all components with decreasing stimulus intensity with the latency-intensity functions of all components in parallel (Figure 8.8.).

Picton et al. (1974) were unable to confirm these parallel latency-intensities functions and found steeper amplitude and latency functions with intensity for the middle and later brainstem components.

The presence of L and H response components of the amplitude-intensities functions of any of the brainstem auditory potentials was not confirmed by either Pratt and Sohmer (1976) and Thornton (1975)b. Sohmer reported regular increases of only the N_1 components with intensity whereas the later components tended to saturate at intermediate intensity levels, whereas Thornton found a systematic relationship between the amplitudes of components N_1, N_3 and N_4 and intensity only (Figure 8.7.). Again both authors find linear increases in response latency of all components with decreasing stimulus intensity with parallel curves for all components.

Pratt and Sohmer (1977) also attempted to relate the amplitude-intensity functions of the brainstem potentials to subjective estimates of loudness, but were unable to do so because of the considerable variability in the sub-

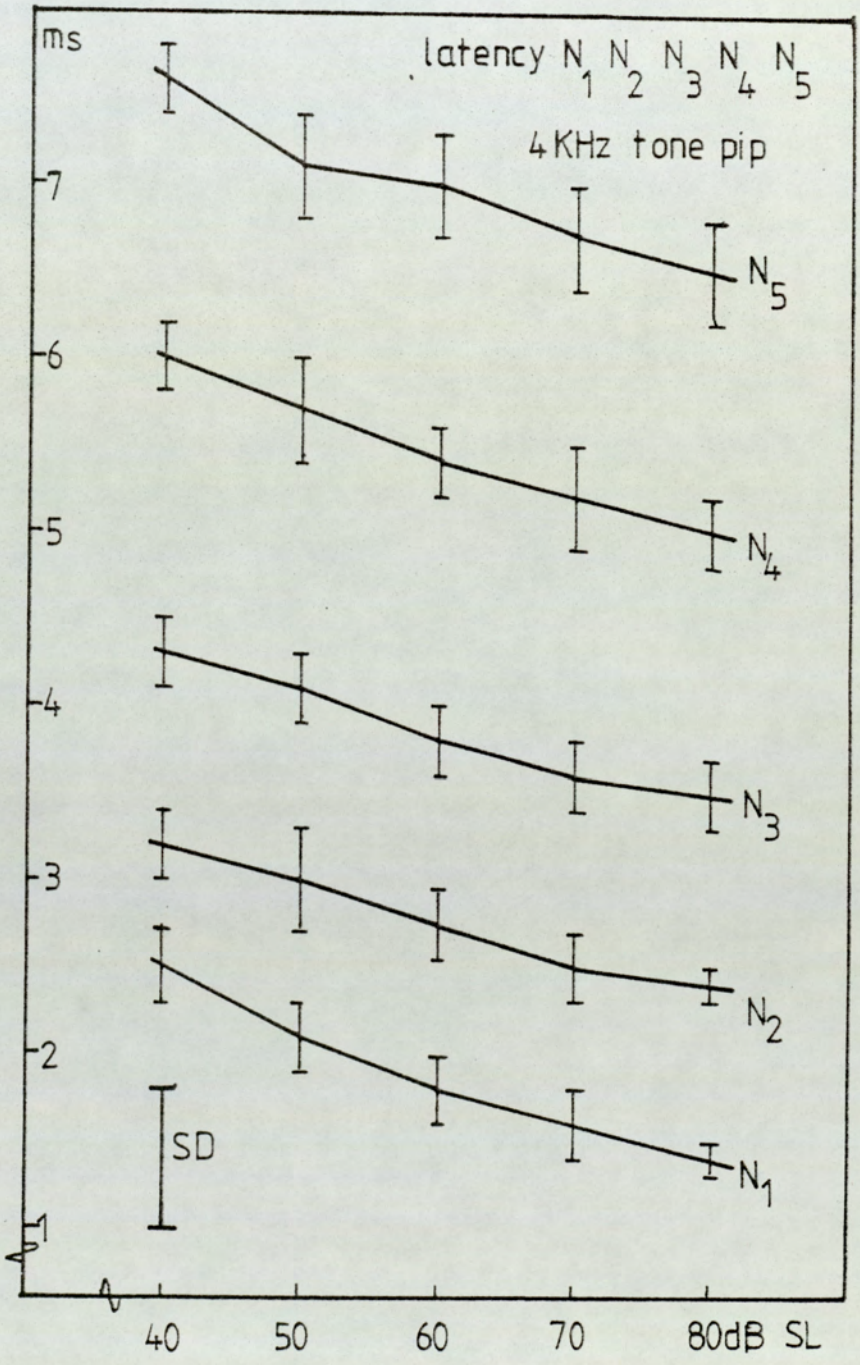


Fig. 8.8.
Latency~intensity functions of the individual brain stem potentials. [Terkildsen et al. 1973]

jective estimates of stimulus intensity. The exponent of their amplitude-intensity function was small and would fit both log and power relationships equally well.

The latency and amplitude characteristics of the brainstem potentials recorded from mastoids ipsilateral and contralateral to auditory stimulation were compared by Thornton (1975). The clear relationships established between response amplitude and latency and stimulus intensity in the ipsilateral mastoid recordings were not so evident in the contralateral derivation.

8.4.3. Stimulus Rate

Rapid decrements in response amplitude were reported in cats (Huang and Buchwald, 1975) at stimulus rates greater than 50 per second and in humans (Jewett and Williston, 1971) where maximum amplitude was attained only with rates as slow as 2 per second.

However, such slow recording rates greatly increases the recording time and are not feasible in routine clinical investigations. Stimulus rates of up to 20 per second are usually acceptable, but at greater than 20 per second the decrement in response amplitude becomes more pronounced.

Differential affects on the individual brainstem potentials were found by Pratt and Sohmer (1976) over stimulus rates of 5 to 80 per second. The amplitude of N_1 was preferentially affected by increasing stimulus rates with relative

stability of N_4, but conversely N_1 latency was unaffected by increasing stimulus rate, but this resulted in accumulative delays in the later components.

8.5. The Affects of Subjective Parameters

8.5.1. Maturation and Ageing

Maturational processes occurring over the first few months of life have reflected in changes in latency, amplitude and waveforms of the constituent components of the brainstem auditory response components. The changes observed in response latency arise from two separate independant sources resulting from maturation of both peripheral and central response mechanisms. Peripheral maturation is reflected in the peripheral transmission time (PTT) as measured by the latency of the N_1 component arising from the auditory nerve, whereas central maturation is reflected in the central transmission time (CTT). This may be measured in a variety of ways by comparing inter-peak latencies of N_1-N_5; N_1-N_3 and N_3-N_5. Such latencies measurements are independant of PTT and reflect maturational pathways.

Brainstem potentials have been studied in newborns by Schulman-Galambos and Galambos (1975) and Starr, Amlie, Martin and Sanders (1977). In the 24 infants studied by Schulman-Galambos and Galambos, only the V wave was measured, as stimulus rates of 33 per second prevented the detection of earlier components. The infants were grouped according

to gestational age at birth and brainstem potentials were recorded from vertex-mastoid derivations to a 60dBSL click stimulus. Each resultant average consisted of a total of 4,096-16,384 responses. The latency changes observed with both age and intensity are shown in Table 8.4., where a progressive decrease in response latency is seen with increasing gestational age at birth.

Age(Wks.)	34-35	36-37	38-39	40-42
Number	6	6	6	6
Stimulus	Latency of V Wave			
Intensity SL				
60dBSL	8.57	8.06	7.87	7.30
50dBSL	8.90(n=5)	8.32	8.29	7.67
40dBSL	9.21(n=4)	8.79	8.55	8.19
30dBSL	9.92(n=1)	9.22(n=5)	8.85(n=4)	8.71

Table 8.4. The affects of gestational age at birth and stimulus intensity on the latency of the V component of the brainstem auditory evoked potentials (Schulman-Galambos, Galambos 1975).

The larger study (n=42) carried out by Starr et al. (1977) included a wider age range of infants from 25 to 44 weeks gestational age. They confirmed the decrease in V wave latency with gestational age at birth with a reduction from 9.9 m.secs. at 26 weeks to 6.9 m.secs. at 40 weeks using a 65dBHL click stimulus. This was accompanied by a change in CTT from 7.2 to 5.2 m.secs. indicating that both PTT and CTT show reductions with age.

Using vertex-mastoid electrode derivations with a stimulus presentation rate of 10 per second they were able to record all brainstem components at intensity levels of 65, 45 and 25dBHL, but in the youngest age group of 25-28 weeks gestational age stimulus intensities of 75dBSL were sometimes required to elicit a clear response. As in the case of adult responses, components, 1, 111 and 1V/V were more stable than components 11 and V1. The maximal changes were found to occur before 34 weeks gestational age.

Older groups of infants up to 18 months of age were investigated by Hecox and Galambos (1974) and by Salamy and McKean (1976) and the latencies and amplitudes of the brainstem components compared to those in control adult groups. Again the study of Hecox and Galambos was confined to the V wave which was found to decrease as a function of age from birth to 18 months while the study of Salamy and McKean reported on all brainstem components and so in addition allowed the relative contributions of peripheral and central maturation to be assessed. The infants tested were grouped as follows:- a) 90 neonates (16 to 96 hours of full term) b) 21 at 6 weeks of age c) 23 at 3 months of age, d) 14 at 6 months of age, e) 10 at 1 year of age and f) 13 children and adults. In addition to these age studies 7 of the infants were studied longitudinally over a period of birth to 6 months. The brainstem response components were recorded from vertex-mastoid derivations to a click stimulus at 55dBSL.

Their results indicate different rates of maturation for PTT and CTT, where PTT, although significantly longer in the newborns, was comparable to that of the adult by the age of 6 weeks. Changes in PTT were attributed to possible maturational changes taking place within the middle or inner ear. The CTT time, however, followed a variable time course, took longer to reach adult levels. Initially, there was a sharp decrease in CTT over the first 6 weeks of life, followed by a fairly constant period from 6 weeks to 6 months of age and a further marked decrease from 6 months to 1 year of age at which point it approached the adult level (see Table 8.5.).

They suggest further myelination or increases in synaptic connections as possible explanations for the decreases in CTT after birth. Examination of the brainstem components of the 7 infants studies longitudinally revealed also maturational processes taking place within the response waveform. Waves 1 and V were present in all age groups and the main changes with age were:-

a) Newborn - Waves 1 and V were present with a small but variable wave 111 in 50% of infants.

b) 6 weeks - Waves 11 and 111 become clearly differentiated.

c) 3 months - Waves 1, 11 and 111 are distinguishable and the adult response pattern identifiable.

d) 6 months - 1 year - although there is little change in the shape of the waveform there is an increase in the stability of the components.

BSEP Latencies - m.s.		1	11	111	1V	V	V1	V-1
Newborns	n	90	54	61	37	90	32	90
	$\bar{X}$	2.12	3.27	4.89	5.96	7.06	8.42	5.12
	S.D.	0.35	0.03	0.35	0.32	0.38	0.45	0.29
6 weeks	n	21	14	20	9	21	15	21
	$\bar{X}$	1.82	2.75	4.37	5.65	6.64	7.98	4.76
	S.D.	0.17	0.78	0.27	0.23	0.23	0.39	0.31
3 months	n	23	13	19	13	23	10	23
	$\bar{X}$	1.82	2.79	4.15	5.43	6.40	7.56	4.67
	S.D.	0.27	0.17	0.20	0.26	0.29	0.30	0.35
6 months	n	14	6	7	7	14	3	14
	$\bar{X}$	1.74	2.88	4.16	5.31	6.34	7.48	4.63
	S.D.	0.02	0.34	0.32	0.34	0.32	0.89	0.35
1 year	n	10	8	8	5	10	5	10
	$\bar{X}$	1.71	2.82	3.92	5.09	5.93	7.14	4.20
	S.D.	0.21	0.27	0.25	0.29	0.30	0.37	0.36
Adults	n	13	13	13	10	13	8	13
	$\bar{X}$	1.57	2.73	3.64	4.82	5.55	6.89	3.99
	S.D.	0.14	0.19	0.24	0.23	0.20	0.23	0.21

Table 8.5. The Effects of Maturation on the Latencies of the Brainstem Auditory Evoked Potentials and on CTT as Measured by V-1 Latency.

Salamy and McKean, 1976.

Maturational changes in response waveform are illustrated in Figure 8.9.

The affects of ageing on the characteristics of the brainstem auditory evoked potentials were investigated by Rowe (1978). Two groups each containing 25 adults of 17-32 years and 51-74 years were compared using stimuli at 30dB and 60dBSL at presentation rates of 10 per second and 30 per second. They found no difference in response characteristics of the two groups under the various stimulus conditions, and no significant differences in CTT. The apparent increase in response latencies in the older groups was solely accounted for by an increase in PTT by approximately 0.3 m.secs. See Table 8.6.

	Latencies of Components-ms.							
	1	11	111	1V	V	V1	V11	1-V
Young								
n	47	38	50	43	50	50	48	47
$\bar{X}$	1.87	2.88	3.83	5.06	5.82	7.37	9.05	3.94
SD	0.18	0.20	0.20	0.23	0.25	0.46	0.47	0.22
Old								
n	50	41	50	24	49	50	41	50
$\bar{X}$	2.17	3.36	4.35	5.43	6.16	7.95	9.30	4.00
SD	0.27	0.31	0.26	0.34	0.26	0.38	0.51	0.32

Table 8.6. The affects of age on the latencies and CTT of the brainstem auditory evoked potentials in response to a 60dBSL click presented at a rate of 10/second. Rowe, 1978.

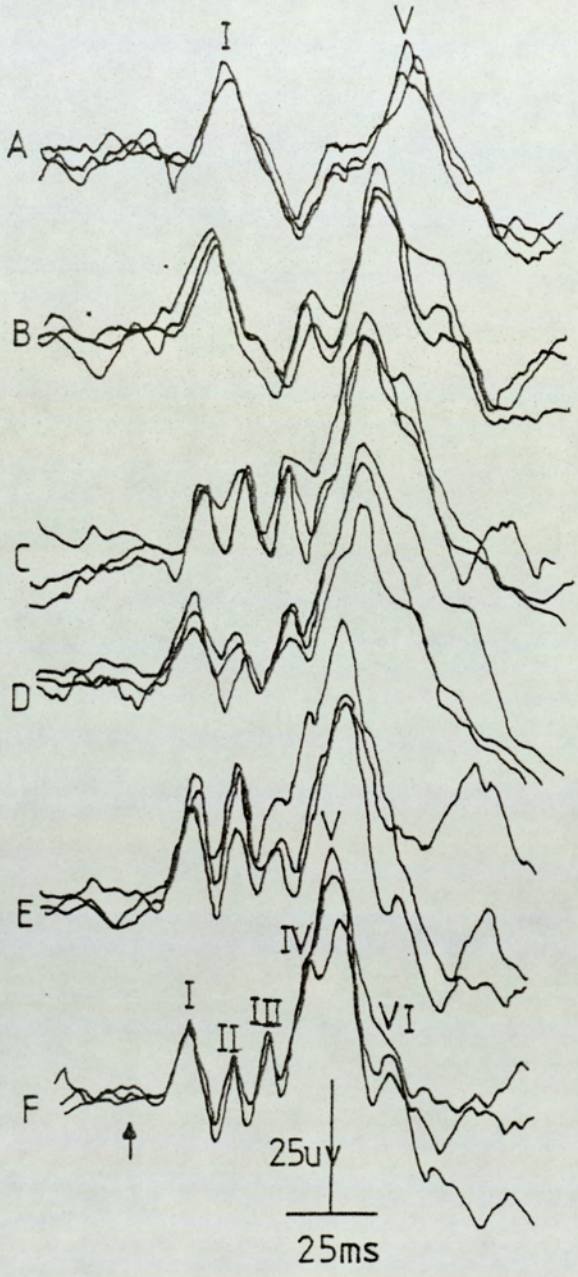


Fig. 8.9.
Maturational changes in the waveform of the brain stem evoked potentials.[Salamy and Mckean]

8.5.2. Sleep and Arousal

Brainstem auditory potentials are universally reported to be stable and independant of both level of arousal and sleep in children and adults (Jewett and Williston, 1971; Picton et al. 1974; Starr and Achor, 1975 and Schulman-Galambos and Galambos, 1975). A study by Amadeo and Shagass (1973) which involved the recording of brainstem auditory potentials through 2-4 nights of sleep in 6 adults, found no changes in response latency or amplitude during wakefulness or sleep stages 2,3-4 or REM (see Figure 8.10.).

8.5.3. Attention, Habituation and Fatigue

The amplitude and latencies of the brainstem auditory potentials are not significantly affected by attention (Picton et al. 1975 and Starr and Achor, 1975), and in general are little altered by fatigue or habituation as they show considerable stability over time, (Jewett and Williston, 1971). Resistance to fatigue and habituation with prolonged stimulation was reported in both children and adults by Schulman-Galambos and Galambos 1975, and by Salamy and McKean, 1976. Amadeo and Shagass (1973) found only minimal effects in comparing the first 2 and last 2 responses during an all-night recording session when there was a tendancy for an amplitude reduction and a lengthening of latency which was significant only for components 111 and 1V.

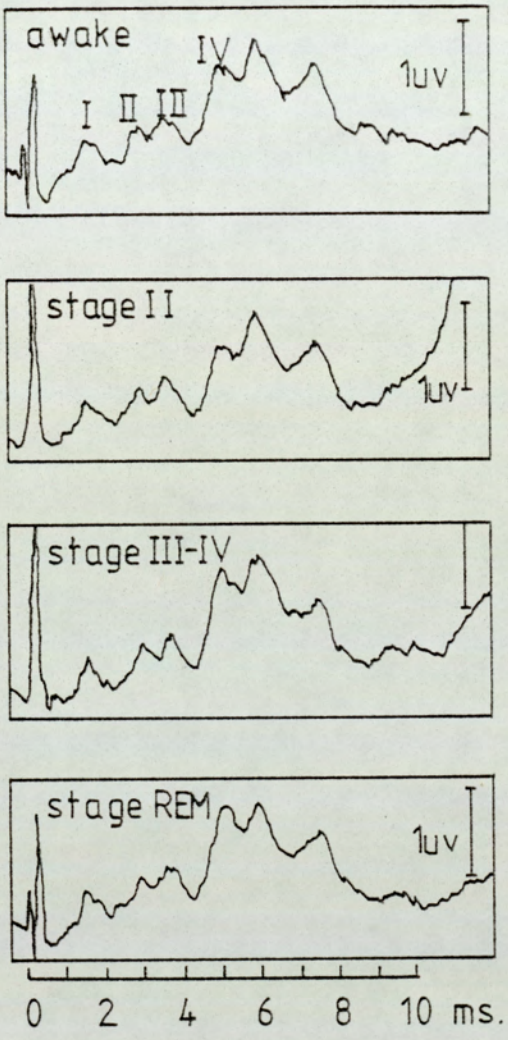


Fig. 8.10.

Brain stem evoked potentials during sleep and wakefulness. [Amadeo and Shagass 1973]

8.6. The Role of the Brainstem Auditory Evoked Potentials in the Measurement of Auditory Activity - Normal Data.

Using either transtympanic or external meatus recording electrodes (Portman and Aran, 1971 and Yoshie, 1968), because of its relatively large amplitude, electrocochleography provides an accurate and reliable measure of hearing to within 10-20dBSL. However, with the use of scalp recording electrodes the amplitude of the N_1 component of the brainstem auditory evoked potentials is much smaller (0.28uV $\pm$ 0.08uV. Starr and Achor, 1975) as compared to the 0.5-5uV. amplitude of the N_1 component from the external meatus (Yoshie, 1968)), and together with the N_2 component is lost well above threshold at approximately 20-30dBSL. Thornton (1975) and Terkildsen et al. (1973) suggest N_3 or N_5 components as possible threshold measures on the basis of their greater amplitude, stability and sensitivity.

Numerous investigations have now confirmed the usefulness and reliability of the N_5 or 1V/V components of the brainstem potentials in the assessment of auditory acuity. In a group of 6 young adults (25-30 years) Starr and Achor, (1973) reported the disappearance of waves 1, 11 and 111 at 25-30dBSL while the 1V-V complex was present to 5dBSL in all subjects. Davis (1976)b and Thornton, (1975) confirmed these findings in that provided the subject was relaxed the V wave was present to 10dBSL.

The disadvantages of using the brainstem potentials to

assess auditory acuity is that their requirement for a click stimulus does not permit the acquirement of frequency specific information, and,being limited to frequencies of 2000Hz and above,provides an assessment of only the basal turn of the cochlea.

Using high frequency tone pips of 2,400 and 4,800Hz Davis and Hirsch (1976) obtained a clear V wave to within 10dB of subjective thresholds whereas with a low frequency stimulus of 500Hz, the response was only detectable to the level of 30-40dBSL. They suggest the alternative use of fast frequency following response in the assessment of low frequency tones, but this again is only detectable to approximately 40dBSL. Brainstem potentials were also used to assess auditory thresholds in a group of 18 children from 4-10 years of age by Sohmer and Feinmesser (1978) and again were present to 0-15dBSL.

Auditory thresholds were measured using wave V of the brainstem responses by Schulman-Galambos and Galambos (1975) in 24 infants of 34-42 weeks gestational age. In the full term infants of 40-42 weeks responses were present at 30dBHL in all infants, whereas in the premature groups of 36-37 weeks and 38-39 weeks responses in all infants were only detected at the 40dB level, and in the youngest group of 34-35 weeks a 100% response rate was only obtained at 60dBSL (relative to adult threshold in their laboratory) See Table 8.7.

Gestational Age Weeks	Number n	60dBSL	50dBSL	40dBSL	30dBSL
34 - 35	6	6	5	5	1
36 - 37	6	6	6	6	5
38 - 39	6	6	6	6	4
40 - 42	6	6	6	6	6

Table 8.7. The Effects of Gestational Age on the Occurence of Brainstem Potentials - Schulman-Galambos and Galambos, 1975.

They conclude that the brainstem potentials provide a reliable measure of hearing acuity in the full-term newborn infant which is reduced somewhat by prematurity.

However, these results, where the responses consisted of an exceedingly large average ranging from 4096 to 16,384 individual responses, were not confirmed by Starr et al. (1977). Using a stimulus rate of 10 per second with an average of 2048 responses they found that in their very young premature group of 25-28 weeks that responses were often only elicited at the level of 75dBSL and suggest that at this age the slow vertex potential response is more effective.

A large group of 220 normal term infants (38-42 weeks) with no detectable hearing defect were tested by Schulman-Galambos and Galambos (1979) within 12 hours of birth.

Responses from all infants were recorded to tone pips of 1000, 2000 and 4000Hz and in a smaller group of 20 infants, threshold assessments were made. The authors rated the reliability of their results as Good, Fair or Poor depending on the degree of noise interference at the time of testing from equipment, patient or environment. 65% of the investigations were rated as Good, 20% as Fair and 15% as Poor. In order to reduce variability from noise and maturation they looked only at the infants who were between 39-40 weeks gestational age at birth whose test situations were rated as good and in all of these cases responses were consistently recorded at 20dBHL and in some cases to 10dBHL. They consider these responses recorded to the level of 30dBHL can be considered as normal.

8.7. The Clinical Applications of the Brainstem Auditory Evoked Response Components

8.7.1. Audiological Assessment

The electrocochleogram recorded from promontary or external meatus electrodes provides not only a reliable and accurate measure of subjective hearing levels to within 10dB of subjective thresholds (Yoshie, 1968 and Yoshie and Ohashi 1969), but also shows characteristic changes in amplitude-intensity functions which enable the differentiation of conductive and sensori-neural deafness. Comparison of 8 normal subjects, 15 patients with sensori-neural deafness and 2 with conductive losses revealed the

characteristic L and H response components in the normal and conductive loss groups, but in the latter group the whole curve was shifted farther to the right on the intensity axis. The degree of shift is proportional to the hearing loss and thus provides an additional measure of auditory acuity. In cases of sensori-neural deafness the response showed several variations, but most typically an overall reduction in response amplitude, a delay in the latency of N_1 and in addition a loss of the L response curve of the amplitude -intensity function.

Brainstem evoked potentials recorded from scalp electrodes can also provide valuable information regarding the nature and localisation of audiological disorders. Galambos and Hecox (1977) report that the latency-intensity function of the V wave in cases of conductive deafness is parallel to the normal curve, but displaced towards higher intensity levels, the amount of displacement being proportional to the hearing loss (Figure 8.11.). The authors give an example of a conductive loss where latency of the V potential at 65dBHL is 7.1 m.secs. This would be comparable to the latency of a 30dBHL response in a normally hearing individual, indicating a 35dB hearing loss.

In cases of sensori-neural hearing losses, which are usually typified by a high frequency loss and by the occurence of recruitment, the latency-intensity functions rise more steeply starting with an initial delay in latency at threshold level which disappears with increasing intensity (Figure 8.11.).

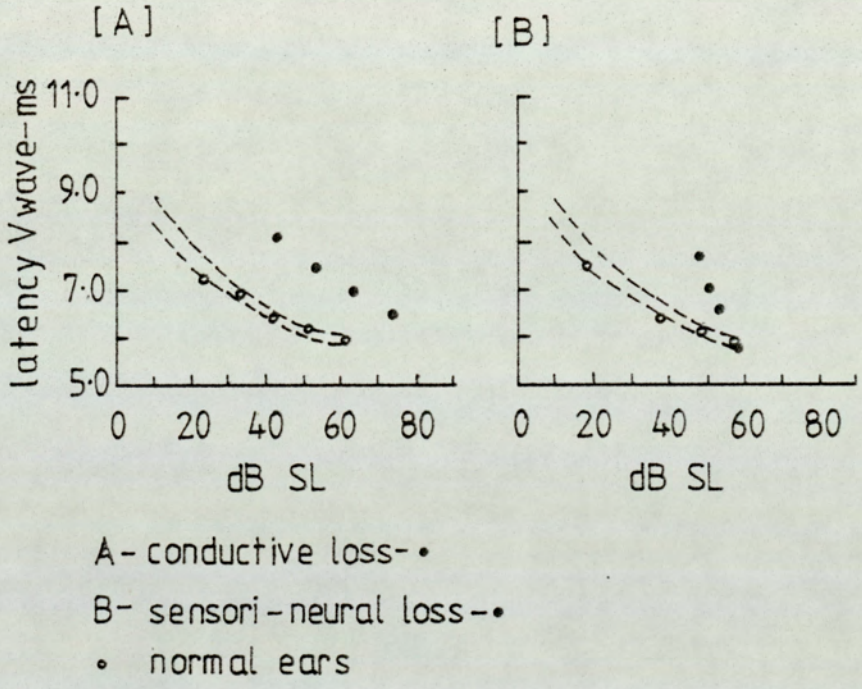


Fig. 8.11.

The effects of sensori-neural and conductive hearing losses on the latency~intensity function of the V wave. [Galambos and Hecox 1977]

Sohmer and Feinmesser (1976) report similar characteristics in the latency-intensity functions of conductive and sensori-neural deafness, but in addition by recording the cochlear microphonic they are able to distinguish the sensory and neural origin of sensori-neural deafness. The recording of a cochlear microphonic with no apparent brainstem potentials would indicate a neural loss while the absence of cochlear microphonic and thus brainstem potentials would be consistent with a sensory loss (when the auditory nerve may or may not be intact).

Later in 1977 the same authors suggest that the brainstem evoked potentials should be used in conjunction with the vertex potential to assist in the diagnosis of non-organic hearing losses. In a group of 30 patients, non-organic hearing losses were suspected on the basis of psychiatric examination and of the discrepancies observed between pure tone and speech audiometry, and the presence of normal speech. The group of patients included both suspected malingerers and true psychogenic deafness precipitated by emotional trauma. Measurement of response thresholds using the N_4 component confirmed the diagnosis of non-organic hearing loss in 25 of these 30 cases.

The chief area of clinical application of the brainstem evoked potentials lies in the audiological assessment of infants and difficult to test young children. Studies on infants with suspected hearing loss or at high risk for possible hearing losses were assessed by Sohmer and

Feinmesser (1972) and Schulman-Galambos and Galambos (1979). Both vertex potential and brainstem potentials were recorded in 31 infants (4-31 months) where hearing losses were suspected (Sohmer and Feinmesser). Amplitude, latency and threshold measurements were obtained from each patient and they found that in cases where a straight forward hearing loss was suspected then good correlations were obtained between behavioural and brainstem threshold estimates. Whereas in cases where additional problems of mental or physical handicap existed then behavioural and brainstem potential thresholds were not so closely correlated, and as was often the case in the vertex potential recording, the brainstem potentials gave the lower threshold estimate indicating the possibility that the inability to respond was due to retardation rather han peripheral hearing loss.

In a group of 220 full-term normal neonates, threshold estimates made by Schulman-Galambos and Galambos (1979) using component V of the brainstem potentials were of the order of 20dBHL. These results were then compared with those of a further two groups of infants, the first consisting of 75 infants at high risk of sensory and CNS disorders arising through prematurity, oxygenation or drug toxicity and the second group of 325 infants who had previously been discharged from intensive therapy units. Of the 75 infants at a high risk group, 4 were found to have a sensory hearing loss which was later confirmed by behavioural testing and similarly 4 of the

second group of 325 infants who presented with language delays were also found to have severe auditory losses.

The reliability of Jewett's wave V in the assessment of auditory function was further confirmed in a study of infants and children from the ages of 6 weeks premature to 15 years (Mokotoff, Schulman-Galambos and Galambos 1977). Two groups of patients were investigated, the first consisted of 38 patients who had already been investigated by other audiological techniques, but had proved difficult to evaluate, and the second group of 43 patients who had undergone no previous audiological investigations. Abnormalities in the V wave response were judged on,

a) no response at 60dBHL
b) prolonged latency of the V wave potential for the age
c) absence of response or delayed latency at one or more intensities below 60dBHL.

In the first group of patients (n=38) agreement between brainstem potential thresholds and previous audiological testing was reached in 27 cases. In 8 of the remaining 11 cases, brainstem potentials indicated normal peripheral auditory function, two of these, however, on the basis of differences observed in speech and pure tone audiometry, were suspected of having a higher cortical lesion and in such cases the brainstem potentials would not be affected.

In the second group of 43 patients, normal brainstem potentials were recorded in 26. Of the remaining cases, both brainstem potentials and impedance measures indicated a sensori-neural loss in 3, a conductive loss in 6 and a mixed loss in 1. The final 7 cases were found to have severe losses of the order of 80dB.

Sohmer and Student (1978) investigated the effects of clinical factors such as autism, minimal brain damage and psychomotor retardation on the brainstem potentials, as diffuse brain damage my influence the characteristics of the brainstem potentials and their relation to hearing acuity. Their studies included,

a) 13 autistic children (4-12 years)
b) 16 children with minimal brain damage (11-13 years)
c) 10 children with psychomotor retardation (2-8 years)

Their results were compared with the brainstem potentials obtained in 18 normal controls (4-10 years).

In the autistic group 4 of the children produced no responses and were found to have a profound cochlear hearing loss. The remaining 9 children produced normal brainstem thresholds, but with the other groups differed from the normal control data in brainstem transmission time (CTT).

Both PTT (latency of N_1) and CTT (N_4-N_1 latency) were

increased in all experiment groups as compared to the normal controls. The psychomotor group showing the greatest delays followed by the minimal brain damage group and finally the autistic group. Thus, the brainstem potentials not only provide a reliable estimation of hearing acuity in these experimental groups, but also provide evidence of some brainstem dysfunction as seen in the delay in CTT.

8.7.2. Neurological Assessment

Great interest has arisen in the possible role of the brainstem potentials in the evaluation of pathological conditions affecting the brainstem. Unlike the area of audiological assessment where alternative objective tests of auditory function exist, the brainstem potentials, because of their clearly established generator sites within the brainstem, offer the neurologist with a practically unique opportunity for the non-traumatic assessment of brainstem integrity. Evidence has been presented for their diagnostic value in the detection and localisation of tumours of the brainstem and midbrain; in the evaluation of brainstem function in coma, vascular disorders and brain death; and in the confirmation of multiple sclerosis and the detection of clinically silent areas of demyelination within the brainstem. They have also been suggested as an on-line monitor of brainstem function during posterior fossa surgery.

Various criteria for response abnormality are used (Sohmer

and Feinmesser, 1974; Starr 1977 and Stockard and Rossiter 1977) the most common being:-

a) absence of specific brainstem components

b) abnormalities in response amplitude in terms of the ratio of components 1V/V:1. This ratio is always greater than 1 for binaural stimulation at intensities of 5-75dBSL and for monaural stimulation over intensities of 5-55dBSL. (Starr 1977). When the ratio is less than 1 then brainstem dysfunction is indicated.

c) abnormalities in response latency - in order to avoid the confusing effects of a peripheral hearing loss which may produce an overall delay in all response components various CTT measures are used including the latency differences between component 1-V, 1-11 and 111-V. Such measures are independant of stimulus intensity (except that it must be high enough to clearly record the earlier components) and delays may be attributed to brainstem dysfunction, (with the exception of maturational changes occurring during the first few months of life). The values of CTT show remarkable stability both within and across subjects. The values obtained by Starr (1977) are shown in Table 8.8.

n = 6	CTT I - V ms						
STIMULUS INTENSITY dBSL	75	65	55	45	35	25	15
MEAN -	3.9	3.8	3.8	3.8	3.8	3.9	4.0
SD	0.2	0.2	0.2	0.2	0.3	0.3	0.3
RANGE	3.5-4.3	3.4-4.2	3.3-4.2	3.5-4.4	3.5-4.1	3.5-4.1	3.5-4.3

TABLE 8.8

Central transmission time as measured by latency differences between peaks I—V. [Starr 1977]

The success of the brainstem potentials in the detection and localisation of brainstem lesions has been clearly demonstrated by Sohmer and Feinmesser (1974); Starr and Achor (1975); Starr and Hamilton (1976) and Stockard and Rossiter (1977). In a study of 100 infants and children with suspected brainstem lesions, Sohmer and Feinmesser, (1974) found that tumours affecting the auditory nerve at the junction with the brainstem (acoustic neuroma, petrous bone meningioma) were associated with the presence of N_1 and possibly N_2, with all subsequent waves on the affected side and cortical response components absent. In cases where clinical symptoms indicated only cortical and cerebllar damage, all brainstem components were present, but when brainstem involvement was indicated this correlated well with abnormalities in the later brainstem components.

Localisation of brainstem and mid-brain tumours by brainstem potentials were later confirmed at autopsy or surgery in the studies of Starr and Achor (1975); Starr and Hamilton (1976) and Stockard and Rossiter (1977). Their general conclusions were that lesions of the mid-brain resulted in an abnormality of components 1V-V11 with possible effects on earlier components due to pressure. Waves 11 and 111 are dependant on the medullary portion of the brainstem, more specifically in the regions of the cochlear nucleus and superior olive respectively. In cases of widespread damage of the brainstem only wave 1 may be recorded.

Thus in summary:-

i) that abnormalities in wave 1 were associated with cochlear dysfunction

ii) abnormalities in wave 11 and all subsequent waves on the affected side were associated with tumours of the cochlear nucleus and of the auditory nerve at the ponto-cerebellar angle

iii) abnormalities in wave 111 onwards were produced by infarcts or haemorrhage in the caudal pons. Waves 1 and 11 are normal.

iv) abnormalities in waves 1V and V were associated with vascular disorders and tumours of the mid-brain and rostral pons. Component 1-111 were normal, but the latency of 111-V waves increased.

v) abnormalities in wave V1 were associated with rostral mid-brain and caudal thalamic tumours.

vi) abnormality in wave V11 was tentatively related to damage of the auditory cortex.

However, the last two components, wave V1 and V11 are quite variable in the normal population and thus abnormality observed must be viewed with caution. In a few of the cases studied the authors found that the brainstem

potentials provided the first only accurate location of brainstem damage while other neurological and radiological investigations were negative.

Evidence presented by Starr (1975); Stockard and Rossiter (1977) and Thornton (1975) provide preliminary indications that brainstem evoked potentials recorded from vertex-mastoid derivations may reflect primarily the activity of the ipsilateral brainstem:-

i) Starr (1975) cites the case of a 22 year old with an Astrocytoma infiltrating the left inferior colliculus, lateral lemniscus , floor of 4th ventricle and left vestibular and cochlea nuclei. Only wave 1 was recorded present from the left mastoid-vertex derivations with left ear stimulation, while all components were recorded from the right mastoid with right ear stimulation, although amplitude of the 1V/V wave was reduced to half of wave 1.

ii) the case of a tumour of the cochlear nucleus and 8th nerve at the pontocerebellar junction produced a normal wave 1 only, with all subsequent components from the affected side abnormal. Whereas all waves from the unaffected side of the brainstem as recorded from the opposite mastoid were normal (Stockard and Rossiter 1977).

iii) Thornton (1975, 1976) gives the example of a patient with a right sided acoustic neuroma. Normal cochlear microphonics were recorded from both mastoid derivations. Binaural stimulation resulted in the detection of all response components N_1-N_5 from the left mastoid and components N_2-N_5 from the right mastoid (Figure 8.12). He suggests that these findings result from bilateral neural representation and the crossing of activity across the brainstem to the affected side behind the site of the lesion. Thus, N_2-N_5 from the right mastoid may be arising solely from contralateral stimulation, the absence of N_1 on this side would suggest no imput from the right ear. This is confirmed by monaural stimulation to the right ear when no response is detected at either mastoid, whereas monaural stimulation of the left ear produces a response identical to binaural stimulation. Such observations have considerable clinical importance, but in view of the problems encountered in neural topographical studies of the scalp distribution of the brainstem potentials and of the differential contributions of the various electrode sites to the resultant response, a great deal more research must be carried out before definite conclusions may be drawn. However, the work of Jewett and Williston (1971) in animal studies would support the reflection of ipsilateralateral brainstem activity at least of the earlier components in the respective mastoid regions with bilateral representation of the later components at the vertex.

The reliability and consistency with which the brainstem potentials could detect brainstem lesions was investigated by Stockard, Stockard and Sharbrough (1977) in 30 patients with known lesions. Abnormalities in the brainstem potentials were detected in -

12 out of 15 patients with subtentorial neoplasms
5 out of 5 patients with acoustic neuromas
4 out of 4 patients with brainstem gliomas
1 out of 1 patients with cerebellopontine angle meningioma
1 out of 2 patients with 4th ventricle ependymona
1 out of 3 patients with cerebellar tumours

Thus, it can be seen that brainstem potential can reliably and consistently detect brainstem abnormalities and in three of these cases were the only diagnostic technique to provide positive evidence of a lesion.

Clear correlations between CATscan abnormalities and brainstem potential results led Gilroy and Lynn (1978) to suggest that their use as an alternative diagnostic technique for olivopontocerebellar degeneration to replace the potentially hazardous technique of pneumoencephalography.

An interesting application of brainstem potentials was suggested by Hashimoto, Ishyama, Totska, Aruga and Johita (1978) as a monitor of brainstem function during posterior fossa surgery to provide a more sensitive indicator of caridiac and respiratory responses.

The other main neurological application of the brainstem potentials at present is in the detection of demyelination within the brainstem. Multiple Sclerosis describes a condition of multiple sites of demyelination within the CNS which results in the progressive slowing of nerve conduction rates and often finally a complete loss of function. The disease process is characterised by periods of activity and remission, the intervals of which vary considerably within and across patients.

Abnormalities in both cervical and cortical somatosensory evoked potentials and in visual evoked potentials to both flash and pattern reversal stimuli have been correlated with sites of demyelination (Halliday, McDonald and Mushin 1973a and 1973b).

In the case of the visual evoked potential, to flash stimulation, the disruption of the response during the active phase of the disease is found to return to normal during periods of remission (except in the later stages of the disease), while the pattern reversal response remains permanently delayed.

Initial studies by Thornton (1975 and 1976); Starr and Achor (1975) and Robinson and Rudge (1975) have indicated that abnormalities in brainstem potentials, in terms of delayed latencies, reduced amplitudes or both, are present in multiple sclerosis not only in cases where there is clinical evidence of brainstem involvement, but also in

cases where no clinical involvement of the brainstem has yet been found. Thus, the authors suggested that the brainstem potentials may be of value in the detection of clinically silent areas of demyelination within the brain and so confirm a diagnosis of multiple sclerosis where only one site of clinical demyelination has been demonstrated.

The decreases in amplitude and delays in the latencies of the brainstem potentials (Figure 8.13) occurring with demyelination may be explained by the loss of synchronisation between the firing of individual neurons due to their different rates of conduction. This would result in an overall reduction in amplitude and a broadening and lengthening of the individual peak latencies. If demyelination was generalised within the brainstem then the latency delays would be accumulative and more marked in the later components.

Brainstem response abnormalities were further confirmed by Robinson and Rudge (1977a and 1977b) in 88 cases of definate multiple sclerosis which were characterised by multiple CNS lesions and by periods of relapse and remission of durations from 1-25 years. They failed to obtain reliable results from the earlier brainstem components (possibly because only 512 sweeps were averaged at a stimulus rate of 20 per second), and only considered the V wave in their analysis. Abnormalities in the latency or amplitude of the V wave (greater than 2 S.Ds.) were detected in 65% of patients. Further analysis found the occurence of brainstem

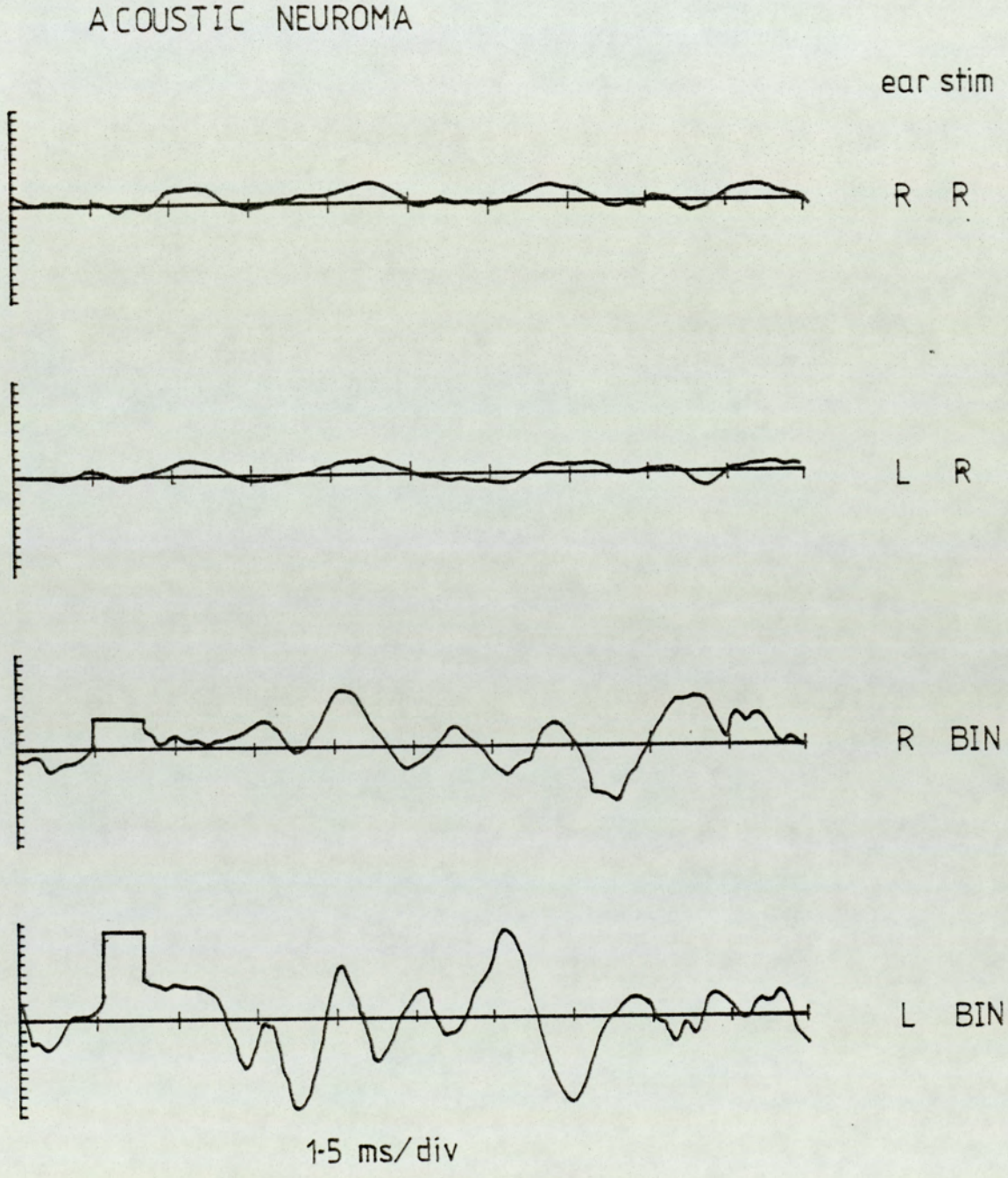


Fig. 8.12.
Brain stem evoked potentials in the case of a right acoustic neuroma [Thornton 1976]

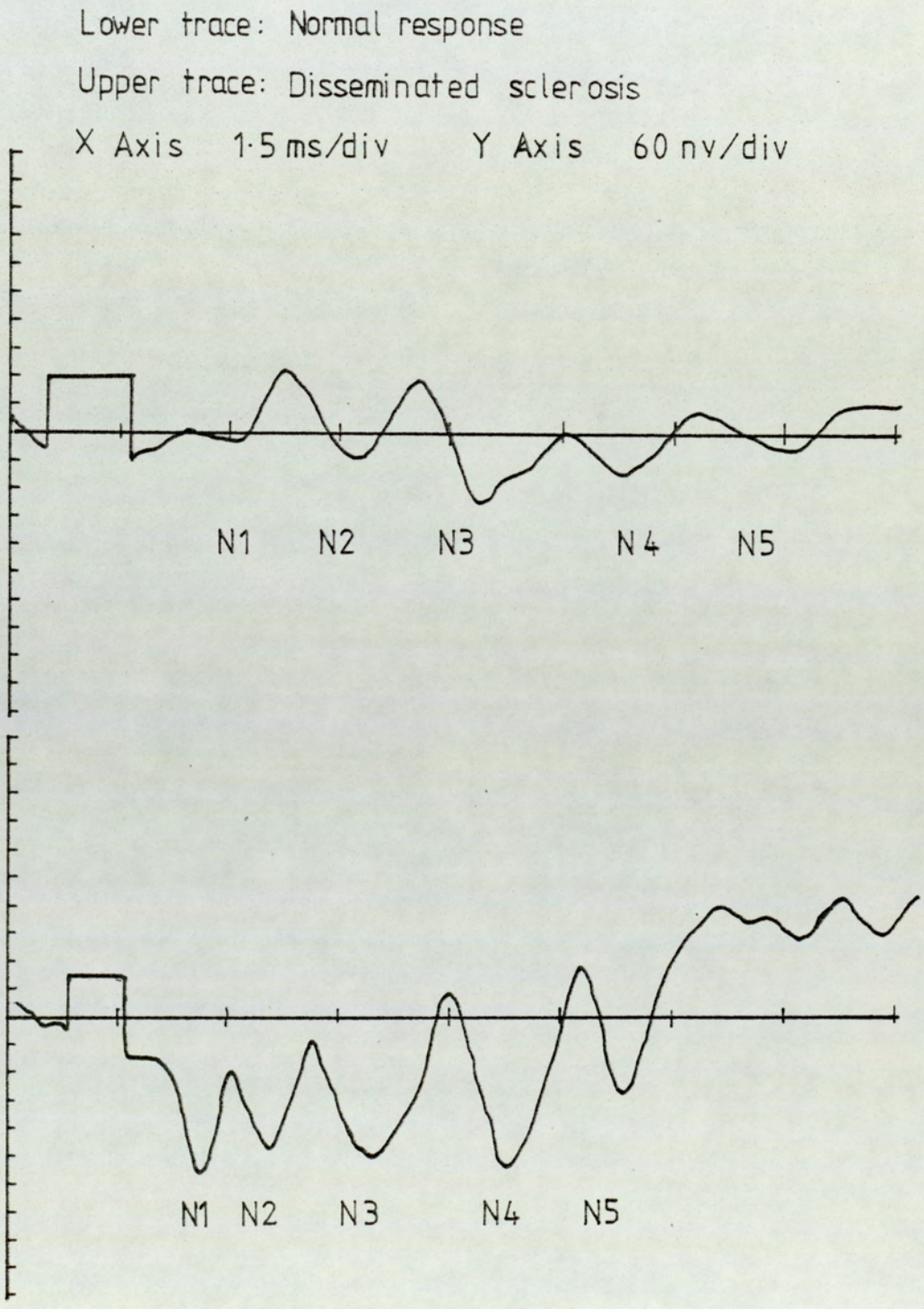


Fig. 8.13.
Changes in brain stem evoked potentials in multiple sclerosis [Thornton 1976]

potential abnormalities to be more highly correlated with multiple sclerosis when there was obvious brainstem involvement. With definite brainstem involvement, brainstem potentials were abnormal in 82%, with suggested brainstem involved (nystagmus) 76% were abnormal and with no clear evidence of brainstem involvement only 51% were abnormal, Stockard and Rossiter (1977) and Stockard, Stockard and Sharbrough (1977) also found that the brainstem potentials were a sensitive measure of demyelination within the brainstem both with and without active clinical involvement. They obtained the following results in 100 cases of multiple sclerosis.

1) Definite multiple sclerosis (n=30) characterised by multiple lesion sites and periods of relapse and remission. Brainstem abnormalities were demonstrated in 93% and more specifically latency abnormalities in 60%.

2) Probable multiple sclerosis (n=30) with multiple lesions, but one attack only. Brainstem response abnormalities were present in 77% and latency abnormalities in 67%.

3) Possible multiple sclerosis (n=40) with a single lesion, but recurrent attacks. Response abnormalities were present in only 35% with latency abnormalities in 17%.

Thus, in this latter group the brainstem potentials have provided the first evidence of more than one lesion site. All authors find an increased reliability in the latency measures of abnormality rather than the amplitude measures and that the sensitivity may be increased by stressing the nervous system by increasing the rate of stimulus presentation.

Evidence of a partial improvement in brainstem abnormalities during a period of remission on ACTH therapy was observed in one case by Stockard and Rossiter (1977). If this becomes a general observation then it would indicate that response abnormalities detected during the active phase of the disease are not entirely due to demyelination, but also to additional factors which resolve during periods of remission. The residual abnormality would be consistent with the degree of demyelination.

This observation of changes in the brainstem potentials during active and remission phases of the disease was also indirectly supported by the findings of Robinson and Rudge (1978) in a study of the stability of brainstem potentials over a period of time. Stability in brainstem potentials was observed over the period of study in both normal controls (n=8) and in 11 out of the 27 multiple sclerosis cases studied who were stable and suffered no relapses during the study. However, in the remaining 16 multiple sclerosis cases where relapses and remissions had occurred during the study, great variability in brainstem

potential was observed. The variability was most evident in cases where initial brainstem potentials were abnormal and thus indicated probable active involvement of the brainstem in the disease process.

8.8. Summary

Clear evidence is presented for the reliability and stability of the brainstem potentials both across and within the population. Considerable maturational changes are reflected within the brainstem potentials over the first few months of life. Progressive decreases in response latencies reflect both peripheral and central maturation processes which proceed at different rates. The response waveform also shows maturation as seen in the increase in complexity and stability of the response. As yet there is little data on the effects of aging, but preliminary reports indicate delays in peripheral transmission time with central conduction time unaffected.

Unlike the slow vertex potential, auditory assessment using the brainstem potentials is limited to the level of the brainstem and to the high frequency response arising from the basal turn of the cochlea, but other factors such as their resistance to change with factors such as sleep, arousal, attention, habituation and fatigue weigh in their favour. As with the slow vertex potential the responses are best recorded in the relaxed state and show increased variability with increases in muscle and movement artifact.

Brainstem potentials have been successfully applied to the assessment of peripheral hearing acuity in all ages using Jewett's wave V or the N_4 component which has been reliably recorded to near subjective thresholds. In addition, the use of latency-intensity functions of wave V enable the differentiation of conductive and sensori-neural hearing losses. Also, in cases of possible brain damage they may provide evidence of brainstem pathology as indicated by increased central transmission times, and thus differentiate between the lack of behaviour responses resulting from hearing loss or cerebral damage.

Perhaps the most important area of application of the brainstem potentials lies in the field of neurology where it offers a practically unique opportunity for the non-traumatic assessment of brainstem function. The fairly accurate location of specific response components to specific generators within the brainstem have enabled their application to the detection and localisation of specific lesions within the brainstem and in the detection of clinically silent areas of demyelination within the brainstem and the confirmation of multiple sclerosis.

However, many authors stress that the findings of abnormalities in the brainstem components should be interpreted with caution, especially in the cases of the later components which appear to result from the composite activity of several neural generators.

8.9. Experimental Section

Brainstem evoked potentials were recorded in 50 normal young adults aged between 17 and 30 years of age. The following characteristics of the brainstem potentials were investigated to provide the normal control data for future otological and neurological investigations:-

i) The effect of stimulus intensity on the latencies of the brainstem potentials.

ii) The effect of stimulus intensity on peripheral and central transmission times.

iii) Differences in latency of the brainstem evoked potentials and of peripheral and central transmission times in male and female subjects.

iv) The effects of stimulus intensity on a) the amplitude of the brainstem evoked potentials and b) the relationship between the amplitudes of components N_4 and N_1

v) The comparison of the individual brainstem components in the measurement of objective hearing thresholds and their relationship to subjective hearing threshold.

vi) The comparison of ipsilateral and contralateral brainstem evoked potentials.

8.9.1. Method

i) Equipment

The stimulus was a 0.1 m.sec. click of alternating polarity (to avoid interference by the cochlear microphonic) which was relayed to the subject through a set of TDH-39 headphones. The click intensity was measured with a Breul and Kjaer sound level meter with an artificial ear attachment.

The electrical activity was recorded from the scalp from silver/silver chloride disc electrodes and amplified and monitored by a 12 channel SLE EEG machine. The preamplifiers of the EEG machine were modified to increase the high frequency cut-off from 300 to 4000Hz to enable the brainstem potentials to be recorded. A Data Lab DL 1000 was used to record the brainstem evoked potentials and a permanent record of each response produced by a JJ X-Y Plotter. The lay-out of the equipment used is shown in Figure 8.14.

ii) Procedure

A total of 50 volunteer subjects with no known hearing defects were investigated. All were between the ages of 17 and 30 years and consisted of school 6th formers and University undergraduate and graduate students. Each subject was seated in a comfortable chair in a sound

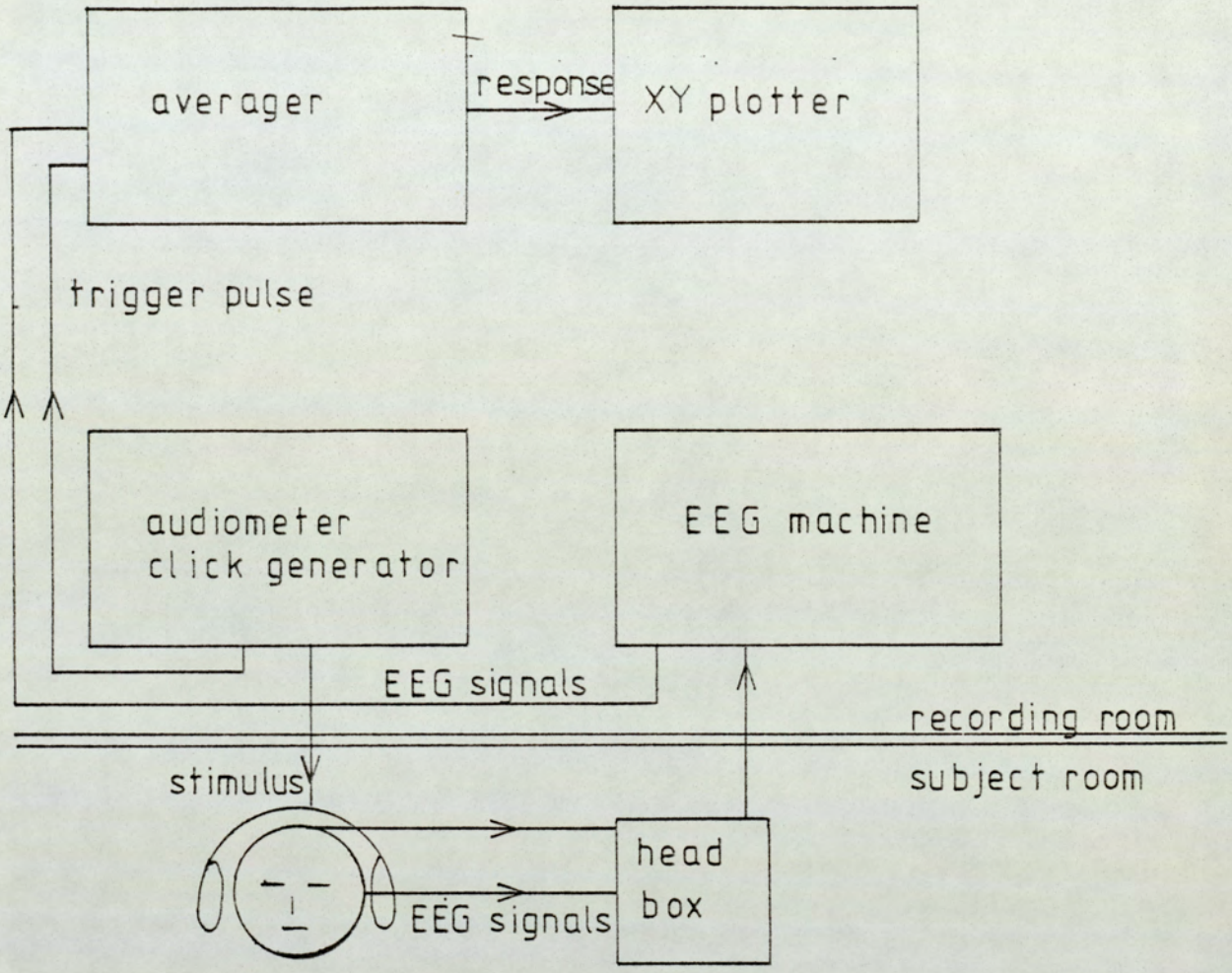


Fig. 8. 14.

Recording equipment for brainstem evoked potentials

damped room. Reading material was provided to maintain a reasonably consistent level of attention and arousal throughout the experiment and each subject was asked to remain reasonably still and avoid gross body or head movements during each recording session.

The electrical activity was recorded from the scalp by silver/silver chloride disc electrodes. Active recording electrodes were placed on both mastoids and at the vertex (C_Z) with an earth electrode at P_Z. The mastoid electrodes were initially attached with adhesive discs and later when satisfactory electrode resistances were obtained they were secured by blenderm. The vertex and earth electrodes were secured with collodium. All electrode resistances were below 5Kohms Brainstem evoked potentials were monitored and recorded from the following derivations:-

a) ipsilateral mastoid to vertex
b) contralateral mastoid to vertex

The averager was triggered externally simultaneously with the onset of the stimulus and each average consisted of 2048 sweeps with a 20 m.sec. analysis time (38 μs. per data point using 2 channel averaging).

A permanent record of each response was obtained by direct write-out on the X-Y Plotter. Amplitude and latency measurements on the brainstem evoked potentials were made either :-

a) Off-line from the plotter write-out

b) On-line by the use of the cursor data and cursor address facilities provided by the Data Lab 1000 Microprocessor.

This provided a measure of latency in terms of data points which was later converted into a real time-scale and a measure of amplitude which was converted to microvolts by comparison with a 5uV. calibration pulse (Lindley and Harding, 1974) which was fed through the whole recording system at the end of each investigation. To enable comparison of amplitudes with those of other investigations, peak-to-peak measurements were made.

Responses were initially recorded to a click stimulus at an intensity of 90dBA presented monaurally at a rate of 10 per second. The stimulus intensity for each successive average was then reduced by 10dB until a response was no longer detectable. In cases of doubtful responses, repeat averages were carried out at the same intensity level. Latency and amplitude measurements of the individual brainstem potentials were recorded as described above. Once the objective threshold of the brainstem potential had been established (that is, the lowest intensity at which a response is detectable) the subjective threshold to the same repetitive click stimulus was measured.

The whole recording procedure for the measurement of brainstem evoked potentials in one ear from 90dBA to

threshold, including the application of the electrodes and the measurement of response amplitude and latencies took approximately 1-1½ hours.

8.9.2. Results and Analysis

In the ensuing results and discussion the brainstem evoked potentials will be described according to the convention of Sohmer and Feinmesser (1967) in terms of negativity at the mastoid and labelled as peaks N_1 to N_5. This does not, however, imply that the mastoid electrodes are active and the vertex electrode inactive as topographical studies have quite clearly demonstrated that both electrodes are active in terms of these far field evoked potentials.

All stimulus intensities are expressed in terms of sensation level - dBSL and related to each individuals subjective hearing threshold.

The measurement of subjective thresholds to within 5dB and brainstem potentials to within 10dB has resulted in two distinct groups of subjects. In one group brainstem potentials are recorded at 0, 10, 20, 30dBSL etc. and in the other 5, 15, 25, 35dBSL etc.

In the following analysis both groups have been combined so that 0 and 5dBSL are grouped as 0dBSL, 10 and 15dBSL as 10dB etc. thus producing brainstem potentials at 10dB intervals from 0 to 80dBSL.

Brainstem potentials were successfully recorded in all subjects. The response recorded from ipsilateral mastoid-vertex derivations consisted of at least 5 mastoid negative components (N_1 to N_5) which were clearly detectable at intensities of 70dBSL and above (Figure 8.15.). The N_{4a} component or Jewett's Wave 1V was not present in all subjects and occurred only as a small shoulder on the rising edge of the N_4 component (Figure 8.15.). The later components N_6 and N_7 were also present on some occasions, but because of variability and possible distortion by the presence of the post-auricular myogenic potential which was also recorded they are not included in subsequent analyses.

i) The Effect of Stimulus Intensity on the Latencies of the Brainstem Evoked Potentials (n=26)

Although brainstem evoked potentials were recorded in a total of 50 subjects, only 26 subjects where response latencies were measured by means of the cursor facility on the microprocessor are included in this analysis. Initially, in order to reduce the time taken for the whole recording procedure, a factor which is extremely important in clinical investigations involving young children, all latency measurements were made off-line directly from the X-Y Plotter write-out.

However, certain technical problems with this plotter did

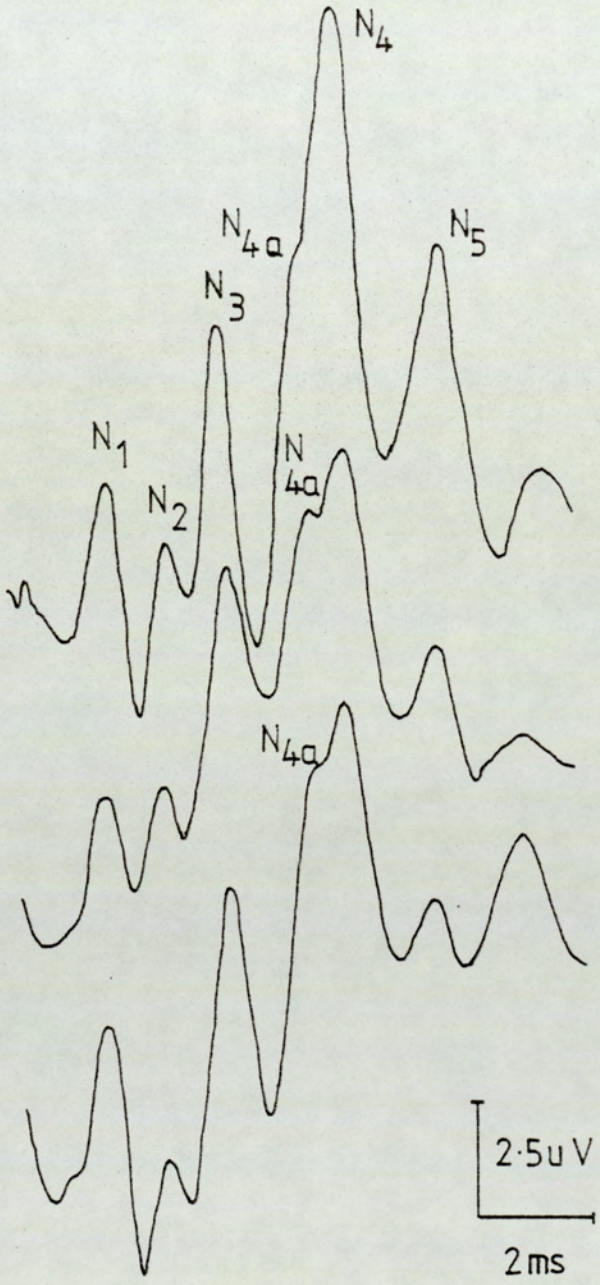


FIG. 8.15 Configuration of brainstem evoked potentials recorded in 3 subjects from ipsilateral mastoid-vertex derivations to a 70dBSL click.

not allow these latency measurements to be made with sufficient accuracy, and thus in all the remaining subjects (n=26), latency measurements were taken directly from the Data Lab which enabled latency measurements to be made to within 38μs.

The gradual lengthening in latency of all response components with decreasing intensity in both ipsilateral and contralateral recordings is seen in Figure 8.16. The means and standard deviations of the latencies of N_1 to N_5 at intensities of 0 to 90dBSL are shown in Table 8.9. and the latency-intensity functions of all components in Figure 8.17 (the 90dBSL group has been omitted because of the small sample size). All components show gradual and parallel increases in latency with decreasing stimulus intensity over sensation levels from 80-40dB. Below 40dBSL the increase in latency with decreasing intensity becomes more rapid especially for the later components N_3, N_4 and N_5. The variation in response latencies (as reflected in the standard deviation) for all components is much greater at low intensity levels. The responses at high sensation levels are characterised by small standard deviations.

ii) The Effect of Stimulus Intensity on Peripheral and Central Transmission Times (n=26)

The latency of the N_1 component provides a measure of peripheral transmission time (PTT) and as has been shown above this shows a gradual progressive increase with

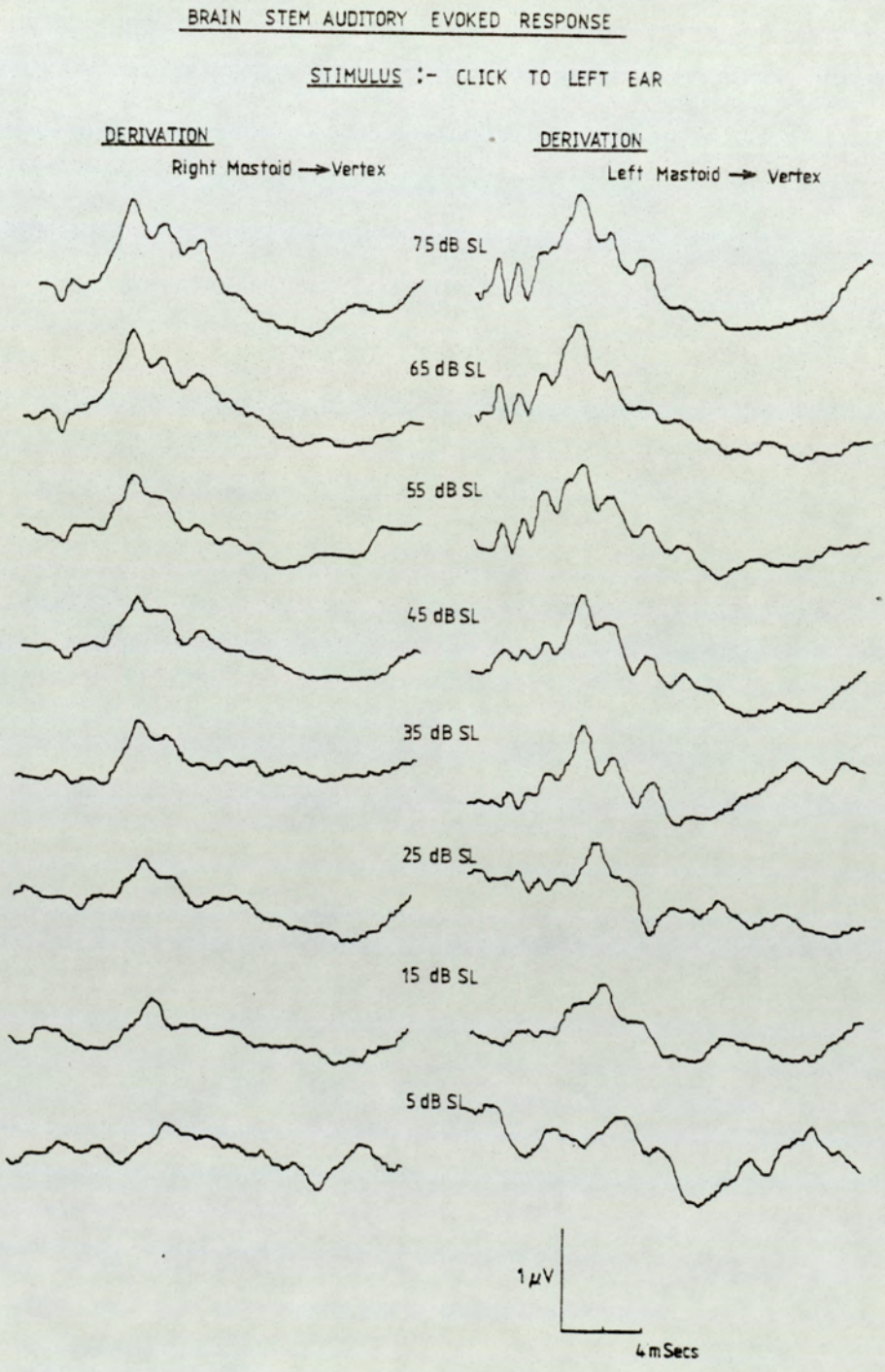


FIG. 8.16 The affects of intensity on brainstem evoked potentials recorded from ipsilateral and contralateral mastoid to vertex derivations.

INTENSITY dBSL		LATENCY - ms.				
		N1	N2	N3	N4	N5
90	n	3	3	3	3	3
	x̄	1.672	2.685	3.661	5.624	7.144
	SD	0.100	0.179	0.087	0.380	0.174
80	n	13	13	14	14	6
	x̄	1.616	2.729	3.729	5.553	7.118
	SD	0.117	0.123	0.138	0.180	0.297
70	n	24	24	25	25	17
	x̄	1.688	2.783	3.784	5.655	7.355
	SD	0.141	0.174	0.141	0.225	0.538
60	n	24	22	25	26	14
	x̄	1.827	2.908	3.926	5.794	7.349
	SD	0.172	0.203	0.163	0.251	0.365
50	n	17	15	21	25	11
	x̄	1.980	2.926	4.182	6,015	7.591
	SD	0.183	0.132	0.331	0.284	0.521
40	n	4	7	18	25	9
	x̄	2.175	3.283	4.374	6.353	7.866
	SD	0.447	0.409	0.286	0.373	0.564
30	n	3	5	11	22	7
	x̄	1.995	3.183	4.894	6.845	8.671
	SD	0.097	0.294	0.382	0.474	0.643
20	n		3	9	26	2
	x̄		3.116	4.484	7.186	9.500
	SD		0.211	1.086	0.475	0.966
10	n		2	2	20	
	x̄		3.572	5.681	7.564	
	SD		0.591	0.500	0.844	
0	n				8	
	x̄				8.113	
	SD				0.574	

TABLE 8.9

Mean Values and Standard Deviations of Brain Stem Evoked Potentials in 26 Subjects from Ipsilateral Mastoid to Vertex Derivations over Intensities of 0 - 90 dBSL.

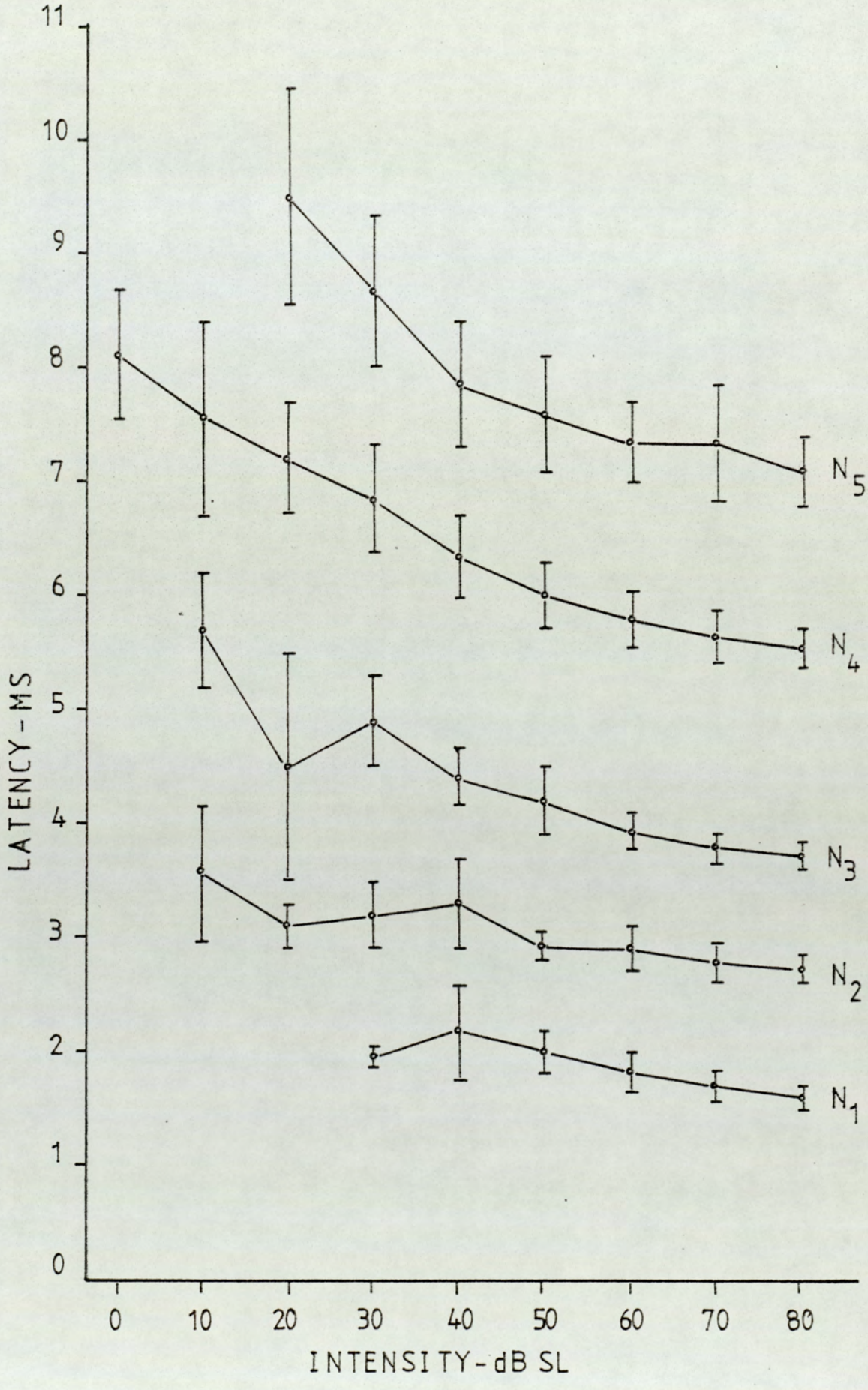


FIG. 8.17 Changes in latency of the brainstem evoked potentials over intensities of O-8OdBSL recorded from ipsilateral mastoid-vertex derivations (n=26)

decreasing stimulus intensity. Central transmission times (CTT) are reflected by the interpeak latencies of the various brainstem response components and are thus independant of PTT. The most consistent components of the brainstem response are N_4, N_3 and N_1 and these components are generally used in the measurement of CTT. The effects of stimulus intensity on PTT and on CTT as measured by the interpeak intervals between N_4-N_1; N_4-N_3 and N_3-N_1, are compared in Table 8.10. and Figures 8.18 and 8.19. Unlike PTT, all measures of CTT remain relatively constant and independant of sensation level over intensities of 80 to 50dB. Below 50dBSL the interpeak time of N_3-N_1 could no longer be measured because of the absence of one or both components (usually N_1). The CTT as measured by N_4-N_1 increased both in time and variability below 50dBSL. while that between N_4-N_3, although remaining apparently stable over lower sensation levels as reflected by the mean value of CTT, also showed a greater variability across subjects.

iii) Differences in Latency of the Brainstem Evoked Potentials and of Peripheral and Central Transmission Times Recorded in Male and Female Subjects (n=16 female, 10 male).

The separation of subjects into male and female groups produced small, but consistent differences in the latencies of all brainstem potentials at stimulus intensities investigated (Table 8.11 and Figure 8.20.). These differences with slightly longer latencies in the male group are most evident over the intensity range of 80-40dBSL where there

INTENSITY dBSL		PT N1 - ms.	CT N4-N1 ms.	CT N4-N3 ms.	CT N3-N4 ms.
90	n	3	3	3	3
	x	1.672	3.952	1.969	1.988
	SD	0.100	0.131	0.104	0.079
80	n	13	13	14	14
	x	1.616	3.949	1.824	2.116
	SD	0.117	0.181	0.141	0.198
70	n	24	24	25	25
	x	1.688	3.969	1.870	2.097
	SD	0.134	0.229	0.139	0.162
60	n	24	24	25	24
	x	1.861	3.963	1.853	2.109
	SD	0.172	0.171	0.163	0.145
50	n	17	17	18	12
	x	1.980	3.941	1.873	2.056
	SD	0.183	0.147	0.144	0.119
40	n	4	4	16	2
	x	2.175	4.056	1.890	1.976
	SD	0.447	0.492	0.352	0
30	n	3	3	9	1
	x	1.995	4.744	1.980	2.736
	SD	0.097	0.422	0.485	
20	n			6	
	x			1.849	
	SD			0.502	

TABLE 8.10 Changes in PTT(N1) and CTT (N4-N1; N4-N3; N3-N1) in 26 Subjects at Intensities of20 - 90 dBSL. Mean Values and Standard Deviations.

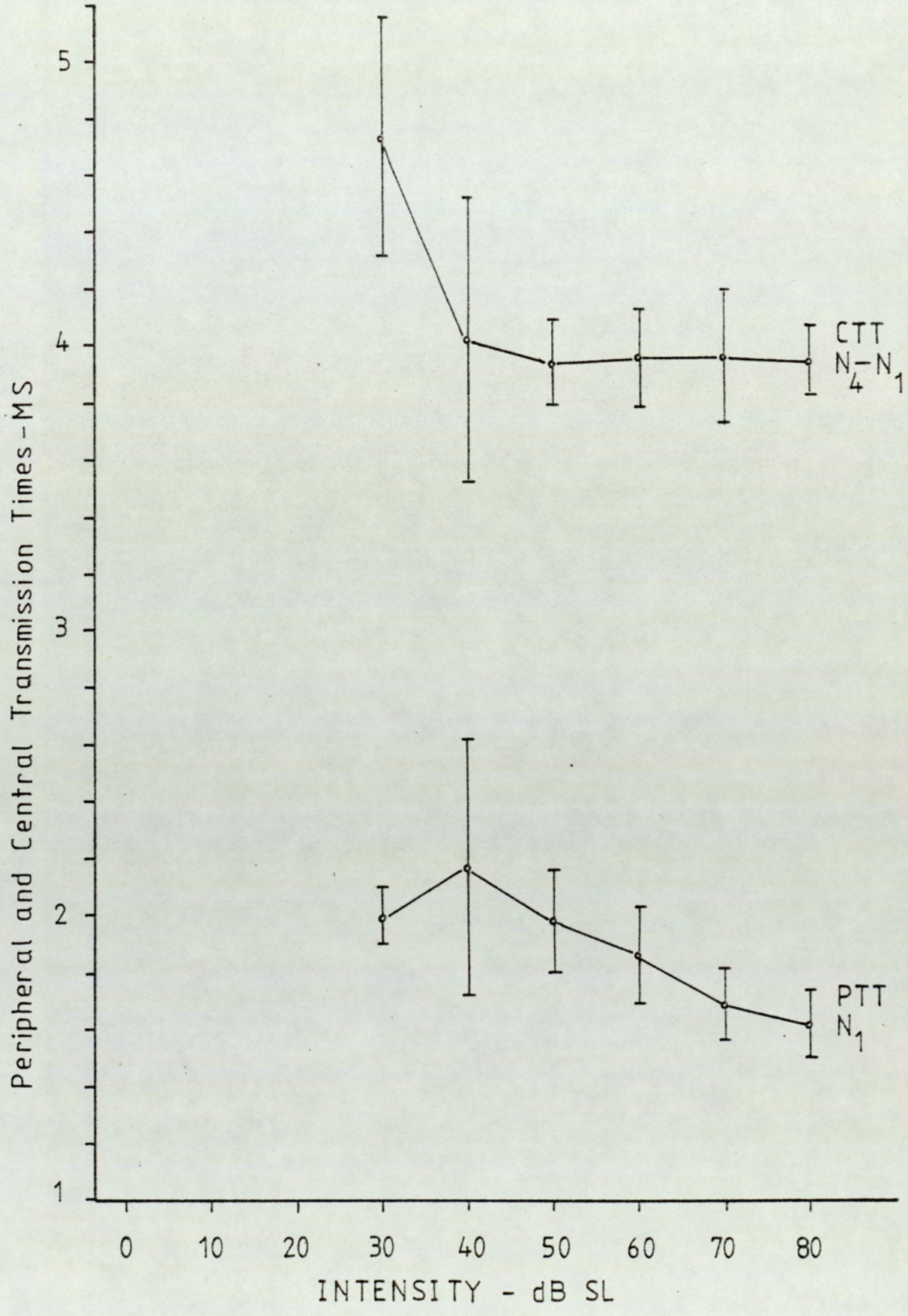


FIG. 8.18 The affects of intensity on peripheral (N_1) and central (N_4 - N_1) transmission times (n=26).

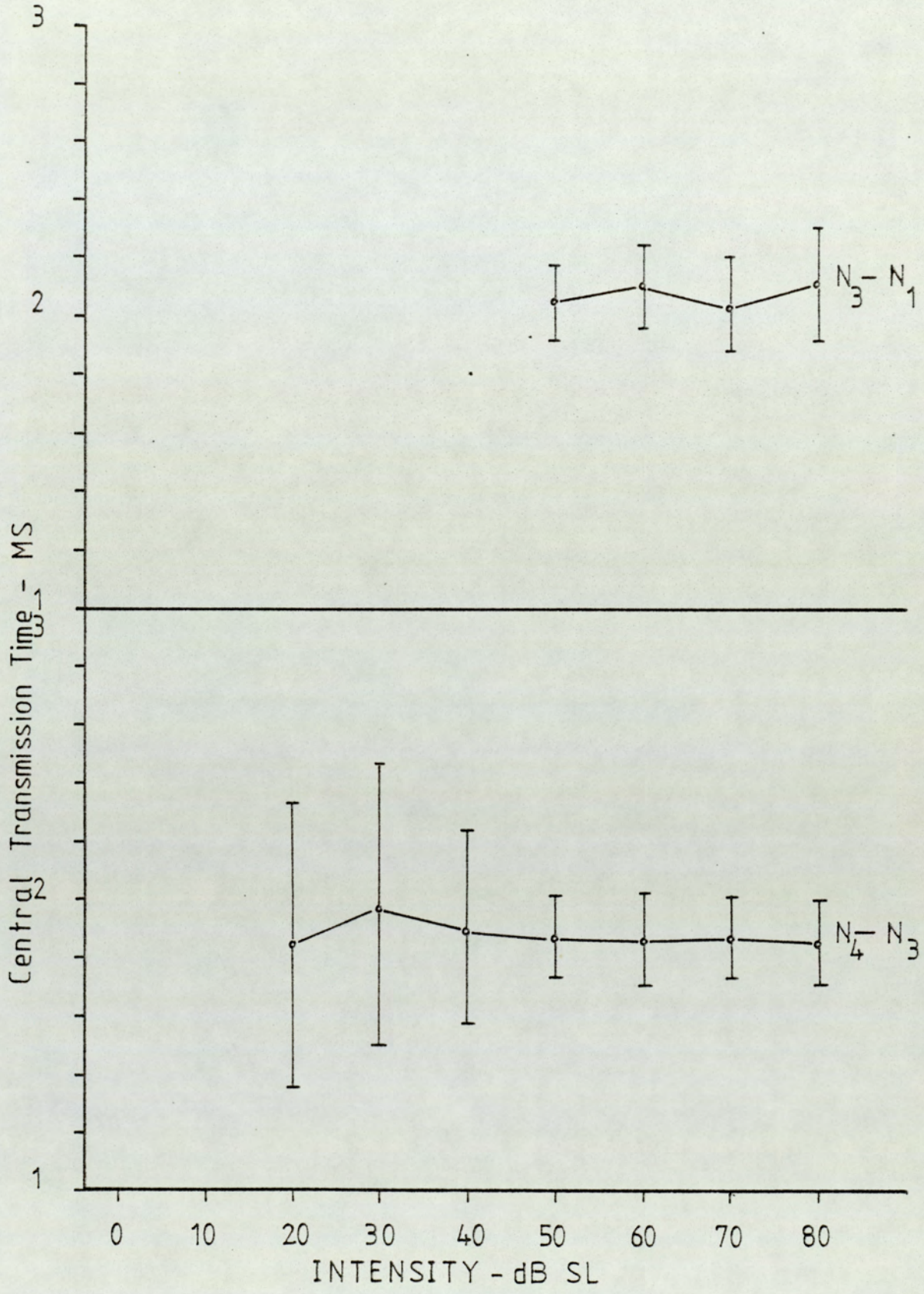


FIG. 8.19 The affects of intensity on central transmission time (N_4 - N_3 and N_3 - N_1) (n= 26).

INTENSITY dBSL		N1		N2		N3		N4		N5	
		M	F	M	F	M	F	M	F	M	F
90	n	1	2	1	2	1	2	1	2	1	2
	x̄	1.710	1.653	2.885	2.584	3.610	3.686	5.586	5.643	7.296	7.068
	SD		0.134		0.053		0.107		0.026		0.161
80	n	5	8	5	8	6	8	6	8	2	4
	x̄	1.618	1.615	2.788	2.692	3.787	3.686	5.611	5.510	7.388	6.982
	SD	0.164	0.091	0.133	0.089	0.091	0.157	0.223	0.148	0.295	0.211
70	n	9	15	10	14	10	15	10	15	6	11
	x̄	1.735	1.664	2.864	2.724	3.852	3.738	5.783	5.571	7.771	7.128
	SD	0.176	0.114	0.154	0.169	0.103	0.148	0.222	0.190	0.622	0.331
60	n	9	15	8	14	10	15	10	16	4	10
	x̄	1.894	1.786	2.958	2.880	3.984	3.890	5.911	5.721	7.676	7.220
	SD	0.202	0.142	0.149	0.225	0.179	0.142	0.230	0.241	0.424	0.259
50	n	6	10	7	8	9	12	10	14	5	6
	x̄	1.988	1.971	2.991	2.869	4.321	4.018	6.128	5.931	7.721	7.482
	SD	0.103	0.238	0.132	0.116	0.389	0.247	0.278	0.273	0.675	0.384
40	n	1	3	4	3	5	13	10	15	4	5
	x̄	2.698	2.001	3.534	2.951	4.415	4.322	6.520	6.421	8.046	7.721
	SD		0.344	0.322	0.240	0.292	0.240	0.383	0.332	0.299	0.715
30	n	1	2	2	3	3	8	9	13	3	2
	x̄	2.106	1.933	3.097	3.242	4.610	5.001	7.103	6.729	8.641	8.748
	SD			0.456	0.226	0.418	0.333	0.524	0.417	0.773	0.280
20	n		1	2	1	2	4	11	15	1	1
	x̄		3.078	3.230	2.888	5.434	5.035	7.331	7.077	10.184	8.816
	SD			0.107		0.161	0.477	0.464	0.463		
10	n		1		2	1	1	8	10		1
	x̄		2.934		3.527	6.004	5.358	8.246	7.388		9.006
	SD				0.591			0.454	0.294		
0	n						1	3	5		
	x̄						6.042	8.372	7.956		
	SD							0.925	0.260		

n = 16 females
n = 10 males

TABLE 8.11

Male - Female Differences in the Latencies of Brain Stem Evoked Potentials - Mean Values and Standard Deviations.

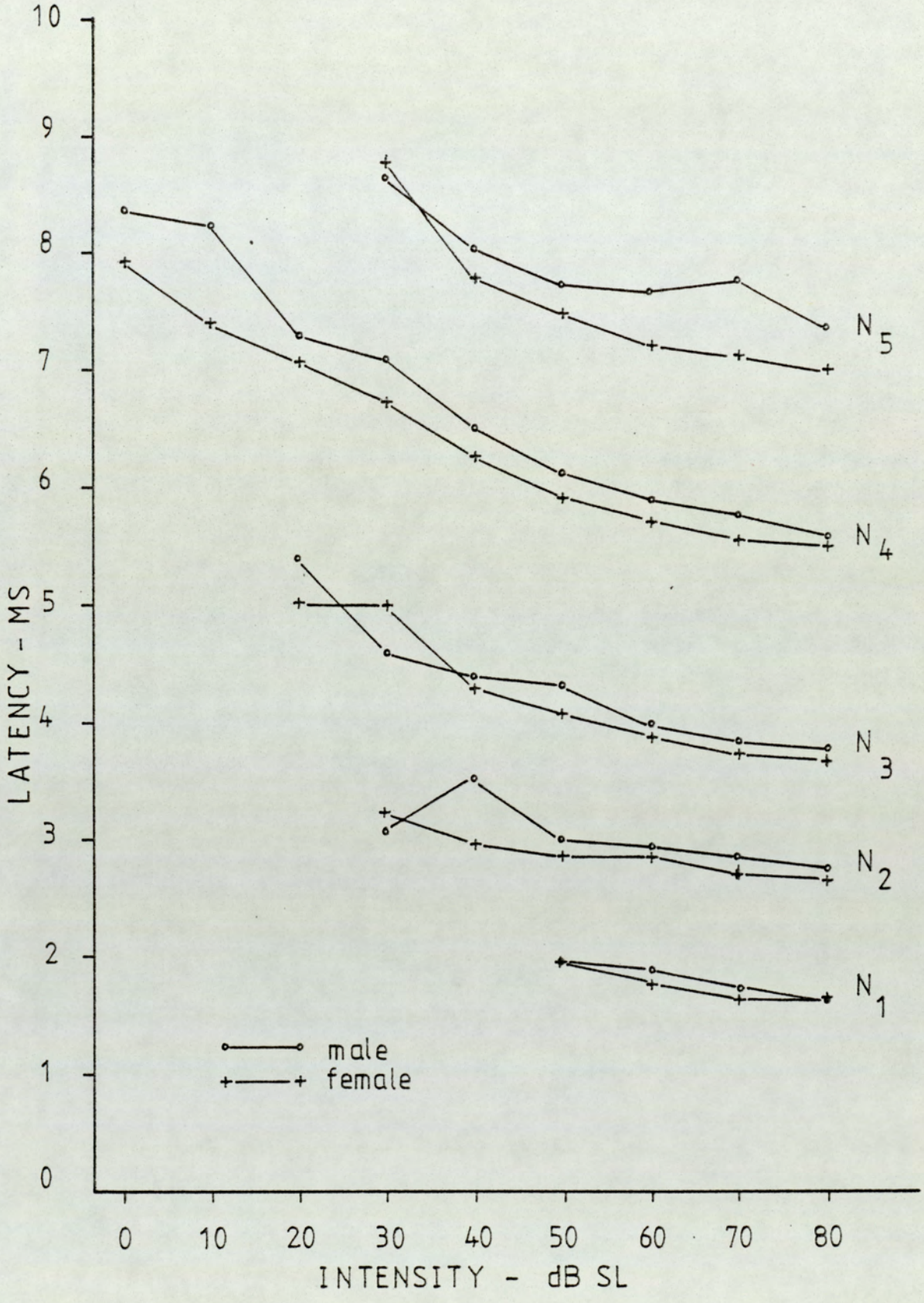


FIG. 8.20 Male-female differences in the latencies of the brainstem evoked potentials (n=16 female, 10 males).

is relatively small inter-subject variation in response latency. Below the level of 40dBSL the male - female latency differences tend to become obscured by the greater latency variability at these low sensation levels. From examination of Fig. 8.20 these male-female latency differences appear to be additive, increasing with each brainstem component and being most marked in the N_5 component. Using the student' t test for significant differences between means, the differences between male and female latencies of the brainstem components reached statistical significant only in the following cases (Table 8.12).

Intensity dBSL	N_1	N_2	N_3	N_4	N_5
80	0.043	1.581	1.407	1.024	1.997
70	1.209	2.081 *	2.123 *	2.564 **	2.821 **
60	1.543	0.872	1.468	2.831 ***	2.503 *
50	0.164	1.913	1.752	1.732	0.741
40		2.616 *	0.697	2.065	0.843

* Significant at 5% level

** Significant at 2% level

*** Significant at 1% level

Table 8.12. t Values for Latency Differences Between Male and Female Brainstem Evoked Potentials.

The difference between male and female brainstem potential latencies is significant at the 5% for N_2 at 70 and 40dBSL; for N_3 at the 5% level at 70dBSL; for N_4 at the 2% level at 70dBSL and at the 1% level at 60dBSL, and for N_5 at the 2% level at 70dBSL and the 5% level at 60dBSL. These findings would support the initial observations that the male-female differences in response latency are additive and most marked in the later components. The significance of the greatest differences observed in the N_5 component is reduced by the greater inter-subject variation in response latency of this component.

As would be expected, these male-female differences in absolute latencies of the brainstem responses are also reflected in male-female differences in PTT and CTT. (Table 8.13 and Figure 8.21.). The difference in male and female CTT, however, only reached statistical significance at the 5% level on one occasion, for N_4-N_1 interpeak times at an intensity of 60dBSL (Table 8.14.).

Intensity dBSL	$N_4 - N_1$	$N_4 - N_3$	$N_3 - N_1$
80	1.474	-	1.467
70	1.896	1.821	0.850
60	2.227*	1.996	0.177
50	0.810	1.712	0.123

* Significant at the 5% Level

Table 8.14. t Values for the Differences in CTT in Males and Females.

INTENSITY dBSL		PTT N1 - ms		CTT N4-N1 - ms		CTT N4-N3 - ms		CTT N3-N1 - ms	
		M	F	M	F	M	F	M	F
90	n	1	2	1	2	1	2	1	2
	$\bar{x}$	1.710	1.653	3.876	3.990	1.972	1.966	1.900	2.033
	SD		0.134		0.160		0.147		0.026
80	n	5	8	5	8	6	8	5	8
	$\bar{x}$	1.618	1.615	3.895	1.824	1.824	1.824	2.188	2.071
	SD	0.164	0.091	0.196	0.161	0.204	0.085	0.123	0.202
70	n	9	15	9	15	10	15	9	15
	$\bar{x}$	1.735	1.662	4.077	3.904	1.929	1.831	2.132	2.074
	SD	0.176	0.114	0.231	0.209	0.165	0.106	0 153	0,167
60	n	9	15	9	15	10	15	9	15
	$\bar{x}$	1.895	1.786	4.055	3.908	1.929	1.804	2.115	2.104
	SD	0.202	0.142	0.142	0.165	0.169	0.143	0.203	0.104
50	n	6	11	6	11	8	10	4	8
	$\bar{x}$	1.997	1.976	3.981	3.920	1.935	1.824	2.033	2.067
	SD	0.100	0.226	0.194	0.120	0.165	0.109	0.791	0.139
40	n	1	3	1	3	5	11		2
	$\bar{x}$	2.698	2.001	4.066	4.053	2.052	1.816		1.976
	SD		0.344		0.604	0.291	0.366		0
30	n	1	2	1	2	3	6		1
	$\bar{x}$	2.106	1.938	4.809	4.713	2.381	1.779		2.736
	SD		0		0.592	0.653	0.250		
20	n					2	4		
	$\bar{x}$					1.675	1.936		
	SD					0.004	0.624		

TABLE 8.13

Male - Female Differences in PTT and CTT in 16 Female and 10 Male Subjects - Mean Values and Standard Deviations.

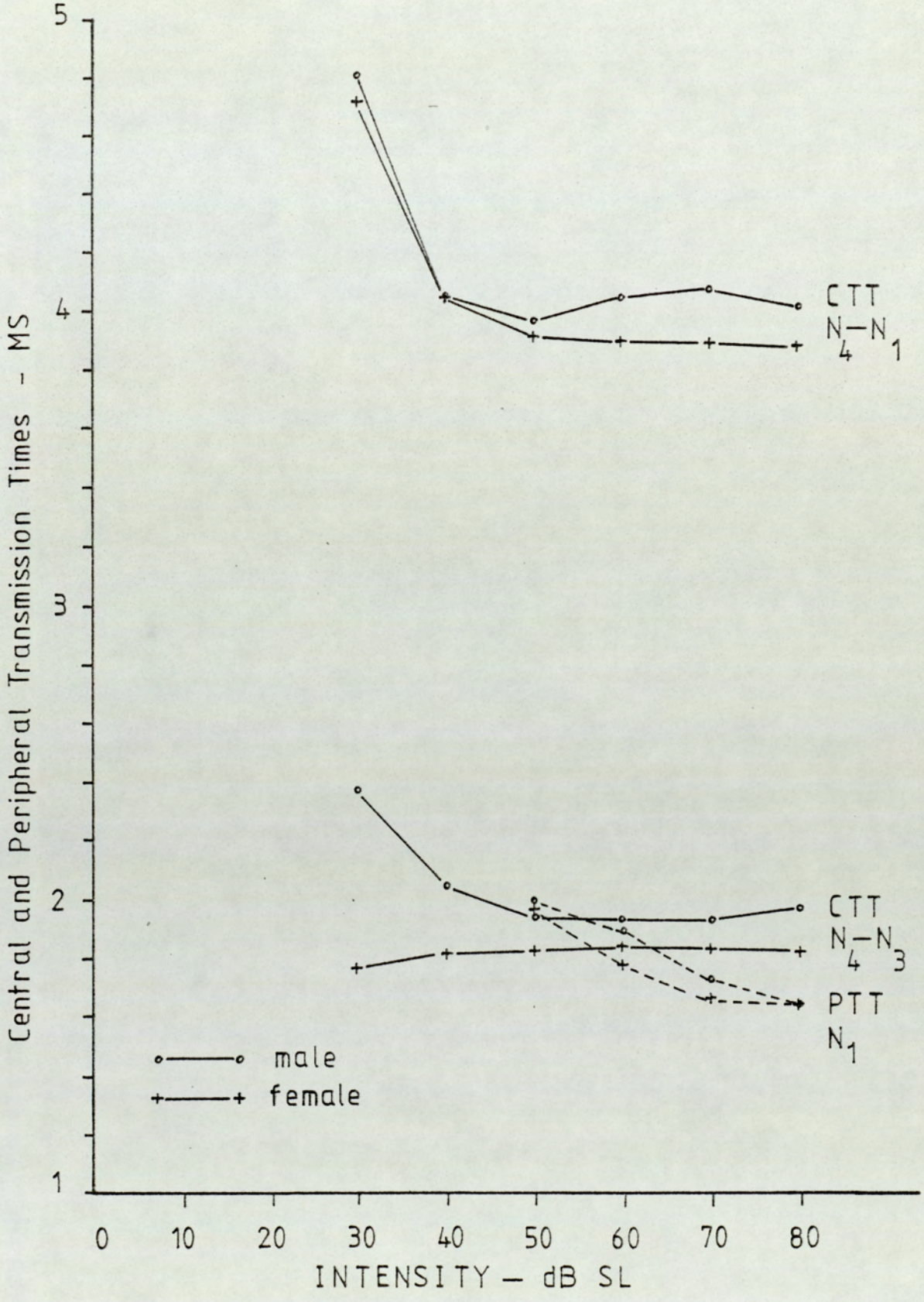


FIG. 8.21 Male-female differences in peripheral and central transmission times (n=16 females, 10 males).

iv) The Effects of Stimulus Intensity on a) the Amplitude of the Brainstem Evoked Potentials and b) the Relationship Between the Amplitudes of Components N_4 and N_1 (n=23)

The amplitude of each brainstem component was measured and converted to microvolts by calculation of peak-to-peak values of each mastoid negative component and the following positive component using the cursor and the facility of the microprocessor. Comparison of these values with those of a 5uV. calibration pulse produced an amplitude measure in microvolts. The mean value and standard deviation of the amplitudes of each component at sensation levels of 0 to 90dBSL are shown in Table 8.15. and the mean values only in Figure 8.22. The variation in amplitude across individuals was large at all intensities and although there was a tendancy for response amplitude to increase with stimulus intensity the individual changes in amplitude with intensity showed no clear relationship. By examination of the distribution of amplitude data for each brainstem component at 70dBSL (Figure 8.23.) and also for the N_4 component at intensities of 80 to 30dBSL (Figure 8.24.) it is evident that, for the majority of subjects, the amplitude measurements for each component fall into a fairly narrow range and that the large variance measures result from a few subjects with unusually large amplitude responses of the order of 2-3uV. Considering the amplitude distributions of each brainstem component at 70dBSL, for the N_1 component 81% of amplitude

TABLE 8.15

The Effects of Intensity on the Amplitudes of the Brain Stem Evoked Potentials in 23 Subjects - Mean Values and Standard Deviations.

INTENSITY dBSL		AMPLITUDE - uV				
		N1	N2	N3	N4	N5
90	n	3	3	3	3	3
	x̄	0.484	0.174	0.499	0.719	0.548
	SD	0.228	0.057	0.370	0.134	0.402
80	n	13	12	12	13	6
	x̄	0.815	0.258	0.594	1.072	0.367
	SD	0.865	0.295	0.464	0.599	0.152
70	n	21	18	21	21	15
	x̄	0.620	0.342	0.526	0.772	0.491
	SD	0.439	0.352	0.630	0.510	0.298
60	n	20	19	22	23	16
	x̄	0.499	0.309	0.287	0.753	0.584
	SD	0.484	0.579	0.151	0.843	0.411
50	n	17	13	18	22	9
	x̄	0.332	0.315	0.212	0.823	0.314
	SD	0.293	0.312	0.124	0.470	0.206
40	n	8	8	14	23	6
	x̄	0.320	0.117	0.210	0.823	0.614
	SD	0.154	0.106	0.114	0.665	0.216
30	n	3	2	10	21	5
	x̄	0.350	0.247	0.230	0.849	0.549
	SD	0.126	0.120	0.244	0.648	0.327
20	n	3		8	22	
	x̄	0.648		0.238	0.802	
	SD	0.895		0.288	0.983	
10	n				17	
	x̄				0.531	
	SD				0.397	
0	n				4	
	x̄				0.360	
	SD				0.253	

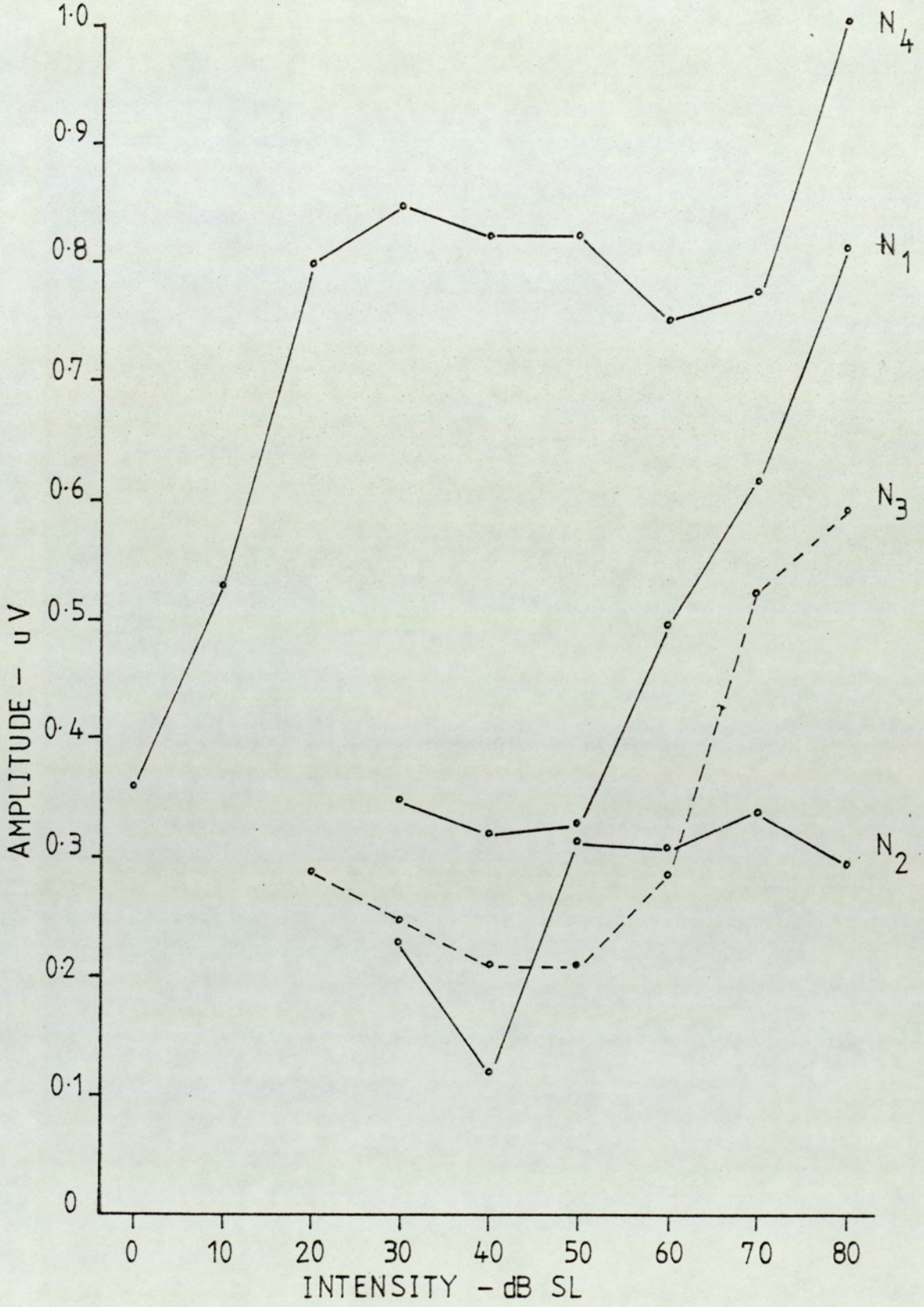


FIG. 8.22 The affects of stimulus intensity on the amplitude of the brainstem evoked potentials (n=23).

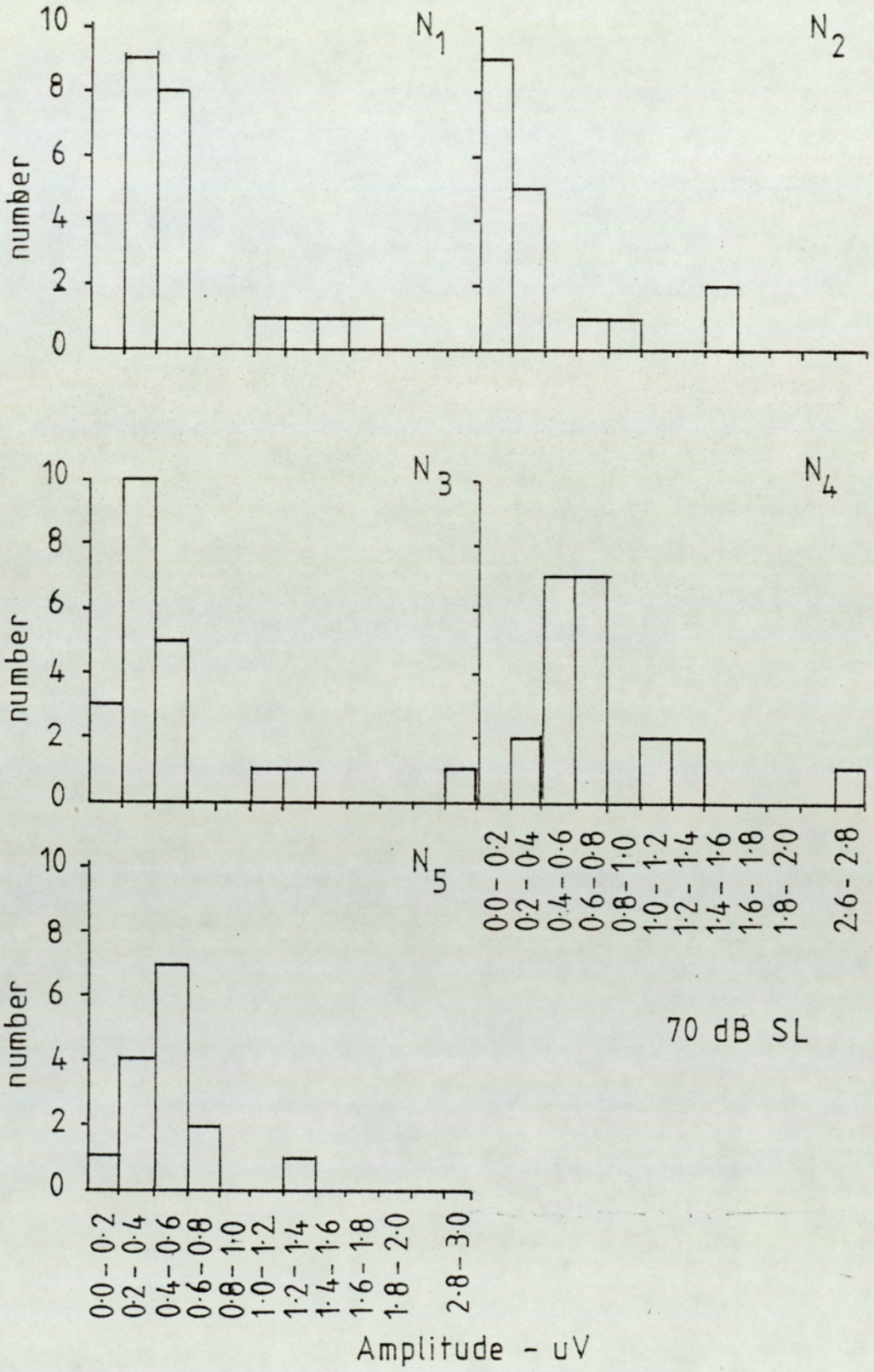


FIG. 8.23 Distributions of the amplitude of the brainstem evoked potentials (n=23).

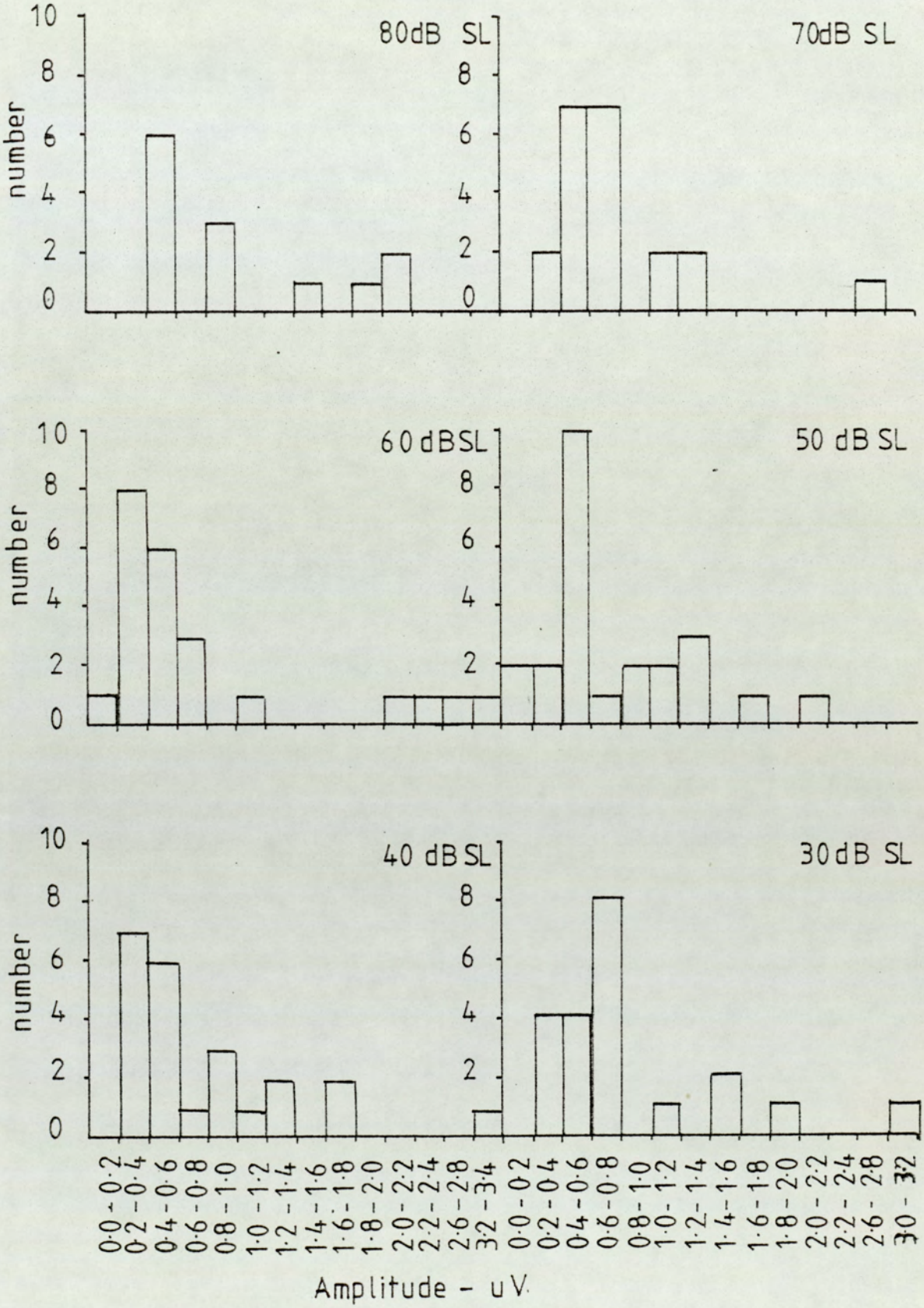


FIG. 8.24 Distributions of the amplitude of the N_4 component at stimulus intensities of 80-30dBSL in 23 subjects.

measures are between 0.2-0.6uV; for N_2, 78% are between 0.0-0.4uV; for N_3, 86% are between 0.2-0.6uV; for N_4. 67% are between 0.4-0.8uV. and for N_5, 73% are between 0.2-8uV. The reasons for the failure to obtain a clear relationship between response amplitude and stimulus intensity will be discussed in Section 8.8.3.

To illustrate the dependancy of both the absolute value of amplitude and its variance on the particular measure of amplitude used, the differences in N_4 amplitude for peak-to-peak measures are illustrated in Table 8.16 where amplitude is calculated-

a) from N_4 to the following positive component and

b) from N_4 to the preceding positive component

Amplitude uV.dB SL		80	70	60	50	40	30	20
N_4-P	n	13	21	23	22	23	21	22
	$\bar{x}$	1.072	0.772	0.753	0.823	0.823	0.849	0.802
	S.D	0.599	0.510	0.842	0.470	0.665	0.648	0.983
P-N_4	n	12	18	20	15	14	8	8
	$\bar{x}$	1.216	1.079	0.871	0.757	0.644	0.586	0.762
	S.D	1.092	0.662	0.683	0.458	0.520	0.297	0.946

Table 8.16. Comparison of N_4 Amplitude using two Different peak-to-peak Amplitude Measures.

The ratios of the amplitudes of components N_4:N_1 were calculated in the 23 subjects over intensities from 80-20dBSL. These ratios are shown in Table 8.17.

A value of greater than 1 indicates that the amplitude of N_4 is greater than N_1, and a value of less than one that N_4 is less than N_1.

Only at an intensity level of 60dBSL is the N_4:N_1 amplitude ratio consistently greater than 1. Again the effects of the choice of amplitude measure can be seen by comparison of the N_4:N_1 amplitude ratio using N_4-P and P-N_4 amplitudes. The values of N_4-N_1 amplitude show considerable variation at all intensities.

v) The Comparison of the Individual Brainstem Components in the Measurement of Objective Hearing Thresholds and their Relationship to Subjective Hearing Threshold.

The percentage occurence of each brainstem component is plotted as a function of intensity in Figure 8.25. The N_1 and N_2 components show a rapid decrease in occurence over intensities from 60 to 40dBSL with N_1 detected in less than 20% at 40dB and N_2 in less than 20% at 30dB. The N_3 and N_5 components show a gradual decrease in percentage occurence as the sensation level is decreased. N_4, however, remains reasonably stable in occurence and is present in 71% of subjects at 10dBSL and in 93% at 20dBSL.

INTENSITY dB SL						
80	70	60	50	40	30	20
1.969	2.399	6.815	3.184	1.324	4.417	6.733
1.302	2.366	2.366	3.625	1.751	2.922	4.722
0.677	1.546	0.629	4.057	0.566	3.093	2.885
0.862*	1.779	1.995	2.454	2.817		
2.009	0.493	0.932	3.506	2.432		
1.766	1.055	0.793	5.992	0.819*		
0.703	1.082	5.331	1.320	3.572		
3.752	2.202	0.748*	7.109	2.439		
0.937*	0.869*	1.631	1.210			
1.275	0.640*	2.389	1.639			
5.962	0.979*	1.478	1.764			
4.241	1.874	0.756*	3.506			
1.525	1.971	1.647	4.885			
	0.752*	2.527	2.376			
	0.698*	0.728	2.145			
	1.224	3.560	1.433			
	1.258	2.828	3.504			
	1.278	0.657*				
	1.078	8.800				
	3.112	1.577				
	1.369					
n	13	21	20	17	8	3	3
$\bar{x}$	2.075	2.092	2.409	3.159	1.963	3.387	4.780
SD	1.603	3.138	2.207	1.668	1.035	0.663	1.924
Range	0.697-4.241	0.493-3.112	0.629-8.800	1.210-7.109	0.566-3.572	2.922-4.147	2.885-6.733
N4 - P% >1	69	71	65	100	75	100	100
P - N4% >1	84	95	80	100	87	100	100

* The ratios marked with * would become 1 when the amplitude is measured to the preceeding positive peak.

A value of greater than 1 indicates that the amplitude of N4 is greater than N1, and a value of less than 1 that the N4 amplitude is less than N1.

TABLE 8.17 The Ratio of Amplitudes of Components N4 and N1 of the Brain Stem Evoked Potentials.

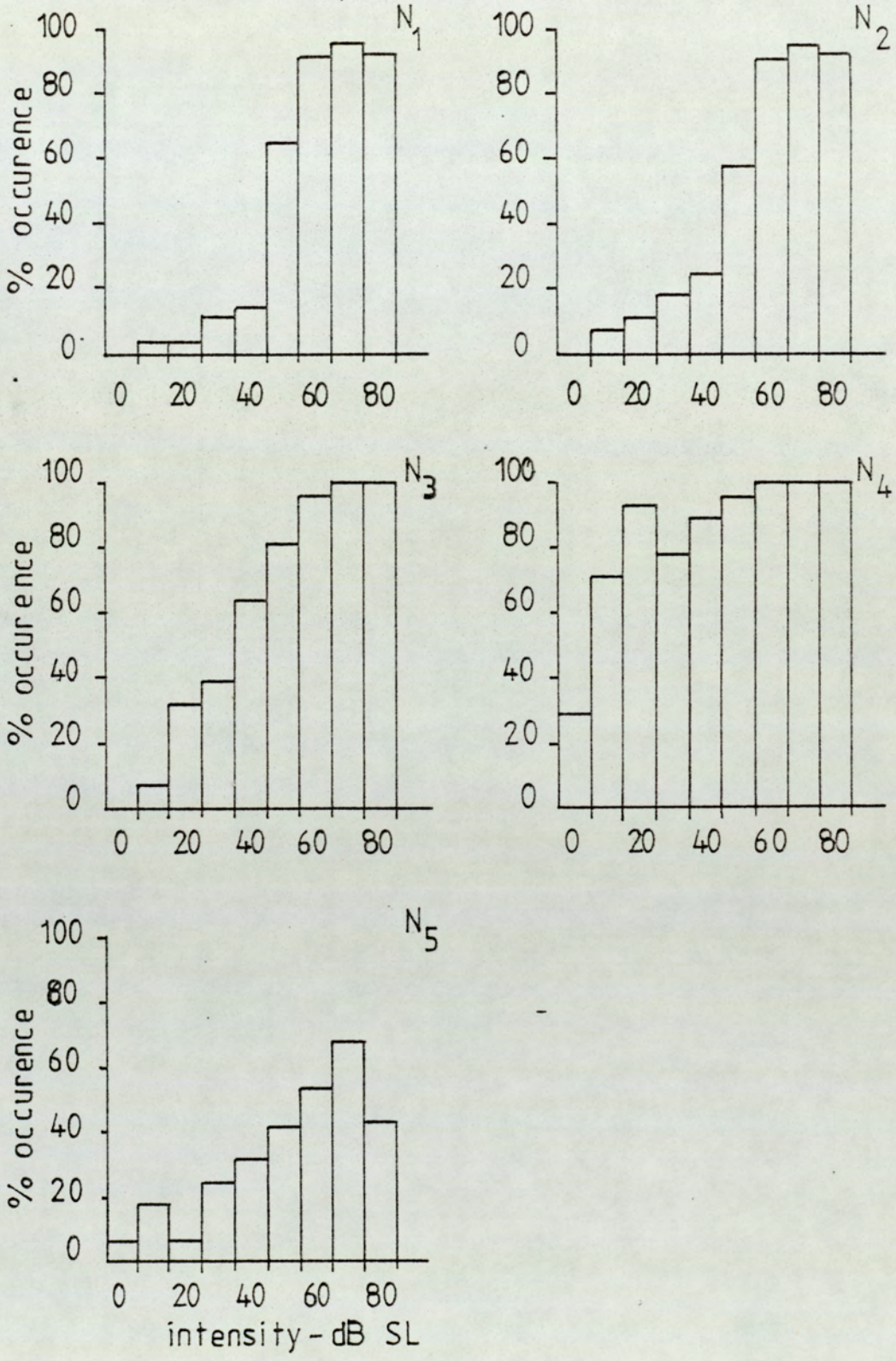


FIG. 8.25 The frequency of occurence of the brainstem evoked potentials as a function of intensity (n=28).

Using the N_4 component, the differences between subjective and objective hearing thresholds were calculated. Objective threshold was defined as the lowest intensity level (to within 10dB) at which N_4 was detectable from either ipsilateral or contralateral recording derivations. Subjective thresholds were measured to within 5dB. The distribution of subjective and objective threshold differences is shown in Figure 8.26. This data is derived from all 50 subjects used in the investigation. The same subjective and objective thresholds were obtained in 12% with 84% within 10dB. The range of differences was narrow, extending from -10dB to +20dB. The mean subjective and objective threshold difference was +7.80dB and the standard deviation 6.93dB.

iv) The Comparison of Ipsilateral and Contralateral Brainstem Evoked Potentials (Ipsilateral n=26 Contralateral n=23).

a) Latency

Comparison of the latency-intensity functions for ipsilateral and contralateral brainstem recordings (Figure 8.27. Table 8.18) show very little difference in either absolute latency measurements or slope of function for any component. The greatest latency differences appear to occur in the N_2 and N_4 components where the contralateral recordings are of slightly longer latencies than ipsilateral recordings over sensation levels of 80-50dB. Using the students' t test

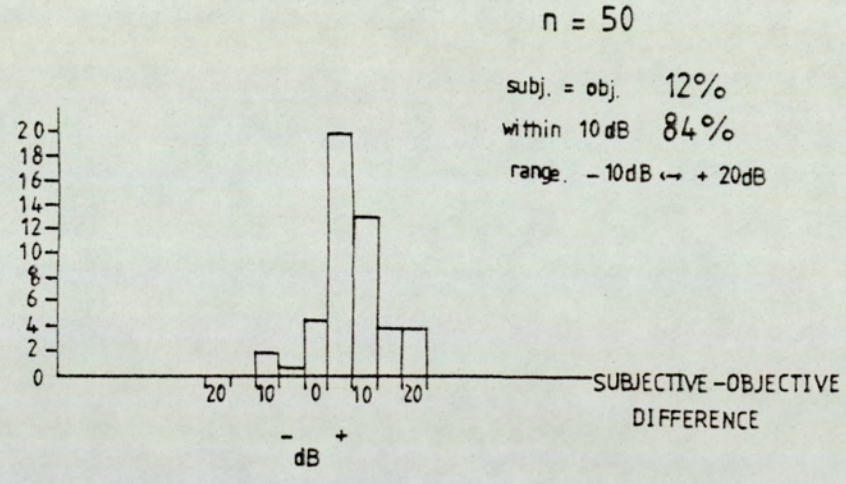


FIG. 8.26 The distribution of subjective and objective threshold differences using the N_4 component of the brainstem evoked potentials. n=50; Mean difference +7.8dB; Standard deviation = 6.93dB.

Intensity dBSL		LATENCY-M.S.				
		N_1	N_2	N_3	N_4	N_5
90	n		3	3	3	3
	$\bar{x}$		2.774	3.521	5.716	7.346
	S.D		0.130	0.058	0.153	0.095
80	n	4	10	9	13	6
	$\bar{x}$	1.605	2.903	3.690	5.743	7.306
	S.D	0.019	0.121	0.128	0.172	0.299
70	n	4	18	18	21	15
	$\bar{x}$	1.662	2.932	3.704	5.746	7.329
	S.D	0.142	0.141	0.154	0.222	0.361
60	n	6	17	15	23	16
	$\bar{x}$	1.773	3.075	3.928	5.965	7.342
	S.D	0.103	0.276	0.285	0.303	0.359
50	n	2	9	9	20	13
	$\bar{x}$	1.733	3.230	4.118	6.104	7.672
	S.D	0.074	0.439	0.405	0.269	0.415
40	n	1	4	7	22	8
	$\bar{x}$	1.976	3.019	4.249	6.388	7.861
	S.D		0.504	0.433	0.325	0.756
30	n	1	2	4	18	5
	$\bar{x}$	1.748	3.591	5.139	6.834	8.436
	S.D		0.832	0.657	0.454	0.837
20	n		1	3	18	
	$\bar{x}$		2.812	4.598	7.196	
	S.D			0.301	0.520	
10	n			1	14	1
	$\bar{x}$			4.940	7.723	8.284
	S.D				0.522	
0	n			1	5	
	$\bar{x}$			6.042	7.515	
	S.D				0.311	

Table 8.18. Mean Values and Standard Deviations of Brainstem Evoked Potentials Recorded from Contralateral Mastoid to Vertex Derivations (n=23)

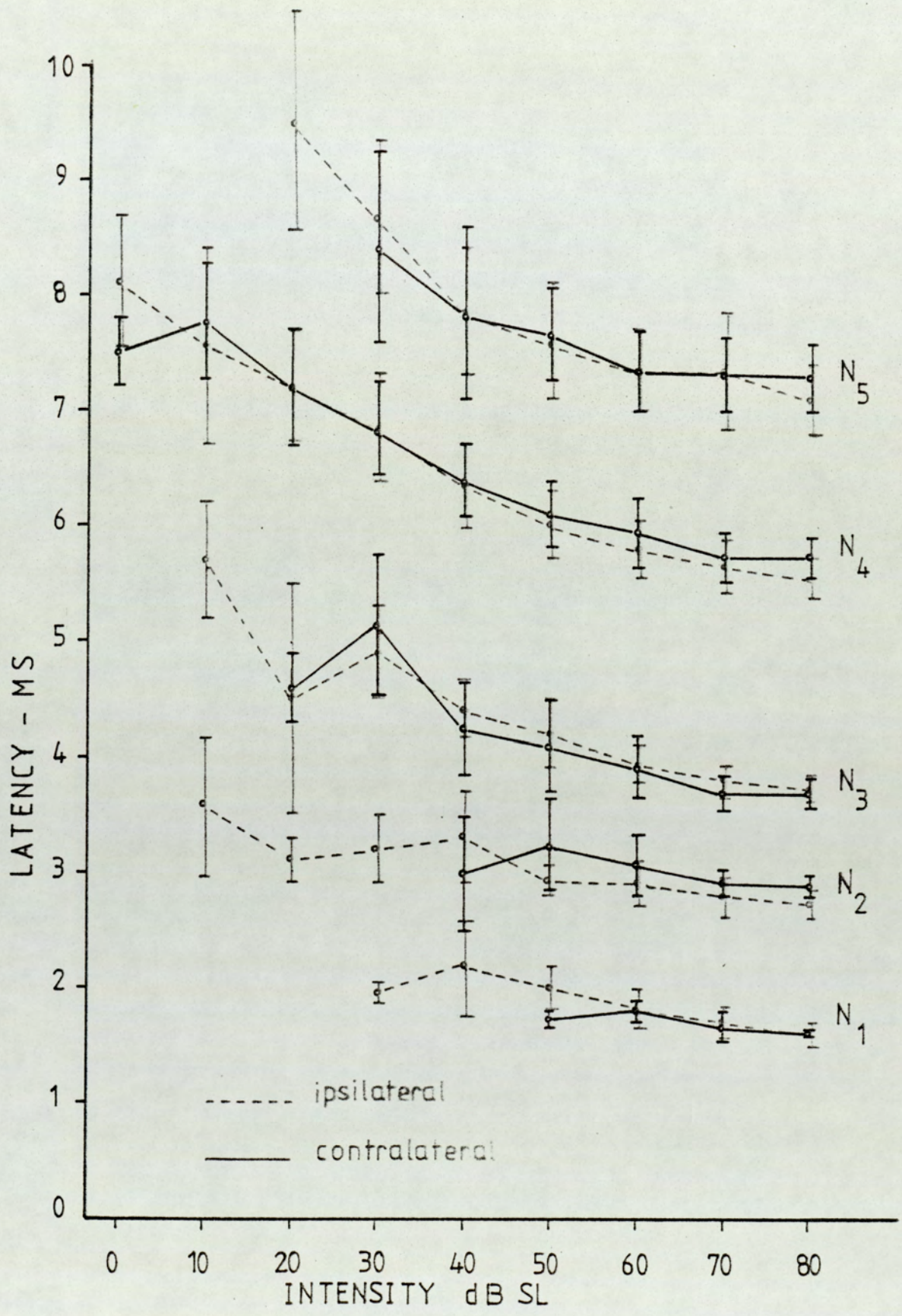


FIG. 8.27 Comparison of latency intensity functions of ipsilateral and contralateral brainstem evoked potentials.

these differences between ipsilateral and contralateral recordings are statistically significant at the 1% level for the N_2 component at 80 and 70dBSL, at the 5% level at 60dBSL and at the 2% level at 50dBSL. The differences between ipsilateral and contralateral N_4 components is statistically significant at the 1% level at 80dBSL and at the 5% level at 60dBSL. (See Table 8.19.).

Intensity dBSL	N_2	N_3	N_4	N_5
80	3.401 ***	0.684	2.805 ***	1.094
70	2.980 ***	1.770	1.378	0.158
60	2.184 *	0.028	2.162 *	0.053
50	2.537 **	0.485	1.070	0.425
40	0.952	0.849	0.341	0.009

* Significant at the 5% level

** Significant at the 2% level

*** Significant at the 1% level

Table 8.19. t Values for Mean Differences in Ipsilateral and Contralateral Brainstem Evoked Potential Recordings.

Comparison of the percentage occurence of the brainstem components in ipsilateral and contralateral recording

derivations shows a marked reduction in the presence of the earlier components in contralateral recordings (Figure 8.28). The N_1 component is only detectable in 17-29% of subjects over intensities of 60-80dBSL. N_2 and N_3 also show reductions in their frequency of occurence in contralateral recordings. Ipsilateral and contralateral differences were least marked in the N_4 and N_5 components.

8.9.3. Discussion

Since this thesis is mainly concerned with the assessment of evoked response audiometry and electrodiagnosis technique, the results will be discussed in terms of the application of brainstem evoked potentials in audiological and neurological assessment. Both areas make quite different demands on the properties and characteristics of the brainstem potentials.

The audiologist requires a close and consistent relationship between the objective hearing assessment of the brainstem potentials and subjective hearing levels, so that accurate assessments of hearing level may be made in clinical populations. The neurologist, however, requires a high degree of stability and reproducibility of the brainstem potentials in terms of amplitude, latency and presence of components, both within and across normal individuals .

Without this reproducibility and stability any abnormalities in response characteristics detected in the presence of brainstem lesions can have little significance.

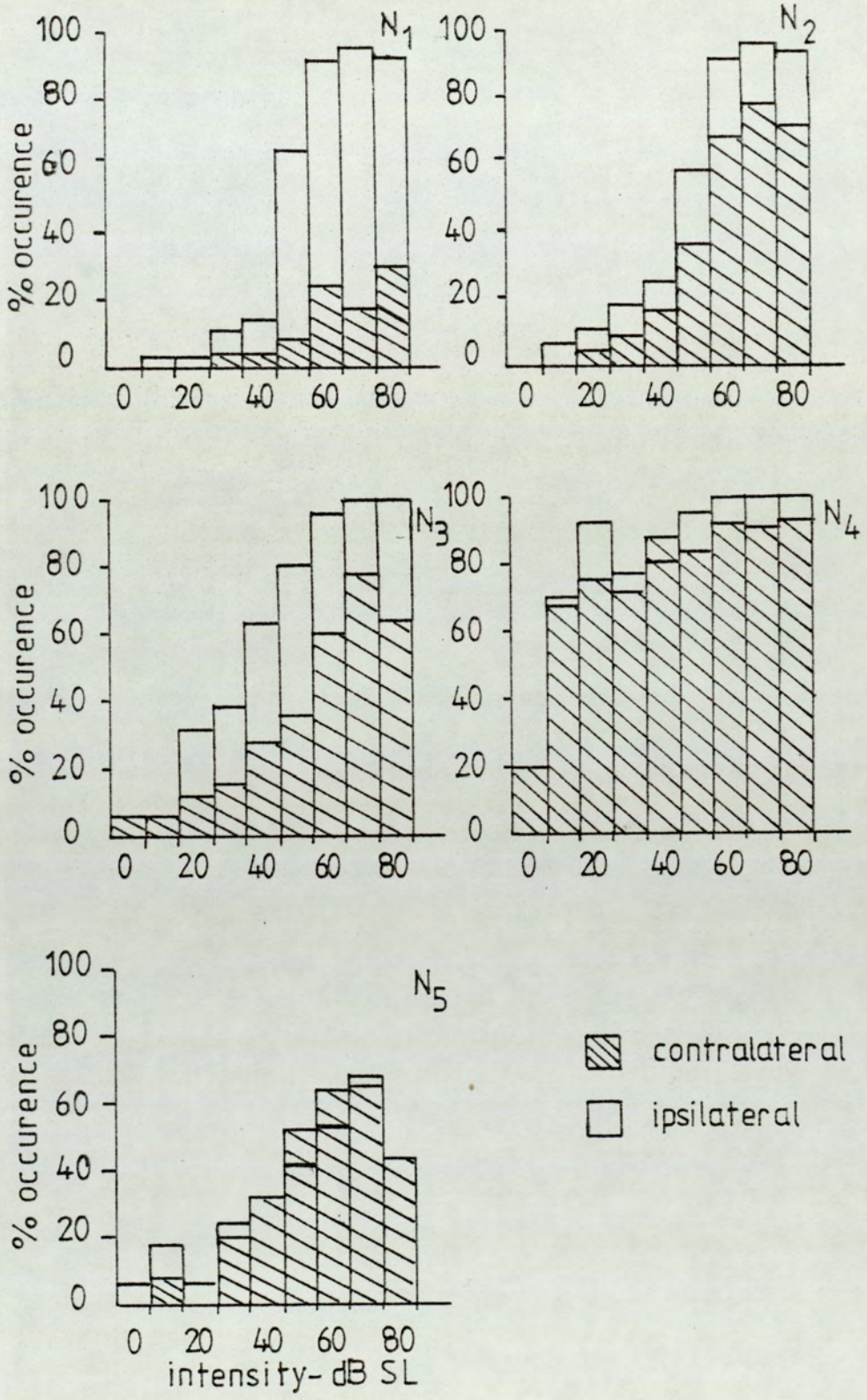


FIG. 8.28 Comparison of the frequency of occurence in brainstem evoked potentials from ipsilateral and contralateral recording derivations.

Audiological Assessment

a) Latencies of Brainstem Evoked Potentials

The absolute latency measurements of the brainstem evoked responses are of the same order as those previously reported (Table 8.1.) and confirm the parallel latency-intensity functions of components N_1 to N_5 reported by Starr and Achor (1975) and by Terkildsen et al. (1973) (Figure 8.8.). The parallel nature of these latency-intensity functions holds only over sensation levels of 40-80dB. Below 40dBSL, although there is an increase in the variability of response latency across subjects, the later components N_3, N_4 and N_5 appear to increase more rapidly in latency with decreasing intensity than the earlier peaks. This latter observation would confirm Picton's findings (1974) of steeper latency-intensity functions for the middle and late brainstem components. The data of Terkildsen are limited to intensities of 40-80dBSL.

Galambos and Hecox (1977) proposed the use of latency-intensity functions of the N_4 component not only in the diagnosis of the nature of hearing disorders (i.e. conductive or sensori-neural, Figure 8.11), but also in the assessment of the degree of possible hearing loss. They cite the case of a conductive hearing loss (see Section 8.7.1.) where the latency of N_4 at an intensity of 65dBHL is 7.1 m.secs. This latency is comparable to the latency of a 30dBHL response in the normal control population and

thus indicates a hearing loss of 35dB. However, using this example with the latency-intensity function for N_4 obtained in this study (Figure 8.17) even when taking into account 2 standard deviations, a latency of 7.1 m.secs. could be recorded from responses at 0 to 40dBSL. The combination of two factors appear to prevent an accurate assessment of subjective hearing level directly from the latency-intensity response curve. Firstly, the variability in latency, although relatively small, is too great to give an accurate assessment of hearing loss and secondly, the relative flatness of the latency-intensity function produces a considerable overlap of latency values over a number of sensation levels. The variability in response latency is more marked at low sensation levels and the flatness of the latency-intensity at higher sensation levels.

This would suggest that the assessment of hearing loss by the use of latency-intensity functions provides a measure of loss in broad-terms of mild, moderate or severe hearing losses, but is not sufficiently accurate enough to reflect the degree of loss in terms of dB.

This may be partially accounted for by the increase in variability of the latencies of the brainstem components across subjects at lower intensity levels. If responses can be recorded at higher sensation levels, and if the hearing loss is not too great, then a more accurate assessment of hearing may be obtained. However, even at

higher sensation levels, although inter-subject latency variability is small, the fairly flat nature of the latency intensity functions still prevents a more accurate assessment of hearing.

b) Amplitudes of the Brainstem Evoked Potentials

The peak-to-peak amplitude measures used in this study were those proposed by Thornton (1975) and adopted by most investigators. The findings in general confirm previous reports of increase in amplitude of all brainstem components with increases in stimulus intensity and also the considerable inter-subject variability in response amplitude (Jewett and Williston, 1971). However, examination of changes in response amplitude with intensity in individual subjects fails to reveal any clear relationship between these two parameters other than a tendancy for higher intensities to produce larger amplitude responses. In a relatively small number of individuals, unusually but consistently large response amplitude were detected of the order of 2-3uV. for N_1 and N_4 components (Figures 8.23 and 8.24). Because of this considerable variability in response amplitude, both within and across subjects, the results do not produce evidence of L and H components in the amplitude-intensity functions of any components. These were observed by Terkildsen et al. (1973) for all brainstem components and for N_1 only by Starr and Achor (1975). Examination of Figure 8.22 indicates that all brainstem components show an increase in amplitude with increasing

intensity which is most regular for components N_1 and N_3, while N_2, as was found by Thornton (1975), varies least with intensity.

Although the visual analysis of brainstem potentials recorded in this study indicate a fairly regular decrease in response amplitude with decreasing stimulus intensity (Figure 8.16), this relationship is not readily reflected in the measure of response amplitude used. As already indicated in Section 8.8.2. the absolute amplitude of the N_4 component can vary considerably depending on the peak-peak amplitude measure used (Table 8.16). Examination of the individual response data provides a possible explanation for the failure to detect a consistent relationship between response amplitude and stimulus intensity.

Comparison of responses shows that at high stimulus intensities all response components are readily detectable, while at lower intensities a number of response components, usually the earlier components and N_5, are not so readily detectable. However, in both cases the later response components are superimposed on a negative shift in the baseline of the response. This phenomena was observed in a fairly large number of subjects. This negative shift, together with a change in the relative occurence of the brainstem potentials with decreasing stimulus intensity produces considerable problems in peak-to-peak amplitude measures. This results in the apparent increase in amplitude of some components - especially N_4 at lower intensity

levels which actually arises from the disappearance of the earlier components. Ideally, peak-baseline measures should provide a more accurate assessment of amplitude, but in the presence of this negative d.c. shift in the baseline it is practically impossible to establish such a baseline.

The effects of this d.c. shift may have possibly been reduced by an increase in the low frequency cut-off point of the band-pass filters used, but with the present equipment this was limited to a maximum of 5Hz. However, this negative shift has also been observed by Thornton who uses band-pass filters of 100Hz.

c) The Relationship of Brainstem Evoked Potentials to Subjective Hearing Level

The data obtained regarding the relationship of brainstem components to subjective hearing threshold confirms that of previous investigations (Starr and Achor 1975 and Davis 1976).

The relationship of the occurence of each brainstem component with intensity is shown in Figure 8.25. The N_1 and N_2 components show a rapid decrease in % occurence from around 60% at 50dBSL to around 20% at 40dBSL, while the later peaks N_3 and N_5 show no definate relationship to subjective hearing thresholds, but just a gradual decrease in % occurence with decreasing stimulus intensity over the whole intensity range.

The N_4 component is consistently recorded in the majority of subjects down to 10dBSL (70%) and shows a clear and reasonably consistent relationship with subjective hearing levels (Figure 8.26.). The distribution of subjective and objective threshold differences is narrow with 84% being within 10dB, with a range of -10dB to +20dB. The mean differences in subjective and objective thresholds recorded in 50 subjects was +7.8dB with a standard deviation of +6.93dB.

These data would indicate that in the group of normal co-operative subjects tested that the N_4 component of the brainstem potentials provides a reliable and accurate assessment of subjective hearing levels. The advantages and disadvantages of the use of this technique will be discussed further in relation to myogenic and cortical recording techniques in Chapter 9.

Neurological Assessment

A number of characteristics of the brainstem potentials are currently used in the detection and confirmation of possible neurological lesions involving either directly or indirectly the function of the brainstem auditory system.

Since the latencies of the brainstem potentials are stable and reproducible not only within subjects, but also across subjects, they have become an obvious choice for the detection of possible neurological abnormalities such as

localised brainstem lesions (Starr, 1977 and Stockard, and Rossiter, 1977), and also of more generalised lesions such as multiple sclerosis (Robinson and Rudge, 1977).

The findings of this study would support the stability of the latencies of the brainstem potentials where variability between the responses of individual subjects is small, especially at higher sensation levels (Figure 8.17.). The latencies of the individual responses are also reasonably stable at intensities of 70dBSL and above, but below this level become dependant on stimulus intensity showing not only an increase in latency, but also an increase in variability with decreasing stimulus intensity. Thus, if absolute response latencies are to be taken as an indication of abnormality, then the stimulus intensity should always be specified in terms of sensation level. Also, the examination of inter-laboratory differences in latencies recorded for the brainstem potentials (Table 8.11) indicates the need for the establishment of adequate control data for each experimental laboratory.

In order to avoid variation in absolute latency measurements arising from different experimental procedures and also to counteract the effects of possible peripheral hearing loss, Starr (1977) introduced the measure of CTT. The values of CTT obtained by Starr for N_4-N_1 are shown in Table 8.8. and he found these to be independant of stimulus intensity over intensities of 75-15dBSL. The values of CTT obtained in this study are shown in Table 8.10 and Figures 8.18 and 8.19. The value obtained for N_4-N_1 latency difference

corresponds closely in both mean and standard deviation in both investigations. However, whereas both means and standard deviations of CTT obtained by Starr remain stable down to 15dBSL, those in this study do not appear entirely independant of intensity. At sensation levels of 80-50dBSL, CTTs are stable showing small and comparable standard deviations, whereas at 40dBSL the N_4-N_1 latency measure begins not only to increase in latency, but also shows a much greater variability across subjects.

Similarly, N_4-N_3 latency, although remaining stable in mean value of CTT, shows a considerable increase in across subject variability at sensation levels of 40dB and below.

Thus, these findings for CTT corroborate those obtained by Starr within the intensity range of 50dBSL and above, below this level they are less stable and thus less reliable.

In addition, in a small number of subjects it was not possible to measure CTT as the earlier peaks N_1 and N_3 could not always be recorded with sufficient clarity to provide a reliable latency measurement. These results, however, do not necessarily imply that inter-peak conduction times do actually increase at intensity levels below 50dBSL, but may merely reflect the inability to measure the less distinct components at lower sensation levels with the same degree of accuracy as at higher sensation levels.

Another criteria for response abnormality commonly used

was the absence of specific brainstem components. Although this appears to be a fairly reliable measure, referral to Figure 8.25., which shows the % occurence of the individual brainstem components at different intensity levels, indicates that even in normal individuals that components N_1, N_2, N_3 and N_5 are not consistently recorded even at high intensity levels. This observation applies even more to the later peaks N_6 and N_7 which were not included in this data anlaysis on account of their variability both in presence and in latency.

An interesting observation within the results was the consistent difference observed in both absolute response latencies and in CTT between male and female subjects, with the females producing slightly shorter response latencies and CTTs. This latency difference appeared to be additive, being most marked in the later brainstem components. Statistically significant differences between males and females were found for N_2 and N_3 at the 5% level and for N_4 and N_5 at the 2% level at 70dBSL and at the 1% level for N_4 at 60dBSL. At lower sensation levels the male-female differences failed to reach statistical significance chiefly on account of the increased variability in latency measurements across subjects (Figure 8.20). The male-female differences in CTT reached statistical significance at the 5% level only for N_4-N_1 at 60dBSL.

Although the source of this difference remains obscure, it may conceivably result from anatomical differences in

head size, or in some metabolic difference which may result in slightly increased rates of nerve conduction in females (ie temperature). However, whatever the cause of these differences they do introduce the possible need for the use of independant normal control data for male and female subjects in cases of neurological assessment.

It may also be of interest in the future to investigate the possibility of circadian variations in the latencies and amplitudes of the brainstem evoked potentials in both males and females, and also for any possible menstrual cycle variations in the female.

Another question which has arisen from the study of brainstem potentials, although not directly related to this study, is the possible effect of ageing on these potentials in terms of both latency and detection of the individual components. Certainly, many patients who present with possible neurological abnormalities tend to fall into older age groups than those included in this and most other studies. Data presented by Rowe (1978) indicated that CTT was unaffected by ageing, although PTT was considerably increased. However, it is certainly possible that general ageing processes may influence the properties of the brainstem potentials either by a decrease in the rate of neural conduction which may be reflected in longer reaction times in older populations and also by poorer synchronisation in neural discharge. If such changes did

occur these would be reflected in increases in response latencies and in CTT, and also in a reduction in the detectability of the response itself and would indicate the need for age matched control data. Although at present brainstem potentials have been recorded in relatively few older or elderly subjects, the failure to consistently record all components of the brainstem response even at higher intensity levels indicates the need for further study.

Although considerable variability in the amplitude of the brainstem potentials across the population has been found, Starr (1977) reports a consistency in the ratio of the amplitudes of components N_4 to N_1 which for monaural stimulation is always greater than one over intensities from 5-55dBSL in normal control volunteers. A ratio of less than one, that is, N_1 amplitude is greater than N_4 is taken as evidence of a possible brainstem abnormality. With reference to Table 8.17, the data obtained in this study does not confirm this finding. The N_4:N_1 ratio of amplitudes shows considerable variation across subjects, and at all intensities, except 50dBSL, shows a small, but consistent number of subjects where N_1 amplitude is greater than N_4 amplitude. In addition, N_1 cannot be consistently recorded at intensities below 50dBSL and thus the number of subjects in which this N_4:N_1 ratio may be measured is considerably reduced below this sensation level.

However, the reliability of the present data is questionable

on account of the problem with choice of amplitude measure and as can be seen in Table 8.17., the change of specific peak-peak measure can also influence the N_4:N_1 amplitude ratio.

The question of whether brainstem potentials recorded from the mastoid ipsilateral to stimulus and the vertex reflect primarily activity in the ipsilateral brainstem has important consequences in neurological assessment. Preliminary evidence in favour of this was presented by Starr (1975); Stockard and Rossiter (1977) and Thornton (1975).

Comparison of data obtained from ipsilateral and contralateral brainstem recordings would also tentatively support those observations, at least for the earlier N_1 to N_3 response components. Comparison of the response latencies from ipsilateral and contralateral recordings reveals small differences which are most consistent for N_2 and N_4 components, both of which show shorter latencies in ipsilateral recordings. These differences reach statistical significance at the 1% level for N_2 at 80 and 70dBSL and also for N_4 at 80dBSL. Such differences in ipsilateral and contralateral latency recordings were also reported by Thornton (1975) in components N_2 and N_3. These data fail to show, however, the polarity inversion of all components reported by Terkildsen et al. 1973 or of the earlier components as reported by Picton et al.(1974). The N_1 component was not consistently recorded in

contralateral derivations. This observation would support its reflection of ipsilateral activity only.

Comparison of the % occurence of the individual components in ipsilateral and contralateral recordings (Figure 8.29.) show a marked difference in the earlier peaks N_1, N_2 and N_3 which are considerably reduced in occurence in contralateral recordings while N_4 and N_5 show little difference. This observation would again tentatively support the reflection of ipsilateral brainstem activity at least for the earlier brainstem components.

However, more definitive evidence awaits more extensive and thorough topographical studies and a greater knowledge of the exact location and orientation of the response generators.

Thus, to conclude, the data obtained in this study provide supportive evidence for the use of the N_4 component of the brainstem potentials for the accurate and reliable assessment of subjective hearing levels in normal co-operative young adults.

The application of brainstem potentials to neurological diagnosis offers great promise, but the results should be interpreted with care. From the data of this study, the brainstem potentials do not appear consistent or reliable enough to stand alone in neurological diagnosis, but may

be of great value in the production of corroborative or supportive evidence of suspected abnormalities using a non-invasive, non-traumatic technique.

CHAPTER 9

9 Summary

The vertex potential provides a reliable and reasonably accurate assessment of subjective hearing thresholds in normal co-operative adults. The reliability of this assessment technique is reduced in adults and more especially in children with hearing defects. The differences between normal and hearing loss groups may be exaggerated by the presence of experimenter bias in the normal hearing group.

The monitoring of both the behavioural state of the patient and the background EEG activity, especially in cases of mental and/or physical handicap is extremely important. This enables such factors as state of arousal; presence of movement or EMG artifact and EEG abnormality to be taken into account when assessing the reliability of the vertex potential in the measurement of subjective hearing levels.

The main area of clinical application of the vertex potential in the adult population is in the confirmation of a suspected non-organic hearing loss. Here it can provide an accurate assessment of subjective hearing levels at all audiometric frequencies in cases of both psychogenic deafness and in medico-legal cases with suspected noise induced deafness.

The vertex potential will also provide a reliable measure

of hearing thresholds in children who are reasonably co-operative. Lack of co-operation has been found to be the exception rather than the rule, provided enough time is spent with the child to put him at his ease and amuse him throughout the investigation. In cases where the reliability of objective assessment is reduced through lack of co-operation or EEG abnormality, the vertex potential may still provide some useful information. In such children, subjective assessment is usually unsuccessful so that a vertex response which can provide a rough estimate of hearing loss in terms of slight, moderate or severe, may still play an important part in the future management of the child. The measurement of the vertex potential is extremely valuable in handicapped children when it may exclude deafness as a possible cause of developmental retardation. The repetition of the auditory evoked response investigation on two separate occasions increases the reliability of its results in difficult to test children.

The differences in reliability of the vertex potential in the measurement of subjective hearing levels in the three subject groups investigated, clearly demonstrates the dangers of generalising from normal to clinical populations and underlines the importance of adequate control data for each group.

In relation to the vertex potential, the measurement of brainstem auditory evoked potentials is still in the early

stages of development.

However, the extreme stability of the components both within and across subjects and their resistance to changes in arousal and attention or with sedation make it a valuable assessment technique in both audiology and neurology. In the present study, the N_4 component of the brainstem evoked potentials provides an extremely accurate and reliable estimate of subjective hearing levels. Although the present literature provides evidence that this reliability is maintained in clinical population and in young children, the number of such investigations is relatively few and further validation studies are necessary.

The greater value of the brainstem evoked potentials may lie in the field of neurological assessment where they offer a practically unique method for the non-invasive assessment of the integrity of the brainstem structures. Evidence has been presented of their potential usefulness in the detection and localisation of space occupying lesions affecting either directly or indirectly the brainstem auditory nuclei and also in the detection of clinically silent areas of demyelination within the brainstem.

In the area of neurological assessment there is a greater need for the establishment of more comprehensive normative data on the brainstem evoked potentials. At present, most normative data are established in young adults, whereas many of the patients presenting with neurological problems

tend to fall into middle and older age groups. This indicates the need for the establishment of normative data at all age groups in order to assess the effects of normal aging processes and decreased efficiency of neural transmission on the amplitude, latencies and detectability of the brainstem potentials.

The post-auricular myogenic potential, on account of its variability, has largely been dismissed from consideration as a technique for auditory assessment. The results of this study indicate that it provides a less reliable and less accurate estimation of subjective hearing threshold. However, the observation that both reliability and accuracy are increased by the enhancement of resting muscle tone makes it of value in the assessment of hearing thresholds in difficult to test young children when, because of increased muscle and movement artifact, both vertex potential and brainstem evoked potential assessment become unreliable.

The vertex potential has the advantage of assessing the whole auditory system, whereas the brainstem potentials and post-auricular myogenic potential are confined to the level of the brainstem and thus are unable to exclude the possibility of more central lesions. Sohmer, Pratt and Feinmesser (1974), however, do not consider this to be a disadvantage as most cases of deafness are due to a peripheral rather than central hearing loss. This is certainly true in the patients who undergo subjective audiological assessment, but in the selected population of the children with varying

degrees of brain damage, the possibility of central deafness must be increased.

Another important advantage of the vertex potential investigation is the ability to reproduce an objective version of the subjective pure tone audiogram and thus provide evidence of frequency specific hearing disorders. Both the brainstem evoked potentials and the post-auricular myogenic potentials are not frequency specific and these responses are only reliably recorded in response to click or high frequency tone pip stimuli.

A major disadvantage of the vertex potential is its variability. This variability occurs not only across the population, but also within each individual with changes in arousal, when different response criteria are necessary to assess responses in sleep and wakefulness and also with sleep stage. The brainstem evoked potentials have the advantage that they are unaffected by the level of arousal and remain stable through wakefulness and sleep. Both the vertex potential and brainstem potentials may be obscured or distorted by increases in movement and muscle artifact within the background EEG and in such cases their reliability in subjective assessment is reduced. If sedation is required the brainstem potentials remain unaffected while the effects on the vertex potential remain controversial.

The post-auricular response tends to stand apart from the vertex potential and brainstem potentials in that it is more

likely to provide a more reliable assessment of subjective hearing levels in the presence of increased EMG activity. In comparison with the vertex potential and brainstem potentials the increase in not only the subjective and objective threshold difference, but also the variability of this difference, make it unsuitable for objective assessment in co-operative patients. However, because of the enhancement of this response by increased muscle tone and also because of its rapidity, it may be the test of choice in some difficult to test children.

Thus, the choice of objective test - if such a choice must be made - will depend on both the clinical details and the behavioural state of the patient. The use of all tests in conjunction would obviously provide a more reliable evaluation of hearing thresholds than any test used alone. In practice, however, it is rarely possible to complete the three investigations in the time a child is willing to remain fairly still and co-operative. Taking into account the relative advantages and disadvantages of each objective technique, the vertex potential appears to offer the most comprehensive audiological assessment, for not only does it reflect the integrity of the whole auditory system, but also provides frequency specific information in terms of an 'objective' audiogram analogous to the pure tone subjective audiogram.

If the results of cortical audiometry are unsuccessful, then brainstem evoked potentials or post-auricular myogenic

potentialsmay be attempted depending on the behavioural state of the patient. This preference for the use of the vertex potential in auditory assessment may result from a greater familiarity with this assessment technique. which has been in use for over 10 years within the Unit. A degree of caution in recommending the use of brainstem potentials in clinical audiological assessment stems from a need for further validation studies of this technique in both clinical populations and young children. Sohmer et al. (1974), however, as a result of several years experience in recording both the vertex potential and brainstem evoked potentials favour the latter on account of their stability and more accurate reflection of subjective hearing levels.

The use of the vertex potential in the assessment of hearing in terms of stimulus comprehension remains controversial. The present study has failed to find any clear correlates of stimulus meaning in the characteristics of the vertex potential, but instead supports its general acceptance as an on-response, whose latency and amplitude characteristics are primarily determined by the physical properties of the stimulus.

Finally, it should be mentioned that evoked response audiometry is not designed as a replacement or alternative technique to conventional subjective assessment which in the co-operative patient is not only more reliable, but considerably less expensive to carry out. Instead, evoked

response audiometry is available for the relatively small group of patients in which subjective assessment is inappropriate or impossible and in such cases it provides valuable information to both the audiologist and clinician to assist in the management and corrective treatment of the patient.

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