A developmental study of Auditory Perception with special reference to right hemisphere functioning.

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by

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Abstract.

The traditional view that the left and right hemisphere is responsible for attending to verbal and sensory material is explored in a developmental study which ranges in age from 4½ years to 18 years.

Experiments on boys and girls used verbal material of increasing difficulty ranging from a random collection, statistical approximations to English prose and normal selections of English prose. The sensory material was composed of edited versions of 4 Seashore tests of Musical appreciation. White noise was used as a competing signal.

Assessment shows that there is a significant advantage for the left ear to attend to pitch sounds. This advantage is maintained throughout all age groups, and both sexes, and is irrespective of ear order and dominance. In contrast the Loudness test, discriminating decibel levels, shows a right ear advantage, irrespective of the ear order. However left handers show a left ear advantage. The reasons for this sensory test (Loudness) to behave as a verbal test are discussed.

The significant factor determining the experimental results is found to be the "ear presented first". This means that when the tests are presented to the right ear first there is a right ear advantage; when the tests are presented to the left ear first there is a left ear advantage.

This ear order is interpreted at the physiological and psychological level. Extreme attention is required for auditory asymmetry to operate and the competing signal of white noise used in the experiments may not simulate a dichotic situation which would produce the difference between ears effects.

The hypothesis that there is increasing lateralisation of function with age is not supported.

The experiments reported here highlight the complexity of defining auditory stimuli as material specific. It seems important to break up sound into its essential elements, irrespective of whether it is cued by the human voice or an instrument, before discussion can be made with respect to the hemispheric level at which it is perceived.

Contents

A DEVELOPMENTAL STUDY IN AUDITORY PERCEPTION

PART I

CHAPTER I

EXTENT OF THE PRESENT STUDY

The present project attempts to clarify certain differences which have emerged from previous studies on auditory perception; by combining and extending Kimura's and Milner's early work and by using large sample groups spread over a greater age range. It is hoped to answer several questions which have emerged from the studies on auditory functioning.

1. Does lateralisation of certain non verbal functions show any progression with age?
2. Are there differences between the right and left ears in auditory perception tasks?

3a. Is performance related to the type of material, in particular to its verbal or non verbal character?

3b. Does the left ear process non verbal material and thus possibly the right ear show an advantage in verbal material?

Before the ways in which these problems have been studied are discussed it would seem appropriate to sketch in the background of work which has been undertaken on certain aspects of auditory functional asymmetries.

The first part of this chapter is therefore devoted to a brief summary of contemporary opinion concerning cerebral dominance and its relationship to possible auditory hemispheric differences.

Background

In 1951 Rosenzweig recorded the electro-physiological responses of the auditory cortices of both hemispheres in 5 anaesthetized cats. By applying electrodes to the cortices the size of the positive deflections was measured. He showed that the response of each ear tended to be larger at the contralateral hemisphere. At the left hemisphere the response of the right ear was the larger of each pair of measurements. At the right hemisphere the left ear response was the larger of each pair of measurements. This tendency held from location to location even though the size of the deflection varied. The contralaterality of cortical representation was the same for each and every animal.

Rosenzweig was also able to show that the ipsilateral representation tended to be about three-quarters of the contralateral representation. He investigated the functional relationship between the two cortical populations by studying the interaction of responses in 2 situations:-

1) simultaneous stimulation and 2) successive stimulation of the 2 ears.

1) In simultaneous stimulation this resulted in partial summation, i.e. the response was somewhat larger than the response of the contralateral ear but not so large as the sum of the contralateral and ipsilateral responses. This finding suggests that the two populations were not entirely independent.

2) When two stimuli were delivered in succession, interaction between the two responses again occurred. If the time interval was brief (under 50 m/sec.), the second response was reduced from its normal amplitude.

Rosenzweig interpreted these findings as showing that the population of cortical units representing the contralateral ear was larger than the population representing the ipsilateral ear and that these two populations overlapped considerably.

These experiments produced convincing physiological evidence that the contralateral auditory pathway appeared to be the stronger in terms of amplitude of the evolved cortical responses.

Behaviourial studies also supported the physiological evidence that the crossed connections to the auditory cortex have a greater cortical representation than the uncrossed connections. Penfield and Evans (1939) found impairment of sound localization for the left ear in a case of right temporal lobectomy. Sanchez-Longo, Forster and Auth (1957), Sanchez-Longo and Forster (1958) and Jerger (1960) have reported similar findings in temporal lobe tumour patients. However, Schankweiler's (1961) work in a similar group did not substantiate these results.

Bocca, Calearo, Cassinari and Migliavacca (1955) in Milan reported impairment in the recognition of words distorted by a low pass filter and imperception of accelerated speech on the side contralateral to a temporal lobe tumour. Sinha at McGill University showed similar defects in the recognition of speech arriving at the contralateral ear in a case of temporal lobectomy. However, this was only demonstrated when the words were presented in a dichotic situation, the other ear being washed with white noise.

Kimura's work (1961a, 1961b) provides additional evidence that the contralateral pathways are the more efficient in auditory perception tasks and that there is some asymmetry of function between both hemispheres. In her original study Kimura utilised Broadbent's technique of feeding different digits into each ear simultaneously, three digits to one ear, three to the other. The most discriminating condition, i.e. two digits at half second intervals, were fed three times into each ear. The subject merely reported all the digits to her in any order. The left temporal group of patients were inferior to the right temporal group beyond .01 level of confidence. The sixty-five patients were all epileptic with no brain tumours or reported diffuse cerebral disease. They were classified as left temporal, right temporal, frontal or subcortical according to E.E.G. recordings. The latter, however, is not a very good discriminatory test, and we have ample evidence from post mortem studies that the brains of epileptic patients frequently show scattered lesions which are not demonstrated by E.E.G. recordings.

However, Kimura found that in patients with epileptogenic lesions of left temporal lobe removal of focus enhances at least for a time the pre-existing contralateral defect.

For the left temporal group Kimura showed there is a small gain on the ipsilateral ear, and a small loss on the contralateral ear. For the right temporal group, if the focus is removed, the same is true. Results were significant beyond the .02 level. If Heschl's gyrus is included in the tissue removed, then the loss on the contralateral ear is greater. These results are in line with Bocca [illegible] 1958, Sinha 1959 and Jerger 1960. These authors all show that if test conditions are difficult enough, post temporal lobectomies produce selective impairment in the discrimination of stimuli to the contralateral ear. Frontal lobectomies show no such trend.

Part of Kimura's data (1961b) also revealed interesting ear score differences. Using digits, higher scores for the right ear were recorded irrespective of lesion focus. She confirmed these findings on a group of normal adults and children of ages five to seven years. It was suggested that if speech is in the left hemisphere the stimuli from the right ear would be perceived more accurately by this route than by the left ear. Kimura went on to demonstrate that the opposite was true for left handed persons who had speech represented in the right hemisphere. (Wada test.) Results again produced .02 level of significance for the left ear's superiority.

Relationship between handedness and the relative efficiency of the two ears was further demonstrated by dividing the patient group into right handers and left handers. The difference between the left handers with speech in the left hemisphere and left handers with speech in the right hemisphere is significant at the .001 level and there was no difference between the two groups with speech in the left hemisphere but differing in handedness. Thus laterality of speech and not handedness appears to be the main factor producing the results. Milner, whose work we shall discuss later, suggests that just as the right ear may be more efficient in recognising verbal material, the left ear (Seashore test) is superior in discriminating non-verbal sensory stimuli material. Darwin (1969) has dealt very authoritatively with the rather facile and specious division of stimuli into verbal versus non-verbal material. He has suggested that the salient feature of classification is whether the stimuli are carried on a variable pitch contour or not.

The problem to find non-verbal auditory stimuli has not been satisfactorily resolved. Some data has been gathered by using clicks delivered to both ears simultaneously. If different numbers of clicks arrive at both ears at the same time (three to the left, five to the right) and the subject is required to report the number of clicks, then individual scores can be assessed for both ears. Kimura (1967), using a group of fourteen student nurses found that there was a slight but not significant difference in favour of the left ear. Murphy (1969) also demonstrated significant ear differences using clicks delivered simultaneously and successively.

Clinical Symptomology in Right and Left Sided Lesions

The possibility that right-sided lesions may be responsible for sensory deficits was first described by Mann (1930) who insisted that an expressive form of amusia showed right sided lesion lateralisation. However, other workers have found temporal lesions to be sited in either hemisphere. Kleist (1962) maintains that hemispheric dominance varies from one subject to another and insists on the bilateral representation of sensory perception. Botez and Wertheim (1959) observed a patient operated on for an oligodendroglioma. He showed expressive vocal and instrumental amusia.

Kohl and Tsabitscher (1953) insist that patients with right hemisphere lesions are unable to recognise correctly musical sounds and PöLTZ (1927) suggests that they present with disorders of the sense of rhythm. With lesions of the left hemisphere there is a lesser disorganisation of musical understanding.

Milner (1961) has described performance differences between patients with right and left sided temporal lobe excisions. Patients with right sided temporal lobectomy did badly on non verbal tests of pitch, rhythm and tonal memory. She has also shown that when speech is represented in the left hemisphere lesions of the left temporal lobe produced disturbances in the recall of verbal material. Immediate recall may be normal but delayed recall after ninety minutes may be impaired. Associate memory learning was also affected after ninety minutes. She considered that the impairment was a verbal one and not a specific auditory deficit, since immediate recall was normal. There were no deficits after right temporal lobectomies. These studies do suggest that speech perception is vulnerable to left sided lesions, but perception of non verbal auditory patterns may be disturbed by lesions of the right hemisphere.

These brief introductory notes on work related to possible functional hemispheric differences in auditory perception highlight some basic assumptions and indicate a certain degree of confusion over the results.

Wolff (1969) supports Neff in uttering a word of warning not to over interpret the results of functional hemispheric differences. He believes that certain criteria must be met before any firm inferences can be drawn.

These are:

1) The accurate assessment of size and extent of anatomical defect. This is often impossible to do as estimates are made very quickly at the time of injury.

2) It is important to establish whether there are other lesions elsewhere in the brain. For example in Kimura's series many epileptic patients who on E.E.G. findings had right temporal lesions were found at post mortem to have lesions scattered throughout the cortex over both hemispheres.

3) The assessment of the state of the arterial supply and venous outflow must be considered and the damaging effects that this has on underlying structure, and also the oedema which an operation itself causes must not be forgotten.

4) It must also be remembered that people with left sided lesions receive medical attention more quickly (because of aphasia, etc.) than right sided patients, and the surgeon is liable to remove more tissue from the right side of the brain than from the left side.

5) It would be essential to have patients free of any destructive progressive lesion and in the war veterans studied by Teuber there are many who are still having seizures.

Hypotheses for the Present Study

However, despite the two major concerns over (a) the patient population examined in auditory perception studies and (b) the inherent problems related to whether the signals to be discriminated can be classified as sensory or verbal, it is reasonable to accept the following basic findings:

1) That the responses to auditory stimuli are larger in amplitude in the hemisphere contralateral to the ear stimulated.

That both ears are represented by independent populations of cortical units although these populations may overlap spatially and functionally to a considerable extent.

2) That there is possibly a relationship between cerebral dominance and hearing as there is between cerebral dominance and speech, and that there may be strong tendencies (environmental or hereditary) for man to develop a greater auditory organisation in the left hemisphere.

3) The third assumption is one to which this study attempted to make some contribution - namely that each hemisphere may be attending to different types of auditory stimuli.

CHAPTER II

DEVELOPMENTAL ASPECTS OF SPEECH AND HEARING

As this present study is specifically a developmental one, some discussion of contemporary opinion concerning early speech development would set in context the role of language in auditory perception.

How Language Arose.

A survey of ideas concerning the origin of speech will be found by reference to Wilson 1941, Critchley 1958 and Diamond 1959. However, a brief precis of relevant papers will be useful to set in context early work on the science of language. Herder (1744-1803) a pupil of Kant, wrote his essay on language, " Über Den Ursprung Der Sprache " in 1772 and here he refuted the thesis that the origin of language was divine and attempted to prove that man developed speech pari passu along with his development of rational processes. Eighteenth century comparative philologists such as Sir William Jones, Schlegel and Grimm made observations which implied that they considered there was a common source at the basis of all languages and used Sanskrit, Greek, Latin and German to further their examples. Muller and Whitney stressed in the nineteenth century the distinctly human character of language and Muller amusingly refers to his four different types of speech, the 'ding-dong', the 'bow-wow', the 'pooh-pooh' and the 'yo-heave-ho' theories. He suggests that the 'ding-dong' theory suggests some natural and inherent connection between words and things (a Plato concept). The 'bow-wow' theory refers to the onomatopoeic quality of speech, and the 'pooh-pooh' theory presupposes speech to originate in ejaculations and interjections which primitive man emitted at times of emotion. The 'yo-heave-ho' theory refers to the sounds associated with communal physical effort.

Wundtin 1928 and Bloomfield in 1940 add gesture as the source of speech and they consider that manual gestures became associated with oral gestures and that these produced sounds, which became linked with meanings of manual gestures. Later these manual gestures were shed and the sounds were left as the sole symbols. There is certainly evidence that the signal systems used by reptiles, amphibia, insects, birds and even fish are a type of communicating system, but whether the chimpanzee's capacity for symbolic thought and speech is language at anything more than a primitive animal level is very speculative. The latest theory concerning the origin of speech which seems to be most satisfying and takes account of not only comparative philology and the communication that is known to exist between animals is the one put forward by Diamond. He stresses three fundamental facts about complete communication and this is that the proportion of verbs to other parts of speech decreases as a particular language develops and that there is one use of language, one function form in which there is a common and universal absence of grammar. The second person singular of the imperative, namely the request for action, is the simple form of the verb without affix and without rules of syntax. He considers that "the first sounds were of the same phonetic type as the articulate utterances of human babes, gasps of the form da, ba, ma and the like and that these were uttered involuntarily in the course of strenuous effort of the arm."

Diamond's theory brings together the hypothesis that speech in its origin was interjectional and related to communal effort and that phonetic accompaniments of gesture became detached from them. And he adds that the intention of the speaker to communicate was necessary in order to obtain the co-operation of his fellows. His basic tenets stress that the detachment of the sound from its bodily accompaniments were as a result of a means of conveying a command or demand and that this would perhaps most naturally come about as a result of distance, the sound enabling one individual to call another to his help or to urge him to action in some emergency.

Linguists now believe that man has an innate biological capacity for language acquisition, a capacity which has been described as species specific and species uniform language acquisition device (McNeil 1966a) which functions uniquely in the language acquisition process and the operation of which is constant for all children. Various biological and neurophysiological correlates of the language learning process have been discovered.

(a) The Development of Speech in the Child.

There would appear to be general agreement concerning the stages of normal development of speech in infancy and these have been described by Jesperson 1922, Buhler 1930, Lewis 1936, Eisensen 1938 and Piaget 1959. All these writers are agreed that the first form of phonation is the undifferentiated cry and that this is a purely reflex response to some external or internal stimulus. One might exclude the colic cry. Eisensen has said that there is possibly no difference in the infant's crying in the relation to the stimulus which evokes it, and even the fondest mother is unable to decide by listening to a child's crying exactly what he needs or wants during the first months of life. After this come different cries which are evoked by different kinds of stimulus and at this stage the mother can frequently recognise the needs of the infant from its cries, so that a scream which may at first be reflex can become a mode of communication if it is used to obtain something from the parent. The third stage of vocalisation is babbling which usually occurs at the end of the second month and here the first sounds are vowels and later the first consonants are usually labials which are then followed by gutturals, dentals and finally nasals. This sequence of sounds has been related to the change from suckling to the eating of semi-solid food and the eruption of the teeth. Jesperson has pointed out with others that it is strange that among infant's sounds one can often detect k's, g's, h's and the uvular 'r' which the child will find difficulty in pronouncing afterwards when they occur in real words or which may be unknown to the language which he will some day speak. The fact that the normal child hears the sounds which it produces is of great importance for the further development of its speech and it has been said that children born deaf begin to babble but soon cease to do so. However, the writer is familiar with a number of children who, profoundly deaf, never demonstrated babbling at any stage of development. Buhler has commented that the psychologically important fact is the formation of strong associations between the auditory impression and the movements which produce it, for this is the essential basis of the later imitation of the sounds the child hears in which it has to translate what it has heard into vocal movements of its own. Some authors refer to a stage of lallation in which the child repeats heard sound complexes or syllables and that it gains some satisfaction from the imitation of the sound it has just produced. This stage occurs during the second six months of life and Eisensen points out that the child who has learned to imitate many sound combinations of his own accidental making has laid the foundations for his next development in speech which is echolalia. Echolalia might be seen to be the imitation by the child of sounds he hears others make but which he does not understand and this occurs at about the ninth or tenth month of infancy. Eisensen insists that 'lallation' and echolalic periods are of tremendous importance because during these stages the child acquires a repertoire of sound complexes which ultimately he will come to be able to produce at will and which he must have before he can learn to speak or acquire a language in the adult sense. The final stage in the development of speech by the child is verbal utterance, a stage which in itself is long and complex.

Diamond (1959) refers to the second six months of a child's life which is the period of imitation, when the consonants whether uttered spontaneously or in direct imitation of adult speech become overwhelmingly plosives: 'p', 'b', 'm', 'n', 'd', 't', 'g' and also 'h', and 's' occasionally appears. The guttural sounds now form a much smaller proportion of the whole and the consonants are to a large degree articulate.

As we have seen the large majority of early vowel sounds are 'a' or a closely related sound. The combination of one of the consonants mentioned with such a vowel sound as a monosyllable or reduplication comprises the sound of the first word, such as 'ga', 'ma', 'ba' or 'da-da', 'ma-ma', 'ba-ba', but a good many are of the type 'mum' or 'maman'.

Eisensen comments that the word first uttered by the child is possibly in all probability an accident, for example the word 'mamma'. This evokes a response in the mother who repeats the sound and the child then imitates the mother's sound. This situation produces satisfaction in the child and when it is again repeated and evokes the same response or the presence of the mother it becomes definitely related to her, that is has a reference to her. He considers that all the first words of children have high emotional content and Lewis stressed that the child's early discrimination is between friendly and unfriendly intonations. Eisensen points out that when a child speaks a word he intends by it to announce his emotional attitude to the word, his desires, wishes or needs in regard to the word and the experiences for which it stands. A single word utterance such as 'mama' is in reality a sentence in that it is used to express a complete thought to communicate the child's reactions about mama at the time the word is uttered. Thus a single word stage usually begins when the child reaches the age of about nine months and at about thirteen months when disconnected words are combined and used in sentences.

McCarthy (1954) in describing first language acquisition suggests that there is good evidence to show that the child easily forms large abstract categories. "Daddy" may be ascribed to all men who come into the house. "dog" may be ascribed to all four footed animals, etc., so that it is possible that cognitive development builds from the abstract to the concrete, from the general to the specific, although vocabulary acquisition appears to build in the opposite direction.

The child arrives at the age of sentence structure with a supply of well practiced nouns, verbs and adjectives and his first sentences are often telegraphese in character. Sentences which utilise 'high' information words, nouns, verbs etc. (contentives) and omit inflections, auxillary verbs, articles, conjunctions and prepositions (functors). It has been suggested that the child selects these 'contentives' because of the manner in which words are stressed in a sentence. Adults tend to stress nouns and verbs because these are the most important part of the sentences and carry the main messages and childrens' first utterances are reductions of adults complete sentence structures. It is interesting to note that when children and adults who have suffered serious cerebral insult effecting the speech centres, recovery of speech appears to be hierarchically organised. Nouns appear first then verbs, adjectives and prepositions in that order. Where damage has been severe language may never extend beyond telegraphese. Conversely in the case of the dementing adult or child, language structure deteriorates with the loss of prepositions and adjectives first, verbs, and last of all nouns.

Brown (1970) has discussed the intricacies of syntax in the development of the child's speech and also the different sentence types which children produce. The yes-no questions, the negatives, the negative tag endings etc. "The baby cries - doesn't he?" etc. Brown suggests that the ability of the child to construct these sentences infers that he has already a sound basis of structural knowledge. Further the reasons for children adopting complex linguistic structures and abandoning primitive speech models are complex and not fully understood. There may be parental and cultural pressures which reinforce syntactically correct utterances.

Brown considers that any form of speech which is produced with very high frequency by parents will be somehow represented in the child's performance even if its structure is far beyond him. He will find a way to render a version of it and will also form a notion of the circumstances in which it is used.

Psychological Processes of Speech Function.

We are aware of the general importance of afferent impulses from muscles for the regulation of movement of the organs involved in the production of sound. Speech is influenced by auditory impulses as well and both are produced by its motor element. Thus at the earliest stage and hence fundamentally speech is a sensori-motor, sensory activity but whereas congenital deafness interferes grossly with the development of speech, when once normal speech has been established, acquired deafness disturbs it relatively little. Observations have been made on the effects of artificial disturbances of what has been termed the auditory feed-back (Lee 1950, Black 1951). One method of investigating psychophysiology of speech has sprung from the development of electronics and the information which it has been able to give to communication theory and practice. One of the important factors which has arisen is that the same phoneme or speech sound can be produced in an unlimited number of ways depending upon the pitch of the voice, the resonance of the vocal organs and so on. By what means do we recognise all these variants as identical? This has been a very difficult question to answer. However, numerous experiments have tended to suggest that the fundamental acoustic determinant of a person's response is the distribution of energy at different frequencies as a function of time, the intensity-frequency-time pattern (Licklider and Miller, 1951). It will be remembered that Liberman, Delattre and Cooper, 1952, artificially produced a single, unvoiced stop consonant at twelve different frequencies and placed it before each of seven vowels. They demonstrated that the subject might hear the consonant as either 'k', 'p' or 't' depending on frequency and the vowel by which it was followed. Hence what consonant is heard depends not only upon the physical stimulus representing the consonant but also on which vowel follows it, from which they conclude that the following vowel plays a critical part in the auditory perception of 'p', 't' and 'k' and in that event the irreducible correlate for 'p' and 'k' is the sound pattern corresponding to the consonant-vowel syllable. This leads us to the fact that a word is then perceived as a whole, which is something different from the mere sum of its parts. This can be illustrated by the general principle that in a given time a much larger number of units of speech, whether they be heard phonemes or printed letters can be recognised if they are presented as words rather than as nonsense syllables, or as sentences rather than isolated words (Egan, 1948). Similarly it has been shown that if telegraphists are tested with a strange code or list of figures they are able to receive only three or four units compared with forty to sixty in the same time if they are presented with morse code arranged in words which make sense (Bryan and Harter, 1897, 1899). All these observations point to the fact that psychologically a word is an organisation of a higher order than the units of which it is constructed and that the organisation of these units which follow one another in time actually modifies the perception of the units themselves. This is an idea closely related to the 'gestalt' approach of Conrad, 1954 and the speech constancies discussed in Chapter III. Going back to Liberman, Delattre and Cooper's experiments, what is still very speculative is how the phonetic pattern is discriminated. We saw that the child hears what we call the same sound produced in many different ways by different people, whereas its own production of this sound is relatively stereotyped. Physiologically, therefore, the first problem is how these widely varying stimuli can produce the same response. That is, by what physiological mechanism the brain responds to a common pattern in the stimuli and disregards the irrelevant elements. Brain (1961) has suggested that the physiological basis of the recognition of a phoneme, that is the basic element of speech, is an auditory phoneme schema; however a phoneme may be uttered it is identified at once without any process of conscious comparison with the standard. The schema is therefore purely physiological. This idea is closely related to those put forward by Conrad, 1954, who distinguished two phases in the understanding of speech in terms of the gestalt theory: "In the first phase, the auditory formation of speech has to be grasped purely auditorally and to be detached from its auditory background without understanding having necessarily taken place at this stage. The individual must be capable of detaching the auditory gestalt as such, clearly and sharply defined, final and constant in its whole structure. In the second phase it is necessary to understand the auditory gestalt as conveying meaning." In Brain's words, a word schema must possess links with the physiological bases of perception and thought and secondly the meaning or words depends on the relationship of each individual word to those which precede or follow it in a sentence, that is upon syntax. He deals with the difficult problem of serial order, that is that a sentence is a series of words which follow one another in time and is subject to laws whereby the meaning of earlier words may modify or be modified by the latter ones. Lashley implies that the physiological activity, excited by the earlier word schemas, is a continuing one, and also capable of modifying or being modified by later ones. Brain (1961) sees the schema as a kind of receptor which is capable of detecting and responding to a pattern in varying stimuli, that is discovering what set of properties of the stimulus are essential for it to be of a given class. He suggests that most of the features which underlie the recognition of a pattern can be explained as the result of calculating the probability that a stimulus possesses a certain set of properties. With regard to speech, the first recognition is of a phoneme. Articulation (Fletcher, 1953) may be considered as a probability. To sum up then, we might say that speech employs a series of complex psychological organisations which can be termed schemas of which one may recognise in relation to spoken speech:

(i) the auditory phoneme schemas,
(ii) central word schemas,
(iii) word meaning schemas,
(iv) sentence schemas and
(v) motor phoneme schemas.

Breakdowns of these complex physiological organisations can result in a number of disorders of speech of which aphasia has certainly been the one most studied by clinicians. However, as yet our understanding of the aphasias is largely empirical. It will be of the utmost importance to learn more about the underlying principles of mechanisms of speech and to correlate psychological and physiological functions by utilising the experimental work of psycholinguistics, phonetics and communication theory.

Mechanisms of Speech Development.

Contemporary workers have advanced various theories to account for the phenomena of speech development in man such as is never found in animals. The tremendous increase in size of the association areas, eg. angular gyri in man may be as a result of the organisation necessary for language function.

Brain, (1961) in discussing speech mechanisms has proposed the development of different schemas acting as receptors against which incoming stimuli may be identified according to the laws of probability. These would be formed at different levels of language function. There is no one to one correspondence between stimulus and receptor but perhaps selection and identification of the material to be monitored. He considers that there is possibly schema at the level of the phoneme and also perhaps at syntax and sentence structure level.

In terms of probability the correct patterns can be recognised. It is the possible laying down of such schemata at different levels of organisation which is responsible for the mechanisms of learning to read, to write and to speak. It is probable that not only must there be agreement on the schemata laid down in the different modalities but that maturational development of the areas responsible for different functions must keep pace with each other. Disturbance in one area or another might possibly be responsible for the child not acquiring complete language function. Roberts has proposed that for the child to acquire total and mature command of speech processes he must "lay down schemas for monitoring each form of language and that all such patterns must be in agreement and undisturbed. In the brain damaged there is usually discrepant performance results in all the modalities."

Penfield and Roberts, (1959) in discussing speech mechanisms, consider the function of the thalamus. Walshe, (1963) however, does not refer to this area as being specific for speech. He does specify an area in the left hemisphere (in right handed people) bounded by the second and third frontal convolutions anteriorly and by the angular gyrus and first temporal convolution posteriorly. He proposes that this area is essential to speech. Walshe considers that the unit of speech is not the phoneme as Brain suggests, but the proposition.

Theories Concerning Psychological Processes Inherent in Language Function.

Luria (1964) has developed a theory concerning language function in terms of his "second signalling system." This may be somewhat similar to Walshe's 'proposition'. Luria suggests that the whole cortex is alerted to respond to a signal received by the primary reception area of vision and audition. After the first arrival of the stimulus, an excitatory current develops, in the intermediate areas, the sub-cortical areas and spreads over the reticular formation, thus spreading to the entire cortex. It is now at the stage that the cortical processes are ready to organise, to generalize, abstract and synthesise. This second signalling system makes language function possible.

Luria understands speech to be a means of deeper analysis and synthesis of reality - "a regulator of behaviour."

The two signal systems of Pavlov is one where the first signal system is concerned with directly perceived stimuli, the second with systems of verbal elaboration. Vygotski (1962) saw human mental development as having its source in the verbal communication between child and adult - "that a function which is earlier divided between two people becomes later the means of organisation of the child's own behaviour." In 1929 he noted that a four year old child will use external speech when confronted by problems. By seven years the external speech has died away to become internalised, so that what needed to be reinforced was already beginning to show features of self-regulation. However, the direct participation of the child's own speech in the process of elaboration of new connections can be disturbed by injury to the brain and by mental retardation or acute organic brain disease. Luria sees the process of elaboration in the brain injured child as being very slow, depending for a long time on reinforcement, and is not reflected in any kind of coherent verbal formulation. Luria observed two twins of five years, monozygotic of retarded speech development, who were removed for three months and placed in parallel kindergarten situations. He found that the first words used by the twins did not have a stable meaning and only acquired meaning by entering into some operative situation. In fact they only understood speech when it was directly connected with a concrete situation. Thus speech was only comprehensible if it was related to a visual situation, and it became incomprehensible if some fragment of the instructions was omitted. Often they snatched at a single phrase of a sentence rather than responded to the total meaning of a sentence. However, after three months, amorphous phrases lost their importance and simple sentences began to supercede autonomous phrases. Luria insists that speech in these circumstances only began to occur when the twins were separated in a situation (playgroup) which necessitated communication. The elementary phrase speech quickly gave place to full value speech activity using a language system and sufficiently clearly separated from direct action.

Luria (1961) sees speech development of the child as arising from play processes wherein the child attaches special significance to specific actions and objects. After this first primitive speech, the need to communicate expresses itself in "narrative and planning speech" wherein the speech is no longer interlocked with practical activity, but expresses the aims of their activity. This step in language development itself feeds and promotes the machination of the child's intellectual and emotional life.

Reynell (1969), a recent worker involved intimately with the diagnostic assessment of young children with communication problems has contributed her own individual approach and suggests that a number of processes must take place before communication can occur. She considers that the first stage, that of "adequate experience of the mode of communication" is essential to normal language development. Extreme cases of deprivation of such experience may be instanced by so-called ferel children (Singh and Zingg, 1942), children reared by wolves. Stage two infers intact sensory channels by which the experience reaches the child, visual, tactile, auditory, etc. Here, deaf blind children are at a great disadvantage being deprived of normal sensory channels. At stage three there must be ability to appreciate meaningful patterns in the stimulus - spatial or temporal patterns. In auditory perception (verbal comprehension) the temporal pattern is more important. In stage four, meaningful patterns of stimuli are incorporated into existing concepts, perhaps modifying and enhancing them. Generalisation, classification and other modes of interrelation of concepts take place, so that new perceptual experiences may modify the whole thought pattern to a larger or smaller extent. These four stages complete the process involved in the reception of language. Stages four to seven are involved in language expression and obviously the development of these processes must depend on adequate language reception. For example, the mechanisms involved in articulated speech (Stage Six) are present in pre-verbal vocalisations before the link with receptive aspects of language, (Irwin 1960) whereas expressive (executive) language cannot occur without some previous receptive learning.

At stage five, thought processes are encoded in some symbolic form - such as planning of patterned movements (gesture) or a pattern of vocalisation, such as verbal language. It is the patterning of the thought processes which will convey meaning in communication which distinguishes this particurlar stage. Stage six will involve the more peripheral aspects of expression such as the ability for co-ordinated arm movements or articulated speech. These are the means for conveying the coded message. Stage seven is concerned with opportunities for communication. Unless the environment is sympathetic and encouraging to attempts at communication there will be little motivation to do so.

CHAPTER III

PROCESSES INHERENT IN SPEECH PERCEPTION

What is then involved in the perception of language? Are there processes in the detection and comprehension of language which are unique to the spoken word?

There is good evidence and a sound background of work to suggest that two sorts of phenomena are operating and are specifically related to the perception of speech. These are the speech constancies and categorical perception.

Joos (1948) first suggested that vowels convey language cues which are dependent on the relationship between the frequencies of their formants and the frequencies of the formants of other vowels which occur in the same auditory context.

Broadbent, Ladefoged and Lawrence (1956) followed up Joos' hypothesis and confirmed his earlier experiments.

Fourcin (1968) has reported that the same effects can be shown for consonants, i.e. the range of formant frequencies can be inferred from the pitch of the voice.

The argument for an acoustic store in the perception of language has been put forward by a number of writers (Neisser 1967, Guttman and Julesz 1963). Neisser suggests that the organism must contrast different stimuli and that the presence of an acoustic store is necessary for this process, i.e. the acquisition of new categories. Experimental work by Eriksen and Johnson (1964) and Neisser (1967) has supported his theories. The importance of the acoustic store phenomenon is that it can be seen as the link between a specific auditory stimulus and the discriminatory process which succeeds the stimulus.

Berliner and Durlach (1968) have reported that plosive consonants and certain other sounds show greater degradation than vowel sounds. If this is true then processes of categorical perception may be different for vowel and consonant sounds.

An important paper by Liberman et al (1967) on the underlying processes in the perception of the speech code using the context of phoneme requires some amplification. The authors were concerned to investigate the mechanism by which the listener was able to decode the sounds and recover the phoneme.

Speech can be followed only if the rate of speech is controlled. At 30 phonemes per second speech becomes unrecognizable and even 15 phonemes per second could become too fast. Also it is necessary to have in speech a sufficient number of identifiable sounds.

Perceiving the basic speech code is basic to language and to man in a way that reading an alphabet is not. Why are speech sounds perceived so well in spite of the limitation of the ear?

Acoustic Cues

Examination of the voiced stop 'd' illustrates the nature of the code. The acoustic cue, for example the second formant transition is a major cue for all the consonants except the fricatives s/s/. When 'd' is placed before 'i' and again when it is placed before 'u' the steady state formants are sufficient to produce the vowels 'i' and 'u'. At the left of each pattern there are rapid changes in frequency of the formants - the formant transitions which are important acoustic cues for the perception of the consonants. The transition of the first or lower formant rising from a very low frequency to the level appropriate for the vowel is a cue for the class of voiced stops 'b', 'd' and 'g'. It would be the same for 'bi, bu' and 'gi, gu' as for 'di, du'. Generally this transition is a cue for the perception of manner and voicing. In the case of 'di' the transition rises from 2,200 cps. to 2,600; in 'du' it falls from about 1,200 to 700 cps. That is, the same phoneme is cued in different contexts by vastly different acoustic features. When we make these sounds (di) divorced from speech they appear to be like a rising whistle or glissando on high pitches; the one from 'du' appears to be like a rapidly falling whistle on low pitches.

The Disappearance of Phoneme Boundaries - Parallel Transmission

It is not possible to cut the 'di' or 'du' pattern in such a way as to only produce 'd'. This is because the formant transition is at every instant providing information about two phonemes, the consonants and the vowel - the phonemes are being transmitted in parallel.

The Locus - An Acoustic Invariant?

There are particular frequencies which characterise sounds. These are known as the locus of that particular consonant. However, the concept is articulatory and not acoustic in nature in that the articulatory tract is closed at very much the same point when 'ds', are sounded. It is generally true that the segmental phonemes are restructured at the level of sound. In the case of 'g, k, n' for example, there is a sudden and considerable shift in the locus as between the rounded and unrounded vowels, creating a lack of correspondence between acoustic signal and linguistic perception. With liquids and semi vowels 'nl, wj' the second formant transition originates at the locus, so the lack of correspondence between signal and phoneme is less striking, but even so the transition cues are not superimposable for occurrences of the same consonant in different contexts.

Constriction Noises.

These are further cues for consonant perception - the noises produced at the point of constriction.

Manner, Voicing and Position.

As well as those cues which are responsible for the perception of the consonant in the initial position in a syllable which have already been mentioned a comparable lack of regularity is also found in the distinctions of manner and voicing and in the cues for consonants in different positions.

The Vowels.

As well as discussing initial consonants it is important to recall that vowels are rarely steady state in normal speech. They show substantial restructuring, i.e. the acoustic signal at no point corresponds to the vowel alone but at any instant the merged influences of the preceding or following consonant (Stevens and House 1963).

In slow articulation then the acoustic cues for the vowels, the noise cue for fricatives tend to be invariant. They differ then from the cues for the other phonemes, which vary as a function of context at all rates of speaking.

Fujisaki and Kawashima (1968) report that short-state friction lasting about 25m/sec. and short vowels show greater categorical perception than longer vowels and friction. Adding a short vowel to the fricatives exaggerates this tendency. Both writers put forward the theory that the detection of vowels and friction are possibly a non verbal process. However, it is difficult to decide what sounds one can categorise as speech and which 'non-speech'.

Darwin (1971) has been interested to investigate the perception of speech and non-speech sounds and has undertaken a number of experiments on speech sounds using pitch and timbre changes. In a series of nicely controlled experiments he has shown very convincingly that a right ear advantage can be obtained using simple phonetic contrasts, regardless of the order in which the sounds are recalled. This advantage appears to be sensitive to certain variations in the acoustic structure of the sounds whilst the recognition response is held constant. Furthermore the place of articulation of fricatives is only recognised with a right ear advantage if appropriate formant transitions are present in the stimulus. These results and the finding that in free recall there is still a right ear advantage on the first and second channels, i.e. whether the right ear is stimulated first or second, upholds the view that the hemispheres differ in their response and perception of different sounds.

Darwin considers that there is no evidence to support the view that only speech signals which give significant contextual contrast will provide a right ear advantage since the voicing of a speech sound is recalled better from the right than from the left ear. This condition occurs only if the consonant is followed by a vowel but is not dependent on the presence of formant transitions.

Darwin was concerned to investigate whether the ear asymmetry effect depended on whether the sounds were (a) material specific and (b) whether preferred orders of report were important as a determinant. He deals with the teasing problem of whether speech sounds and other sounds are fundamentally different in character and considers that this problem can be resolved if there is appropriate decoding of speech signals. He suggests that one system can efficiently deal with signals arising from the speech apparatus and those occurring in the environment.

In his pitch change experiments he has demonstrated a left ear advantage on both the first and the second channels. There is still a left ear advantage whether the change is caused on a speech sound or is made up of discrete notes or is a glissando. The alignment of the phrases within a dichotic pair is shown to be important in two ways:

(a) Overall scores are lower when the phrases are perfectly synchronised.

(b) When the phrases are staggered, the leading ear is reported more accurately than the lagging ear - a 'capture' effect. Darwin considers that these effects probably bear little relevance to cortical asymmetry but more to influencing the magnitude of the ear difference measured in per cent correct.

In the speech sound experiments there appears to be a right ear advantage for the recall of initial and for released and unreleased final plosive consonants even when order of report artefacts are accounted for. The right ear effect is rather greater in amplitude for released finals on the first than on the second channel. This finding would tend to refute the hypothesis that the effect is greater on the second channel and support the view that perceptual rather than memory processes are responsible for the underlying asymmetry.

An experiment on fricatives shows that the right ear advantage is dependent on the particular acoustic features in the stimulus rather than on the recognition response. The right ear advantage for the recall of place of articulation depends on the presence of appropriate formant transitions in the stimulus, whereas a right ear advantage for voicing depends upon the presence of a succeeding vowel. The latter finding would query the supposition that only speech signals which show acoustic variation with context give a right ear advantage.

The experiments in steady state vowels confirm other work which indicates that vowels do not give a significant ear advantage. The foregoing results pose the question whether the hemispheres do analyse different acoustic features in the signals or whether there is no right ear advantage until after categorisation of the sounds.

Darwin tested this theory and produced equivocal results. He found that subjects did not show a significant left ear advantage in steady state timbre experiments.

Summing up the results of his experimental work Darwin finds that there is no reliable evidence to dispute the hypothesis that ear asymmetry differences may be dependent on the functional characteristics of the two hemispheres. However, he does insist that it is difficult to demonstrate whether the differences occur before or after categorisation of the material, since his own results demonstrate ambiguity on this particular point.

There is little doubt that Darwin's work has contributed significantly to the research on auditory perception. One might comment that his subject population is certainly a highly selective one - an undergraduate Cambridge group. This would presuppose them to be a highly fluent and verbal group (with possibly greater temporal cortical organisation) and that any results should be seen as specific to a highly intelligent non-random sample. The other point to be made is that no formal audiometry was carried out and it is not sufficient to suppose that because no hearing deficits were reported by the students that this was necessarily so. Darwin has also suggested that further research should be devoted to looking at the results of unilateral lobe damage. It would indeed be most unfortunate if work was concentrated on such a clinical group. Both neuro surgeons and neurologists alike are arguing with a good deal of supporting evidence that it is unwise to draw inferences with regard to neural functioning in patients with diseased brain states.

There have then been no adequate definitions of what sounds can be considered "speech" and which "non speech". It is just conceivable that we could say that all sounds which are generated by the vocal tract can be identified as speech sounds, and those sounds will vary with the physiological and anatomical constraints put upon the vocal chords, the larynx and the lungs, in fact with all the organs which relate to breathing and the production of sound.

Thus it is possible that although there may be different processes involved in the perception of speech and non speech, there has not as yet been any convincing experimental evidence to show this, and that sounds produced by the human vocal tract and by the environment may or may not be subject to different mechanisms of perception dependent on their auditory structure.

CHAPTER IV

LATERALITY OF FUNCTION

Any work which intends to look at possible lateralisation of function in man should perhaps make some reference to the question of bilaterality at the biological level. It seems therefore justifiable to bring together a number of contemporary viewpoints concerning man's dual brain.

J.Z. Young (1969) considered that bilaterality was originally a necessity for nervous systems that operate by means of a map-like analogue system and that dual representation of the nervous system evolved from homeo-stats whose neural memories contain maps of the surroundings, viz. cyclops, crustaceans and cephalopoda. With the higher vertebrates and mammals two eyes would seem to provide the best opportunity to search a large visual field. But if the computing system needs topologically correct mapping, two eyes involve two brains. At least for systems with relatively simple codes and mapping operations, one in the middle would not do, because one eye is unable to survey the whole field.

In mammals, for example in the cat, (Hubel and Wiesel, 1959) there is a point to point projection from retina to cortex and the congruence of the two maps is well known. This suggests an analogue mapping which as the coding system has become more refined departs from the strict isomophism of the lower phyla organisms. Nevertheless, two sides of cortex are still present in man. However, Young suggests that we have abandoned bilaterality, for man is able to do moderately well without the non-dominant hemisphere or the callosum between them. Perhaps the non-dominant hemisphere is now a vestige.

Bodian (1969) adds a point to Young's argument that unilateral dominance may have evolved within the primates because of some selective advantage, i.e. that decussation may be seen as a simple defensive mechanism and that there is an adaptive advantage for a crossed connection in the central nervous system.

Scheibel (1958) does not see bilaterality as a system in obsolescence but more as a new means for assessing the environment. Workers have suggested five critical steps in development of forebrain from rodent to man, each characterized by one more complete cell division and thus increases in cell population. From the monkey to man the functional non parity of the hemispheres may be responsible for man's symbolic operations viz specialisation and language. Scheibel does not contribute to the pessimism of Young's views concerning the dual hemispheres and their possibly vestigial roles. He considers with Tschirgi (1958) and Mach (1959) that an animal whose brain is bilaterally symmetrical is unable to differentiate between stimuli arriving at homologous points. "Awareness of spatial position is dependent upon asymmetry of the perceiving system, and evolution consists of increasing that asymmetry." Man is thus able to distinguish between right and left.

Why then have two brains if one will do? It is possible that there are morphological and functional reasons for this in that once the notochord has been laid down as a neural tube, it is necessary that bilateral mechanisms develop from it in order to maintain the organism's stability in the environment.

Thus Young's biological interpretation of cerebral duality seems to view man's possession of a second (minor) brain as purely vestigial.

These somewhat pessimistic conclusions might well lead us on to a consideration of the important and manifold functions which the leading left part of the brain has assumed. An understanding of the relationship between speech sounds and cerebral dominance was historically one of the most significant contributions which scientists made in the nineteenth century, and we shall now consider these.

Historical Development of Speech and Hearing Studies.

Most of the early work on speech perception has come from neurologists in their examination of patients with cortical lesions. It is difficult to assess with any degree of precision the results of these papers (many anecdotal in nature) as a great deal of information which today would be considered necessary to make a clinical interpretation is of necessity missing.

In 1836 Marc Dax addressed the Congres Meridionel, pointing out the importance and role of the left hemisphere. Broca (1865) thirty years later realised that all his aphemia cases were results of left sided lesions. When he published his first paper Dax's son wrote to the medical press claiming that his father's paper had been ignored. Such was the beginning of ideas concerning lateralisation.

Later in the same decade Bastian (1869) described two patients with "word deafness". He drew conclusions from these two case histories that informed contemporary neurological opinion as to the anatomical localisation of the speech areas. Wernicke (1874) extended Bastian's diagrammatic theory as to the location of the areas specific for certain speech sounds and comprehension, etc. When Lichtheim in 1885 demonstrated a patient with word deafness who showed a lesion similar to that described by Wernicke, the necessary proof for Wernicke's diagrammatic approach seemed proven. Later (1890) Hughlings Jackson* countered the early localisation

* under Jackson

theories insisting that language was too complex a process to be neatly divided into its sensory and motor aspects. From the study of patients who showed stereotyped utterances yet retained comprehension he proposed that "mentation is dual, and that physically the unit of function of the nervous system is double the unit of composition, not that one half of the brain is automatic and the other voluntary." (As Wernicke and his school had suggested.)

As well as these nineteenth century case histories reporting patients with language and speech disorders there were a number of papers referring to what was labelled as the musical aphasias. Charcot in 1876 categorised these cases in the same way that the aphasias had been classified. In 1926 Henschen undertook the investigation of a large series of patients with amusia and he concluded that music is represented in both hemispheres but that the hearing and comprehension is specific to the left temporal lobe. He also thought that the amusic patient had lesions relating to the left hemisphere. He did, however, accept that there was more involved to the perception of speech than the auditory processes reaching "auditory word centres". Henschen also made a distinction between the auditory perception of words and the "storing of word memories" and saw these two as being distinct processes - possibly involving different areas of the brain.

Kleist (edited 1962) in a discussion relating to speech and cerebral dominance maintained basically the earlier theories proposed by Henschen and considered that speech deafness occurred with lesions in the left temporal lobe in most cases, but in the left handed and ambidextrous patient the lesions were in the right temporal lobe. He did, however, repeat the Helmholtzian view that there was a distinction between the perception of noises and phonemes and the perception of tones.

Feuchtwanger (1930) and Ustvedt (1937) also drew attention to the relationship between speech and music. Ustvedt was at pains to emphasise the possible connections between the emotional aspects of music and the thalamic processes. He saw the cortex as being a possible "association centre." He pointed out from his study of aphasic patients, many of whom had musical deficits, that they were able to tap a rhythm more easily if this was associated with a melody than if the rhythm was given without a melody, concluding that the processes involved in melody perception were more susceptible to disease than the processes involved in detecting rhythm.

Quensel and Pfeiffer (1923) report the case of a man who suffered gun shot wounds in 1916 with a residual left hemiparesis. He was said to have had difficulty in reading and understanding speech but intact verbal comprehension - although the last two would appear to be incompatible. Previously able to play the accordion, he was now unable to detect melodies although his rhythmic sense was unimpaired. An E.N.T. examination showed left ear hearing loss and some loss in the right ear. However, it is difficult to interpret the significance of these rare case histories as in point of time the neurological and E.N.T. examination must have been somewhat gross in nature and no inferences can possibly be made with regard to specific deficit and anatomical foci.

The speech therapist today is all too familiar with the relationship between the audiogram and the pattern of speech which may accompany it, and it is possible that a number of these early so-called aphasias may have been patients with high or low frequency loss rather than a so-called "central" hearing deafness.

There have been two reported cases of so-called word deafness in the absence of peripheral hearing loss (Hemphill and Stengel 1940) and Klein and Harper (1956). Both patients recognised sound and had less difficulty in recognising musical and environmental sounds, but were unable to understand spoken speech although Hemphill and Stengel's patient was able to follow written instructions. Audiograms on both men were reported to be normal. However, Martin (1970) reports the case of a child who had scored normal audiograms at five teaching hospital hearing centres but who was found to be subsequently profoundly deaf at the Nuffield Centre where more sophisticated hearing tests were employed. Thus it would be unwise to draw any firm conclusions with regard to the Hemphill and Klein case histories. The aetiologies of these two case histories is uncertain. It may be true that there is a general distortion in terms of auditory input or less likely that there is a selective impairment of the mechanism responsible for the perception of speech but both views must be treated with a certain degree of caution. In a recent case seen at Great Ormond Street there was difficulty in naming (nominal aphasia) after a left cranio-phayngioma had been removed. The patient, a five year old girl, was able to achieve correct responses if she was able to handle the objects.

The loss of non verbal auditory skills in patients who still maintain intact verbal abilities has been reported by Spreen, Benton and Fincham (1965) and Wertheim and Botez (1961) Wertheim, (1964). The first case is of a sixty-five year old patient with a left hemiparesis who although he comprehended speech, was unable to describe non verbal sounds. However, the audiogram showed a high frequency loss and the sounds may well have come within the range of this loss.

Wertheim's case relates to a professional violinist who showed some receptive musical loss after a luetic cerebral arteritis in the left hemisphere. He also showed some impairment of his melodic and rhythmic sense.

MacDonald Critchley (1958)* makes the point that there is considerable clinical data which indicates that:

* See Critchley.

1) Disordered articulation is commonly a striking sequel of disease of minor hemisphere - though it may be transient. If dysarthria is severe there is as well as a disorder of speech a poverty of language which mimics an aphasia.

2) Creative literary work may be hampered after minor hemisphere disasters.

3) There may be word blocking or word fending or 'metonymous paralogia'.

4) Delays in identification of language by the patient through auditory or visual channels may be present.

5) Difficulties in learning are frequent in lesions of the right hemisphere.

6) There may be difficulties in understanding the meaning of pictorial matter which can be seen as a modality of symbolic formation.

MacDonald Critchley's work would suggest that the left hemisphere cannot be considered to have an exclusive monopoly of language function.

Summary

Summing up then it would seem that the clinical evidence from the study of the right and left hemisphere lesions has resulted in a certain amount of confusion and uncertainty as to the roles which each hemisphere plays in auditory functioning. Workers have found patients who demonstrate disruption of language and sensory perception irrespective of which hemisphere is damaged. So much for the evidence of individual clinical case histories; it will be instructive to review the large scale studies which have been made on patients with gross lesions affecting the temporal areas.

Large Scale Studies.

Luria (1961, 1964) in studying a large number of men with gun-shot wounds showed deficits affecting phonemic perception after left temporal lobe damage. He also demonstrated that performance on rhythmic tests and tonal pattern tests could be equally sensitive to either left or right temporal lesions. Feuchtwanger (1930) supports the theory that tonal pattern discrimination is affected by either right or left sided damage. More detailed studies with respect to isolation of specific brain tissue damage have come from Meyer and Yates (1955) and Milner (1961 and 1967). They have shown that verbal memory is definitely impaired after removal of the left temporal lobe but not after removal of the right temporal lobe. Non verbal auditory skills are affected by right temporal excision (Milner 1961). Most affected was the tonal memory test from Seashore. A series of patients seen at John Hopkins by Chase (1967) has substantially shown the same results.

What evidence can we gain from the study of patients after hemispherectomy or comissurotomy? Carmichael (1966) reporting on the current states of hemispherectomised child patients found that children who were hemiplegic before the acquisition of speech had no gross clinical disturbance of speech after hemispherectomy, irrespective of which hemisphere was removed. When the hemiplegia had followed the acquisition of speech functions, removal of the dominant left hemisphere led to failure of speech functions, but with later recovery, in all but one instance. Similar partial recoveries from aphasic disturbance have been described after removal of the speech-dominant left hemisphere for glioma in adults

(Crocket and Estridge 1951, . Smith 1966).

Wilson (1970) in a large-scale review of fifty patients after hemispherectomy reports that forty-two patients retained unimpaired speech functions irrespective of whether the right or left hemisphere had been removed. Removal of the left hemisphere was followed in one patient by an ostensible improvement in speech. Post operative dysphasia or aphasia occurred in six patients, all but one having had the left hemisphere removed. In half, the loss of speech was permanent, but as these patients showed gross mental retardation it would be difficult to assess the effect of this on their language function. Wilson also discusses two children aged 1½ and 2½ who had acquired speech. In the case of the younger a right hemispherectomy and in the case of the elder a left hemispherectomy was performed. They subsequently developed perfectly normal speech function.

Sparks and Geschwind (1968) in a paper "Dichotic Listening in Man After Section of Neo-Cortical Commisures" discuss a patient who had all the interhemispheric connections severed and a right hemisphere section performed. For a short time after surgery there was a complete extinction of all sounds applied to the left ear. After some time, however, he did show a 35% detection of sound. The authors put forward a tempting theory of compensatory ipsilateral pathways being used rather than the contralateral temporal pathways. They conclude that the callosal pathways may be more important from the right to the left temporal lobes when dichotic verbal tasks are offered to the subject, rather than the callosal pathways from the left to the right temporal lobes.

Zangwill (1967) has reviewed a group of patients after left hemispherectomy. The patients, however, showed such gross impairment of all functions that exploration of specific perceptual anomalies was not possible.

There are now a large number of studies to indicate that right hemispheric symptoms have been shown to be characterized by complex perceptual changes, visuo spatial or visuo constructive deficits. (Lange 1936, Hebb 1939, Brain 1941, Paterson and Zangwill 1944, McFie, Piercy and Zangwill 1950, Hécaen (1959), MacDonald Critchley 1952, Milner 1958, Zangwill 1960). Milner 1967, Cohen 1959, Ettlinger 1960 and Lands[illegible]ell (1961) have shown right hemisphere lesions to be associated with various pictorial disabilities. In the auditory sphere impairment of binaural localisation with right parieto-temporal lesions has been noted. (Teuber and Diamond 1956).

However, it is important to emphasise that these right and left differences are a matter of degree rather than differences in kind and they do tend to be small.

Brain (1961) in a discussion of language and dominance accepts that there is some correspondence between the site of the lesion and the function disturbed. He postulates that anterior lesions disturb expressive speech and posterior lesions disturb receptive speech. He considers that engrams are possibly stored in both cerebral hemispheres and that the transfer of language functions can occur from the dominant to the other hemisphere if the dominant hemisphere is damaged before the age of four or five years. He quotes the case of a child with damage of the left hemisphere who had acquired speech and was aphasic. The child recovered speech and later an intracarotid injection of sodium amytal on the right side which had caused aphasia demonstrated that the right hemisphere was now concerned with speech. Can it be inferred, he asks, that the equi-potentiality of both hemispheres for language is universal? He considers that there is some evidence to suggest that some adults differ from others in having bilateral representation of language.

Summary

Do these case histories perhaps suggest some functional differentiation between the hemispheres in their abilities to perceive different classes of sounds? As yet there has not been sufficiently convincing clinical evidence which would support this hypothesis. The series of cases studied is small and it calls for a much more carefully controlled investigation of a larger series with specific known lesions before any firm conclusions can be drawn. However, it is possible that expressive speech shows much greater disturbance after damage to the left hemisphere whilst the perception of other sounds shows less marked disturbance.

CHAPTER V

EXPERIMENTAL WORK ON AUDITORY PERCEPTION

Kimura's studies on auditory perception have been the subject of much criticism and since the present study is interested to follow up her work it would be important to examine those papers which refuted her findings:

To summarise briefly her findings it will be recalled that Kimura showed by the use of dichotic stimulation that

1) the contralateral pathways are the more efficient in auditory perception tasks and

2) that there was some asymmetry of function between the two hemispheres.

She confirmed these findings on a group of epileptic patients and on a group of normal adults and children of ages five to seven years. She suggested that if speech is in the left hemisphere the stimuli from the right ear would be perceived more accurately by this route than by the left ear. She demonstrated that the opposite was true for left-handed persons who had speech represented in the right hemisphere.

Bocca et al (1955) considered a group of tumour patients and could find no difference in performance between patients with right and left temporal lesions.

Bocca (1958) used test words so that one ear received the words undistorted, but with low intensity; the other ear received the same words simultaneously but with all frequencies above 500 cps. removed. Under these conditions, each ear used alone yielded only a 50% articulation score (only half the words were recognised) but binaural listening yielded significantly better results. Such binaural interaction is reduced or absent with hemispheric lesions and Bocca believes that the impairment is specific for involvement of auditory cortex rather than brain-stem structures and that the tests show lateralisation since the lower scores result from giving the frequency filtered speech to the ear opposite the cerebral lesion and the low intensity speech to the ipsilateral ear.

Matzker (1959) gave identical test words through earphones to the two ears, one ear receiving frequencies between 500 - 800 cps., the other those between 1,500 and 2,400 cps. Normal subjects were able to perform a binaural synthesis gaining a good articulation score while each ear did poorly. Patients with cerebral lesions, old people and children did badly on binaural synthesis.

Teuber (1961) used tests involving duality judgement for dichotic clicks. He considered that the threshold in the normal lies between 1 and 2 m/sec. while many brain-injured patients require more than twice as much separation in time, before they hear the clicks as separate.

Calearo and Antonelli (1963) followed up Kimura's work by giving normal subjects a low pass filtered and an interrupted speech test. Their results showed no difference between left and right ear scores. However, this test was diagnostic in locating unilateral damage. Kimura (1963) remarked that in her 1961 experiments the only condition which had shown inter-hemispheric differences had been that of simultaneous stimulation.

Other criticisms of Kimura's paper and its interpretations came from Inglis (1962) who discussed the results in terms of not perceptual differences but more of memory differences.

That is to say, the hemispheres may have different capacities in terms of a storage mechanism - the right hemisphere being inferior in this respect. Unless data can be separated into perceptual and memory terms there is no way of knowing which mechanism is operating as all auditory material by definition must be recalled in order to assess it. Broadbent (1957) has shown that subjects tend to report all the digits from one ear first and that the first ear reported is also the more accurate. Thus Kimura's material could be interpreted as an order effect and errors in recall are due to short term auditory storage effects and not defects of auditory perception.

However, there is certainly no doubt that whether perception or memory is operating the fact remains that material is recalled first and better from the right ear. Oxbury, Oxbury and Gard~~e~~ner (1967) prefer to think that the better scores on the right ear are due to a tendency for the right ear to enter the 'p-system' earlier than the left ear.

What experimental evidence is there for subjects to report better from the ear first recalled?

Ear Order Effects.

Broadbent first showed this effect when he presented subjects with three pairs of digits at ½ second intervals, one digit of each pair to either ear of his subjects. They were allowed to recall at will. Subjects showed a marked preference to recall from one ear before any from the other ear. The second group of subjects were given idential conditions except they were directed to report the digits in their order of arrival. Scoring was only correct if they did so. Digit presentation was varied at ½, 1, 1½ and 2 second intervals between digit pairs. Higher scores were obtained under the slowest conditions. This effect occurred also with other modalities using the eyes and the ears as the two channels.

Others (Satz 1968, Bryden 1962) found the same results, namely that the rate of presentation of material produced an increase in the use of ear-order. Yntema and Trask (1963) showed that grouping by ear can be overcome if the material to be recalled is syntactically and semantically grouped. They suggest that incoming data is possibly tagged and that this mechanism overcomes the ear-order effect. This ability to overcome ear-order when semantic and syntactic grouping occurs would seem to constitute a condition where it is easier for the cognitive processes to assemble material which is sequentially and not laterally presented, that is to travel forwards and not sideways (Yntema and Trask). 1963.

Serial Order Effects.

Broadbent (1958) discusses the possibility that order of presentation and order of recall effect the efficiency of performance. That is to say, a person will recall the first half of the material more efficiently than the second half if recall is in the same order, the primary effect. If recall is reversed, that is the second half being recalled first, then the total material has equal numbers of errors. The results are the same under simultaneous dichotic stimulation.

Further work along these lines has supported Broadbent's p-system and s-system experimental model. That is to say, that although the unattended ear can respond to some material when the other stimulated ear is in a state of extreme attention, there are certain complex situations which are not capable of being attended to and subsequently processed. Oxbury (1967) has suggested that the right ear material is attended to immediately whilst the left ear material is held in store. In terms of Broadbent's (1958) model the right ear passes into the p-system first. The more attractive theory is Inglis' who suggests that the serial order effect is not a laterality effect but points to the greater efficiency of the storage system which deals with signals fed into the right ear, (and thus transmitted to the auditory cortex in the left hemisphere).

This would explain why one ear (in free recall) tends to get recorded first and that the greater number of errors recorded from the second ear is due not to auditory defects but more to the fact that the material from the second ear must be kept in store longer. Inglis does, however, postulate that there is "a tendency for the material presented to the right ear to be reported first." He gives no reason for this - and Kimura of course would insist that there are real perceptual differences. This may be true just as it is true that the greater number of people use the right hand and that there is some tendency in the development of homo sapiens to favour greater organisation of one side of the brain (and the body). There are, of course, good phylogenetic biological reasons for duplication of functions in the human body in terms of the self-preservation of the species, so that if one side of the body is damaged the other side is capable of taking over its functions.

We can summarise by saying that in dichotic stimulation one ear (the right) tends to get reported first and that under conditions of free recall there are higher right ear scores than left ear scores.

Bryden (1962) gave his subjects three pairs of digits at half second intervals and asked them to report one ear before the other. The right ear scored a greater number of successes than the left. There were slightly more errors when the left ear was recorded first. However, when scoring was aligned to count only those responses correct for order of report there was a slight but insignificant preference in favour of the right ear. Statistical significance was reached when four pairs of digits were used and not three.

Thus we can suggest that serial order effect is not entirely responsible for right ear advantage.

Oxbury, Oxbury and Gardiner (1967) did not confirm Bryden and Broadbent's results. They requested subjects to recall digits after stimulation to one ear. They found no significant differences in total scores. There was, however, some interaction between ears and order of report. Right ear responses were less accurate when reported on second channels, though left ear scores did not show this difference. The writers discuss this point and suggest that although right ear stimuli are responded to first after stimulation, left ear stimuli are held in store, i.e. Broadbent's 1958 thesis that the right ear passes into the p-system first.

Various objections have been raised to this study, mainly that the number of trials were small and that the earphone channels were not reversed between subjects. (Darwin's unpublished thesis, 1969).

Inglis (1962) accepts that there is an ear preference but prefers to explain that this is due not to perceptual differences but differences in storage efficiency. Bryden (1967) disclaims this memory view by pointing out that differences are shown both on first and second channels reported. However, objections can be levelled at this argument on the count that his scoring is questionable. He uses per cent correct as a measure of the magnitude of the laterality effect on the two channels, and this would not seem an appropriate measure for the comparison of scores over a widely differing level of performance. It would seem important to establish the fact that the second channel shows a greater tendency to ear difference than the first channel, but as yet there is no evidence to support this possibility. Leaving aside the memory-perception controversy we must accept that attention is a factor which must influence to some extent the experimental situation. We could substitute the greater memory facilities of the left hemisphere for a theory involving the greater attentional capacity of the left hemisphere.

Triesman and Geffen (1968) found that when subjects were requested to tap in response to target words while shadowing a message with the other ear, results showed that differential performance appeared only when the subjects were involved in tasks which were not receiving their full attention. The authors sum up by commenting that these results support the idea that the right ear dominance is primarily a quantitative difference in the distribution of attention to the right and left ear inputs reaching the left hemisphere speech areas.

Experiments with Sensory Stimuli.

Up to now we have discussed the possible asymmetries resulting from the use of material which might be called verbal. What about sounds that can be referred to as non-verbal, that is emitted from non-human sources, and is there a possible functional asymmetry affecting the processing of what is traditionally referred to as non-verbal or sensory material? Can we show material specificity for ear advantage? Kimura's (1964) experiments with musical excerpts would suggest that we can. Chaney and Webster's (1966) experiments tend to support Kimura's work. Briefly they asked subjects to distinguish between sonar produced sounds and speech sounds. Speech signals did appear to be more quickly and more accurately responded to by the right ear whilst sonar signals were recognised better by the left ear.

Shankweiler (1966) used Kimura's melodies for assessment of forty epileptic patients before and after temporal lobectomies. Half the patients had the right lobe removed and half the left lobe. There were no significant differences between scores pre-operatively. Post operatively those who had left temporal lobes removed showed no change and those with right lobes excised showed significant loss. The patients who had Heschl's gyrus removed showed the greatest sensory loss. These results support Milner's finding that the right temporal lobe appears to be functionally superior for assessing non-verbal auditory material. Milner (1961) followed up the work of Diamond and Neff (1957) who showed that bilateral lesions of auditory cortex can impair tonal discrimination patterns in the cat. She was interested to look for similar deficits after temporal lobectomy in man. Both Kimura's (1961a) and Milner's (1956) results are also indicative suggestive of the superiority of the contralateral pathways over the ipsilateral pathways.

Choosing Seashores Tests of pitch, loudness rhythm, time, timbre and tonal memory, Milner (1961) used thirty-eight patients with temporal lobe lesions. Twenty-two patients had left sided lesions, sixteen had right sided lesions. (All had speech areas in the left hemisphere). The main group were twenty-seven patients tested pre and post-operatively (two weeks after operation) after unilateral temporal lobectomy. Sixteen operations were on the left and eleven on the right. The remaining (eleven subjects) were only tested post-operatively. <u>The amount of the tissue removed was slightly greater in the right hemisphere</u>.

Results showed that error scores increase post-operatively after operation to the right hemisphere on tests relating to time ($p > .05$), loudness ($p > .05$) and for timbre ($p > .01$) and tonal memory ($p > .01$). Pre and post-operative comparisons thus show increased difficulty in discrimination after right temporal lobectomy but not after left lobectomy.

Various objections can be raised to Milner's study. There is no reference to method of testing the subjects and whether ear order effects were considered and taken account of in the experimental model.

Milner herself points out that the results must be viewed with caution and that the data could be interpreted in a number of different ways. That in fact auditory functions may be more diffusely represented in the right than in the left hemisphere.

In an attempt to find non-verbal auditory stimuli Murphy (1969) used clicks because these stimuli reduced the role of attention and memory processes and permitted a more thorough investigation of ear asymmetry effects. She used 20 university students male and female aged 18 - 28 years. Pulses of 10 were delivered to one ear and white noise delivered to the other ear. The students were asked to discriminate between clicks delivered simultaneously and successively. The difference between ears was significant at the 10% level, the R.T. to stimuli presented to the left being significantly faster than the R.T. to stimuli presented to the right ear.

Handedness was analysed and there was no significant interaction between hands and ears.

In a further experiment she showed there was no difference between ears when students knew which ear was to be stimulated. She found however that the right ear showed a greater practice effect than the left ear.

In order to investigate the possibility that white noise accentuated the ear asymmetry effect she tested students with contralateral white noise and without contralateral white noise. She found that the difference between ears was greatest when contralateral white noise was presented with the clicks. These findings support Rosenzweig's hypothesis that there is a partial occlusion of the ipsilateral pathways by the presentation of binaural stimulation.

Murphy considers that her experimental results show that attention mechanisms play some part in the ear asymmetry effect but that division of attention is not a necessary condition for the demonstration of the ear asymmetry effect. She suggests that the signal detection tasks involve the use of pitch cues and that the smaller the contra-click interval of the signal the more the task approximates to a test of discrimination of non verbal auditory stimuli.

Luria also investigated perception and reproduction of pitch relationships and to do this he used only very simple tests. That is, he asked the patient to estimate the pitch of two notes. As well as investigating pitch, he explored the reproduction of rhythmic structures. He requested the patient to repeat rhythms by tapping them out. Results showed that in patients with lesions of frontal lobes, rhythm tapping was impaired. However, he is not very clear on the functional aspects relating to these tests. Feuchtwanger (1930) has shown that difficulty in perceiving pitch occurs in left and right temporal lesions and Schlesinger quotes Gelb and Goldstein's patient, a man with gunshot wounds to the left temporo-occipital lobe who was unable to recognise simple rhythm or to determine time intervals between two notes. He had no difficulty, however, in understanding spoken language.

Summary

We have seen that some biologists consider that brain duality may well be a system in obsolescence for man appears to be able to manage relatively well with only the dominant hemisphere.

Early case histories of patients showing poverty of auditory discrimination in understanding speech and musical sounds do not give consistent evidence as to hemispheric localisation. However there does appear to be a general acceptance with numerous exceptions to the rule that in right handed patients the removal of the left hemisphere may result in some disruption of speech function and that the removal of the right hemisphere may interfere with the detection and appreciation of musical sounds. If, however, lobectomies are performed before the child has achieved speech then the remaining hemisphere is able to achieve the function of both. But it must be remembered that the large series (Carmichael (1966), Wilson (1970)) which looked at post lobectomy cases drew attention to the fact that most of the patients operated on were subnormal and severely subnormal and thus their level of comprehension was very low. Any evidence offered by these patients as to hearing ability must be viewed cautiously.

When we consider the experimental work an auditory asymmetry there appears to be some evidence that under dichotic stimulation conditions the contralateral pathways are more efficient than the ipsilateral pathways. Ear advantages, however, are only significant under conditions of simultaneous stimulation. Kimura and Milner's evidence indicates some material specificity for both ears, namely that in the normal population the right ear is dealing more efficiently with verbal processes and the left ear is recognising more efficiently sensory material. However, despite Kimura's work there are a number of studies on a normal population as well as individual clinical case histories of patients after temporal lobectomies which question any differentiation of the hemispheres in auditory perception tasks. Recent work on non auditory stimuli using clicks have suggested that these signals could be valuable for the following reasons:

The use of clicks is a simple task, and the range of cues and strategies available to these is narrower. The problem of individual differences in musical experience is overcome and the role of perceptual phenomena rather than memory is accentuated.

CHAPTER VI

CHILD STUDIES

This particular study on auditory perception is interested to look at the normal, healthy development of auditory perception in children aged from five to seventeen. Although considerable attention and concern has been directed to unusual communication disorders in children (Alquin College Conference, York, 1970) and clinicians have been particularly interested in the effects of high and low frequency hearing loss in children, most developmental studies have been directed to looking at performances of retarded or learning-disturbed children.

The problems inherent in child assessment may be partly responsible for the scarcity of work devoted to developmental studies in audition. We shall mention only the most relevant papers relating to auditory perception.

Kimura (1963b) in her earliest study on speech lateralisation in young children used dichotic stimulation.

She presented pairs of digits simultaneously to both ears so that different digits arrived at the same time at the two ears. The subject reported what he had heard in any order. Results showed that children who had speech represented in the left hemisphere (WADA Test) gained higher scores and more accurately reported digits fed into the right ear. She found that boys were inferior to girls at five and six but not beyond that age.

Bakker reported (1968 and 1969.) ear asymmetry with monaural stimulation with children. There was left ear dominance for non verbal material for both the normal and learning-disturbed children. Furthermore, a trend for verbal material being better received and retained through the right ear was observed. These results may be considered rather striking since ear asymmetry subsequent to monaural stimulation has been rarely, if ever, observed (Kimura 1967 and Satz 1968). In his latest study Bakker (1970) has found that ear asymmetry subsequent to monaural stimulation depends on the length of the series (digits and sound patterns) and that lateral dominance as well as lateral awareness are related to the phenomenon.

Bakker argues that competition between the ears is not a necessary condition (Kimura, 1967) and that competition would rather seem to be one of the factors that determine the degree of ear-asymmetry. Bakker has also been interested to look at the relationship between ear-asymmetry and other forms of lateral dominance. Satz (1968) appeared to establish a relationship between hand preference and ear asymmetry and showed that between ear differences for verbal material were significantly greater with right handers than with left handers. This finding was supported by Curry and Rutherford(1967) Curry finding significant left ear preference for non verbal material with right handers but not left handers.

In this particular investigation Bakker used 175 girls and boys randomly selected of age groups varying from seven to thirteen. He tested for hand and eye dominance using the Harris Tests of Lateral Dominance. A total of eighteen series of digits and eighteen sound patterns were presented to each ear separately. Right and left ear series were selected on a random basis. There were six series of four digits, eight series of five digits and four series of six digits. Sound patterns were dots and dashes generated by a buzzer. Results showed that medium list lengths (five digits, four sound patterns) show the greatest between ears difference scores. The normal girls show a significant right ear dominance for verbal material, the normal boys do not. Overall groups show a strong left ear dominance for non verbal material. The relation between ear-asymmetry and list length is non-linear in nature, in dichotic stimulation the between ears difference scores become greater as the list length increases, i.e. the harder the test becomes.

With regard to hand dominance right handers showed a right ear dominance for verbal material, especially in the older age groups. Non right handers do not show a right ear dominance for verbal material. Right handers show a left ear dominance for non verbal material in the older age groups only. Non right handers show a left ear dominance for non verbal material in the younger age groups only.

Bakker also found a relationship between eye dominance and ear asymmetry. Non right eyed children did not show ear dominance for verbal material, although they did show to a lesser degree than right eyed children, a left ear dominance for non verbal material.

Bakker in discussing his results does make the point that his ear-asymmetry results may be due to the ordered recall rather than the free recall which is usually the condition used in dichotic stimulation. He suggests that none of the hemispheres has the exclusive capacity to mediate temporal order. Efron found similar results when asking subjects to indicate which stimulus was perceived first, e.g. the right or the left. Clearly verbal labels (perhaps mediated in the language area of the cortex) have to be applied in order to meet the requirement.

Perl (1970) showed that order in which right and left ears are stimulated may be a source of variance. He showed that the right-left ear scores for both verbal and non verbal material differed as a consequence of whether the right or left ears were stimulated first or last. Bakker (1970) analysed effects of ear order in a group of primary school children. The absolute values of right-left ear scores were analysed in a two (ear order: right first vs. left first) by two (material: verbal vs. non verbal) by two (sessions: first vs. second) design with repeated measures in the last two factors. Absolute factors were taken because they indicate the degree of asymmetry. Results showed neither ear orders nor sessions significant. Only factor material was significant showing a greater degree of ear-asymmetry with non verbal than with verbal material.

The right minus left ear scores with non verbal material were greater in the second than in the first session. As to verbal material, differences were about equal in two sessions.

Thus ear order did not show a significant effect on degree of ear-asymmetry. These results contradict Perl. However, the tasks were different. But the material by sessions interaction effect is comparable with Perl's findings. Perl found much greater right-left difference scores for non verbal material with than without binaural practice beforehand. In Bakker's paper right-left differences for non verbal material appeared to be greater in the second session than the first session. Why this practice effect occurs with non verbal material and not with verbal material is not understood. Piaget's theory that novelty facilitates learning processes may be relevant in this context.

Summary

In summary then there appears to be certain evidence to support the adult studies that children demonstrate some auditory lateralisation of function at an early age and that verbal stimuli are more efficiently attended to by the left hemisphere and non verbal stimuli are more effectively responded to by the right hemisphere both under conditions of dichotic stimulation and monaural stimulation.

Handedness is also related to ear differences. Right handers show a right ear dominance for verbal material, left handers do not show a right ear dominance for verbal material. The same is true of non verbal material. Right handers show a left ear bias for non verbal material and left handed children show a left ear preference for non verbal material at the early ages but not in the older age ranges.

CHAPTER VII

AUDITORY PATHWAYS

Before discussing the methodology used in the present experiments it would seem obligatory to devote some part of this study to the physiological concomitants of auditory perception. A study of the auditory pathways is strictly relevant to any experimental work in auditory perception for the assumptions made in an experimental model may neither be feasible nor realistic in the light of current physiological knowledge of the organisation of auditory fibres, nuclei and auditory processes.

The next section is thus devoted to recent work by neurophysiologists concerned with tracing the extent and influence of the different areas which go to make up the auditory system. The auditory system has many more relay stations than the visual processes and although there is general agreement as to some tonotopic organisation of the auditory cortex it is generally conceded that the auditory cortex is not nearly so clearly defined or systematised as the visual cortex.

What then are the major relay stations? We shall plan this chapter then by first referring to the different organs and anatomical areas which are considered responsible for hearing and then discuss the early theories, i.e. history relating to audition. From this will emerge recent work devoted to neurophysiological correlates of frequency and intensity experiments. Unless otherwise stated all the experimental work relates to animal studies.

It is traditional to consider the auditory pathways as commencing in the internal ear with the basilar membrane and its associated structure, because it is at this point that the acoustic signal which has existed as a pressure wave in bone, or aqueous medium is first recoded into a new form. Hair cells attached to the membrane vary in number from species to species, as does their arrangement. Birds have about 30 hair cells in a transverse row across the membrane, mammals only 4 or 5. In man there are one inner hair cell and 3 outer hair cells on the basal end of cochlea, at the apical end the number of outer cells is about 25,000 in man (Guild 1932), 12,300 in cat (Schubrecht 1960) and in the pigeon 15,000 (Stopp and Whitfield).

It is from these hair cells that the auditory nerve (8) originates. Radial fibres innervate the inner hair cells and each fibre has a termination on two or three adjacent cells. There are some 30,000 auditory nerve fibres and ganglion cells in man (Rasmussen 1940) and about 39,000 in cat (Schubrecht 1960).

The central ends of the auditory nerve fibres divide in a regular manner to send each a branch to the dorsal and the ventral cochlea nucleus. From the cochlea nucleus the fibres terminate in cell groups somewhere between the ponto medullary junction and the mid-brain. These are the cell groups which comprise the superior olivary complex. There is considerable variation in the relative size of the various components from species to species.

Despite numerous studies (Papez 1930, Rasmussen 1946, Stotler 1953) there is a good deal of uncertainty as regards the precise connections of the various members of the superior olivary nuclei. However, by combinations of transverse and longitudinal sections of the brain stem in conjunction with electro physiological recording, Jungert (1958) and Rosenzweig have shown that fibres cross over from the ipsilateral to the contralateral lemniscus via the reticular formation at all levels from that of the olive to that of the inferior colliculi. Jungert did show, however, that these fibres which crossed over did not recross at any higher level.

As well there appear to be considerable projections from the auditory system to the cerebellum. Snider (1948) and Jungert (1958) refer to auditory fibres reaching the cerebellum directly from the medulla but they do not define their origin.

Ablation studies have shown the widespread distribution of the afferent geniculo-cortical connections. Those projecting to the primary auditory area appear to come almost entirely from the anterior part of the nucleus (Diamond and Neff 1957). The posterior part of the nucleus, on the other hand, projects to the so-called insulo-temporal cortex, which is outside the 'true' auditory area.

In the light of these widespread connections it is questionable what should be considered as the 'auditory cortex'.

The Cochlea.

The cochlea itself consists of a fluid filled channel divided into three longitudinally by Reissner's membrane and the basilar membrane, or by analogous partitions in birds and reptiles. The cochlea is nearly always straight in these latter cases, but in mammals assumes the coiled form from which the name derives. The only functional reason for a coiled cochlea which has been put forward is Bekesy's 1953 (a) suggestion that the curvature of the tectorial membrane serves to limit its bending to a localized region. Although the frequency range of man with a 35mm cochlea (20 c/s - 20 kc/s) is clearly greater than that of the pigeon with a 5mm cochlea (40 - 4,000 c/s), yet the cat with a 22mm cochlea has a range from 40 c/s - 80 kc/s and the tonal discrimination is almost as good as in man.

The basilar membrane varies progressively in width and in stiffness from one end to the other (Bekesy 1947). Consequently any mechanical disturbance sets up a travelling wave which moves at a gradually decreasing velocity from the basal to the apical end. It behaves as a tapered low-pass filter so that low frequency components of a disturbance progress further along the membrane towards the apex than do high frequency ones. The work of Bekesy and the later experiments of Tasaki, Davies and Legouix (1952) discount any sort of resonance hypothesis and is the most powerful piece of evidence for ruling out such hypotheses.

Between the mechanical vibration of the basilar membrane and the discharge of nerve impulses in the cochlea nerve lie the transducer mechanisms. Little is known about these mechanisms. Distribution of the auditory nerve terminals in the cochlea of the cat has been studied by Retzius (1884) and more recently by Fernandez (1951) who showed there to be four different types of fibres. There have been great technical difficulties in making recordings of the afferent nerve fibres. Tasaki (1954) examined fibres in the cat arising in the basal region and found that these would respond to low frequency as well as high frequency tones. Kiang (1966) has published data on some 1,500 units obtained from the cat's auditory nerve in the anaesthetized animal. He was unable to find any behavioral criterion by which fibres could be divided into categories that might be related to inner and outer hairs or radial and spiral fibres. This means that the fibres themselves show several different types of response and in the absence of stimulation the fibres may be silent or discharging spontaneously. For a given frequency the rates of discharge of these fibres will vary according to their position in the array. Change of frequency will translate the active array and increase in intensity will widen the array and may add additional fibres within it, so that a change in stimuli will result not in an entirely different set of fibres being activated but in a change of 1% of the fibres, the other 99% remaining common to both situations.

What is the physiological evidence for laterality?

There seems now plenty of evidence that afferent fibres come predominantly from the contralateral side at the level of the superior olives.

Tsuchitani and Boudreau (1966) have clarified this organisation and Galambos et al (1959) found that 80% of the afferent units were activated by contralateral stimulation. In general those units which responded to contralateral stimulation did not respond to ipsilateral stimulation and vice versa. In single unit studies Galambos et al (1959) found that 30% of units were activated by contralateral stimuli. These tests were carried out in cats with both clicks and tones and again a differential response to the two types of stimuli were observed.

Hall (1964) in studying the properties of single neurones in the cat to binaurally presented clicks, found that some units would respond to clicks presented to either ear. Of these the majority showed summation of response when stimuli were presented to both ears, the summation being greatest when the two clicks were presented simultaneously. However, a few showed a 'cyclic' type of summation in which the degree of summation went through successive maxima and minima as the interval between the stimuli was progressively changed.

Moushegian, Rupert and Whitcomb (1964 a) report units which were activated from the ipsilateral rather than the contralateral side but these appear to be less common than those described by Hall.

Hall observed an intensity effect which recalls the 'time/intensity trading' effect. If the click intensity is the same at the two ears then the response diminishes as the ipsilateral click is advanced in time relative to the contralateral click. If the relative timing is held constant, then the response increases as the ipsilateral click is made relatively less intense. Whitfield considers that the effect of intensity may be due simply to a change in latency affecting the time of arrival at the nucleus. Galambos et al (1959) found that latency decreased with increasing intensity.

The response of the accessory nucleus to tonal stimuli has been investigated by Moushegian, Rupert and Whitcomb (1964 b). They found that units may be bilaterally excited, or excited by one ear and inhibited by the other. The frequency response areas for the two sides were approximately the same but not identical. The units which were examined appear to have contained a higher proportion of ipsilaterally excited / contralaterally inhibited neurones than vice versa but since the sample was small (8 units) it is impossible to say whether tonal responses really differ from click responses.

Patterns of Neuronal Discharge.

Rose et al (1963) have described the firing patterns of neurones in the inferior colliculus. It appears that successive but otherwise identical stimuli produce different responses, although having some features in common.

The basic pattern is one in which a 'silent period' follows an early response followed again by a sustained discharge.

Hird, Goldberg, Greenwood and Rose (1963) showed that where a unit had an onset burst, the latency to the first spike was very stable and was a monotonic function of intensity. The initial spike latency decreased with increasing stimulus intensity.

Binaural Stimulation.

Research has been devoted to the binaural interaction at cells of the inferior colliculus because of the possible reflex involvement and sound localisation. Erulkar (1959) and Hird (1963) found that some units could be activated by tones presented to either ear, though there might be some disparity between the best frequencies on the two sides (2,900 - 3,100 c/s).

When one ear is stimulated and there is excitation of a neurone in the colliculus, a stimulus delivered to the other ear alone may produce in the same neurone either excitation or no discharge at all. If there is stimulation the spike counts (Hird et al 1963) are smaller for an ipsilateral than for a contralateral stimulus. Stimulation of both ears produces a larger effect than stimulation of either ear alone. Erulkar (1959) showed that however if the first stimulus precedes the second by an interval of more than 4 milliseconds, response to the second stimulus is completely suppressed and that this interval can extend to as long as 120 milliseconds before suppression fails. Summation occurs only for intervals less than 4 milliseconds. Hird found that when stimulus of one ear produces a discharge and the other ear does not, binaural stimulation may produce a significantly lower spike count than when the effective ear is stimulated alone. Thus stimulation of the ineffective ear produces an inhibitory effect. Hird (1953) showed that usually the effective ear was the contralateral one, though for some neurones the reverse was true.

The effects of binaural stimulation on the discharge pattern then are variable. Erulkar (1959) in moving the click sound from one side of a cat's head to the other found the latency progressively increased and Hird (1963) had the same results with tone bursts. Thus although stimulation of the ipsilateral ear produces effects (shorter latency and increased discharge) in the initial firing of the nerve cells, its effect on the sustained discharge is inhibitory. Thus it seems that there is no pattern between stimulus parameters and pulse distribution results.

Frequency Discrimination.

There is good evidence to suppose that monaural frequency discrimination is possible. Work in this field has suggested that the majority of frequency discriminating units may be connected only to one ear for it has been shown that few binaural units are excited by stimuli from either side. Erulkar (1959) has reported a number of units having a response of 1,980 - 3,400 c/s on the ipsilateral side and 1,900 - 3,700 c/s on the contralateral side. Hird (1963) similarly showed a unit where the range of frequencies was nearly but not quite coextensive on the two sides. There is little quantitative data to show the proportion of neurones on the colliculus which are under binaural stimulation. The medial geniculate body unlike the inferior colliculus does not appear to have any tonotopic organisation. Its connections with the cortex and its specific role in audition is still unknown.

The Auditory Cortex.

Although we know that the inferior colliculus is a significant structure in audition, the role of the auditory cortex, its extent and position is much less certain. Part of the nucleus appears wholly auditory and at the cortical level there appears to be 90% of a very small area which is almost purely auditory. However, there are extensive regions surrounding this small area which appear to be less concerned with audition.

How does one delimit the auditory areas? Various methods have been used and one which has proved fruitful is the procedure based on ablation studies.

Diamond and Neff (1957) showed that ablation of the primary auditory area (A1) produced severe retrograde degeneration in the cells of the principal nucleus of the medial geniculate body. Also Diamond, Chow and Neff (1958) found that removing the insular-temporal cortex caused diffuse degeneration in the posterior part of the geniculate body. Another method employed has been that of electrical stimulation of different areas in the auditory cortex. As early as 1876 Ferrier showed that in small mammals (cat, etc.) stimulation of the ectosylvian region had evoked movements of the animal's head and ears as if it was attending to a sound. Bremer (1939) recorded electrical responses to clicks and tones.

However it was not until Woolsey and Walzl's (1942) heroic detailed anatomical study that there was real evidence of point to point projection of the cochlea on the auditory cortex.

Two years later Tunturi provided direct evidence (in the dog) of orderly representation of frequency in the cortex. He utilised 'tone pips' and the result of his experiment was to map a number of overlapping areas for frequencies between 100 and 16,000 c/s. Hird (1953) confirmed Tunturi's results using the same technique in the cat.

However this tonotopic organisation was brought into question by Erulkar, Rose and Davies (1956) and subsequently by Evans and Whitfield (1964) who carried out extensive studies of single units on the anaesthetized auditory cortex of the cat. They showed that many units could not be made to respond to tones at all and that it was impossible to assign any particular characteristic frequency to them. However, the disparate results of these various experiments may be due to the particular technique which Tunturi employed (profound anaesthesia and strychninisation) and also the possibility that the auditory cortex of the dog may be anatomically somewhat different from the cat. It is possible that the techniques used showed the organisation of the underlying fibre pathways rather than the cortex itself.

Butler, Diamond and Neff (1957) and Neff (1960) have shown that the auditory cortex is unnecessary for frequency discrimination but essential for the discrimination of temporal patterns of stimuli (sequential patterns).

Whitfield and Evans (1965) have isolated cortical units which are able to distinguish the orientation of a changing stimulus.

Frequency and Pitch.

Whitfield (1967) makes the interesting comment that from earliest times man has been intrigued with the mechanisms of pitch discrimination at the expense of the much more important understanding of animal and speech sound patterns. He thinks that this may be due to man's familiarity with musical instruments and his need to find physiological analogues in the receptor mechanisms. Perhaps it is man's earliest experience of music with its arrangement of pitch sounds in a pleasing sequence which has determined his direction of interest.

HISTORY

Interpretations of Mechanisms of Hearing.

For over 1,200 years the ear was thought to contain air and it was this implanted air which was the main key to hearing. Bauhin in 1605 suggested that the cavities of the ear may be responsible for resonance but Du Verney (1683) initiated the selective resonance theory which dominated thinking for the next 180 years. Over the next 100 years his theory was modified so that the cochlear partition was included and seen as a vibrating structure. The compound microscope in 1830 gave impetus to anatomical investigation of the inner ear, and Helmholtz revived these early resonance theories rather than initiated them.

Ohm's Law of 1843 gave further impetus to the study of frequency discrimination. The law briefly stated that any periodic complex sound wave could be represented as the sum of a number of sinusoidal frequency components (single tones) suitably combined. Thus hearing was seen to be reduced to recognition of individual frequencies. Helmholtz linked this theory with the idea of cochlea resonators. He suggested that there was one resonator for each discriminable tone and that each was connected to the brain by its own individual nerve fibre. For the next half century work was directed towards isolating these specific resonators and the rods of Corti were proposed as the responsible resonators but it was soon seen that the number of these were insufficient for the theory to be credible. Next the transverse fibres of the basilar membrane received attention but these were likewise insufficient in number to support the theory. However, the resonator hypothesis is untenable since the vibrations of the basilar membrane exhibit properties incompatible with the existence of individual resonators. The 'volley theory' which states that each cycle of sound wave elicits a response in at least one fibre in the array so that the stimulus frequency is represented in the combined pattern was devised to overcome the objections to the classical 'telephone' of Rutherford (1886). The latter had suggested that frequency was signalled directly in terms of pulses/sec. but this theory did not stand up when it was shown that a nerve fibre cannot carry more than 500 or 600 pulses per second. The volley theory theoretically surmounted these difficulties. But the general weight of evidence indicates that though information about the stimulus frequency is available over part of the frequency range in the form of intervals between nerve impulses, this is an epiphenomenon which is not made use of by the nervous system for stimulus for query identification. In seeking to interpret the auditory codes it is imperative to distinguish between what is <u>information</u> for the nervous system and what is information for the experimenter. To sum up then, it can be shown that frequency analysis is not a peripheral phenomenon in the sense that one fibre or group of fibres is uniquely activated by a specific tone (Helmholtzian). Neither is the telephone hypothesis tenable and there is good evidence against it even as a mechanism for low tones. The extensive work of Bekesy (1947) and his colleagues has established beyond reasonable doubt that activity in the form of mechanical vibration spreads progressively along the basilar membrane from the basal to the apical end as the stimulating frequency is lowered. Bekesy's work on the vibration patterns of the basilar membrane shows then that the system is behaving as a tapered low-pass filter. Each frequency gives rise to a unique pattern and this contains the necessary data to define the frequency and intensity. The threshold/frequency response curve of a single auditory nerve fibre reflects the vibration amplitude envelope of the basilar membrane. Moushegian, Rupert and Galambos (1962) have shown that units in intact animals will respond to wide ranges of frequency at moderate intensities. It follows then that a given stimulus excites many auditory fibres. However, it is possible that the positional selectivity which most workers have been seeking, occurs at a higher level in the nervous system. Despite considerable work on the threshold/frequency response curve of units at all levels from the cochlea nucleus to the cortex, no experimental work has shown any narrowing of response areas at the higher centres and in fact (Whitfield 1967) wider response areas are found at the cortex than at the cochlea nucleus. It seems fairly clear then that the effect of any single tone stimulus is to activate a considerable fraction of the fibres in auditory pathway at all levels and that a high proportion of these fibres will be activated by other frequencies which the whole system can discriminate from it.

One of the striking features of the auditory system is that the mean pulse rate for a given stimulus falls progressively the higher we ascend the system. Hilali and Whitfield (1953), Hird et al (1963) demonstrated this discharge rate for units of the trapezoid body and inferior colliculus respectively. Allanson and Whitfied (1955) considered in detail the relation between the structural arrangement of the cochlea nucleus and the input/output relationship and drew attention to the role of inhibition in effecting this change. The effect of the inhibiting network is to produce the steep intensity/response-rate relationship near threshold. Their work was further supported by Greenwood and Maruyama's (1965) work.

Mutual Distribution.

If two tonal stimuli are sounded simultaneously and are close together in frequency then the activity pattern in the nerve array will overlap. However, if we transfer this pattern via the 'squaring' mechanism of the cochlea nucleus there will be a single block of active fibres covering the active array. One would suppose that some of the fibres in the middle of the array are activated by either tone separately, are inhibited when both tones are sounded together and drop out. Thus an 'inhibitory gap' is produced and the identity of the two stimuli preserved.

It seems then that in elaborating a sensation from a given auditory input the system behaves serially. The number of choices which can be made at any given instant on the basis of the transmitted information is not large, and the choice is made within the limits set by stored information about what has gone on before. The choice is limited because of immediate experience (just received information) and of past experience (information).

In 1958 Fry and Denes constructed a machine which would convert spoken English into typewritten text. They broke up the frequency spectrum of speech via a microphone and suitable band-pass filters into 1/3 octave bands. They thus had 18 channels which could measure the activity or inactivity produced by successive speech sounds. They also stored in the machine's memory information about the nature of English so that it could relate these inputs to the speech sounds. They did this by storing the formant frequencies of the sounds and also the transitional probabilities of letter combinations, i. e. the probability of "i" being followed by "n" was 0.23 whilst the probability of it being followed by "l" was 0.02. Thus the machine structure, the comparatively small information flow in its 'input' channels in terms of English language and the resultant output had a high degree of accuracy. It would seem that the nervous system works along a parallel method. It uses the incoming signal to select the most probable from a limited number of possibilities based on its past experience. This of course explains why it is possible to construct more than one input signal which will give rise to the same probability decision - such as occurs in sensory illusion.

The frequency/intensity pattern in the auditory pathway we have seen extends as far as the inferior colliculus. Beyond this spatial aspects of the pattern appear to be found. Tonotopic arrangement is not the rule in the medial geniculate or in the primary auditory cortex.

Ablation animal studies have shown a number of inconsistencies in their results. If after training followed by ablation of a specific area, there is no change in the response it is possible to conclude that the region was not essential in the behaviour pattern. If, however, behaviour is lost, it is difficult to say whether the discrimination or the response have been affected. Even retraining procedures may infer that one part has taken over the role of the ablated region.

Thompson (1959) has pointed out that although a cat can learn to distinguish between two tones of different frequencies it takes 1,000 trials to do so. If, however, it is offered a neutral stimulus of eight tone pips of one frequency and an avoidance stimulus of a similar number alternating between the two frequencies it takes 600 trials to learn the response. However, if the tone to be discriminated is presented against a background of the first tone then the response can be learned in 120 trials. The relationships of the stimuli to the response required is also important. Diamond, Goldberg and Neff (1962) found that when the alternation was the avoidance signal and the single tone the neutral signal then the discrimination could be learned in about one third of the number of trials which were necessary if the signals were interchanged.

These sorts of signal experiments have been used in ablation studies of frequency discrimination.

Allen (1945) using the single tone signal found that dogs could not relearn this discrimination after any of several auditory ablatives. Meyer and Woolsey (1952) using an alternative method found that cats could perform just as well after a complete bilateral cortical ablation of auditory areas as they could normally. However, if the 'second' somatic (S11) area was removed the response was lost and could not be relearned. Nevertheless cats can learn the 'tone versus background' discrimination in the absence of the whole of the auditory cortex (Goldberg, Diamond and Neff 1958), (Diamond, Goldberg and Neff 1962). Therefore we seem justified in concluding that the cortex plays no part in discrimination ability since the most accurate discrimination which the animal can make can be carried out without the temporal cortex. On the other hand, discriminations requiring assessment purely of a change in frequency with time needs some part of the primary or secondary auditory area. (Evans, Ross and Whitfield 1965). These workers showed tonotopicity to be entirely absent in the primary auditory cortex of the cat and concluded that this area was most likely not concerned with frequency discrimination. Whitfield and Evans found numbers of units in this region which were responsive to changes of frequencies and were in fact frequency orientated, i.e. they responded to a rising tone but not to a falling tone in the same frequency range. There is thus electro-physiological evidence for just the kind of temporal pattern sensitive units which could be required by the behavioural findings.

Feher and Whitfield (1966) found cortical units which would respond only to a tone changing in frequency presented against a background of a steady tone.

A recent paper published by Goldstein et al (1970) investigated the functional properties of cortical cells in cats using the single unit technique and an anaesthetised muscle relaxed preparation. Previous work has discussed the columnar organisation according to depth. In order to say that the auditory system is tonotopically organised one must demonstrate an orderly change of best frequencies (B.F's) with change of position (Evans E.F. and Whitfield I.C. 1965) (Hird J. et al (1963), Rose J.E. et al 1963). Goldstein's results were in agreement with Hird and Evans. Experiments showed that the characteristic frequencies of units was a function of distance in the posterior-anterior direction. There appears to be a qualitative difference between tonotopic organisation of sub cortical structures and of the primary auditory cortex. Units with high frequency are usually found in the anterior region of A (primary auditory cortex) and seldom found in the posterior region and the situation is reversed for units with low frequency. For mid-range B.F. there is much overlap. If we ask what region of the primary cortex is responsive to moderately intense tonal stimuli of a given frequency we find the representation to cover most of the auditory cortex for all frequencies except at the extreme ends of the cat's auditory spectrum. Goldstein's study failed to reveal any organisation related to depth in the cortex. Thus the auditory cortex seems to be different from the somesthetic and visual cortices in that it is less tightly organised.

Studies in Man.

Bilateral damage to the temporal cortex in man sparing underlying areas is comparatively rare. Schneider and Crosby (1962) studied a case of vascular damage to the auditory cortices (which at post-mortem showed that the underlying areas were not entirely invaded). The patient had marked bilateral hearing loss and was unable to understand speech, although he was able to co-operate and comprehend if communicated with by writing. He also recognised differences in the pitch of tones.

Attention was drawn earlier to the possible relation between the characteristic formant frequencies of vowels and the patterns of activity in the auditory pathways. It is evident then that recognition of direction of frequency change is the important factor in making the distinction between speech sounds.

Intensity and Loudness.

The intensity of a sound seems to be signalled in terms of the number of active fibres in the total array, although discharge rate obviously plays a part at lower neural levels. Raab and Ades (1946) showed that the intensity difference limen (DL) for 1,000 c/s in the cat is about 2 db. Cats were trained to make this discrimination and then the auditory cortex was bilaterally ablated. Discrimination was lost but the cats could be retrained to have the same DL as before. Also if the inferior colliculi and the efferent pathway were destroyed, the discrimination was again lost. Again retraining could restore the DL but the discrimination was much poorer with DL raised to 10 or 12 db. One might conclude that the inferior colliculus is the central factor in the discrimination, but when Raab and Ades ablated the inferior colliculus whilst leaving the system otherwise intact, they found no loss (even temporarily) of the discrimination. Thus we are left with the possibility that the ascending pathways via the geniculo-cortical system are utilised in discrimination. It seems clear then that the discrimination of normal intensity sounds need not involve the cortex and that some degree of discrimination may be at sub-collicular level. However, the role of the centrifugal pathways has not been clarified yet.

What then is our knowledge of the principles underlying sensory neural mechanisms? Neurophysiologists have for a long time been obsessed with the idea that each neurone or group of neurones in a particular place must respond uniquely to a particular stimulus or as Whitfield (1963) says, the 'where' idea.

To summarise:

1. All sensory inputs involve activity in a large area of the array and any behavioural output (albeit a motor response) involves a great number of channels and routes.

There is no reason why stimulus and response should be linked through channels kept uniquely for that purpose and it would seem wasteful if this were so.

2. The second principle is economy of information in the time domain. Sensory pathways do not appear to have a very high informational capacity, compared with the potential data in the signals with which they deal. It is possible that the nervous system finds it economic to store large amounts of data about the transitional probabilities of events within its experience and to assess the crude inflow in terms of these probabilities. In this way the channel input is economically utilized in signalling those aspects which are relevant to the particular state of the organism, and is not wasted in describing useless features of the input. Disadvantages of this approach are that sometimes the wrong answer is given, viz sensory illusions.

3. The third principle is that of 'gating'. Some experiments on ablation and behaviour are only explicable in terms of a possible direct potential connection between sensory input and the motor output at the brain stem level and this connection operates or does not operate according to whether the gate is opened or not opened by the centrifugal fibres forming part of a second 'discriminatory' loop.

What are the changes involved in the mechanism of learning? Are they inter-cellular or intra-cellular or both, for this is the key to the nature of the system of stored information.

The problem of storage is linked to our ignorance concerning the behaviour of individual neurones. The 'billiard-ball' neurone, which is a system of algebraically related inhibitory and excitatory synapses determining an all-or-none output may be a useful model for some neurones but it is clear that it is not applicable to the majority of neurones.

The complexity of the problem eludes us every time a yet smaller sub-unit of the nervous system is examined - for we find that a behavioural model of the black box makes little contribution to our understanding of the mechanism.

The ground which has been covered in this chapter is essential for the understanding and the interpretation of the results in the present developmental study, and frequent reference will be made in the discussion (Part 2) to the experimental work carried out by neurophysiologists and discussed in this last chapter.

CHAPTER VIII

METHODOLOGY

Aim

To attempt to explore the extent and nature of left and right hemisphere functioning and its development it was decided to compare the right and left ear performances of 64 children ranging in age from 4½ years to 18½ years.

The selected experimental tasks were of two kinds:

a) verbal
and b) sensory.

Sample.

Sixty-four children (32 boys, 32 girls), ranging from five to eighteen years were selected to take part in the experiments. As the Heston Hearing Clinic was used for the experiment the children were mainly resident in the environs and attending local primary and secondary schools. The project was discussed with the Heads of each school and the final selection was made by them. It was stressed, however, that we required children with no known neurological deficit, without colds, catarrh or hayfever and that the range of abilities and intelligence should be normally distributed within the group. Parents were circularised and the proposed research discussed. Over three hundred parents were contacted before the required number of children were obtained. Each child was paid five shilling for his co-operation. The final group of children was of necessity a pre-selected one as one suspects that only the conscientious, socially orientated parent volunteers for experimental research work of this nature.

The sixty-four children fell into four age groups, determined by birth date at the time of the experiment.

Age group 1 comprised 16 children ranging from 5 - 7½ years (8 boys, 8 girls).

Age group 2 comprised 16 children ranging from 8 - 10½ years (8 boys, 8 girls).

Age group 3 comprised 16 children ranging from 11 - 13½ years (8 boys, 8 girls).

Age group 4 comprised 16 children ranging from 14 - 18 years (8 boys, 8 girls).

Experimental Tasks.

1) Verbal Tasks.

The verbal material consisted of word strings varying between a random collection and normal English prose, and at an intermediate level, statistical approximations to English prose. The choice of this type of material has been based on the findings of Miller and Selfridge (1950) who were concerned to find out how well people remember sequences of symbols that have various degrees of contextual constraint in their composition. The experimental literature testifies to the fact that nonsense is harder to remember than sense. (And, more surprisingly, that the memorability of different type of nonsense varies in an orderly way).

They accordingly drew up lists of different order approximations which were given to subjects to recall. Results showed that there was a substantial increase of material recalled as the order of approximation increased. The material recalled decreased as the length of the list increased. Two variables emerged - length and order of approximation which in fact interacted. Marks and Jack (1952) followed up the Miller-Selfridge experiments which they felt were open to criticism because there was (i) no control group and hence their ten subjects may have shown practice effect, and (ii) the method of scoring: Marks and Jacks considered that the score should relate to the longest segment of words correctly recalled and not the number of correct words recalled, also (iii) the textual material was misnamed in that parts of more than one sentence appeared in the longer lists. Marks and Jacks' study attempted to modify these errors. Eighty subjects were used and assigned at random to four groups (equal males and females). Second, third and fifth order approximations were used for three of the groups and fully textual material for the fourth group. The textual material was chosen from novels. All material was wire recorded. Subjects were required to repeat the words in the exact order in which they heard them. Failure was defined as any omissions, inversions, or additions or a word or words. Subjects score was the number of words in the longest segment he was able to recall correctly. The results showed that order of approximation significantly affects the ability to recall.

In this project selected verbal material was selected because of the inferences arising from Miller's and Selfridge's original experiments. By so doing we hope to discriminate certain perceptive and recall features which may be central to the auditory perception problem. Also by using sequences of symbols that have various degrees of contextual constraint in their composition we hope to look at the assumption that the left hemisphere is more involved in the comprehension of language than the right hemisphere.

Mark's and Jack's scoring method has been adopted in this present study.

The Three Verbal Tests selected were:

1. Approximation 1 words
2. Passage of approximation 3 material.
3. Textual material.

No. 1 was of first order approximation, consisting of words weighted for frequency, which were selected from books in Swiss Cottage Children's Library. (Cambridge randomised tables were used to identify the particular book, page and word.) Words were offered in a monotonous speech pattern with a pause of one second between each word. The test comprised five separate memory sequences of increasing list length offered consecutively with a long pause between each list length for recall. First list length comprised two approximation 1 words, second four, third six and so on. See Appendix.

Approximation 3 material was achieved with the help of children aged five to nine years resident in the Hospital for Sick Children. Two words were offered to each child and he was requested to complete with a word of his own. Various problems were noted when the material was gathered in so far as the children at the early age range frequently offered clang associations, repetitions or substitutions of the last word rather than a meaningful sequence. There were also a number of nonsense words unrelated to the stimulus words. However, as the material was intended for children of just this age range it was decided that the resultant word salad may well have some meaningful significance and the text was retained intact.

Miller and Selfridge have commented that "if the nonsense preserved the short range associations of the English language that is so familiar to us, nonsense is easy to learn, and thus it is familiar dependencies rather than meaning per se that facilitates learning."

The material was offered in the same manner as for approximation 1, i.e. the first message comprised four words, the second message six words, until the list increased to sixteen words. There was a long pause between each message to allow time for the child to respond verbally. This silent interval of tape avoided the noise interference of having to stop and start the tape recorder after each response.

Textual material was a prose extract, selected randomly from four children's books.

The selection was offered as for approximation 1 and approximation 3, and the child responded after each group of stimulus words.

2. The Experimental Sensory Tasks.

The non verbal material consisted of short sensory discrimination tasks using pairs of stimuli differing in pitch, loudness and at a more complex level, rhythm, as well as a task of tonal discrimination.

The four sensory tests were edited versions of Seashore's Tests of Musical Appreciation.

1. Pitch Test
2. Loudness Test
3. Rhythm Test
4. Tonal Memory Test.

1. Pitch Test

In this test pairs of tones were presented. In each pair the listener was asked to decide whether the second tone was higher or lower than the first tone. The stimuli were derived from a beat frequency oscillation through a circuit producing pure tone lacking in harmonics and overtones. The tones were about 500 cycles and had a duration of .6 secs. each. The frequency difference between the tones in the pairs were as follows:-

Example 1	2 tones with a 40 cycle difference
" 2	" " " " 30 " "
Test Proper (1)	2 " " " 17 " "
	2 " " " 12 " "
	2 " " " 5 " "
	2 " " " 4 " "
	2 " " " 3 " "

2. <u>Loudness Test.</u>

Seven pairs of tones were presented. The child was asked to indicate for each pair whether the second tone was stronger or weaker than the first. The stimuli were derived from the same apparatus used for the pitch test, but the frequency was held constant at 440 cycles. The intensity differences between the tones in the pairs were as follows:-

Example 1.	showed a 6 decibel difference
" 2.	" "" " "
Test Proper (1)	2 tones with 4 decibel differences
	2 " " 2.5 " "
	2 " " 1.5 " "
	1 " " 1 " "

3. <u>Rhythm Test.</u>

Six pairs of rhythmic patterns made up the rhythm test. The child was asked to decide whether the two patterns in each pair were the same or different. The source of the stimuli was a beat - frequency oscillation set at 500 cycles. Tempo was constant at the rate of 92 quarter notes per minute and the particular rhythm items selected were as follows:-

1st example	4 notes in 2/4 time
2nd example	" " " " "
Test Proper	3 items of 5 notes in 2/4 time
	2 " " 6 " " 3/4 "
	1 item " 7 " " 4/4 "

4. Tonal Memory.

This test had in all five items. A Hammond organ was used as the stimulus source. The 18 chromatic steps upward from middle C were used, tempo was carefully controlled and intensity was constant.

1st example	2 phrases of 3 tone span
2nd "	" " " " " "
Test Proper 1	2 phrases with 3 tone spans
2	" " " " "
3	" " " " "
4	" " " " "
5	2 phrases with 4 tone spans.

In each pair one note was different in the two sequences and the child was requested to count and identify which note was changed.

Parallel Forms of Experimental Tasks.

Two distinct but parallel forms (Forms 1 + 2) of the verbal and sensory tests were devised and each form had 2 different orders of the material. Thus 4 different tapes were used in the experiment.

The verbal material for Form 2 was gathered in the same manner and from the same sources and only differed in content from that described for Form 1. The sensory tests were selected again from edited Seashore material and maintained the same decibel frequency, rhythmic pattern and tonal memory spans as the original form.

In the analyses of results these forms were regarded as equivalent.

Instruction.

Prior to the main test each subject was given practice with some preliminary examples. (See Appendix 2 for tapes). They were subsequently offered no further help or correction.

Method of Child Testing. (Subjects)

Appointments were sent to the schools so that two children would arrive at the same time. The age and sex of the children in the total groups was randomised in testing so that any wearing of the tapes would be spread evenly over the whole age range. Audiometry on every child was carried out before auditory testing commenced. Every child was seen individually and asked a number of questions relating to age, class and handedness, etc., (see Appendix C) and the testing procedure was discussed with him in a friendly, informal manner. No child showed any apprehension and the majority appeared to enjoy the proceedings. Each ear was tested separately. There was a rest of forty minutes between recordings on each ear whilst the second child was being assessed.

The ear order and the forms used in testing were randomised for each group.

White noise used as a counter balance at times had to be adjusted with the younger age groups from the decibel level previously agreed upon (Mark 5,4) as some of the smaller children considered it to be an irritant and were distressed by it. The experimenter had to accept this condition and considered that this may have been a variable the consequences of which could be significant.

It was clear in a number of cases that the younger, duller children did not understand the instructions and in tests of discrimination and judgement many were unable to respond at all. Notwithstanding this, all children received the same test conditions irrespective of age and intelligence. Testing was only interrupted if headphones required adjusting in terms of fit, or ear muffs became uncomfortable in the heat (there were several hot days) or the child felt unwell. A number of the younger children were inattentive and several distractible and it was obvious that responses were purely random. However, these are the predictable hazards of testing any group of very young children.

Test Conditions and Equipment.

Children were seated in a sound-proofed room in a comfortable arm-chair. Two Uher tape recorders, one (A) supplying the recorded auditory test material (see appendix) the other (B) supplying white noise, were connected to stereophonic headphones which were then adjusted to fit the individual child. An independent lead from the tape recorder A enabled the experimenter to monitor the procedure. Half the children in each age group, i.e. four boys, four girls, had the right ear stimulated first by the test material and half had the left ear stimulated first by the test material.

On each ear half the children had Form 1 first and half Form 2.

Some reference should be made to the quality of the recording on A and B tape recorders. Although it had originally been decided to maintain the volume at a certain level, 64 db., there were occasions when the volume was altered to 62db. or 66 db. Several of the children, although showing normal audiometries, requested the volumes to be decreased or increased. It may well have been that in these cases there were marginal hearing losses and in fact some of these children were subsequently found to do badly in "loudness" and "pitch" tests, or it is possible that a few were incubating colds and had some prodromal symptoms relating to loss of acuity. It should be remarked here that normal audiometry is a gross measure of auditory functioning, especially in young children. Bearing in mind these cautionary factors relating to children with so-called normal audiometries, one would hope that the group finally selected did not demonstrate any marked unilateral or bilateral hearing loss.

N.B. The normal threshold of hearing for pure tones is referred to as 0 db. but losses up to 20 - 25 db. are assumed not to be significant.

Results Part II Chapter 9

LIST OF TABLES

LIST OF TABLES

RESULTS

Scoring Methods

The second part of this study will deal with the results which were gained by our children during their testing sessions. We derived a laterality index $\frac{R-L}{R+L}$ for every test which the child undertook, where R stands for correct right ear scores, and where L stands for correct left ear scores. In the verbal tests a subject's score was derived from the number of words in the longest segment which he was able to repeat correctly. Inversions, repetitions, omissions and additions of a word or words counted as errors.

In the sensory tests the final result was the number of correct items scored for each test.

There were several children in the first age group who were unable to respond to the Tonal Memory test and the Rhythm test and for whom no score was achieved. Reasons for non-response may have been several. It is possible these children did not understand what was required of them or when they did answer the responses were incorrect and hence no final total score was achieved on either ear.

In order to complete an analysis of variance on the total group it was necessary to give these non-responders a laterality index, and it was decided for statistical reasons to substitute the blanks by a laterality index which was derived by a 1st order regression procedure. The values estimated change with the shape of the matrix; since the technique treats the matrix as a regression type observation matrix, each row is an observation - each column is a variable.

Table 1a shows the distribution of missing laterality indices (resulting from a total failure to score on either ear) on the 7 tests in the 4 age groups. The missing laterality indices are marked as a dash, thus -. All the tables show missing laterality indices marked in this way. Where a child gains equal scores in both ears the laterality index is marked as a zero, thus .00.

The other tables which refer to raw scores and not laterality indices show the number of missing observations scored in each age group. Missing observations in these tables refer to the number of occasions on which a child failed to make a score either on the right or the left ear. However if a child made a score on one ear alone, a laterality index was still computed for him as follows:- $\frac{R-L}{R+L}$. (* N.B.)

In Tables 11 and 12 the missing laterality indices have been estimated by the first order regression as described above and included in the calculations. All the other tables show "real" observations and not estimated missing values.

The assessment of handedness and eyedness involved asking each child to demonstrate his hand and eye preference for the objects listed. Lateral awareness was assessed by asking the child to point to his left foot, right hand, left ear and right eye. All 64 children gained 100 % lateral awareness.

For a child to be designated as <u>left handed</u> only those children who preferred the left hand on all tests, and were left eyed and left footed were included in the left handed group.

* N.B. A score of zero was used in the formula when there was a missing observation.

Missing Laterality Indices.

Table No. 1a shows the distribution of missing Laterality Indices for 9 children. It is clear from the table that test No. 4 (Tonal Memory) produced the greatest number of failures to score. It will be remembered that this test is possibly the most difficult of the sensory tests in that children are required to remember a particular sequence of notes and to recall which note of the sequence has been changed when the sequence is replayed. A correct response demands not only the ability to remember the tonal pattern but the ability to discriminate specific tonal changes. This test is possibly the most intellectually demanding of all the sensory tests.

TABLE NO. 1a

DISTRIBUTION OF MISSING LATERALITY INDICES (DESIGNATED BY -) FOR SPECIFIC CHILDREN ON PARTICULAR TESTS IN THE AGE GROUPS

			L		P		R		TOM		A_1		A_3		TEM	
AGE GROUP	CHILD NO.	TESTS:	1		2		3		4		5		6		7	
		SEX:	M	F	M	F	M	F	M	F	M	F	M	F	M	F
1	1							-		-						
	2									-						
	10									-						
	*11		-													
	12								-							
	14								-							
2	17						-									
	28								-							

* indicates the left handed child

RESULTS

Equivalency of Forms

Table 1b sets out the raw score totals on all 7 tests for Form 1 for each age group.

Table 1c sets out the raw score totals on all 7 tests for Form 2 for each age group.

Table 1d shows that Form 1 scores sum to a total of 2,396, and Form 2 scores sum to a total of 2,386. The total number of raw scores which all the children could have obtained if all responses were correct was 4,480 on each Form.

The results of Table 1d indicate that both forms were comparable in content and degree of difficulty.

TABLE NO. 1b

SUBJECTS RAW SCORES SUMMED FOR EACH AGE GROUP ON ALL TESTS FOR FORM 1

AGE GROUP	TESTS:	L	P	R	TOM	A_1	A_3	TEM	TOTAL
1 N = 16		49 (3)*	64	54 (3)	29 (6)	58	78	108	440
2 N = 16		62	74 (1)	88	49 (2)	78	102	133	586
3 N = 16		91	78 (1)	95	68	88	114	151	685
4 N = 16		89	81	87	66	82	116	164	685
TOTAL:		291	297	324	212	306	410	556	2396

* The number of missing observations is designated by the numbers in brackets. Total = 16.

TABLE NO. 1c

SUBJECTS RAW SCORES SUMMED FOR EACH AGE GROUP ON ALL TESTS FOR FORM 2 AND SHOWING ALSO NUMBER OF CHILDREN FAILING TO RESPOND ON EACH TEST

AGE GROUP	TESTS:	L	P	R	TOM	A_1	A_3	TEM	TOTAL
1 N = 16		42 (2)	59	53 (1)	23 (8)	66	82	112	437
2 N = 16		77	71	91	49 (2)	68	98	133	587
3 N = 16		78 (1)	73	93	72	84	112	156	668
4 N = 16		82	81	84	65 (1)	86	128	168	694
TOTAL:		279	284	321	209	304	420	569	2386

Number of missing observations designated by numbers in brackets. T = 15.

TABLE NO. 1d

SUBJECTS RAW SCORE TOTALS FOR FORM 1 & FORM 2 SUMMED OVER ALL AGE GROUPS

AGE GROUP	N°	FORM 1	M.O'^{S}	FORM 2	M.O'^{S}	TOTAL
1	16	440	12	437	11	877
2	16	586	3	587	2	1173
3	16	685	1	668	1	1353
4	16	685		694	1	1379
TOTAL		2396	16	2386	15	4782

N.B. M.O'^{S}. Here and in subsequent tables M.O'^{S} refer to the number of occasions on which the child failed to make a score on either the left or the right ear.

TABLE NO. 2

The majority of children demonstrated equal laterality on both ears for all tests. Positive and negative scores were nearly equal and consistent throughout the age groups.

There is no evidence to suggest that negative and positive values increase with the older age groups and thus there is no evidence for increasing lateralisation with age.

TABLE 2

TITLE: Frequency Distribution of all subjects negative and positive value Laterality Indices on all tests in the 4 Age Groups.

M.O's	AGE GROUP	NEGATIVE RESPONSES	ZERO RESPONSES	POSITIVE RESPONSES
23	1	32	36	37
5	2	35	42	33
2	3	36	43	33
1	4	31	48	33

TABLE NO.3

It is clear from the distribution of score values in Table 3 that when the left ear was presented first negative responses were scored and when the right ear was presented first positive values were scored. This result was later confirmed by the analysis of variance where differences by ear presented first was found to be a significant factor. This means that higher scores were always made by the ear first tested.

TABLE NO. 3

TITLE: Frequency Distribution of negative and positive value Laterality Indices of all children in all age groups for both ears.

M.O's	EAR TESTED FIRST	NEGATIVE INDICES	ZERO INDICES	POSITIVE INDICES
13	Left	86	76	53
18	Right	48	84	83

N.B. 9 Missing L.I's where children failed to obtain a score on both ears.

TABLE NO.4

Table 4 considers the frequency distribution of the children's Laterality Indices broken down by tests.

For 5 tests the ear presented first appears to be an important factor in determining whether the child gains a right ear bias or a left ear bias. That is to say when sounds are applied to the right ear first greater or equal positive values are scored; when sounds are applied to the left ear first greater negative values are scored. The two tests which are exceptions are Loudness and Pitch. Loudness shows a positive score value irrespective of ear presented first. Pitch shows a negative score value irrespective of ear presented first.

TABLE NO.4

TITLE: Frequency Distribution of positive and negative value Laterality Indices for every Test in all age groups.

	TESTS:	Total Responses			Ear Tested First					
					Left			Right		
12 O's		Neg.	Zero	Pos.	Neg.	Zero	Pos.	Neg.	Zero	Pos.
6	(L) 1	19	15	29	11	7	13	8	7	16
2	(P) 2	29	18	17	12	11	9	17	7	8
4	(R) 3	11	35	16	7	16	7	4	17	9
19	(TOM) 4	19	24	15	10	10	6	9	8	9
-	(A) 5	13	38	14	9	15	9	4	23	5
-	(R_3) 6	22	21	21	18	10	4	4	11	17
-	(TEM) 7	22	18	24	20	7	5	2	11	19

N.B. 9 Missing L.I's

Raw Scores converted into Laterality Indices

Table 5 reports the Laterality Indices' means for both males and females in all 4 age groups for the 7 tests. The appendices tables 9, 10, 11, 12, sets out the laterality indices achieved by the 64 children on all 7 tests. The left handers are indicated by an asterisk.

Table 5 means for each age group clearly shows which tests achieved left and right ear bias.

Negative values indicate left ear bias; positive values indicate right ear bias. Tests 1, 3, 6, 7, suggest a right ear bias. Tests 2, 4, suggest left ear bias. It will be seen that 2 sensory tests, loudness and rhythm, appear to behave in the same way as the verbal tests. In fact loudness and rhythm show greater mean positive values than the 3 verbal tests.

Pitch and Tonal Memory show negative values and left ear bias. The Pitch tests appear to be the most strongly lateralised of all the 7 tests and shows a negative direction (left ear bias) at all age levels for both sexes with the exception of the females at age group 4.

The tonal Memory test which has strong pitch discrimination components is less strongly lateralised although it achieves negative values for all age groups except the oldest girls. At this age group the girls maintained equal ear discrimination (.00) as in the pitch tests.

Apart from the Pitch test all the other tests suggest that degree of lateralisation is slight and that both ears and hence both hemispheres are involved with the processing of sensory and verbal sounds.

TABLE NO. 5   L.I.^{s} MEANS x100 FOR ALL AGE GROUPS AND BOTH SEXES ON ALL TESTS

TEST	1 LOUDNESS		2 PITCH		3 RHYTHM		4 TONAL MEMORY		5 APPROXIM-ATIONS (1)		6 APPROXIM-ATIONS (3)		7 TEXTUAL MATERIAL	
SEX / AGE GROUP	M	F	M	F	M	F	M	F	M	F	M	F	M	F
1	1.37	-1.75	-4.37	-1.25	3.12	2.00	7.50	-7.62	1.25	-3.75	0.75	0.75	1.62	1.5
2	1.75	2.62	-3.12	-6.87	1.00	2.12	-2.5	-1.25	2.5	-1.25	0	-1.5	1.5	4.62
3	1.75	7.87	-1.25	-5.0	0	2	-2.5	-3.75	0	-1.25	0.75	3.00	-1.5	0
4	1.87	4.37	-4.37	0	1.12	0	-1.25	0	2.5	-1.25	-3	-2.37	1.5	-1.88
ALL AGES	1.68	3.28	-3.28	-3.28	1.31	1.53	-0.31	-3.155	1.56	-1.87	-0.375	1.156	0.78	1.06
MEANS ALL AGES BOTH SEXES	2.48		-3.28		1.42		-1.42		-0.16		0.39		0.92	

N.B. Missing values calculated
and included.

MEAN SCORES X 100

Table No. 6 sets out subjects' raw score totals* for 1st and 2nd ears (i.e. 1st and 2nd channels)* summed over all age groups.

It will be seen that at every age level more responses were scored when the 1st ear was stimulated irrespective of whether this was the right ear or the left ear. This was the most significant factor to emerge in the experiments and the possible reasons for this result are taken up in the discussion.

The appendix tables nos. 13 - 20 show all subjects' raw scores on all tests for 1st and 2nd ears.

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* 1st channel refers to the ear which is stimulated first.

* 2nd channel refers to the ear which is stimulated second.

TABLE NO. 6

SUBJECTS RAW SCORE TOTALS FOR 1ST, AND 2ND CHANNELS SUMMED OVER ALL AGE GROUPS.

AGE GROUP	1ST CHANNEL	M.O's[+]	2ND CHANNEL	M.O's	TOTAL
1	456	10	425	14	881
2	618	2	563	3	1181
3	692	1	650	1	1342
4	710		668		1378
TOTALS	2476		2306		4782

[+] M.O's = No: of Missing observations.

Table No. 7 sets out the age group totals gained by the right and left ears for all 7 tests. Missing values have not been included.

Again it is clear that Pitch (Test 2) appears to be the Test which discriminates most between ear differences, with the greatest total of raw scores being achieved by the left ear. Loudness and textual material (Tests 1,7) show the next greatest between ear differences with the right ear achieving the greater raw score. All the other tests show a surprising equality of raw score responses.

SUBJECTS' RAW SCORE FOR BOTH EARS OVER ALL AGE GROUPS FOR ALL TESTS

TESTS	1		2		3		4		5		6		7	
EARS	R	L	R	L	R	L	R	L	R	L	R	L	R	L
AGE GROUP 1	45 (2)	46 (3)	57	66	54 (1)	53 (2)	21 (7)	25 (7)	60	68	82	78	118	108
AGE GROUP 2	74	65	64 (1)	81	91	88	48 (1)	50 (3)	74	72	98	102	142	132
AGE GROUP 3	86	75 (1)	71	81	94	93	64	68	86	86	118	110	156	154
AGE GROUP 4	90 (1)	83 (1)	74	87	88	87	66 (1)	65	82	80	118	121	172	166
TOTAL	295	269	266	315	327	321	199	208	302	306	416	411	588	560

TABLE NO. 7

N.B. No's of missing observations designated by nos in brackets.

Table No. 8 has extended the information in Table No. 7 and shows the total raw scores gained by right and left ears for the sensory and verbal tests. The results are in the expected direction. The left ear gains more total raw scores than the right ear on sensory tests. The right ear gains more total raw scores than the left ear on the verbal tests. However, it is important to note that the differences are small.

In the case of the sensory tests left minus right ear scores equal 27 points.

In the case of the verbal tests right ear minus left ear scores equal 29 points.

TABLE NO. 8

RIGHT AND LEFT EAR TOTALS FOR SENSORY AND VERBAL TESTS

	RIGHT EAR TOTAL	M.O's	LEFT EAR TOTAL	M.O's	DIFFERENCES BETWEEN EARS	TOTAL M.O's
	Raw Scores		Raw Scores			
Sensory Tests	1086	14	1113	17	27	31
Verbal Tests	1306		1277		29	0

Table No. 9 shows the total raw responses gained by each age group. As to be expected the total number of raw responses increases with the age of the child. The greatest raw score increase occurs between age groups 1 and 2 (children aged 5-7½. 8-10½ respectively) and the next greatest increase in raw score total occurs between age groups 2 and 3 (children aged 8-10½ years, and 11-13½ years respectively). Raw score increase is much less between age groups 3 and 4 (children of 11-13½ and 14-18 years respectively). These results suggest that children of 11, 12 and 13 years are effectively retaining almost as much material as children of 14-18 years. Appendix table No.21 lists the total raw scores gained on all tests by every child in the 4 age groups.

TABLE NO. 9

Subjects Raw Score totals summed over all age groups

Age Group	M.D's	Total raw responses
1	23	881
2	5	1181
3	2	1342
4	1	1378
TOTAL	31	4782

Table No. 10 differentiates raw score totals between males and females.

At age group 1 males scored more points than females but at every subsequent age group females scored more points.

Total gains over all the age groups showed that females achieved more points than males. The difference between male and female total scores was 130 points.

Appendix table No. 22 lists the childrens individual scores subdivided by sex.

TABLE NO. 10

SUBJECTS 1. TOTALS OF RAW SCORES OVER ALL AGE GROUPS SUBDIVIDED BY SEX

AGE GROUP	MALE RESPONSES	M.O's	FEMALE RESPONSES	MO's	TOTALS	Total M.O's
1	460	6	421	17	881	
2	555	5	626		1181	
3	662	1	680	1	1342	
4	648	1	730		1378	
TOTAL	2325	13	2457	18	4782	31

TABLE NO. 11

Analyses of Variance of Laterality Indices.

The first Analysis of Variance considered the factors of age, sex, tests, ear presented first, and how these might affect the value of the laterality index. An analysis of variance was performed on the laterality indices and the only factor which significantly affected the index was 'ear presented first'. There was a slight significant inter-action between the tests and the ear presented first.

This analysis indicated that the tests did not produce significantly different results. However, this first analysis result can be criticised since the fact that it was the same children who took each of the seven tests for a particular age group, sex and ear presented first was lost in the analysis.

In order to include this fact a second analysis of variance was carried out with the ear test data for each child utilised. This second analysis was not subject to the above criticism and showed that the results were the same as before. The only factor affecting the data significantly being the 'ear presented first'.

In order to consider whether the individual tests produced significantly different results a two way analysis of variance, distinguishing only the factors children and tests was carried out. This third analysis indicated that at the 5% level of significance the tests did produce significantly different results. The data from this third analysis of variance was used in conjunction with the first full analysis of variance including all factors, to produce a fourth 'two-stage' analysis of variance. This analysis overcomes the original criticism in that the variation generated by the children within each group is accounted for. The effect is to split the "computer" residual for the full factorial analysis into 2 components "subject within groups" and a new "residual" component. This final analysis of variance produces the results much as before.

At the .5% level the <u>ear presented first</u> emerges as the significant factor. Interaction between ear presented first and tests is slightly significant (at the 5% level). Also at the 10% level the tests themselves produced a significant result.

TABLE NO.11 FULL ANALYSIS OF VARIANCE OF LATERALITY INDICES

FIRST STAGE				SECOND STAGE					
Source	Sum of Squares	Degrees of Freedom	Mean Sum of Squares	Source	S.S.	D.F.	M.S.S.	F.	Sig.
CHILDREN	9,018.77	63	142.98	Age	2.02	3	0.672	.00	
				Sex	59.23	1	59.233	.38	
				Ear First	1,094.69	1	1,094.698	6.99	0.5%
				Age & Sex	223.34	3	74.448	.48	
				Age & Ear First	44.46	3	14.822	.10	
				Sex & Ear First	1.01	1	1.012	.01	
				Age & Sex & Ear First	78.92	3	26.3062	.17	
				Subject Within Group (Residual A)	7,515.10	48	156.56		
Tests	1,406.33	6	234.39	(Tests)	1.406.33	6	234.39	1.9960	10%
TESTS X CHILDREN	41,624.55	370	112.49	Tests & Age	872.19	18	48.455	.41	
				Tests & Sex	703.58	6	117.264	1.00	
				Tests & Ear First	1,659.64	6	276.606	2.36	5%
				Test & Age & Sex	1,290.70	18	71.706	.61	
				Tests & Age & Ear	2,129.53	18	118.307	1.01	
				Tests & Sex & Ear	332.42	6	55.404	.47	
				Tests & Age & Sex & Ear	1,753.79	18	97.433	.83	
		Tests x Subjects within Groups)		Residual B (Residual)	32,882.7	280	117.44		
Total	52,049.6	439	118.56	Total	52,049.6	439	118.56		

N.B. 9. Missing L.I's have been accounted for (See Scoring Method p.99)

TABLE NO. 12

Orthogonal Comparisons.

The previous analysis of variance showed that the tests s.s. of 1406.33 is significant at the 10% level. It is now important to enquire which tests or combination of tests are responsible for this difference.

To investigate further this difference in the behaviour of the 7 tests a series of comparisons were made to assess whether certain contrasts between tests were significant.

Any two comparisons are orthogonal if the product of the corresponding coefficients of each test sum to zero. Since the set of six (one less the number of tests) comparisons are orthogonal the total of their s.s. = test s.s. and each comparison s.s. has 1 degree of freedom.

We test the significance of the contribution made by each comparison by dividing the s.s. by the overall residual s.s. (117.44) (Table No. 11). The only significant comparison (at 0.1%) is Loudness vs. Pitch. At the 25% level Rhythm vs. Tonal Memory is also significant.

Thus differences between Loudness and Pitch account for the significance of the tests s.s. in Table No.11.

Note that for the above comparisons to be orthogonal we need an equal number of observations for each test. Thus missing observations have been estimated.

The fact that 2 sensory tests have been shown to be significantly different from each other suggests the possibility that they are being processed by different functional areas.

TABLE NO. 12 ORTHOGONAL COMPARISONS OF L.I.^{s} FOR ALL TESTS

TESTS	L	P	R	TNM	A1	A3	TSM				
TOTAL SUMS	159.36	-209.92	90.88	-91.04	0.00	12.8	62.08	COMPARISON	DENOMINATOR	SUM OF SQUARES	SIGNIFICANCE LEVELS
LOUDNESS (L) VS. PITCH (P)	1	-1						369.28	128	1065.50	At 0.1%
RHYTHM (R) VS. TONAL MEMORY			1	-1				181.92	128	258.55	At 25%
L + P VS. R + TNM	1	1	-1	-1				-50.56	256	9.98	Not sig.
APPROX. 1 (A1)+ APPROX. 3 (A3) VS. TEXT MATERIAL (TXMT)					1	1	-2	-111.40	384	32.29	Not sig.
A1 VS. A3					1	-1		-12.8	128	1.28	Not sig.
L, P, R + TNM VS. A1, A3 + TXMT	3	3	3	3	-4	-4	-4	-453.1	5376	38.19	Not sig.
SUM										1405.79*	

*This does not add up to 1406.33 because the rounding methods used in both tables are not the same.

N.B. MISSING L.I's have been accounted for. (See Scoring Methods p. 99)

Table No. 13a lists the laterality indices of all the left handed children on all 7 tests for every age group.

Thirteen children out of the total 64 children were shown to be strongly lateralised in hand, eye and limb function. This frequency represents 21.5% incidence in the total group and is high compared with normal sample studies.

The means totals for both sensory and verbal tests show small negative values.

Table No. 13b lists the L.I's Means of all right handers for all age groups and both sexes over all tests. Tests (2) Pitch and (4) Tonal Memory show small negative values. The other five tests give zero or small positive values.

TABLE NO. 13a

LATERALITY INDICES OF LEFT HANDED CHILDREN

AGE GROUP	CHILD NO.	TESTS: L 1		P 2		R 3		TOM 4		A_1 5		A_3 6		TEM 7	
	SEX:	M	F	M	F	M	F	M	F	M	F	M	F	M	F
1	9		.00		.05		.08		.00		.00		.00		.00
1	11*	-		.00		-.08		.10		.00		.06		.19	
2	22		.07		-.15		.00		-.10		.00		-.06		-.06
2	24	-.28		-.30		.00		-.20		.10		.00		-.06	
2	30		.00		.00		.00		.00		.10		-.06		-.12
3	35	.00		-.05		.00		-.10		-.10		.00		-.12	
3	43	.07		.05		.00		.00		.00		.06		-.12	
3	44	-.14		.00		.00		.00		.00		-.12		-.06	
3	48	-.07		.10		.00		-.10		.00		.06		.00	
4	49		.00		.00		.08		.00		.00		.00		-.06
4	51	-.14		.00		-.17		-.10		.10		.00		-.06	
4	52	.07		.00		-.08		.00		.00		-.12		.00	
4	61		.07		.00		.00		.10		-.10		.00		.00

M.O. Only 1 L.H. child* recorded a missing observation. (Child No. 11 on test 1 (L)).

TABLE NO. 13b

L.I. MEANS OF ALL RIGHT HANDERS FOR ALL AGE GROUPS AND BOTH SEXES OVER ALL TESTS

AGE GROUP	TESTS:	1		2		3		4		5		6		7	
	SEX:	M	F	M	F	M	F	M	F	M	F	M	F	M	F
1 N = 16		.01	-.01	-.04	-.01	.03	.01	.07	-.07	.01	-.03	.00	.00	.01	.01
2 N = 16		.01	.02	-.02	-.06	.01	.02	-.02	-.01	.02	-.01	.00	-.01	.00	.03
3 N = 16		.01	.07	-.01	-.05	.00	.02	-.02	-.03	00	.01	.00	.03	.01	.00
4 N = 16		.01	.04	-.04	0	.01	.00	-.01	0	.02	-.01	.02	.02	.01	-.01
Means All Ages Both sexes		.02		-.03		.01		-.01		.00		.00		0.1	

Table No. 14 indicates clearly that left handed children gained negative values for both verbal and sensory tasks. The laterality indices means for sensory tests showed a slightly greater negative value than the laterality means for verbal tests.

These results are in the expected direction for left handed children and supposes that language function is possibly represented in the right hemisphere as well as the left hemisphere.

TABLE NO. 14

MEANS TOTALS OF LATERALITY INDICES ON VERBAL AND SENSORY TESTS FOR LEFT HANDED CHILDREN

Total Laterality Indices Means for Verbal Tests = -.04

Total Laterality Indices Means for Sensory Tests = -.065

Table No.15 records the t-tests for the means of L. I's between the right and the left handers on all tests and all age groups.

Results show that the 2 groups did not behave differently in their performance on any of the 7 tests.

TABLE NO. 15

T-TESTS FOR MEANS OF L. I'^{S} BETWEEN RIGHT AND LEFT HANDERS ON ALL TESTS AND ALL AGE GROUPS

TEST:	1			2			3			4			5			6			7		
	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.
L.H.	12	-.012	.102	13	-.035	.098	13	.0008	.065	13	-.031	.082	13	.00	.147	13	.010	.072	13	-.027	.082
R.H.	51	+.023	.141	51	-.033	.112	50	.0196	.125	46	-.01	.141	51	-.002	.072	51	.0025	.082	51	.013	
T.		1.046			.058			.516			.793			.069			.300			1.538	
P.		N.S.			N.S.			N.S.			N.S.			N.S.			N.S.			N.S.	

N.B. Missing Laterality Indices accounted for; see sample size.

HISTOGRAM DATA

Histograms have been plotted for every individual test and for each age group. In order to look at any significant trend the laterality indices have been rounded to the nearest one decimal place, with .-5 rounding up. The red shading indicates females and 'l' refers to those children who showed strong left-sided function.

A glance at each histogram supports the analysis of variance results that ear presented first appears to be the major determinant in functional asymmetry. However the histogram for 'P' (Pitch) shows clearly that this test is not affected by this factor at the earlier age groups. (See Appendix A).

CHAPTER 10

Discussion of results

Discussion

Before discussing the results some comments should be made about the sample of children.

The Sample

Over all they were a delightful and enthusiastic group.

Testing took place in June and July and there were a number of children in the older age groups who were manifestly volunteering because they had little to occupy themselves after the end of term and 'O' level exams.

Although the 16 children in age group 4 had been selected by their form teachers to cover a normal ability range, a number of the brighter ones did not present themselves for testing and substitutes had to be found. These substitute children appeared on presentation to be rather less able than the rest of the group and spontaneously commented that they had volunteered because they had 'nuthin to do'. The other age groups 1, 2, 3, all appeared to distribute normally intellectually. The first age group were a vulnerable group and it was clear that some of the smaller ones (4½ - 5 years) did not understand the directions. There were several who were restless and a number who made complaints about the heat, the ear phones and the volume of sound.

Their distress was summed up succinctly by one small boy who announced "Please miss, me brains are bruised and me ears are deaf."

There were in addition a few hazardous and humorous incidents. The small girl who needed the lead entwined around her neck otherwise she 'couldn't hear proper'. On investigating the necessity for this she said "Well you see I can't hear unless it (the sound) goes down my throat". There was also the morning when the electricity failed due to a mains cable being severed. The children enjoyed this interval and played happily in the field devouring biscuits and orange juice.

An interesting comment about the audiometry of children in the Heston area was made by Dr. Fisch the E.N.T. surgeon who is Director of the Heston Hearing Centre. He considered that children living in this area served by

London Airport might possibly demonstrate some loss of hearing acuity. All the audiograms of our children were within normal levels but the limits of normal are wide and certainly there were very few children who showed 'better than average' acuity.

This is an interesting point and may be relevant to the present study.

Equivalency of Forms

The results (table 1) have shown that there should be no concerns over the two different forms of material which were used on each ear.

The total raw scores gained by Forms 1 and 2 were almost equal. This close approximation was due to the fact that the original sensory and verbal material for both forms was selected and gathered in one operation and the material was halved, each half making up the test items for Form 1 and 2.

Clearly it is important for each form to be equivalent as differences may have constituted a significant source of variation in the results.

Positive Findings

In the discussion of the results it is proposed to deal with the positive findings first and then to consider the reasons for the negative findings.

First Finding

1. Ear Order

The distribution of scores showed a marked variation when ear order was defined. Tables 3, 4, and 6 indicate that when the left ear was stimulated first the child gained a negative laterality for the test and when the right ear was stimulated first the child gained a positive laterality for the test.

These results were confirmed by the analysis of variance (table 11) where differences by ear presented first were found to be significant at the 10% and 5% level.

It will be remembered that in our earlier discussion of factors affecting auditory asymmetry we referred to other experimental work which instanced ear order as a source of variance. However, ear order in Broadbent and Inglis's work refers to a dichotic situation in which one ear (in free recall) tends to get recorded first and where it is supposed the greater number of errors recorded from the second ear is due not to auditory defects but more to the fact that the material from the second ear must be kept in store longer.

In our experimental situation the ear order refers to a rather different effect. There is no true dichotic situation and reference will be made to this factor later in the discussion. However, it is important to note that in our tests the children were not required to "hold in store" any competing signals and were only requested to repeat information heard on one channel. It is clear then that irrespective of the ear stimulated, it was material heard on the first channel and on the first occasion which was shadowed most efficiently. A recent paper reporting similar results comes from Perl who showed that order in which right and left ears are stimulated may be a source of variance. He found that the right minus left ear scores for both verbal and non-verbal material differed as a consequence of whether the right or left ears were stimulated first or last. Bakker (1970) however analysed values of right - left ear scores in a two (ear order: right first versus left first) by two (material: verbal versus non-verbal) by two (sessions: first versus second) design with repeated measures in the last two factors. Absolute factors were taken because they indicated the degree of asymmetry. Results showed neither ear orders nor sessions significant, ($F = .25$ d.f. = 1/118 p 7.25 and $F = 10$ d.f. 1/118 $p > .25$ respectively.) Only factor material was significant, ($F = 8.80$ d.f. 1/18 p >. 005) showing a greater degree of ear asymmetry with non-verbal than with verbal material. The right - left ear scores with non-verbal material were greater in the second than in the first session. With verbal material differences were about equal in the two sessions. Thus ear order in Bakker's work did not show a significant effect on degree of ear asymmetry. These results contradict Perl as they do ours. However, it must be pointed out that the tests used by Bakker are different to our own.

There may be a number of physiological and psychological factors which could be held partly responsible for our present results. It is possible that there is greater stimulation of cortical units during the first recording session and that the contralateral pathways are being more efficiently used when novel material is the stimulus. At the second recording a rerun of the same material in a different form may not fire as many cortical units. There is some evidence to suggest that there is a normal delay in firing of neurones after successive stimulation. Also the psychological factors would of course be significant here. The effects of fatigue and boredom, with resultant inattention to the task may be reflected in the distribution of scores on the second channel. In effect, these factors may well be of sufficient weight to overcome the laterality effect. It has been noted repeatedly that auditory asymmetry is optimally observed only under conditions of <u>extreme</u> attention. Treisman and Geffen (1967) found that attention was an important factor which influenced the experimental situation. Subjects were asked to tap in response to target words whilst repeating a message which was played into the other ear. There was no difference in performance between ears except when the subjects were involved in tasks which were receiving their full attention. The writers consider that these results support the idea that right ear dominance is primarily a quantitative difference in the distribution of attention to the right and left ear inputs reaching the left hemisphere speech areas. However, Shankweiler (1969) found that when a subject is requested to report sounds from a particular ear there are fewer errors of attention for vowels than for consonants but that consonants show a greater right ear advantage than vowels. So selective attention may be a variable with other mechanisms responsible for the ear difference effect, but it is not the main causative factor. Others who found results similar to ours are Oxbury Oxbury and Gardiner (1967) who requested subjects to recall digits <u>after</u> stimulation to one ear. They found no significant difference in total scores. There was, however, some interaction between ears and order of report. Right ear responses were less accurate when reported on second channels, though left ear scores did not show this difference. The writers discuss this point and suggest that although right ear stimuli are responded to first after stimulation, left ear stimuli are held in store, i.e. Broadbent's 1958 thesis that the right ear passes into the p-system first. Darwin has made the point that this study showed certain imperfections. The number of trials was small and the headphones were not reversed between subjects.

So it appears that we may not invoke perception (Kimura 1961 b), short term memory (Inglis 1962) or attention (Treisman and Geffen 1967) to account for the ear order effect found in our experiment.

What of the physiological correlates of auditory stimulation?

Rosenweig used five anaesthetized cats and recorded the electro physiological responses to simultaneous and successive stimulation of the two ears. Simultaneous stimulation resulted in <u>partial</u> summation, i.e. the response is somewhat larger than the response of the contralateral ear but not so large as the sum of contralateral and ipsilateral responses. This indicates that the two populations of cortical units are not entirely independent. When two stimuli are delivered in succession, interaction between the two responses again occurs. If the time interval is brief, under 50 m.sec., the second stimulus is reduced from its normal amplitude. The larger the first reponse the smaller the second response. Amplitude of the ipsilateral response is two thirds the amplitude of the contralateral response. Again when the right ear is stimulated the response at the left hemisphere appears to be the larger of each pair of measurements.

These interesting results infer that there is a band of neurones which is shared by both hemispheres, in fact an area of overlapping cortical units. Other work by Erulkar (1954) and Hird (1953) found that when stimulus of one ear produces a discharge and the other ear does not, binaural stimulation may produce a significantly lower spike count than when the affected ear is stimulated alone. Thus stimulation of the ineffective ear produces an inhibitory gap. Hird showed that usually the effective ear was the contralateral one, though for some neurones the reverse was true.

In our experimental model it must be remembered that the ear presented first was an unstimulated ear and that the ear presented second had already been subject to a period of white noise. So that in the first stimulus condition one may assume both ipsilateral and contralateral pathways are being utilised. In the second stimulus condition the ear which has been subject to white noise is now being stimulated and the response may not be as great as that recorded during the first recording, i.e. some of the fibres may fall out during this second stimulus period - the ipsilateral or contralateral fibres which respond during the first stimulus condition of white noise may not respond as effectively during the second recording. Some evidence for advancing this point of view comes from an important study by Starr and Livingstone (1963). They have shown there to be a wide distribution of activity evoked by clicks and by sustained white noise. They recorded evoked responses to white noise in the central auditory pathways in both waking and anaesthetized cats. In waking cats, the amplitude of the initial response to the rush of white noise decreased at ascending levels of the auditory pathways. After the initial response all stages up to the level of the inferior colliculus showed a gradual increase in response amplitude which continued for half an hour or more when continuous noise was presented.

These findings could suggest that the behaviour of neurones to successive stimulation might show the type of inhibitory gap which we have suggested. Our children were only rested for half an hour between each ear recording.

However, despite the neurophysiological factors which may be involved in the ear order effect found in our group, it seems reasonable to assume that if there is a threshold and individuals are unable to discriminate until the stimulus has reached a specific level, then order effects will probably apply, and this dominates the laterality effect. Thus if there is a threshold in operation decisions will be made by ear presented first.

Second Finding.

2. Tests which show laterality. A. The Pitch Test
B. The Loudness Test

Tables 4, 5 and 7 suggest that there are certain tests which indicate an ear bias irrespective of ear presented first.

The Pitch test (test 2) gains a negative score and thus a left ear preference when either the left or right ear is stimulated.

The Loudness test (test 1) gains a positive score and thus a right ear preference when both left and right ears are stimulated.

These effects can be seen by a straight count of raw score response (table 7).

The analysis of variance (table 11) has confirmed that there are certain tests which behave differently from each other, (at the 10% level of significance), and the orthogonal comparisons (table 12) have indicated that there are significant contrasts between the Loudness and Pitch tests (at the 0.1% level of significance).

Pitch is not affected by ear presented first. When pitch sounds are presented to the right ear first scores show a negative laterality value. When presented to the left ear first the negative value still holds over all age groups (table 4)

The laterality Means tables for each sex and each age group (table 5) suggest that boys demonstrate more asymmetry on pitch tests at an earlier age than do girls. However there does not appear to be any increasing lateralisation with age.

Nevertheless it is important to remember that these sex differences are very small and do not reach a significant level in the analysis of variance tables (table 11).

A. The Pitch Test

The result from the pitch experiments does make an important contribution to our understanding of auditory perception because the negative scores were derived from experiments on frequency sounds in a monaural setting. It was shown that the total group maintained a <u>left</u> ear advantage for pitch discrimination irrespective of ear presented first (table 4). It will be remembered from our original discussion in Part I on speech sounds and dominance that Darwin showed that simple pitch sounds give a left ear advantage when carried on a word but do not cue a phonemic distinction. Haggard (quoted by Darwin) found that when a voicing dimension is cued only by a change in pitch (Haggard 1969 b) in a dichotic listening paradigm, the recall of this feature shows a right ear advantage. It seems likely that the pitch sounds which cued voicing in Haggard's experiments would show a left ear advantage in a suitable non speech context, as we have found. As Darwin comments, Haggard's results show that it is not the extraction of the acoustic cue which is important but its phonetic relevance. In our particular pitch experiments the children were requested to judge whether the second of two frequencies was higher or lower than the first frequency. These stimuli were simple pitch sounds unrelated to a verbal context.

That negative values for pitch tests still hold true for our left handed group is an interesting point which warrants some discussion.

Left Handedness and Dominance

We should, perhaps, make some comment about our high incidence of true left handers in the total sample. Only those children who were shown to be left sided on eye, hand and limb function were included in our left handed sample.

Reference to Appendix B will indicate the various functions which were finally selected as relating to dominance. Children who showed some preference to left handedness in certain functions but who showed mixed dominance in visual preference and limb function were not included in the final left handed sample.

Frequency estimates of true sinistrality in the normal population have varied with various observers - Burt (1921) in a survey of elementary school children found that 6.2% of boys and 3.9% of girls were left handed - an average of 5.1%. Gordon (1921) found 7.2% of elementary school children were left handed. It is as well to remember that since the time when these estimates were made the pressure on left handers to use their right hand (shifted sinistrals and the ambidextrous) has been lifted and the 'true' incidence of left handers in the population may well have increased. Our incidence is in fact particularly high and represents nearly 20% of the entire group. The reasons for this are speculative and we must accept this as a particular bias of our sample.

Patterns of scores in the left and right handed group

(1) t-tests.

Table No. 15 shows that there was no significant difference between the performance of right handers and left handers on the 7 tests. The laterality values on all tests in both groups were extremely small suggesting that over all the tests there was no marked exclusivity of ear preference for either group.

(2) However left handers tend to score zero or negative on textual material whilst right handers show a tendency to score positive on this test (Table 13a). This finding suggests that ear preference is in the predicted theoretical direction. All the 31 missing observations occurred with the sensory tests and I think that it can be assumed that the left handed group

were more able with sensory material than the right handed sample.

(3) Left handers score zero or negative on pitch tests throughout all age groups (table 13). Right handers also score negative values on pitch tests (table 13b). This suggests that the pitch test gives a negative laterality index irrespective of ear tested first and dominance. There appears to be some age and sex difference on this test - boys achieving laterality earlier than girls (table 5). However, there is no evidence that there are increasing negative values with increasing age, i.e. increasing lateralisation of function with age.

(4) It is interesting to record that in the left handed sample there was only 1 missing observation.

Kimura (1963b) has shown that speech lateralisation in young children as determined by an auditory test has already occurred by the ages of five and six. We assume from our results that auditory dominance for frequency discrimination has also been established by the ages of five to seven years when our youngest age group was tested.

The fact that we have been able to show lateralisation of function in the discrimination of pure pitch sounds does imply that pitch sounds remain largely unaffected by the particular listening technique utilised, in effect a left ear advantage for pitch sounds is not dependent on a dichotic situation.

Some evidence to support the large influence which the right hemisphere appears to exert on the perception of frequency sounds may be found in Goldstein's group of patients who had their left hemisphere removed. He found post-operatively that there were relatively small hearing losses for high frequencies and that post-operative speech showed improvement in the modulation of their speech contours.

Botez and Wertheim (1959) also report a man with skull injury and generalised epileptic attacks who had a right fronto-temporal craniotomy. This helped the epilepsy but after a short period the seizures recommenced. Later the removal of a calcified oligodendroglioma in the right hemisphere was performed. After the operation there were some dysphasic disorders of the expressive type and changing of the rhythm and pitch of the voice. He was not able to earn his living as a musician because his singing was "wrong" and he was unable to play his accordion. Repetition of phrases showed disturbances in articulation as did reading. The patient complained that he was unable to sing as the <u>pitch</u> of his voice was constantly changing. Rhythm of the voice was also affected. Opinion was that the patient had a bilateral representation of expressive and receptive language and a unilateral representation (in the right hemisphere) of expressive musical functions.

Apart from these clinical studies there have been several papers devoted to looking at ear response to musical stimuli. Kimura presented two auditory tests on different days to twenty female right handed nurses. They were:

A Digit Test. A presentation of groups of digits in pairs. After three pairs (six digits) subject was asked to report all the numbers she had heard in any order she liked.

A Melody Test. Excerpts were from solo passages in concerts from Mozart, Vivaldi, etc. Eighty passages taped and classified into twenty sets of four. Within each set of four melodies the same instrument was used and an attempt was made to have the pitch range and tempo very similar leaving the melodic pattern as the main clue. Original passages were then re-recorded to make melodies of four-second duration. For each set of two of the four melodies was heard in one ear at the same time that the other was played in the other ear. There was then a four-second interval of silence and the four melodies were played in normal binaural succession, i.e. with the same melody in each ear. There was a three-second gap between melodies. Thus the first two melodies heard dichotically were repeated separately and the subjects simply had to identify which two they were, replying simply with the second and third or first and fourth. The position of the repeated melodies was varied in a counter balanced manner from set to set. The score was the number of correct identifications.

Results showed that the score for the left ear was significantly superior to that of the right ear on the melodies test (t ratio = 3.57 $p > .01$) and that the right ear was superior in the digits test (t ratio = 2.83 $p > .02$).

The asymmetries observed here occur only under conditions of dichotic stimulation. In an unpublished study, quoted by Kimura, the timbre test of the Seashore Battery was presented to a group of normal subjects one ear at a time on two separate occasions. This procedure yielded no difference between ears. Similarly the right ear effect for digits only occurs to a significant extent with dichotic presentation. One reason for this may be that dichotic listening puts more demands on the system than does monaural listening.

Kimura's study on melodies suggests that the sensory cues which are being responded to in discrimination may be pitch cues for the melodic line of a passage is composed entirely of pitch changes. This would fit in with our results.

What may we learn from the neurophysiologists and their electrophysiological experiments on the auditory system, with regard to electrical response to frequency sounds? Evans, Ross and Whitfield (1965) have shown that whereas cats can learn the 'tone v.s. background' discrimination in the absence of the whole of the auditory cortex (Goldberg, Diamond and Neff 1958) discriminations requiring assessment purely of a change in frequency with time needs some part of the primary or secondary auditory area. These workers showed tonotopicity to be entirely absent in the primary auditory cortex of the cat and concluded that this area was most likely not concerned with frequency discrimination. Whitfield and Evans (1965) found numbers of units in this region which were responsive to changes of frequencies and were in fact frequency orientated, i.e. they responded to a rising tone but not a falling tone in the same frequency range. Goldstein (1970) working on unanaesthetized cat muscle preparation found that fibres responded to high frequency sounds in the primary auditory cortex and that low frequency sounds were best responded to in the posterior region. Mid range best frequencies showed considerable overlap. Moderately intensive tonal stimuli of a given frequency was represented over most of the auditory cortex. Goldstein's study failed to reveal any organisation related to depth in the cortex.

Although these studies on the cat do not give us information with regard to any possible hemispheric organisation in man, they do suggest that neurones which are responsive to sounds of differing frequencies may not be arranged in the tight and circumscribed manner which we associate with the visual and somesthetic cortices. Investigation of neural mechanisms responsible for frequency sounds in man may well reveal greater regions of activity in the auditory fibres supplying the right hemisphere. But it is important to remember that neurophysiologists consider that fibres responding to differing frequencies are activated <u>at all</u> levels in the auditory pathways and are not delimited by any particular region of the auditory system.

Summing up the clinical and experimental test results we appear to have firm and convincing evidence that the right hemisphere appears to be more involved in the processing of pitch sounds than the left hemisphere and that this holds irrespective of handedness. It may well be that the sensory stimuli which have been found to be more sensitive to right hemisphere lesions are stimuli which were <u>pitch based</u> rather than generically sensory. This would account for the confusing results, which might be due to loudness, rhythm and timbre aspects of the stimuli.

It would seem imperative to separate out the sensory tests into their particular and specific acoustic features. It is only by doing so are we able to discriminate what is being responded to. For example, Kimura's melodies are a series of complex pitch changes. Loudness tests involve detection of decibel range carried on the same pitch sound and may have quite different patterns of response. This is in fact our next significant finding.

<u>Tests which show lateralisation</u>

<u>B. Loudness Test</u>

Reference to the Loudness Test results (tables 4, 5, 7, 12) show that this test does not behave as a sensory test with expected negative laterality values. It gives instead small positive values. Twenty-nine subjects out of the total sixty-four scored positively in this test, nineteen scored negatively and sixteen scored zeros (table 4).* An analysis of left handers and right handers on loudness tests indicates that whilst right

* See over.

As on the pitch test it is again true that the direction of the L.I is maintained irrespective of which ear is tested first.

handers over all score positive on this test, left handers over all score negative (tables 13a, 13b) In fact the loudness test shows relevant dominance and simulates the same pattern of response as the textual material test. The orthogonal comparisons indicate that at the 0.1% level significance, the loudness test is different from the Pitch Test. Do we have other evidence to suggest that decibel discrimination may be a function shared by both hemispheres but responded to slightly more by the left hemisphere?

Again we may cite Goldstein's series of left hemispherectomy cases. Speech was found in all four patients to be lacking in proper control of loudness and tempo preoperatively. One might suppose that the diseased hemisphere (left) was influential in determining the intensity of the speech pattern. Milner in her group of temporal lobectomy cases found that post-operative error scores increased after the removal of the right hemisphere on test relating to time, loudness, timbre and tonal memory (Seashore tests). However, we have earlier mentioned certain objections which may be raised to the technique employed in this study.

Shankweiler (1966) used Kimura's melodies for assessment of forty epileptic patients before and after temporal lobectomies. Half the patients had the right hemisphere removed and half the patients had the left hemisphere removed. There were no significant differences between scores pre-operatively. Post-operatively those who had the left temporal lobes removed showed no changes and those with right lobes excised showed significant loss. These results parallel Milner's except that they do not agree with Kimura's findings that normals show higher scores for the left ear. Luria (1961), Feuchtwanger (1930) however report various case histories of patients who show diminished perception of sensory stimuli with both right and left lesions.

How do these disparate psychological experiments accord with the electro physiological data which has been undertaken on "intensity".

Kiang (1966) has published work concerned with the behaviour of 1,500 units obtained from the cat's auditory nerve. He was unable to find any behavioural criterion by which fibres could be divided into categories that might be related to the inner and outer hairs of the radial and spiral fibres arising from the cochlea. This means that the fibres themselves show several different types of response and in the absence of stimulation the fibres may be silent or discharging spontaneously. For a given frequency the rates of discharge of these fibres will vary according to their position in the array. <u>Change of</u> frequency will translate the active array and <u>increase</u> in intensity (decibel stimulation) will widen the array and may add additional fibres within the array. Greenwood and Maruyuma's (1965) work on the mutual distribution of neuronal discharges to intensity sounds has relevance to our loudness test results. They found that if two tonal stimuli are sounded simultaneously and are <u>close</u> together in frequency then the activity pattern in the nerve array will overlap in both hemispheres. When this pattern is transferred by the squaring mechanism of the cochlea nucleus there will be a single block of active fibres covering the active array. Some of the fibres appear to be activated by either tone separately but are inhibited when both tones are sounded together and drop out. Thus an inhibitory gap is produced and the identity of the two stimuli preserved. So that the "intensity" of a stimulus is represented by the number (width) of active fibres in the array whereas different frequencies will be represented by <u>different</u> blocks of active fibres.

Now we might suppose that architecturally the left hemisphere is served by a greater array of auditory fibres than the right hemisphere and that although both hemispheres are responding to intensity stimuli such as our tone pips of differing decibel range (Loudness Test) the left hemisphere by virtue of its apparent greater complexity may be marginally firing neurones in somewhat larger (wider) fibre blocks. Raab and Ades' (1946) work on intensity and loudness responses in the cat suggest that the cortex itself may not be responsible for making intensity discrimination responses. Cats were trained to discriminate between two sounds of differing intensity range and then the auditory cortex was bilaterally ablated. Discrimination was lost but the cats could be retrained to have the same intensity difference limen (DL) as before. These workers also destroyed the inferior colliculi and the efferent pathways. Discrimination was again lost but retraining could be restored if the DL was raised to 10 or 12 db. It seems clear then that the discrimination of normal intensity sounds need not involve the cortex and that some degree of discrimination may be at sub-collicular level. Whatever the overall role of the left and right temporal lobes in intensity discrimination may be, the neurophysiological evidence must make us cautious with regard to summary judgements about functioning at <u>hemispheric</u> level. It would seem that intensity discrimination may be more specifically related to areas outside the true auditory cortex and its pathways and may well be responded to at brain-stem level. Thus to ascribe judgements relating to the detection of differing degrees of loudness to be a function of one or other of the hemispheres does not appear to stand up to what we know of the neurophysiology of the auditory system. The complexity of the problem may well be reflected by the conflicting evidence which we find in the various psychological experiments on loudness tests.

The foregoing discussion has centred on the significant findings from the experiments. It is now important to explore the possible reasons why the verbal tests did not demonstrate greater ear assymmetry.

The Verbal tests - The complexity of the 'right ear effect' for speech sounds.

Approximations 1.3 and textual material (tests 5, 6 and 7) show a right ear bias in terms of raw score response. (table 7). The verbal tests also score more positive responses than the sensory tests (table 8), despite the fact that the Loudness test distorted the bias of the sensory tests as a group.

The difference between sensory and verbal tests did not reach statistical significance.

However, if tables 5, 7 are consulted it is seen that the L.I's and raw score totals for textual material appear to operate in the predicted direction more consistently than those of approximation 3. This is a significant point and requires some amplification.

It will be remembered that the verbal material was chosen to signify different levels of meaningfulness. The latter factor is one which has been often implicated as being related to lateralisation of function.

Bartz, Satz et al (1967) investigated recall strategies and ear asymmetry where meaningfulness was contingent upon the temporal pairing of individual dichotic pairs of stimuli. The stimulus material were simple two syllable words or words in which each syllable was not a meaningful word by itself (ab - le - ai - ther, etc.) and compound two syllable words in which each syllable was a meaningful word by itself: foot-ball, moon-glow. Sixty subjects were randomly assigned to four groups of fifteen subjects each. The four groups differed in the type of word presented, simple or compound and in terms of which ear was presented the first syllable of the words. Earphones were reversed. One group presented simple words heard the first syllable of these words in the right ear, the other simple word group was presented the same words but heard the first syllable in the left ear. Identical arrangements were conducted for the compound word groups. The subjects thus listened to three blocks of ten trials in a single experimental session, first digits, then three words, then five words in the third and final block of trials. The number of stimulus items correctly recalled were analysed by means of analysis of variance.

Results in this experiment revealed that in rapid rate (2 per sec.) dichotic listening subjects did not report meaningfully (switch channels) even though meaningful word associations existed between temporal pairs. The result showed that the right ear was superior to the left on the delayed channel for all conditions and that the ear order effect (EOR) held for digits, and both types of words.

Bartz's findings question Emmerich et al (1965) on the influence of meaningfulness in dichotic listening. The procedural difficulties which Emmerich employed may have accounted for his positive results. Bartz's results indicate that the asymmetry holds for stimuli other than digits. Recall for the right ear was found to be superior to the left ear for all types of stimulus material.

The writers consider that evidence does point to a built in central mechanism(s) for explaining the laterality effect (Bocca et al 1955, Galambos et al 1959, Rosenweig 1951, Tunturi 1946). Kimura (1961b) demonstrated under dichotic stimulation that the ear contralateral to the dominant speech hemisphere was more efficient. This relationship only occurred for simultaneous presentation of digits. Right ear superiority in Kimura's study may be explained on the basis of greater representation of crossed auditory connections and the consistent lateralization of left brained speech in right handers.

Thus because of the built in efficiency of the right ear, presenting the first syllable of simple words to the right ear results in greater mean recall for the right over the left ear. When the more salient syllable is presented to the left ear the ears did not differ in mean recall, possibly because of the lesser efficiency of the left ear and the greater efficiency of the right ear when employed as a storage channel.

This explanation - the passing of the more salient of simultaneous stimuli into the p-system also holds for the results found with three compound words. The findings with five words showed the effects of saliency of stimuli to a lesser extent than did the results with three words. It may be that the effects of ear asymmetry were greater under the five word conditions. The right ear was recalled first on a majority of five word trials, suggesting that subjects may concentrate on the right (more efficient) ear when the amount of dichotic stimulation is increased. Unlike recall for three words the right ear was superior in recall to the left under all word type x channel conditions with five words.

The saliency effect and the laterality effect may have been placed in competition when the more salient stimuli were presented to the left (and less efficient) ear.

In Broadbent's model the ear order report (EOR) is a consequence of the difficulty in switching channels under rapid rate dichotic stimulation. Stimuli from one ear is passed into a p-system and a filter mechanism shunts the stimuli presented to the other ear into a temporary store (s-system). The findings of Bartz's experiments suggest that when dichotic stimuli differs in 'attention value' or saliency, the more salient are passed into a p-system and the less salient are shunted into a temporary store by the "filter". It is possible that white noise has a very low degree of saliency in that it is consistent noise with no specific features which demand continuous processing. The subject does not in fact have to switch channels but is able to attend to stimuli which is presented to one ear only.

Bartz's findings imply that irrespective of <u>material type</u> the right ear effect still holds. Nevertheless our own results do indicate slightly greater lateralisation of function for material which is sequential and syntactically and semantically intact. Approximation 3 scores did not show the same degree of asymmetry as Textual Material scores. However, the degree of right ear advantage may be important here and it is just possible that in our experimental model we have isolated this factor. That is to say that under monaural stimulation - accepting that white noise does not simulate a dichotic listening paradigm - the more significant the material the more effectively is it attended to by the left hemisphere. Nonsense material (approximation 1 Test) does not show the same degree of lateralisation. Some support for our finding comes from Sperry and Gazzaniga* (1967) who have reported patients who have undergone sections of the cerebral commiures. They comment that whilst some comprehension of spoken verbal material is possible in the right hemisphere verbal report is not. Thus localisation of speech function in the left hemisphere seemed to be total, whilst localisation of verbal comprehension was predominant in the left hemisphere.

Other writers have shown the right ear effect for speech sounds. Shankweiler and Studdert Kennedy 1967 a, b, found significantly greater scores for the right ear than for the left ear in free recall paradigms for initial and final stop consonants and Haggard (1969) showed the same effect for labials and semi vowels in a simple, nonsense syllable context. Darwin (1969) in an experiment where order of report was controlled gained greater right ear scores for stop consonants. However, all these experiments

+ under Gazzaniga

do not discriminate whether the difference between ears occurs before or after the sound has been categorised as a particular phoneme.

Darwin (1971) has recently carried out two experiments which examined the perceptual processes which might occur before classification as a phoneme. The experiments themselves and the implications drawn from the results has a relevance which is central to our hypothesis concerning speech and non speech sounds, or what we have referred to as verbal and sensory material. Darwin makes several points which are basic to the content of his experiment, namely that the sounds of speech are a subset of the sounds of the environment. Since they are subject to the phonetic constraints imposed by the anatomy and physiology of the vocal tract and to the phonological and allophonic constraints imposed by particular languages, perceptual efficiency is only obtained if these constraints are utilized. Phonetic constraints are of two types. In the one type the articulatory specifications for some phonemes are incomplete (for bilabial stops there is only a general movement of the lips and jaw). In the second case there are variations in size and shape of the tracts producing the sound. Lieberman et al (1967) has extensively studied the first set of relations and he was concerned to discover by what mechanism the listener decodes certain sounds and recovers the phoneme. In fact, why are speech sounds perceived so well in spite of the limitations of the ear? In order to look at the basic speech code he examined the voiced stop 'd' and considered that there were basic parameters common to all speech sounds.

Although our own experimental material has not broken down language into component speech particles, it is obviously important to do so in order to understand what is going on at the perceptual level. It will be remembered (Part I) that Lieberman listed the basic parameters in terms of (1) the acoustic cues, (2) the parallel transmission of the phonemes, (3) the locus of a particular consonant, (4) constriction noises and (5) manner, voicing and position.

The Vowels

As well as discussing initial consonants it is important to recall that vowels are rarely steady state in normal speech. They show substantial restructuring, i.e. the acoustic signal at no point corresponds to the vowel alone but at any instant the merged influences of the preceding or following consonant (Stevens and House 1963).

In slow articulation then the acoustic cues for the vowels, and the noise cue for fricatives tend to be invariant. They differ then from the cues for the other phonemes, which vary as a function of context at all rates of speaking.

So much for the first set of relations which are important to the perception of the speech code. The second type of variability has received little attention. The relationship is not a simple one for a number of reasons, viz. women's vocal tracts are smaller and show different anatomical proportions, (quoted by Darwin, 1969, Chiba and Kajujama 1941). Also when vowels are spoken by different individuals the formant frequency of that vowel varies between speakers, between vowels and between individual formants. The perceptual system compensates in part for these permutations since it is able to interpret widely differing variations in the range of the first two formants (Ladefoged and Broadbent 1957). Performance on the right ear is significantly better when formant transitions are added, while that on the left ear is not. Thus it appears that only the right ear can utilize effectively the additional information present in the formant transitions. In Darwin's experimental work the analysis of results was made in terms of simple per cent correct scores, the differences found under the various stimulus conditions may have been due to changes in preferred order of report. However, a scoring system was devised to counter the order of report effects. The results showed a similar pattern to that obtained with both simple per cent correct scores. The right ear advantage is greater when appropriate formant transitions are present than when they are absent. The presence of a succeeding vowel in the absence of formant transitions does not appear to influence the ear advantage. The ear difference is not simply a function of the recognition response class but it also influenced by the particular cues used to achieve a given response. This suggests that the difference between the ears is occurring before or during the classification of the sound into features and that it is not simply a consequence of an overall difference for the phonemic response. The presence of a right ear advantage for condition (2) argues that the ear difference for the individual features is not a consequence of the ear advantage for the entire response but rather that the ear advantage for particular features precedes that for the entire response.

These experiments on speech particles by Darwin do point to a real between ear difference when certain sounds are presented in a dichotic situation. Is the same true when subjects are presented with signals which are not matched with equivalent noise? The children in our series had a competing input of white noise. We do know that the ear difference effect is dependent on the competing stimulus. Initial and final plosive consonants give a reliable right ear advantage when opposed by another such consonant (Shankweiler and Studdert-Kennedy, 1967b). However, plosive consonants embedded in a nonsense word and opposed by white noise give no ear difference (Corsi, 1967, quoted by Darwin, 1969). Darwin showed no ear difference using initial plosives rather than embedded ones in one ear and noise on the other. Thus it seems clear that the between ears difference is significantly affected by the nature of the opposing noise.

Notwithstanding the inadequacy of white noise as a competing input our group did show a small but significant preference to report more efficiently sequential and meaningful material from the right ear. (Textual material and to a lesser extent Approximation 3). Verbal material (Approximation 1) of a nonsense kind showed no such asymmetry and gained equal laterality (tables 4 and 5). It is possible that the implications here are that the left hemisphere is more efficient and shows greater retentiveness for significant material than the right hemisphere (Meyer and Yates 1955). And we accept that the more significant the material the more efficiently it may be recalled. This is the Inglis hypothesis that the right ear effect may be linked with the greater efficiency of the left hemisphere to retrieve material which is easier to remember, hence in our experiments Approximation 3 and Textual Material. Inglis bases his assumption on the possibility that the left hemisphere shows greater storage facilities than the right hemisphere. Our results presume that retrieval of the more meaningful material is linked to the slightly greater storage facilities of the left hemisphere.

If we like to use Brain's terminology the left hemisphere shows greater facility in dealing with the auditory gestalt at a word meaning scheme level.

There is certainly sufficient clinical material (neurological and neurosurgical) to substantiate our results that the left hemisphere shares the major responsibility in memory and learning tasks.

The superiority of the right ear for discriminating words meaningfully is emphasised in Goldstein's paper on four patients who had right hemiplegia from infancy and whose left hemisphere was removed. There appeared to be significant impairment in discrimination of words presented to the right ear on word discrimination tests. The measured impairment in the discrimination of speech has a parallel in the report of three of the patients on the distinctness of speech presented to each ear. Two patients volunteered that the words sounded 'clearer' in the left ear than the right ear. Thus there appeared to be impaired ability to understand distorted speech in spite of normal thresholds for pure tone and speech. This impairment is marked in the ear contralateral to the pathologic hemisphere and did not change after surgery.

Bocca et al 1955 reported similar findings in cases of unilateral lobe tumors. For this test of discrimination for speech, they distorted speech by filtering out most of the high frequency components. 60% - 80% of this speech was understood correctly by "normal subjects". Patients with tumours of left temporal lobe missed a large percentage of the words even though they had normal thresholds. Impairment however diminished in 20-30 days following excision of the affected temporal lobe.

It is difficult to determine whether specific lesions in the temporal lobe are responsible for impairment in discrimination or whether change to cerebral tissue in general is responsible.

In Goldstein's group discrimination did not improve in either ear following hemispherectomy and it would suggest that preoperative impairment did not result from a nociferous influence of remote abnormal cortex on normal cortex.

However, removal of the left hemisphere did result in major improvements in behaviour and this suggests that the abnormal activity in the pathologic hemisphere may disrupt the functioning of the intact hemisphere.

Meaningfulness and Right Ear Advantage

Our own experimental results do then show some point of correspondence between the meaningfulness of the material and the degree of right ear advantage. Nonsense material does not discriminate between right and left ear scores, whereas Approximation 3 and Textual Material does to a small extent give a right ear advantage. (table 5) Furthermore these tests do distinguish and separate out the right and left handers in the predicted directions (table 13, Chart 3).

Bartz's experiments showed that the right ear advantage was greatest under the five word condition recall and that the right ear was more efficient when employed as a storage channel. Our experiment showed that the right ear effect only held for Approximation 3 and Textual Material. It is possible that there may have been a similar asymmetry with regard to the Approximation 1 test if the stimulus condition had been a truly dichotic one.

Summary and Conclusions

We cannot stress too much our own position in this sensory versus verbal dichotomy. It would seem to be imperative that we must always analyse the particular ingredients of each test and acknowledge that no test is just a verbal or a sensory test but is composed of many elements common to both situations. For example, voices are cued by both pitch, rhythm and timbre just as pitch is related to its own acoustic framework whether it is carried on a single click or tone pip sound of a particular intensity. Darwin's work has shown us how important it is to break up sound into its essential elements before we may make decisions with respect to the level at which it is being perceived.

Negative Findings

Although we have only shown a general and not a significant ear advantage for sensory versus verbal material, our experimental results and their implications have highlighted the complexity of defining auditory stimuli as material specific. Not only must we analyse and separate out the specific concomitants of any signal carried on a sine wave, we must also define at what level it is being responded to before we can begin to discuss the problems of auditory perception and its hemispheric correlates.

Lateralisation of Function with Age.

One of the basic hypotheses we were unable to support is the possible increasing specialisation of the hemispheres with increase of age, that is to say, that auditory function lateralises with maturation of the central nervous system.

Although there appeared to be some evidence that boys showed laterality for pitch earlier than girls when this was explored further there did not appear to be any increase in lateralisation at the upper age groups. Laterality appears to operate at the middle age ranges (9 - 14 years) but did not increase after this age.

In the loudness test (table 5) there is some slight evidence (a slight increase of Laterality Indices Means with age) to show that the older females may show more lateralisation of function than the younger females. The latter demonstrate equal laterality with the ear presented first being the major factor. Older males also show equal laterality with no bias towards ear presented first. The younger males show a high proportion of zeros with no bias amonst the remainder. There is some agreement with the

Pitch test results in that if lateralisation of function is operating it does so at the middle age range (9 - 14 years) but appears to remain steady or diminish after this age.

We were unable to show increasing lateralisation of function with respect to the other tests.

If we remember that the recall of verbal material is dependent upon language acquisition of the child it would seem naive indeed if we were to expect that auditory perception should behave differently from speech lateralisation. For in speech we have sufficient clinical and experimental evidence to show that in right handed children the left hemisphere is already playing its dominant role at a very early age.

Kimura (1963b) found that as early as four years of age spoken material arriving at the right ear is more accurately recorded than spoken material arriving at the left ear.

Our youngest child was four years nine months, a girl and it does appear that our findings support Kimura's that lateralisation of function (if any) has already occurred before the age of five. In our separate analysis of the data in the youngest children (Age Group 1) there was a slight suggestion (not reaching statistical significance) that lateralisation of function in the hypothesised direction was already present.

With regard to certain non verbal abilities, Ghent (1961) found that thumb sensitivity was not developed until six years in girls and later in boys, that is, later than the right ear effect in children. However, some criticism can be made of Ghent's study in that he used two different modalities within the same experimental situation. It will be remembered that we were particularly interested to look at possible lateralisation of the right hemisphere and in order to do this we used the sensory stimuli of differing frequency and decibel signals. However, our tests were not based on pure response to these sounds but on an intellectual judgement and discrimination of differences between two stimuli. We found no evidence to support the hypothesis that there was increasing preference by one or the other hemisphere to make these judgements with any increased maturation of the central nervous system.

Therefore to sum up then, except for the pitch experiment and the loudness test where we were able to demonstrate a sex difference in terms of earlier discrimination of pitch sounds by boys, and some preference by girls at 9 - 14 years to show greater right ear advantage than younger children in the loudness test, we were unable to demonstrate any increasing specialisation with age of either hemisphere to respond to differing stimuli.

There are possibly a number of factors which may be responsible for our non significant results with respect to (1) ear advantage and material specificity and (2) lateralisation of function with age. These factors could be:

A. Methodological and procedural.
B. The particular experimental sample.
C. Complexity of the subject.

With regard to A, I think it should be accepted that the use of white noise as a competing input does not in any way simulate a dichotic listening situation. Darwin has pointed out the importance of matching noise with a signal and in our experiments white noise did not in any sense produce a comparable competing stimulus for the experimental tasks. In Darwin's words, "Perhaps no steady state discrimination can give an ear difference". We have mentioned earlier that there were occasions when the decibel range of the white noise had to be adjusted for comfort and the reduction in decibel limen of this competing input may have significantly affected the test results. Given that our technique more nearly replicated a monaural setting, the analysis of our results appears more reasonable and comprehensible. For there is no experimental evidence which has shown the ear effect in such a listening paradigm.

B. The Experimental Sample.

If we accept that children should be given every possible consideration when they are employed as subjects in an experimental project we must also accept that the comfort of the child must take precedence over the niceties of adhering to the proposed experimental model. Thus the lowering of the decibel level in the white noise inputs (from approx 64-62db.) may well have meant that we were no longer maintaining a dichotic situation and therefore our comments concerning saliency of the competing input may only relate to our own experiments with children. White noise may in fact be a sufficiently competing input if it is sustained at a particular level and if used on an adult population where the stress threshold would be supposedly higher.

The minor adjustments and changes in procedure which were undertaken in the interests of the children must be accepted as central to all child assessment and are probably responsible for some of our equivocal results. We should also refer to the strong bias of left handedness in our total sample. There seems no good reason for this and as we have stated previously we have included in our left handed group only those who demonstrated strong unilateral motor function, so there can be no suggestion that we have a sample of children with mixed dominance. Thus the high proportion of sinistrals would certainly have distorted the total group analysis.

Knox and Boone (1970) compared the ear preference of normal subjects who were strongly left or strongly right handed using competing verbal messages (Kimura subtests) which had been altered by adding white noise and random interruptions. Under these difficult listening conditions left sided subjects demonstrated a significant left ear effect. The authors conclude that when the tested side of motor function (handedness and footedness) show marked exclusivity there is a significant tendency for ipsilateral ear preference when the dichotic listening tasks become difficult.

C. The Complexity of the Problem.

Originally we had assumed that we might be able to designate material as either sensory or verbal. Throughout our discussion it has become increasingly clearer that these labels are in fact meaningless except in the broadest categorical sense and that it is essential for the stimulus to be broken down into its basic acoustic features, before we can make predictions about how it is being attended to. Darwin has shown that steady state vowels can give a right ear advantage and that simple pitch sweeps give a left ear advantage when carried on a word but do not cue a phonemic distinction. Here then it is not the extraction of the acoustic cue which is important but its phonetic relevance. Thus particular acoustic features themselves are not completely responsible for the ear difference effect. Halwes (1969) found that subjects made most errors from the inappropriate combinations of correctly extracted features. He suggests that both hemispheres are capable of extracting acoustic features but that these must be built up into phonetic responses in the left hemisphere. So what we may have is a system by which both hemispheres are capable of analysing the input stimulus into its simple acoustic features but that some transformation occurs at cortical level of these essential features into probable phonemic categories.

APPENDICES TABLES.

Appendices Tables. A

SUBJECTS RAW SCORES ON ALL TESTS FOR FORM 1 (AGE GROUP 1)

Tests	1				2				3				4				5				6				7			
Sex	M		F		M		F		M		F		M		F		M		F		M		F		M		F	
Ear Child No:	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
1			5				3				-				-				2				4				6	
2				4				5				4				-				4				4				6
3	2				1				4				1				4				4				6			
4		5				4				3				1				4				4				6		
5				4				3				6				2				4				6				12
6			2				5				6				1				4				8				10	
7		4				7				6				3				4				4				10		
8	6				3				1				1				4				6				6			
9			4				4				5				-				4				4				6	
10				-				6				-				-				4				4				4
11	-				3				4				4				4				6				12			
12		-				4				-				-				4				4				4		
13				7				5				5				5				4				6				8
14			1				1				3				-				-				4				6	
15		1				2				1				6				4				4				6		
16	4				10				6				5				4				6				8			

Appendix table no. 1

Test 1 = Loudness
Test 2 = Pitch
Test 3 = Rhythm
Test 4 = Tonal Memory
Test 5 = Approx. 1
Test 6 = Approx. 3
Test 7 = Textual Material

AGE GROUP 2.

SUBJECTS RAW SCORES IN ALL TESTS FOR FORM 1 (AGE GROUP 2)

Tests	1				2				3				4				5				6				7			
Sex	M		F		M		F		M		F		M		F		M		F		M		F		M		F	
Ear Child No:	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
17			4				5				5				5				4				6				10	
18				7				5				6				5				6				4				6
19	7				5				6				5				4				12				10			
20		5				6				6				4				4				4				6		
21				2				7				5				2				4				4				10
22			4				3				6				3				4				4				8	
23		2				2				4				-				4				6				6		
24	1				-				6				2				6				6				6			
25			3				4				5				5				6				10				10	
26				1				4				5				5				6				10				10
27	3				9				6				3				4				4				8			
28		3				5				6				-				4				6				6		
29				5				5				6				4				4				8				8
30			7				4				6				4				6				6				10	
31		5				2				6				1				6				6				10		
32	4				7				6				1				6				6				10			

Appendix table no. 2

AGE GROUP 3.

SUBJECTS RAW SCORES ON ALL TESTS FOR FORM 1 (AGE GROUP 3)

Tests	1				2				3				4				5				6				7			
Sex	M		F		M		F		M		F		M		F		M		F		M		F		M		F	
Ear Child No:	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
33				4				7				6				5				6				12				10
34			4				5				5				1				4				6				6	
35		7				4				6				4				4				6				6		
36	5				4				6				5				6				4				6			
37			6				4				6				4				6				8				10	
38				-				7				7				4				4				4				6
39	5				4				6				4				4				4				10			
40		5				6				6				4				6				6				8		
41				6				5				6				4				8				12				16
42			7				5				6				5				4				4				6	
43		6				5				6				5				6				8				12		
44	4				4				6				5				6				8				8			
45			7				4				6				5				8				12					14
46				4				5				6				5				4				6				6
47	6				6				5				3				6				12				14			
48		7				3				6				5				6				6				12		

Appendix table no. 3

SUBJECTS RAW SCORES ON ALL TESTS FOR FORM 1 (AGE GROUP 4)

Tests	1				2				3				4				5				6				7			
Sex	M		F		M		F		M		F		M		F		M		F		M		F		M		F	
Ear Child No:	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
49				7				4				4				5				4				4				8
50			6				8				6				5				6				8				12	
51		4				1				6				1				2				6				8		
52	6				5				5				5				6				6				12			
53			7				5				6				5				4				8				10	
54				3				7				6				5				4				6				8
55	5				6				6				1				4				6				10			
56		5				4				6				4				6				6				12		
57			5				7				5				4				6				8				12	
58				6				5				4				4				4				8				10
59	5				3				5				4				4				6				10			
60	6				5				6				5				8				6				14			
61				5				4				6				4				6				10				12
62			7				5				6				5				8				12				12	
63		7				8				4				4				4				6				8		
64		5				4				6				5				6				10				12		

Appendix table no. 4

AGE GROUP 1.

SUBJECTS RAW SCORES ON ALL TESTS FOR FORM 2 (AGE GROUP 1)

Tests	1				2				3				4				5				6				7			
Sex	M		F		M		F		M		F		M		F		M		F		M		F		M		F	
Ear Child No:	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
1				1				2				-				-				4				4				6
2			-				2				1				-				2				4				6	
3		2				8				3				-				2				4				6		
4	2				4				5				5				4				6				6			
5			2				2				1				-				6				6				10	
6				3				1				4				-				4				4				6
7	4				9				4				2				6				6				6			
8		4				4				4				3				4				8				8		
9				4				1				4				3				4				4				6
10			4				3				5				-				4				4				6	
11		-				3				5				3				4				4				6		
12	2				3				1				-				4				4				6			
13			6				4				5				1				6				6				12	
14				3				1				2				-				6				6				10
15	1				2				3				1				2				4				6			
16		4				10				6				5				4				8				6		

Appendix table no. 5

AGE GROUP 2.

SUBJECTS RAW SCORES ON ALL TESTS FOR FORM 2 (AGE GROUP 2)

Tests	1				2				3				4				5				6				7			
Sex	M		F		M		F		M		F		M		F		M		F		M		F		M		F	
Ear Child No:	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
17				7				7				5				5				4				6				6
18			7				5				6				5				4				8				10	
19		5				6				6				4				4				10				6		
20	6				5				6				2				4				8				8			
21			4				4				5				2				4				4				8	
22				2				6				6				4				4				6				10
23	6				2				6				1				4				4				6			
24		5				6				6				4				4				6				8		
25				2				4				6				5				6				6				8
26			3				3				6				4				4				8				12	
27		3				6				5				-				4				4				6		
28	5				2				4				-				4				6				6			
29			5				4				6				5				4				4				6	
30				7				4				6				4				4				8				14
31	5				4				6				1				6				6				10			
32		5				6				6				3				4				8				12		

Appendix table no. 6

AGE GROUP 3.

SUBJECTS RAW SCORES ON ALL TESTS FOR FORM 2 (AGE GROUP 3)

Tests	1				2				3				4				5				6				7			
Sex	M		F		M		F		M		F		M		F		M		F		M		F		M		F	
Ear Child No:	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
33			5				5				6				5				4				8				10	
34				2				6				3				4				6				6				10
35	7				4				6				4				4				6				6			
36		3				4				6				5				4				6				8		
37				7				6				6				5				6				6				10
38			3				6				6				5				4				6				8	
39		3				4				6				5				4				4				6		
40	4				2				6				4				6				4				12			
41			4				4				6				5				8				10				10	
42				4				4				6				5				4				6				8
43	7				6				6				5				6				8				8			
44		6				4				6				5				6				10				10		
45				6				5				6				5				6				6				12
46			6				3				6				4				4				10				10	
47		5				5				5				2				6				8				10		
48	6				5				6				4				6				8				12			

Appendix table no. 7

SUBJECTS RAW SCORES ON ALL TESTS FOR FORM 2 (AGE GROUP 4)

Tests	1				2				3				4				5				6				7			
Sex	M		F		M		F		M		F		M		F		M		F		M		F		M		F	
Ear Child No:	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
49			7				4				5				5				4				6				6	
50				7				7				6				5				6				12				14
51	2				1				4				-				4				6				6			
52		5				5				6				5				6				10				12		
53				6				4				6				5				4				6				12
54			5				6				6				4				4				8				12	
55		5				4				3				2				4				4				6		
56	3				4				6				4				8				10				14			
57				4				4				6				2				6				12				14
58			7				5				4				4				2				6				10	
59		7				2				6				4				6				8				10		
60		-				5				6				5				6				10				12		
61			6				4				6				5				4				10				12	
62				6				9				6				5				6				10				10
63	7				2				6				5				4				6				8			
64	6				4				5				5				6				6				12			

Appendix table no. 8

AGE GROUP 1.

LATERALITY INDICES FOR BOTH SEXES ON ALL 7 TESTS

Tests	1		2		3		4		5		6		7	
Sex	M	F	M	F	M	F	M	F	M	F	M	F	M	F
Child No:														
1		.28		+.05		-		-		.10		.00		.00
2		-.28		-.15		-.25		.-		-.1		.00		.06
3	.00		-.35		.08		.1		.10		.00		.00	
4	-.21		.00		.16		.4		.00		.06		.00	
5		-.14		-.05		-.42		-.2		.1		.00		-.06
6		-.07		.2		.16		.1		.00		.12		.12
7	.00		.10		-.16		.1		.1		.06		-.12	
8	.14		-.05		-.08		-.2		.00		-.06		-.06	
9		.00		.05		.08		.00		.00		.00		.00*
10		.28		-.15		.41		-		.00		.00		.00
11	-		.00		-.08		.1		.00		.06		.19	*
12	.14		-.05		.08		-		.00		.00		.06	
13		-.07		-.05		.00		-.40		.10		.00		.12
14		-.14		.00		.08		-		-.3		-.06		-.12
15	.00		.00		.25		.10		-.1		.00		.00	
16	.00		.00		.00		.00		-.00		-.06		.06	

Appendix table no. 9

* = left handers

AGE GROUP 2.

LATERALITY INDICES FOR BOTH SEXES ON ALL 7 TESTS

Tests	1		2		3		4		5		6		7	
Sex	M	F	M	F	M	F	M	F	M	F	M	F	M	F
Child No:														
17		-.21		-.10		.0		.0		.0		.00		.12
18		.00		-.05		.00		.00		-.10		+.12		+.12
19	.14		-.05		.00		.10		.00		.06		.12	
20	-.07		-.05		.00		-.20		.00		.12		.06	
21		.14		-.15		.17		.00		.00		.00		-.06
22		.07		-.15		.00		-.10		.00		-.06		-.06*
23	.28		.00		.17		.10		.00		-.06		.00	
24	-.28		-.30		.00		-.20		.10		.00		-.06	
25		.07		.00		-.08		.00		.00		.12		.19*
26		.14		-.05		.08		-.10		-.10		-.12		.06
27	.00		.15		.08		.30		.00		.00		.06	
28	.14		-.15		-.17		-		.00		-.06		.00	
29		.00		-.05		.00		.10		.00		-.12		-.12
30		.00		.00		.00		.00		.10		-.06		-.12
31	.00		.10		.00		.00		.00		.00		.00	
32	-.07		.05		.00		-.20		.10		-.06		-.06	

Appendix table no. 10

* = left handers

AGE GROUP 3.

LATERALITY INDICES FOR BOTH SEXES ON ALL 7 TESTS

Tests	1		2		3		4		5		6		7		
Sex	M	F	M	F	M	F	M	F	M	F	M	F	M	F	
Child No:															
33		.07		-.10		.00		.00		-.10		-.12		.00	
34		.14		-.10		.16		-.30		-.10		.00		-.12	
35	.00		-.05		.00		-.10		-.10		.00		-.12		*
36	.14		.00		.00		.00		.10		-.06		-.06		
37		-.07		-.10		.00		-.1		.00		.12		-.06	
38		.21		.05		.00		.10		.00		.06		.06	
39	.14		.00		.00		-.10		.00		.00		.12		
40	-.07		-.25		.00		.00		.00		-.06		.00		
41		-.14		-.05		.00		.10		.00		-.06		.00	
42		.21		.10		.00		.00		.00		-.06		-.06	
43	.07		.05		.00		.00		.00		.06		-.12		*
44	-.14		.00		.00		.00		.00		-.12		-.06		
45		.07		-.10		.00		.00		.10		.18		.06	*
46		.14		-.10		.00		-.10		.00		.12		.12	
47	.07		.05		.00		.10		.00		.18		.12		
48	-.07		.10		.00		-.10		.00		.06		.00		

Appendix table no. 11 * = left handers

AGE GROUP 4.

LATERALITY INDICES FOR BOTH SEXES ON ALL 7 TESTS

Tests	1		2		3		4		5		6		7	
Sex	M	F	M	F	M	F	M	F	M	F	M	F	M	F
Child No:														
49		.00		.00		.08		.00		.00		.00		-.06 *
50		-.07		.05		.00		.00		.00		-.12		-.06
51	-.14		.00		-.17		-.10		.10		.00		-.06	*
52	.07		.00		-.08		.00		.00		-.12		.00	*
53		.00		.05		.00		.00		.00		.06		-.06
54		.14		-.05		.00		-.10		.00		.06		.12
55	.00		.15		.25		-.10		.00		.06		.00	
56	-.14		.00		.00		.00		.10		.12		.06	
57		.07		.15		-.08		.20		.00		.19		-.19
58		.07		.00		.00		-.20		-.10		-.06		.00
59	-.14		.05		-.08		.00		-.10		-.06		.00	
60	.43		-.25		.00		.00		.10		-.12		.06	
61		.07		.00		.00		.10		-.10		.00		.00 *
62		.07		-.20		.00		.00		.10		.06		.06 *
63	.00		-.30		+.17		.10		.00		.00		.06	
64	.07		.00		.00		.00		.00		-.12		.00	

Appendix table no. 12 * = left handers

AGE GROUP 1.

SUBJECTS RAW SCORES ON ALL TESTS FOR 1ST EAR AGE GROUP 1.

Tests	1				2				3				4				5				6				7			
Sex	M		F		M		F		M		F		M		F		M		F		M		F		M		F	
Ear Child No:	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
1			5				3				-				-				2				4				6	
2			-				2				1				-				2				4				6	
3	2				1				4				1				4				4				6			
4	2				4				5				5				4				6				6			
5				4				3				6				2				4				6				12
6				3				1				4				-				4				4				6
7		4				7				6				3				4				4				10		
8		4				4				4				3				8				8				8		
9			4				4				5				-				4				4				6	
10			4				3				5				-				4				4				6	
11	-				3				4				4				4				6				12			
12	2				3				1				-				4				4				6			
13				7				5				5				5				4				6				8
14				3				1				2				-				6				6				10
15		1				2				1				0				4				4				6		
16		4				10				6				5				4				8				6		

Appendix table no. 13

SUBJECTS RAW SCORES ON ALL TESTS FOR 1ST EAR AGE GROUP 2.

Tests	1				2				3				4				5				6				7			
Sex	M		F		M		F		M		F		M		F		M		F		M		F		M		F	
Ear Child No:	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
17			4				5				5				5				4				6				10	
18			7				5				6				5				4				8				10	
19	7				5				6				5				4				12				10			
20	6				5				6				2				4				8				8			
21				2				7				5				2				4				4				10
22				2				6				6				4				4				6				10
23		2				2				4				-				4				6				6		
24		5				6				6				4				4				6				8		
25			3				4				5				5				6				10				14	
26			3				3				6				4				4				8				12	
27	3				9				6				3				4				4				8			
28	5				2				4				-				4				6				6			
29				4				5				6				4				4				8				8
30				7				4				6				4				4				8				14
31		5				2				6				1				6				6				10		
32		5				6				6				3				4				8				12		

Appendix table no. 14

SUBJECTS RAW SCORES ON ALL TESTS FOR (1ST EAR) AGE GROUP 3.

Tests	1				2				3				4				5				6				7			
Sex	M		F		M		F		M		F		M		F		M		F		M		F		M		F	
Ear Child No:	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
33				4				7				6				5				6				12				10
34				2				6				3				4				6				6				10
35		7				4				6				4				4				6				6		
36		3				4				6				5				4				6				8		
37			6				4				6				4				6				8				10	
38			3				6				6				5				4				6				8	
39	5				4				6				4				4				4				10			
40	4				2				6				4				6				4				12			
41				6				5				6				4				8				12				16
42				4				4				6				5				4				6				8
43		6				5				6				5				6				8				12		
44		6				4				6				5				6				10				10		
45			7				4				6				5				8				12				14	
46			6				3				6				4				4				10				10	
47	6				6				5				3				6				12				14			
48	6				5				6				4				6				8				12			

Appendix table no. 15

SUBJECTS RAW SCORES ON ALL TESTS FOR 1ST EAR (AGE GROUP 4)

Tests	1				2				3				4				5				6				7			
Sex	M		F		M		F		M		F		M		F		M		F		M		F		M		F	
Ear	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
Child No:																												
49				7				4				4				5				4				4				8
50				7				7				6				5				6				12				14
51		4				1				6				1				2				6				8		
52		5				5				6				5				6				10				12		
53			7				5				6				5				4				8				10	
54			5				6				6				4				4				8				12	
55	5				6				6				1				4				6				10			
56	3				4				6				4				8				10				14			
57				4				4				6				2				6				12				14
58				6				5				4				4				4				8				10
59		7				2				6				4				6				8				10		
60		-				5				6				5				6				10				12		
61			6				4				6				5				4				10				12	
62			7				5				6				5				8				12				12	
63	7				2				6				5				4				6				8			
64	6				4				5				5				6				6				12			

Appendix table no.16

SUBJECTS RAW SCORES FOR ALL TESTS ON 2ND EAR (AGE GROUP 1)

	Tests	1				2				3				4				5				6				7			
	Sex	M		F		M		F		M		F		M		F		M		F		M		F		M		F	
	Ear Child No:	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
AGE GROUP 1	1				1				2				-				-				4				4				6
	2				4				5				4				-				4				4				6
	3		2				8				3				-				2				4				6		
	4		5				4				3				1				4				4				6		
	5			2				2				1				-				6				6				10	
	6			2				5				6				1				4				8				10	
	7	4				9				4				2				6				6				6			
	8	6				3				1				1				4				6				6			
	9				4				1				4				3				4				4				6
	10				-				6				-				-				4				4				4
	11		-				3				5				3				4				4				6		
	12		-				4				-				-				4				4				4		
	13			6				4				5				1				6				6				12	
	14			1				1				3				-				-				4				6	
	15	1				2				3				1				2				4				6			
	16	4				10				6				5				4				6				8			

Appendix table no. 17

AGE GROUP 2

SUBJECTS RAW SCORES ON ALL TESTS FOR 2ND EAR (AGE GROUP 2)

Tests	1				2				3				4				5				6				7			
Sex	M		F		M		F		M		F		M		F		M		F		M		F		M		F	
Ear Child No:	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
17				7				7				5				5				4				6				6
18				7				5				6				5				6				4				6
19		5				6				6				4				4				10				6		
20		5				6				6				4				4				4				6		
21			4				4				5				2				4				4				8	
22			4				3				6				3				4				4				8	
23	6				2				6				1				4				4				6			
24	1				-				6				2				6				6				6			
25				2				4				6				5				6				6				8
26				1				4				5				5				6				10				10
27		3				6				5				-				4				4				6		
28		3				5				6				-				4				6				6		
29			5				4				6				5				4				4				6	
30			7				4				6				4				6				6				10	
31	5				4				6				1				6				6				10			
32	4				7				6				1				6				6				10			

Appendix table no. 18

AGE GROUP 3

SUBJECTS RAW SCORES IN ALL TESTS FOR 2ND EAR (AGE GROUP 3)

Tests	1				2				3				4				5				6				7			
Sex	M		F		M		F		M		F		M		F		M		F		M		F		M		F	
Ear Child No:	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
33			5				5				6				5				4				8				10	
34			4				5				5				1				4				6				6	
35	7				4				6				4				4				6				6			
36	5				4				6				5				6				4				6			
37				7				6				6				5				6				6				10
38				-				7				7				4				4				4				6
39		3				4				6				5				4				4				6		
40		5				6				6				4				6				6				8		
41			4				4				6				5				8				10				10	
42			7				5				6				5				4				4				6	
43	7				6				6				5				6				8				8			
44	4				4				6				5				6				8				8			
45				6				5				6				5				6				6				12
46				4				5				6				5				4				6				6
47		5				5				5				2				6				8				10		
48		7				3				6				5				6				6				12		

Appendix table no. 19

SUBJECTS RAW SCORES ON ALL TESTS FOR 2ND EAR (AGE GROUP 4)

AGE GROUP 4

Tests	1				2				3				4				5				6				7			
Sex	M		F		M		F		M		F		M		F		M		F		M		F		M		F	
Ear Child No:	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
49			7				4				5				5				4				6				6	
50			6				8				6				5				6				8				12	
51	2				1				4				-				4				6				6			
52	6				5				5				5				6				6				12			
53				6				4				6				5				4				6				12
54				3				7				6				5				4				6				8
55		5				4				3				2				14				4				6		
56		5				4				6				4				6				6				12		
57			5				7				5				4				6				8				12	
58			7				5				4				4				2				6				10	
59	5				3				5				4				4				6				10			
60	6				5				6				5				8				6				14			
61				5				4				6				4				6				10				12
62				6				9				6				5				6				10				10
63		7				8				4				4				4				6				6		
64		5				4				6				5				6				10				12		

Appendix table no. 20

TOTAL RAW SCORES OF EACH CHILD FOR THE 7 TESTS

Child No.	1st Age Group	Child No.	2nd Age Group	Child No.	3rd Age Group	Child No.	4th Age Group
1	37	17	79	33	93	49	73
2	40	18	84	34	68	50	108
3	47	19	90	35	74	51	51
4	59	20	72	36	72	52	94
5	64	21	63	37	90	53	89
6	58	22	70	38	70	54	84
7	75	23	53	39	69	55	66
8	62	24	63	40	84	56	92
9	51	25	84	41	110	57	95
10	44	26	79	42	74	58	81
11	58	27	65	43	94	59	80
12	36	28	55	44	89	60	94
13	80	29	73	45	102	61	94
14	43	30	90	46	79	62	107
15	37	31	74	47	93	63	79
16	86	32	84	48	92	64	92

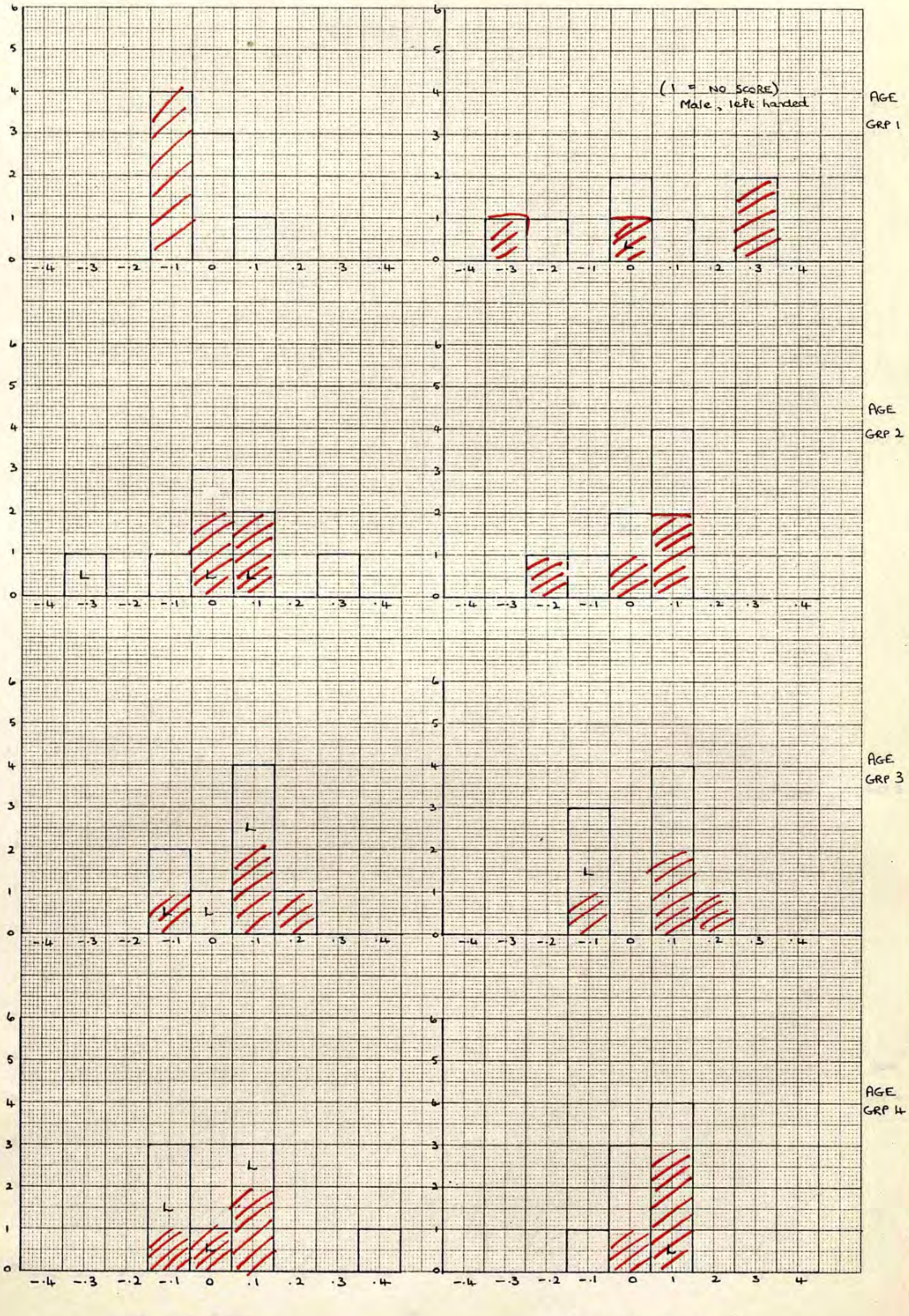
Appendix table no. 21

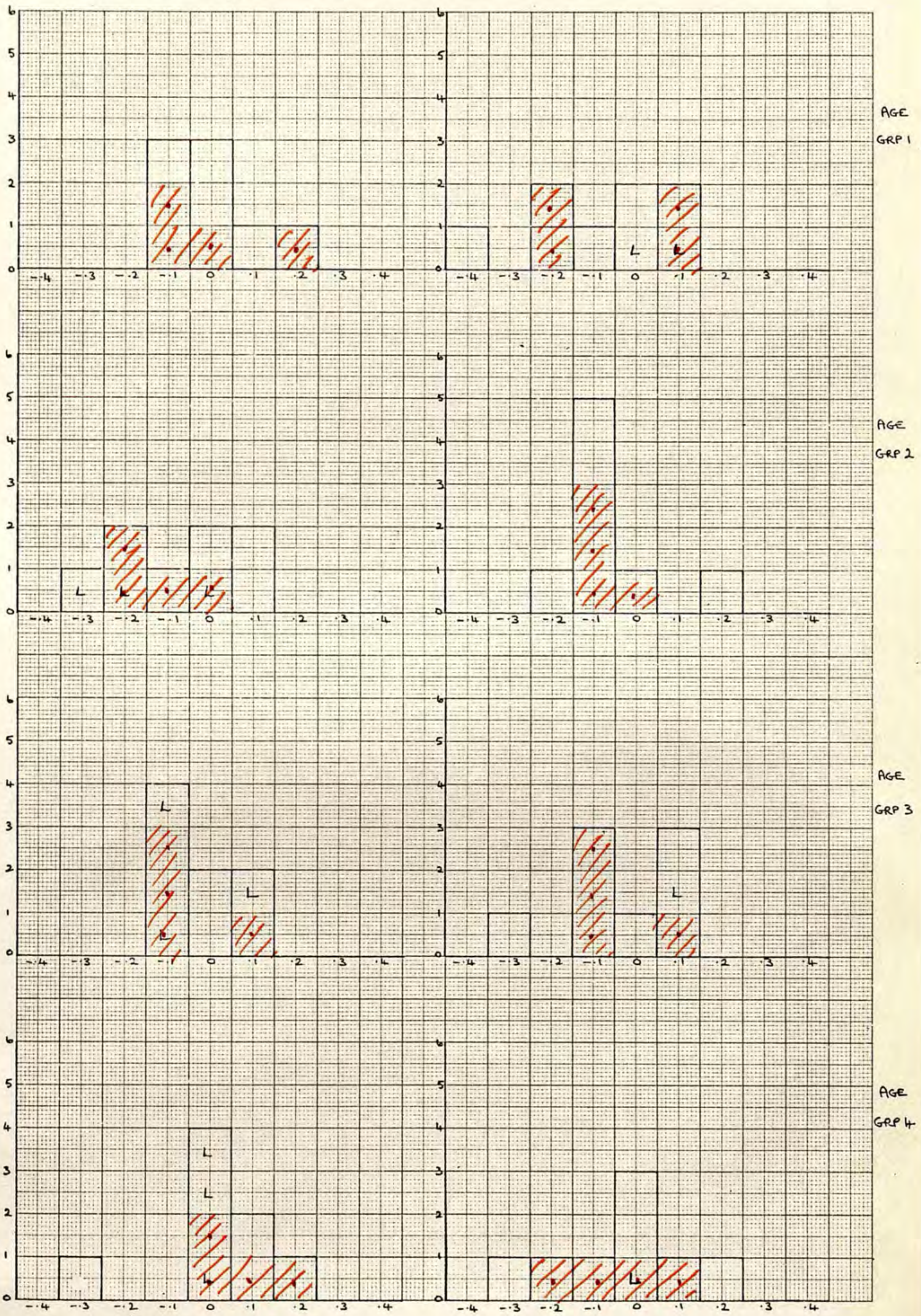
RAW SCORE TOTALS FOR ALL CHILDREN OF EACH SEX SCORED OVER ALL TESTS

Child No.	Age Group 1		Child No.	Age Group 2		Child No.	Age Group 3		Child No.	Age Group 4	
Sex	M	F		M	F		M	F		M	F
1		37	17		79	33		93	49		73
2		42	18		84	34		68	50		108
3	47		19	90		35	74		51	51	
4	59		20	74		36	72		52	94	
5		64	21		65	37		90	53		88
6		58	22		70	38		70	54		84
7	75		23	53		39	69		55	66	
8	62		24	63		40	79		56	92	
9		53	25		84	41		104	57		95
10		44	26		81	42		74	58		81
11	58		27	65		43	94		59	80	
12	36		28	52		44	89		60	94	
13		80	29		73	45		102	61		94
14		43	30		90	46		79	62		107
15	37		31	74		47	93		63	79	
16	86		32	84		48	92		64	92	

Appendix table no. 22

APPENDIX A - HISTOGRAMS

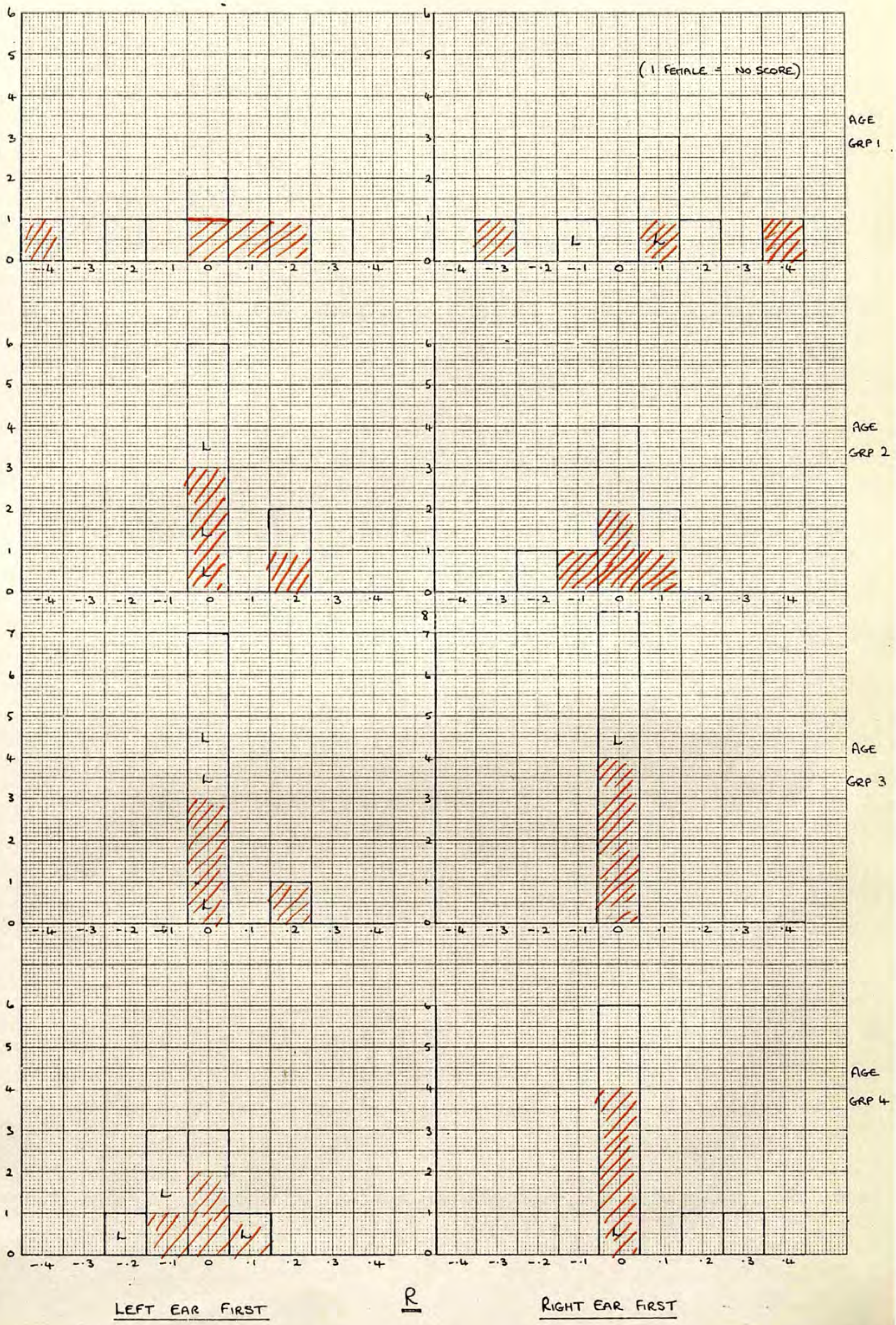

(1 = NO SCORE)
Male, left handed
AGE GRP 1
AGE GRP 2
AGE GRP 3
AGE GRP 4
0
1
2
3
4
5
6
-·4
-·3
-·2
-·1
0
·1
·2
·3
·4
L
LEFT EAR FIRST
L
RIGHT EAR FIRST

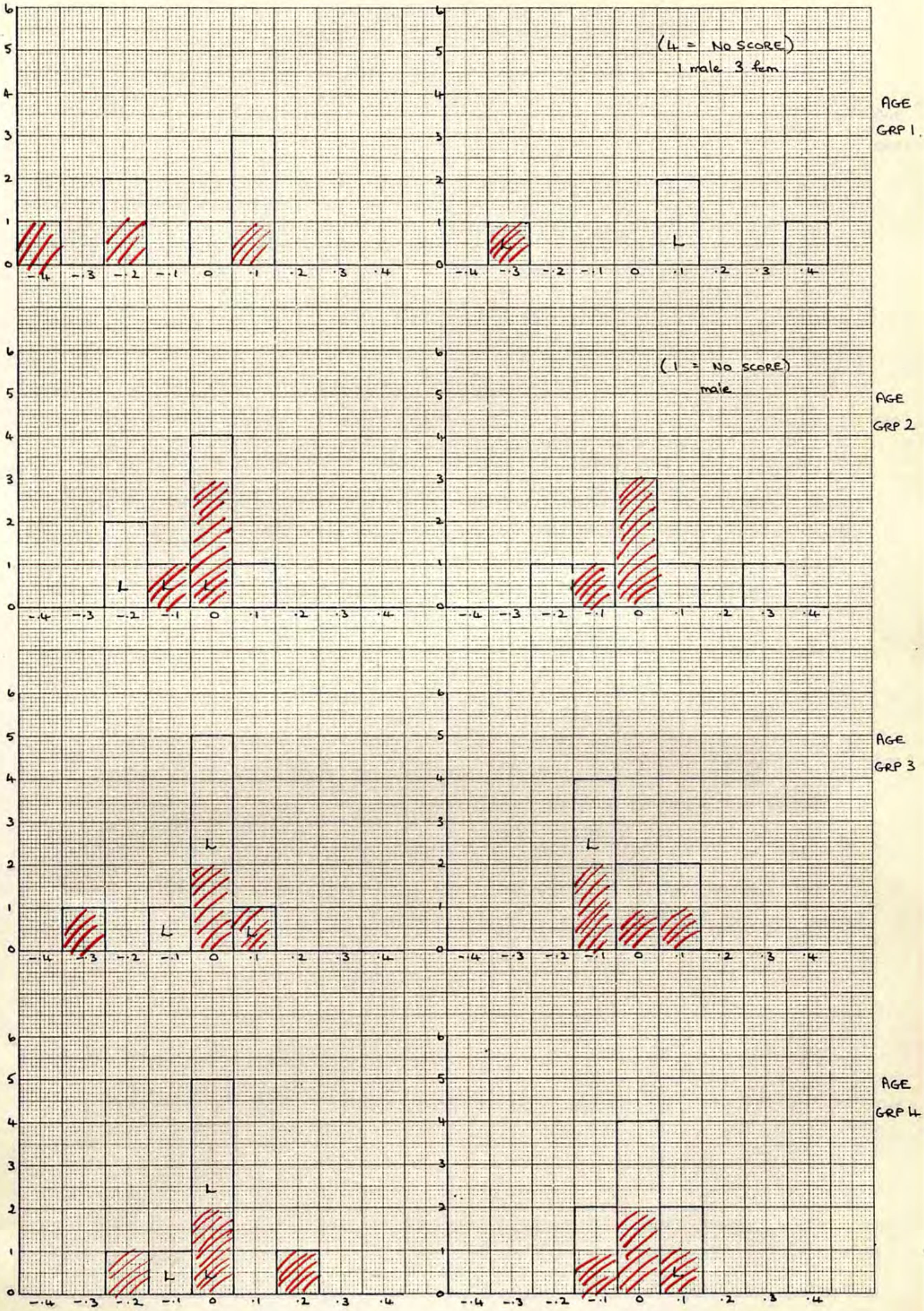


LEFT EAR FIRST

P

RIGHT EAR FIRST

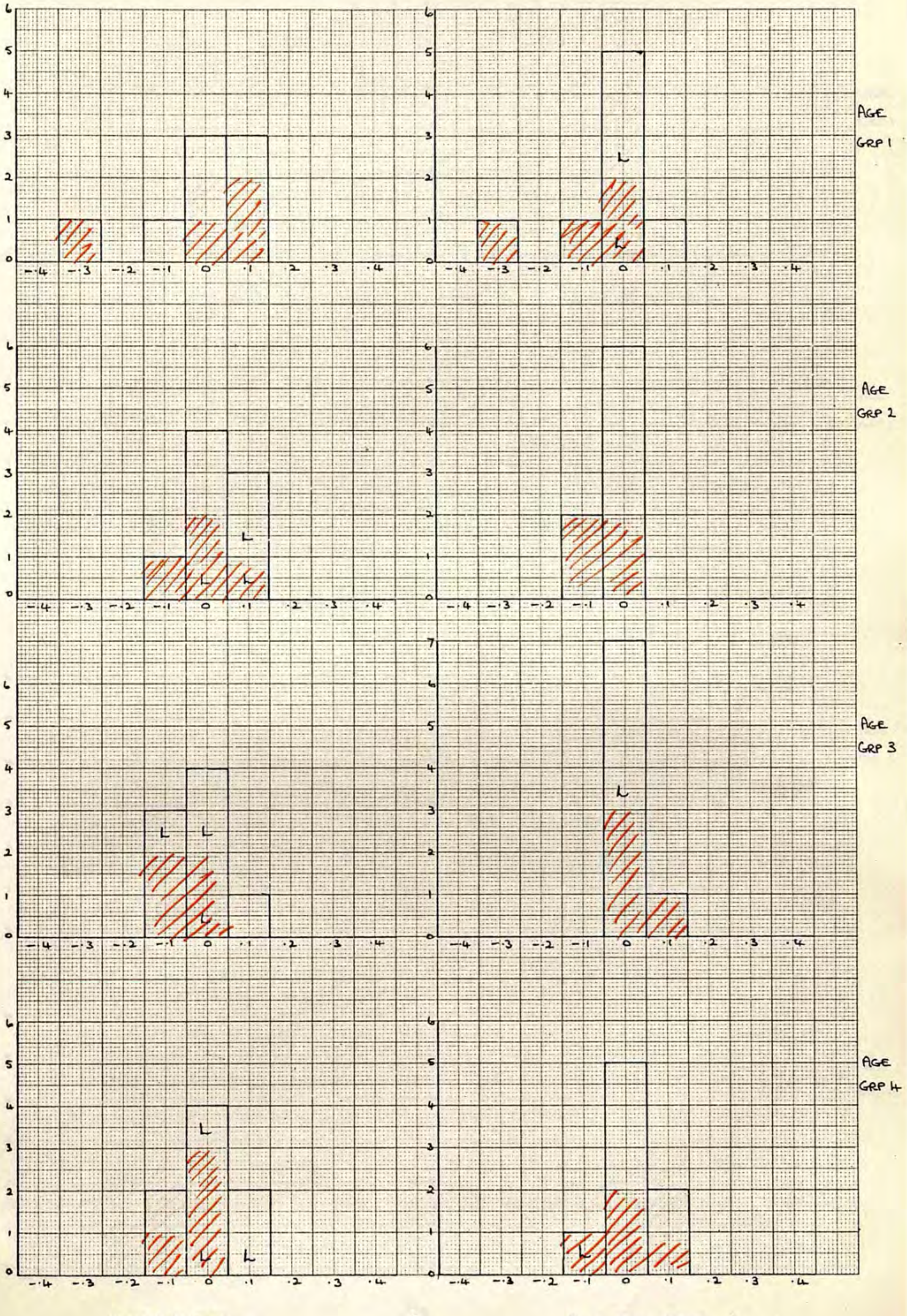

(1 FEMALE = NO SCORE)
AGE GRP 1
AGE GRP 2
AGE GRP 3
AGE GRP 4
0
1
2
3
4
5
6
7
8
-·4
-·3
-·2
-·1
0
·1
·2
·3
·4
L
LEFT EAR FIRST
R
RIGHT EAR FIRST



LEFT EAR FIRST

TOM

RIGHT EAR FIRST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LEFT EAR FIRST
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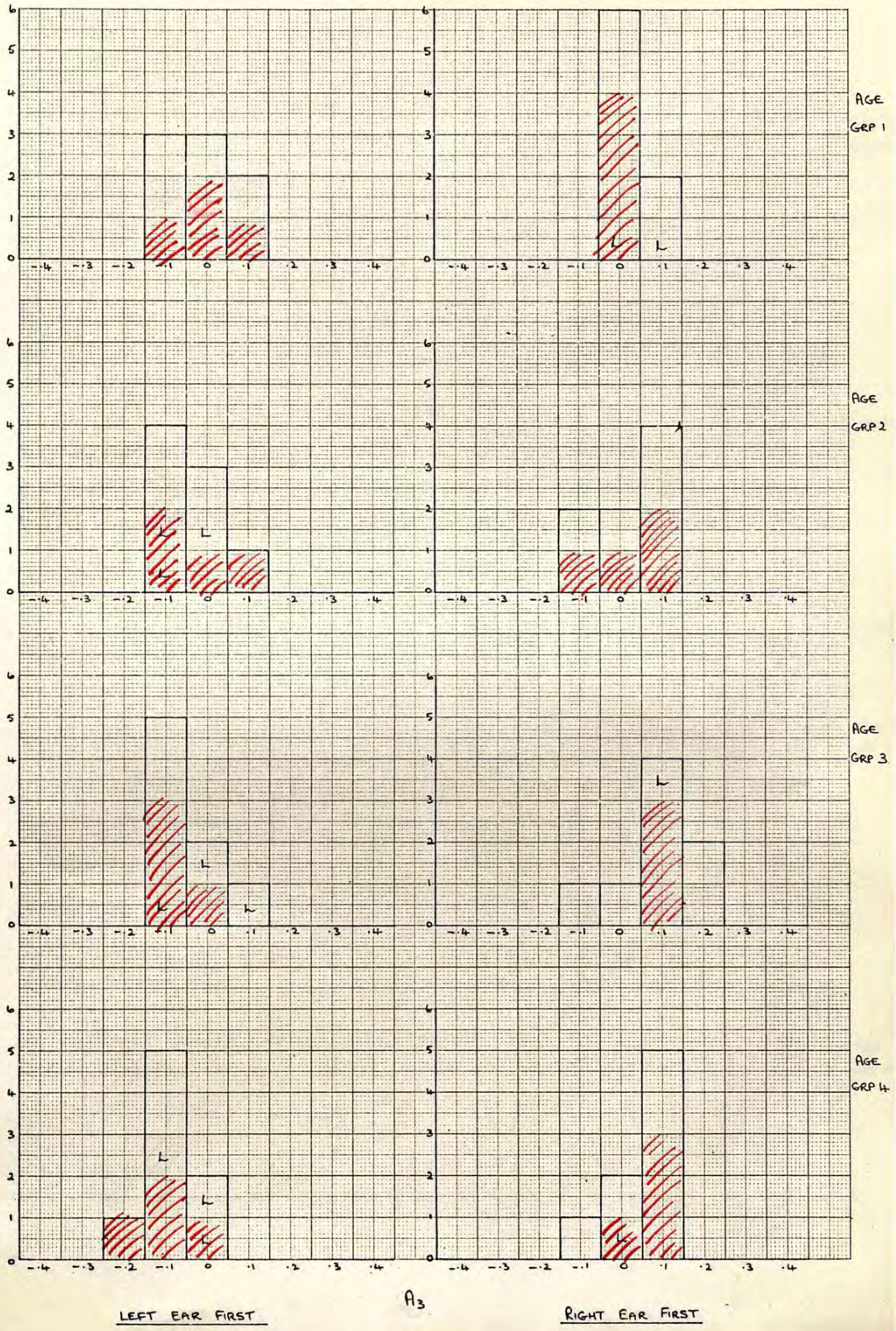
A₁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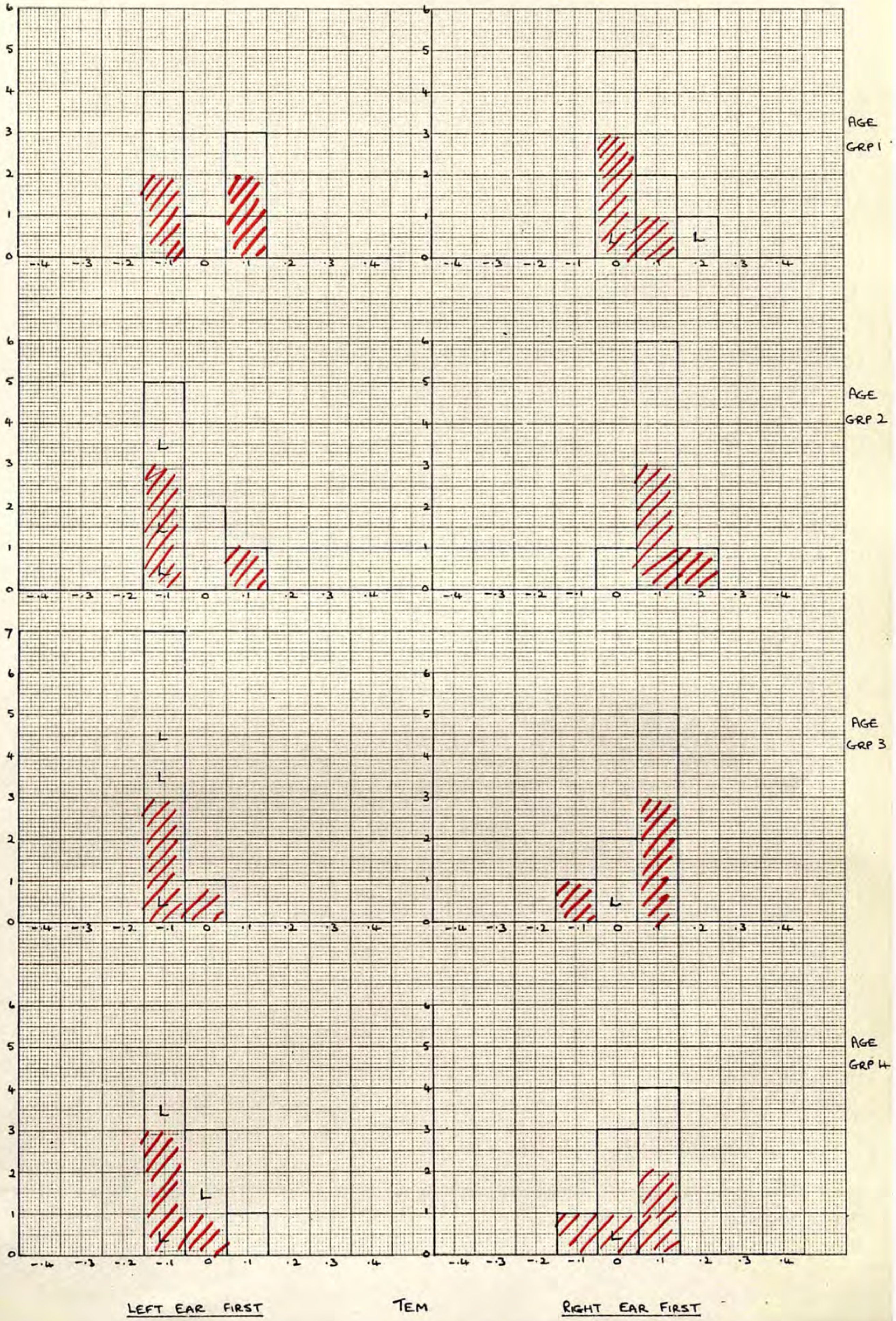
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LEFT EAR FIRST
TEM
RIGHT EAR FIRST

APPENDIX B

TEST ITEM SHEETS (FORM 1)

NAME:

	Preferred Hand	
	R.	L.
Handedness		
1. Scissors		
2. Knife without fork		
3. Hammer		
4. Screw driver		
5. Writing		
6. Drawing		
Eyedness	Preferred Eye	
1. Microscope		
2. Kaleidoscope		
Lateral Awareness	Correct	Wrong
1. Lt. foot		
2. Rt. hand		
3. Lt. ear		
4. Rt. eye		

Results

Hand Dominance	R.	L.	Mixed
Eye Dominance	R.	L.	Mixed
L. A.	% Correct		

NAME: SEX: D.O.B:

AGE:

ADDRESS:

AGE GROUP:

DOMINANCE:

FORM 1
Order A

Rt. ear 1st
2nd
Lt. ear 1st
2nd

Test	Score
L.	
R.	
A 3	
P	
TO M	
TE M	
A 1	
Recall	
Digits	
Words.	

1) Loudness

	S.	W.
1)	1	
2)		1
3)		1
4)	1	
5)	1	
6)		1
7)		1

T =

2) Rhythm

	S.	D.
1)	1	
2)		1
3)	1	
4)	1	
5)		1
6)		1

T =

3) A_3

2) To The

4) President said silly Meg

6) thought that the boat sailed into

8) quiet time was once an old dog sat

10) in the three looked green except a cockroach wriggled slowly

12) but there she stayed for lunch we sat outside wrong silly said

14) Me prayers at night I want chocolates now please will you come here you

16) You are mad why I don't like medicine no I won't thank you ever very much lamp.

T =

4) Pitch

	H	L
1)		1
2)		1
3)		1
4)	1	
5)	1	
6)		1
7)		1
8)	1	
9)		1
10)	1	

T =

5) Tonal Memory

	1	2	3	4
1)		1		
2)			1	
3)			1	
4)	1			
5)				1

T =

Textual Material

2) The scholar
4) therefore began to search
6) at the foot of the tree
8) where the roots spread and at last in
10) a little hollow he found a glass bottle he picked
12) it up and holding it to the light he perceived a thing
14) in shape like a frog which kept jumping up and down
let me out
16) cried the thing again and the scholar thinking no evil
drew out the stopper of the

T =

Approx. 1

2. the been
4. she easy happen run
6. goats had a her gleaming after
8. place which the father arrival chapter stood you
10. it that's fell for then eager file utmost passing asked

Recall

4 8 5 2

We are going swimming this afternoon

APPENDIX ~~B~~ c

TEST ITEM SHEETS (FORM 2)

NAME:

Handedness

1. Scissors
2. Knife without fork
3. Hammer
4. Screw driver
5. Writing
6. Drawing

Eyedness

1. Microscope
2. Kaleidoscope

Lateral Awareness

1. Lt. foot
2. Rt. hand
3. Lt. ear
4. Rt. eye

Preferred Hand	
R.	L.

Preferred Eye	

Correct	Wrong

Results

Hand Dominance R. L. Mixed

Eye Dominance R. L. Mixed

L. A. % Correct

NAME: SEX: D.O.B:

AGE:

ADDRESS:

AGE GROUP:

DOMINANCE:

FORM 2

ORDER A

Rt. ear 1st

2nd

Lt. ear 1st

2nd

Test	Score
A 1	
L	
TO M	
P	
TE M	
A 3	
R	
Recall Nos	
Words	

Approx. 1.

2) Temperatures he's

4) Doctor buy hooray made

6) Rushed on presently heart the handkerchief

8) Very invisible now they moorhens at a below

10) Restless off examining ready Betty tree patted sugar rat don't

T =

Loudness

	S	W
1)	1	
2)	1	
3)		1
4)	1	
5)		1
6)	1	
7)		1

T =

Approx. 3.

4) tie with you up

6) I ashtray think the same old

8) game table that has candle there is a

10) stable for Jesus Christ Amen however that's the last bookcase

12) in the room is necessary good well waterworks oh how gracious you

14) are silly people are dozey what does the electrician say the stile lie down

16) please there sir over you go in to the hospital is full good yes no thank-you

T =

Rhythm

	S	D
1)		1
2)	1	
3)		1
4)	1	
5)		1
6)	1	

T =

Recall

7 8 6 4

We have holidays for Easter week

Tonal Memory

	1	2	3	4
1)		1		
2)		1		
3)	1			
4)	1			
5)				1

T =

Pitch

	H	L
1)	1	
2)		1
3)		1
4)	1	
5)	1	
6)	1	
7)		1
8)		1
9)	1	
10)		1

T =

6) Textual Material

2) It took

4) Many willing hands to

6) Get the hen house on the

8) Can't but this was finally done and away

10) Went Billy and Betty through the water with the queer

12) Load after them the chickens had been captured and put into crates

14) There were many sights to be seen about Meadow Brook that afternoon and the

16) boys did not miss any of them in one of the village streets Bert caught a

T =

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