ABSTRACT

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Dichotic Listening in Hearing-Impaired Children

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Ear asymmetry for dichotic digits was used to indicate speech laterality in 19 hearing-impaired and 19 normal-hearing children. Sequences of 2, 4 and 6 digits were also presented monaurally. Whereas for the normal-hearing group right-ear dichotic scores were significantly superior, inter-subject variability resulted in a non-significant right-ear trend for the hearing-impaired group, with individuals showing marked right or left-ear advantage. The groups did not differ significantly in relative right-left hand proficiency. No correlation was found between hand and ear laterality in either group, nor between degree of ear asymmetry and vocabulary scores for hearing-impaired

subjects. Discrimination of a dichotic pair by the latter subjects rarely occurred, with one digit apparently masking or suppressing the other. Prediction of speech lateralization in hearing-impaired children from dichotic digit scores was not recommended.

Dichotic Listening in Hearing-Impaired Children

DICHOTIC LISTENING
IN
HEARING-IMPAIRED CHILDREN

by

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INTRODUCTION

While studies of lateralization of speech and language mechanisms in the brain have been carried out in relation to handedness, brain injury, learning disabilities and short-term memory, no direct investigation has been made of the development of cerebral laterality in children with severe hearing impairment dating from birth or early childhood. Hearing-impaired children are of special interest because they do not develop verbal skills without training and, by age six, when laterality is already developed in normal children (Kimura, 1967), their language abilities are at a rudimentary level.

It is not known whether speech and language processes are lateralized in children with limited verbal ability, nor whether the degree of lateralization increases as a function of language growth. Nor is it known how the development of handedness is related to speech laterality in such children.

The purpose of the present study was to determine whether cerebral laterality of speech and language mechanisms could be assessed for hearing-impaired children in terms of ear asymmetry on a dichotic digits task.

REVIEW OF RELEVANT LITERATURE

Dichotic Listening

The ability of listeners to respond to two simultaneous messages was studied by Broadbent (1954), Cherry (1953) and Tolhurst & Peters (1956) with reference to the reception of competing signals by operators in aircraft control towers and combat information centers.

The dichotic digit task which was developed by Broadbent (1954), involves the simultaneous presentation of pairs of different digits to each ear by means of a stereophonic tape-recorder and earphones. Generally, three pairs of digits are presented in quick succession (0.5 seconds between pairs) and the subject is asked to recall as many digits as possible. Broadbent observed that subjects tended to report all digits arriving at one ear before reporting those presented to the other ear. This order of report was called an 'ear order' by Bryden (1962), who studied order of report in dichotic listening in relation to presentation rate. With slower presentation rates (e.g. 2

pairs per second) his subjects mainly used a 'temporal order' in which the digits were reported as separate pairs in the order of their arrival at the ears.

Kimura (1961a, 1961b) used the dichotic listening technique to study the effects of temporal-lobe damage on auditory perception. She found that removal of one temporal lobe reduced the recall of digits from the contralateral ear for dichotic, but not for monaural presentation. Furthermore, right-ear recall was superior for subjects whose speech was lateralized in the left hemisphere, whereas left-ear recall was superior when speech was lateralized in the right hemisphere, as determined by the Wada Sodium Amytal Test described by Milner (1962).

Electrophysiological evidence from animal studies (Rosenzweig, 1951; Tunturi, 1946) indicated that although each ear has neural connections with each hemisphere, the contralateral connections are either stronger or more numerous. On the basis of this supporting evidence, Kimura proposed that when speech is represented in the left hemisphere, spoken digits presented to the right ear are processed more efficiently than those presented to the left ear because of the stronger contralateral neural connections. Similarly, she suggests that when the right hemisphere is dominant for speech, recall of digits from the left ear is superior. Kimura therefore concluded that the dichotic digit test would be a reliable predictor of cerebral laterality for speech and language functions.

Kimura's studies aroused widespread interest in the use of the dichotic listening technique as a means of investigating cerebral laterality for different types of stimulus material and in different groups of subjects. Right-ear superiority in normal subjects has been consistently confirmed for verbal material including digits, words and nonsense syllables (Bryden, 1964; Bartz, Satz & Fennell, 1967; Curry & Rutherford, 1967; Dirks, 1964; Satz, Achenbach, Pattishall & Fennell, 1965) and backwards speech sounds (Kimura & Folb, 1968). Right-ear superiority has also been found for consonants, but not for vowels (Shankweiler & Studdert-Kennedy, 1967). Left-ear superiority has been demonstrated for melodic patterns (Kimura, 1964; Shankweiler, 1966), environmental sounds (Curry, 1967) and sonar signals (Chaney & Webster, 1966) in subjects who showed right ear superiority for verbal material.

Attempts to account for ear asymmetry in dichotic listening entirely in terms of attention or order of report (Inglis, 1962, 1965, 1968; Oxbury, Oxbury & Gardiner, 1967) have been unsuccessful (Borkowski, Spreen & Stutz, 1965; Bryden, 1969; Cooper, Achenbach, Satz & Levy, 1967; Satz, 1968; Satz, Achenbach, Pattishall & Fennell, 1965). However, demonstration of ear asymmetry has been shown to be markedly test-dependent. Test variables found to be important are: rate of presentation (Bryden, 1962; Bartz, Satz & Fennell, 1967), task difficulty (Satz et al., 1965), type of material (Bartz, Satz, Fennell & Lally, 1967; Bartz, Satz & Fennell, 1967; Chaney & Webster, 1966; Curry & Rutherford, 1967; Shankweiler & Studdert-Kennedy, 1967), instructions as to order of report (Satz et al., 1965; Wilson, Dirks & Carterette, 1968) and intensity level (Brunt & Goetzinger, 1968).

Dichotic listening has also been studied in relation to normal and abnormal brain function (Kimura, 1961a; Milner, Taylor & Sperry, 1968; Schulhoff & Goodglass, 1969), stutterers (Curry and Gregory, 1969), handedness (Curry, 1967; Curry & Rutherford, 1967; Satz et al. 1965, 1967; Zurif & Bryden, 1969), and selective listening ability (Treisman & Geffen, 1968; Treisman & Riley, 1969).

Dichotic Listening in Children

Kimura (1963) devised a simplified form of the dichotic digits task to discover when right-ear superiority first appears in children. It consisted of single pairs, two pairs and three pairs of digits. Subjects were 145 boys and girls, aged four to nine years, of above average intelligence and from a high socio-economic background. They were encouraged to repeat as many digits as they could remember, in whatever order they pleased. Left-handed children were excluded from the study. Right-ear superiority for spoken digits was observed in the group as a whole, including bright four year olds, both boys and girls, who were able to complete the task. Replication of the study (Kimura, 1967) with children aged five to eight years from low-to-middle-class families, showed that cerebral laterality was established at five years in girls, but not until a year later in boys. Kimura concluded that it was not clear which factors - intelligence, home background or verbal ability - were critical for the earlier development of cerebral dominance among the four year olds of the previous study.

Inglis & Sykes (1967) failed to confirm Kimura's findings of right-ear superiority in a study of 120 normal children aged five to ten years. The results of the two studies cannot be compared because of the very different scoring procedures. Inglis & Sykes assumed that children would use the 'ear order' of report observed by Broadbent (1954) and scored digits as correct according to that order only. Thus assumption is untenable, since Bryden (1962) observed that subjects, while mainly using a particular order of report, did not use it exclusively.

Maccoby & Konrad (1966) used a dichotic word task to study selective listening in normal children. Subjects were 32 pupils each from kindergarten, second and fourth grade classes. Single pairs of words were spoken simultaneously at three-second intervals, one word being spoken by a man and the other by a woman. Subjects were instructed to repeat only the words spoken by the man (or woman). Accuracy was extremely low, being approximately 35% in kindergarten pupils, almost 50% in second grade children and just over 50% even among children in grade four. Accuracy was found to increase with age. This selective listening task appears to be more difficult for children than Kimura's dichotic digit task in which subjects reported words from both ears in any order. Findings with respect to right or left-ear superiority were not reported.

Dichotic Listening in Children with Special Disabilities

Dichotic listening procedures have also been used to assess cerebral laterality in children with disorders of language, learning, or reading, for whom incomplete cerebral lateralization is often inferred from observation of mixed hand, eye and foot preferences. Taylor (1962) used Kimura's method in a study of 29 children aged 7 to 12 years who had reading difficulty and in a control group of normal readers. He reported right-ear asymmetry for both boys and girls in the control group, and also for the girls who had reading difficulty. Ear asymmetry was not observed in the boys who were poor readers.

Witelson (1962) compared the performance of 24 children with learning disorders, aged 9 to 11 years, with that of normal controls on a dichotic digits task. The control group was superior to the experimental group in total recall, but significant right-ear advantage was not observed in either group. A significant difference was found, however, in the orders of report used by the two groups. For slow rates of presentation, the control group used 'temporal order', and with fast rates used 'ear order' in reporting the digits. In contrast, the subjects with learning disorders more frequently reported the digits in 'temporal order', even at the fastest rate of presentation.

Zurif & Carson (in press) compared 14 normal readers with 14 dyslexic subjects, all fourth grade pupils, on a series of perceptual tasks which included a dichotic digits test. The normal readers recalled significantly more digits than those who were dyslexic, but a significant level of ear asymmetry was attained by neither group. Failure to obtain significant right-ear advantage in their normal subjects may have been due to the choice of task which was perhaps less appropriate for 10 and 11 year old children than for the younger children studied by Kimura.

Jones & Spreen (1967) used the dichotic listening technique to study the relationship of intelligence to the development of cerebral laterality for language function in 32 children, aged 6 to 12 years and with I.Q.'s ranging from 69 to 95. Concrete and abstract monosyllabic nouns were presented, three pairs in a set. A significant right-ear advantage was found in spite of the low level of recall (27%) on the task. The asymmetry was not found to vary significantly as a function of either mental or chronological age in these children.

Urbano & Scott (1969) used a dichotic digit test with mentally retarded children to determine how far digit span and practice affected performance. They found no practice effect but reported that children with higher digit spans (6.2) were more successful in recalling dichotic digits than those with low spans (4.0). Performance on the task was not found to be related to mental age as measured by the Peabody Picture Vocabulary Test. Findings with respect to ear asymmetry were not reported.

Dichotic Listening and Early Lateralized Brain Damage

Goodglass (1967) used a dichotic digits task with children and adolescents most of whom were hemiplegic as a result of extensive unilateral brain damage in infancy or early childhood. The performance of 17 subjects with left cerebral lesions and 7 subjects with right cerebral lesions was studied on a dichotic task consisting of 2-digit pairs. Both groups were similar in overall efficiency and also in the degree of superiority shown by the ear ipsilateral to the injured hemisphere. The most striking finding was the almost complete suppression of input to the ear opposite the injured hemisphere, in contrast to equal efficiency of both ears in a monaural condition. He concluded that "The massive suppression effects... seem to call for a mechanism other than the difference in efficiency between crossed and uncrossed pathways to the auditory cortex (p. 303)" and suggested that this extinction of auditory input is comparable to sensory extinction in other modalities, reported in persons with lateralized lesions.

Cerebral Dominance and Childhood Brain Injury

The effects of brain injury in childhood, either before or after the acquisition of speech, have provided some information about the development of cerebral dominance. For example, Basser (1962) reported that when extensive damage is sustained by the left cerebral hemisphere during the first few years of life, surgical removal of the damaged hemisphere at a later date rarely produced language disability, indicating that speech had become lateralized in the right hemisphere. Rasmussen (in Zangwill, 1964) reported on children aged two, three and five years whose left hemispheres were damaged after speech acquisition. They showed aphasic symptoms for several months, but then regained speech. At a later date, sodium amytal tests revealed that speech representation had been transferred to the right hemisphere. Such flexibility of hemispheric lateralization seems to diminish with increasing age, and language disturbances following brain injury at a later age are more likely to be permanent (Piercy, 1964).

On the basis of findings regarding flexibility of brain function, Zangwill (1964)speculated that at birth the two hemispheres have almost equal potential with regard to the acquisition of speech, with lateralization developing, almost certainly within the second year of life. It is not clear, however, whether specialization is mainly acquired by "learning", as suggested by Jung (1962) or whether it is innately determined and in some way linked to the genetic control of handedness (Zangwill, 1964). Teuber (1967) in summing up present knowledge of the problem (Millikan & Darley, 1967) stated that it is "still not known how early the differentiation between hemispheres arises, whether before birth or soon thereafter, whether predominantly as an effect of genetic factors, or as a result of use (p. 213)."

Lansdell (1969) studied 18 brain-injured adults with speech represented in the right hemisphere. He investigated verbal and nonverbal factors of intelligence in relation to the age at which the neurological disorders had first appeared. He found that the earlier the brain damage, the greater their verbal ability and the poorer their nonverbal performance. He speculated that speech and language mechanisms might have appropriated much of the right hemisphere tissue which normally contributed to nonverbal performance.

Handedness and Cerebral Dominance for Speech

Although lateral preferences of hand, eye and leg have been considered to be related to cerebral laterality for language, little attention has been given to the study of their development from infancy. Gesell & Ames (1947) carried out a longitudinal study of lateral preference on a small number of children. They reported that while unilateral preferences were generally observed in the first year of life, marked shifts occurred from time to time until unilateral dominance, usually right-sided, was established by about eight years.

Belmont & Birch (1963) asked children aged 5 to 12 years to pantomime four activities, and considered that preference was established only if one hand was used exclusively. They found that unilateral hand preference was often not completely developed before nine years.

'Handedness' implies skill as well as preference, yet manual dexterity is not usually measured in terms of right versus left proficiency. Benton, Meyers & Polder (1962) showed that self-reports on hand preference were significantly correlated with manual dexterity in right-handed, but not in left-handed individuals. Barnsley & Rabinovitch (1970) further pointed out that the full range of skills involved in hand performance should be taken into account. They carried out a factor analytic study of handedness, and found that, in adults, stated hand preference was poorly correlated with relative right versus left hand proficiency. On the basis of this work, Barnsley (Ph.D. thesis in preparation) developed a battery of tests designed for use with six-to-seven year old children. These tests were employed in the present study and are described later.

The relationship between handedness and cerebral dominance for speech has long been a source of confusion and controversy. Satz et al. (1967) attributed this largely to the manner in which the variables have been assessed. For example, manual laterality has usually been evaluated only in terms of preference. In order to clarify the relationship between manual laterality and speech laterality in normal adults, Satz and his co-workers assessed handedness by a multivariate analysis of manual test scores, and speech laterality by scores derived from a dichotic digits task. Their results confirmed those of Benton et al. (1962) that self-reports of left handers were not predictive of manual proficiency. Whereas performance of self-classified right handers on manual tests correlated highly with their verbal reports of hand preference, self-classified left handers varied in both manual and speech laterality. A more significant relationship between speech and manual laterality was obtained when subjects were test-classified.

Trieschmann (1968) also used a series of manual tasks to establish hand proficiency in 30 normal and 30 problem readers, all boys aged 7 to 9 years. She found that the groups did not differ with respect to the incidence of handedness versus undifferentiated handedness. Ambilaterality did not occur more frequently in these problem readers. She suggested that the higher proportion of mixed handedness frequently reported for poor readers may have been due to the less precise evaluation of handedness in terms of preference rather than proficiency.

Handedness in Hearing-Impaired Children

Studies of handedness in hearing-impaired children have been concerned either with preference or with dexterity of the preferred hand, and not with relative right-left hand proficiency.

Myklebust (1960) reported the use of the Harris Tests of Lateral Dominance (1947) to indicate hand, leg and eye preference in 291 hearing-impaired children aged 6 to 20 years. Of these subjects, 85% were consistently right-handed, 10% were left-handed and 5% were ambilateral. Myklebust (1960, p. 198) considered that this higher-than-normal incidence of atypical laterality was probably due to a higher incidence of central nervous system disorders.

Gottlieb, Doran & Whitley (1964) found that 14% of their 82 hearing-impaired subjects, aged 17 to 20 years, were non-right-handed, as compared with 8% of normal-hearing controls. They also reported that students who showed right-hand and right-eye preference achieved higher speech grades than students with comparable hearing loss who were left-handed or had mixed laterality.

Short-Term Memory in Hearing-Impaired Children

Myklebust (1960) considered that sensory deprivation was bound to affect perceptual organization. Memory, defined as "the ability to associate, retain and recall experience (p. 73)" in hearing-impaired children would therefore be unlike that of normal-hearing children. Whereas the study of auditory memory in hearing-impaired children has been neglected, presumably because it is grossly defective, there have been several studies of visual memory.

Blair (1957) found significant differences in the visual memory of 53 hearing-impaired children, aged 7.5 to 12.5 years, as compared with normal-hearing controls. The deaf subjects were significantly better than control subjects on the Knox Cube Test and on Memory-for-Designs, and equalled controls on Object Location. These tasks required recall of pattern of movement, changes in design, and position of objects in an array. In contrast, the performance of hearing-impaired subjects on memory span (Digit Span Forward, Picture Span, Domino Patterns and Digit Span Reversed) was significantly inferior. Normal-hearing subjects were more efficient in recalling digit sequences in the given, than in reverse order, whereas hearing-impaired subjects showed equal recall on the two tasks. Deficiency of visual memory for digit spans presented in sequence was also reported by Pintner & Paterson (1917) and was attributed to lack of auditory imagery and verbalization in deaf children, a view with which Blair concurred.

Conrad (1970) studied the performance of deaf boys, aged 12 to 17, on a visual memory task in which they were asked to recall a series of five or six letters from a known set of nine (B C H K L T X Y Z). The letters were viewed simultaneously, but had to be reproduced in the same left-to-right sequence in which they had been presented. Results confirmed a previous experiment (Conrad & Rush, 1965) that the recall of visual material by deaf subjects was inferior to that of normal-hearing persons. Analysis of confusions indicated that the latter used an acoustic/ articulatory code to assist recall, while deaf subjects appeared to use a mixture of articulatory and shape cues.

The immediate recall of simultaneous and sequential presentations of visual stimuli was compared in 14 normal-hearing and 42 deaf children by Withrow (1968). He studied meaningfulness of stimuli - meaningful silhouettes, familiar geometric forms and random geometric forms - and rate of presentation. Of particular interest was his finding that the groups were equivalent with respect to recall of simultaneous presentations. The normal-hearing group not only surpassed the deaf in the recall of sequential presentations, but also exceeded their own scores for simultaneous presentations, though Withrow suggested that this may have been due to less than optimal viewing time in the simultaneous conditions. He concluded that since language is essentially time-based, hearing-impaired children should receive specific training in the use of temporal cues either in lipreading or fingerspelling in order that reliance on spatial cues might be reduced.

Discrimination of Competing Auditory Stimuli by Hearing-Impaired Children

The ability of hearing-impaired subjects to process two different acoustic stimuli at the same time has not been directly investigated. The only study which has some bearing on this problem was undertaken by Ling & Maretic (In press). Profoundly deaf children were trained to listen to and repeat consonant/vowel (CV) syllables. Subjects were tested before and after training, under three conditions: conventional amplification to both ears, conventional amplification to the left ear and transposed (coded) speech to the right, and the reverse. Thus under the first condition, the same acoustic form of the syllable was heard in both ears. Under the two remaining conditions, a different acoustic version of the syllable was presented to each ear. These were intended to be complementary rather than competing and it was hoped that they would be integrated at the cortical level. Of particular interest was that subjects, irrespective of training condition, discriminated vowels significantly better with conventional amplification to the left ear and transposed speech to the right ear, than under the reverse condition. Differences between mean hearing levels for left and right ears were negligible. Ling & Maretic interpreted this as indicating that, under competing conditions, vowel cues were more efficiently received through the left ear. This led them to postulate either that the vowel elements were processed as non-speech signals or that laterality effects in these subjects had not developed in the normal way (Shankweiler & Studdert-Kennedy, 1967; Studdert-Kennedy & Shankweiler, in press).

Rationale of the Present Study

The main purpose of the present study was to determine whether cerebral laterality for speech and language functions could be predicted by ear asymmetry on a dichotic digits task. Further, if cerebral laterality were indicated, what relationships would be observed between the degree of lateralization and language proficiency as measured by scores on the Peabody Picture Vocabulary Test, and also between speech laterality and manual laterality as assessed by tests of hand proficiency.

Ear asymmetry was evaluated by means of a dichotic digits test, essentially the same as that used by Kimura (1963) in her first study with children. The test consisted of sets of single-digit, 2-digit and 3-digit pairs. Only the numbers one to nine were used. These were well-known to the children and could be discriminated largely on the basis of vowel cues, even by profoundly deaf subjects.

The sets of single-digit pairs were included to provide information about the ability of hearing-impaired children to process two different acoustic stimuli (spoken digits) presented simultaneously, one to each ear (i.e. dichotically).

Recall of 2-digit and 3-digit pairs also involves short-term memory for auditory sequences, adding not only to the complexity of the task for the subjects, but also making the results more difficult to interpret. A monaural task was therefore included:

a) to ensure that subjects were able to hear and repeat tape-recorded digits equally well with either ear,

b) to facilitate the interpretation of right and left ear performance on the dichotic test and

c) to measure the ability of hearing-impaired subjects to hear and repeat sequences of digits (auditory recall).

Sequences of two, four and six digits were chosen to correspond with the single-digit, 2-digit and 3-digit pairs of the dichotic test.

Finally, cerebral lateralization of speech and language functions was studied in relation to language proficiency and manual laterality in hearing-impaired as compared with normal-hearing children.

METHOD

Subjects

Two groups of subjects were studied: one consisting of 19 children with impaired-hearing, and the other, of 19 children with normal hearing. The groups were matched by pairs for age and sex.

Hearing-Impaired Subjects

The hearing-impaired subjects were 12 girls and 7 boys selected from about 120 pupils attending the Montreal Oral School for the Deaf, the Mackay Centre for Deaf and Crippled Children and from former pupils of these schools who were receiving their education in regular classes. Preliminary selection excluded children whose pure tone audiograms indicated a discrepancy of 30 dB or more between ears, children who became deaf after learning to talk, children of less than average scholastic ability, and children whose teachers reported marked behavior or learning problems.

A screening test was administered to the remaining 44 children who were required to repeat tape-recorded single digits, presented monaurally. The major criterion for acceptance of subjects was the ability to discriminate the digits equally well with either ear, with at least 50% accuracy. Twenty five children succeeded. Six of these, however, aged five to six years, had to be discarded at a later stage because of difficulty in obtaining stable thresholds of auditory detection, because of limited co-operation or short attention span. Thus, 19 children were finally available as subjects.

Table 1 shows sex, chronological age, raw score on the Peabody Picture Vocabulary Test, vocabulary age (average age at which a normal-hearing child achieves the given raw score), years of hearing aid use and etiological factors. The Peabody test was administered by the experimenter, who encouraged subjects to lipread as well as listen to the test words. School and hospital records were inspected for

Table 1.

Sex, Chronological Age, Peabody Picture Vocabulary Test (PPVT) Raw Score, Vocabulary Age, Years of Hearing Aid Use and Etiological Factors for the 19 Hearing-Impaired Subjects

Subject	Sex	Chronol. Age (Yrs-Mo)	Peabody Picture Vocabulary PPVT Raw Score	Vocab. Age	Yrs. of Hearing Aid Use	Etiological Factors
* D 1	F	14 - 7	56	6 - 2	10	Unknown
* D 2	F	13 - 7	82	10 - 10	9	Viral Inf. at birth
* D 3	F	13 - 7	39	3 - 9	9	Viral Inf. at birth
D 4	F	12 - 3	20	2 - 6	1.5	Unknown
D 5	F	12 - 1	53	5 - 8	6	Familial
D 6	F	10 - 8	22	2 - 7	3.5	Familial & Anoxia at birth
D 7	M	10 - 6	26	2 - 10	1.5	Hyperbilirubenemia
D 8	F	9 -10	24	2 - 8	6	Unknown
D 9	F	9 - 8	33	3 - 4	6	Unknown
D 10	M	9 - 6	28	2 - 11	6	Unknown
D 11	F	9 - 4	53	5 - 8	4.5	Unknown
D 12	M	9 - 2	32	3 - 2	1.5	Unknown
* D 13	F	9 - 0	45	4 - 6	6	Birth Injury
* D 14	F	8 -11	46	4 - 7	4	Unknown
D 15	M	8 - 9	30	3 - 0	6	Meningitis at 1 Yr.
* D 16	M	8 - 5	54	5 - 10	5	Unknown
D 17	F	8 - 0	57	6 - 4	1	Familial
D 18	M	7 - 6	12	2 - 2	0.5	Hyperbilirubenemia
D 19	M	6 - 3	35	3 - 6	1	Familial

* Full-time pupil in a regular school

cause of deafness.

Two individual hearing aids were worn by each of 11 subjects while the remainder each used one aid with a Y cord connected to a receiver in each ear. Hearing aids were worn at all times by most of the subjects.

Table 2 gives pure tone hearing levels (ISO), determined immediately prior to the experiment, for the frequencies 250, 500, 1000 and 2000 Hz. There was no significant difference between pure tone hearing levels for right and left ears ($t = 0.80$).

Normal-Hearing Subjects

The normal-hearing subjects were pupils in the two schools in which the Montreal Oral School for the Deaf has special classes for deaf children. A child of the same sex and with birthday nearest to that of the hearing-impaired child was selected from the class register, providing he was in the appropriate grade for his age. The mean age of the hearing-impaired group was 10 years 1 month, and of the normal hearing, 10 years 0.5 months.

Table 2.

Pure Tone Hearing Levels in dB (ISO) at 250, 500, 1000, and 2000 Hz for the 19 Hearing-Impaired Subjects

Subject		Pure Tone Hearing Level in dB (ISO) 250	500	1000	2000 Hz	Subject		Pure Tone Hearing Level in dB (ISO) 250	500	1000	2000 Hz
D 1	R	50	65	85	85	D 11	R	90	95	105	105
	L	45	55	80	90		L	80	95	110	105
D 2	R	75	85	95	100	D 12	R	75	90	95	100
	L	75	80	105	-		L	75	95	100	-
D 3	R	65	80	85	100	D 13	R	85	100	100	100
	L	70	85	90	95		L	85	90	100	95
D 4	R	70	75	75	60	D 14	R	40	35	50	65
	L	80	80	75	65		L	45	50	60	55
D 5	R	90	95	110	100	D 15	R	70	75	90	75
	L	85	100	110	105		L	85	95	100	100
D 6	R	15	85	90	100	D 16	R	65	65	75	75
	L	20	60	90	-		L	50	55	80	75
D 7	R	30	60	65	70	D 17	R	60	95	110	105
	L	40	60	65	65		L	65	90	95	95
D 8	R	90	105	-	110	D 18	R	50	55	90	75
	L	85	100	110	110		L	55	65	70	75
D 9	R	85	90	-	105	D 19	R	85	95	100	80
	L	90	95	-	-		L	80	95	100	85
D 10	R	90	110	-	-						
	L	85	105	-	-						

- No response at 110 dB.

Apparatus

The Digits Tests were recorded with two Sony 777 stereophonic tape recorders. A Sony TC 252 stereophonic tape recorder was used to present the tests. Subjects with normal hearing used a Sony Stereo Headset Type DR-3C from the monitor position. To obtain sufficient gain, hearing-impaired subjects wore TDH 39 headphones connected to the speaker outputs. A VU meter was used to determine the output from both monitor and speaker circuits. The tape recorder, headphones and microphones were used as an amplifying system for the hearing-impaired subjects when instructions relating to the Digits Tests were being given.

The following standard equipment obtained from the Lafayette Instrument Co., Lafayette, Indiana was used for the assessment of hand proficiency:

a) Groove type steadiness tester 4605 B,

b) Hole type steadiness tester 4605 C,

c) Stop clock 54014,

d) Hand dynamometer 4205, and

e) Hand tally counter.

Digits Tests

The auditory stimuli were the spoken digits 1 to 9 recorded by a female speaker. A monaural test and a dichotic test were constructed. The digits used in the two tests are shown in order of presentation in Table 3.

A practice series of 50 single digits was recorded in random order on both channels, a) as a screening device, b) as practice, particularly for the hearing-impaired subjects, in the task of listening to and repeating digits without the aid of lipreading, c) to familiarize the experimenter with the subjects' speech and d) to establish the level at which each channel should be set for the test.

Monaural Digits Test

The monaural test consisted of ten sets each of 2-digit, 4-digit and 6-digit sequences. The digits were arranged in unsystematic order and no digit occurred more

Table 3.

Digits Used in the Monaural and Dichotic Tests and their Order of Presentation

Order	Channel	Monaural Sequences				
1.	I	65	82	91	26	41
2.	II	54	29	15	68	47
3.	II	3896	5462	9527	6843	2694
4.	I	6548	7435	2381	5147	3596
5.	I	257186	918253	584237	462391	154829
6.	II	953217	146923	278694	831956	524139

Order	Channel	Dichotic Pairs									
1.	I	7	1	3	5	6	2	5	4	9	7
	II	6	4	7	3	5	1	7	8	6	3
2.	I	45	16	28	46	73	85	97	84	35	94
	II	31	72	54	25	91	39	63	96	41	62
3.	I	192	397	623	983	562	253	371	798	124	187
	II	734	218	857	412	437	789	452	423	967	639

than once in a sequence. Five sequences at each level of difficulty, a total of 60 digits, were used to test each ear. The digits were tape-recorded in such a way that the entire test could be presented in the same order to each subject without reversing earphones or altering volume settings of either channel during the test.

Thus five 2-digit sequences were recorded on Channel I, followed by five on Channel II; five 4-digit sequences on Channel II, followed by five on Channel I; and five 6-digit sequences on Channel I, followed by five on Channel II. According to their assigned listening condition, half of the subjects in each group began the test with the right ear and the other half with the left.

Dichotic Digits Test

The dichotic test comprised ten sets each of single-digit, 2-digit and 3-digit pairs. One member of each digit pair was recorded on Channel I and the other on Channel II so that they could be presented simultaneously, one to either ear, forming a dichotic pair. The digits were recorded with 0.5 seconds between pairs.

To achieve the closest approximation to simultaneity, each pair was recorded and played back until a satisfactory sample was obtained. A digit pair was considered to be simultaneous if the needles on the VU meters for each channel showed peak intensity at the same time. Although more elaborate techniques to achieve synchrony of dichotic pairs have been developed (Carr, 1969; Studdert-Kennedy & Shankweiler, 1970), the present method seemed entirely adequate for the purposes of this study.

The pairs of digits were also equated with respect to volume of peak intensities, since attenuation of one member of a pair tends to increase reception of the other member (Tolhurst & Peters, 1956). This factor has particular relevance with hearing-impaired subjects.

The final tape consisted of a practice series of 50 single digits recorded on both channels, a monaural test consisting of 10 sets each of 2-digit, 4-digit and 6-digit sequences followed by a dichotic test consisting of 10 sets each of single-digit pairs, 2-digit pairs and 3-digit pairs.

Procedure

Listening Conditions. Since the comparison of right and left ears was crucial to the study, listening conditions were counterbalanced to avoid bias due to equipment or tapes. For normal-hearing subjects, who used headphones from the monitor position, the right and left earphones were reversed for alternate subjects. For hearing-impaired subjects who used headphones from the speaker output, four conditions were available since both channels and headphones could be used in either normal or reverse position.

Ascertainment of listening level. For subjects with normal hearing, the volume controls were set to provide equivalent loudness in both ears at a standard level of 55 dB SPL.

For hearing-impaired subjects the threshold of detection for digits was established for each ear, using the method of limits. The volume of each channel was then raised 15 dB. This procedure was used because loudness balance was too difficult for most of the subjects. The practice series of digits was presented one at a time monaurally and the subject was asked to repeat them. The digits were then presented binaurally at the levels which had been ascertained monaurally. The subject was then asked a) if this was a comfortable listening level, and b) if one ear was louder than the other. Adjustment was made when necessary.

<u>Practice</u>. Subjects were given practice in listening to and repeating digits presented monaurally, but no practice was given for the dichotic condition.

<u>Administration of the Digits Tests</u>. All subjects were given the monaural, followed by the dichotic test. A brief rest was given between tests with the headphones removed. The testing session lasted about half an hour.

For the monaural test, subjects were told which ear to attend to and how many digits to expect. The tape recorder was stopped at the end of each set to permit the subject adequate time to respond. The experimenter entered the responses on the data sheet. The 6-digit sequences were discontinued for those who failed the first two sets at a 6-digit level, and were not presented at all to subjects who failed at a 4-digit level. This was to avoid fatigue or loss of attention.

Before beginning the dichotic test, subjects were told that they would hear a number in the right ear and a different number in the left ear at the same time. It was emphasized that they should listen for two numbers. Similar instruction was given prior to the 2-digit and 3-digit pairs.

Scoring. On the monaural test, a digit was scored as correct only if it retained its position in the sequence.

For the dichotic test, scoring was more difficult, since pairs of digits presented simultaneously have to be repeated sequentially.

The most common orders of report (Bryden, 1962) are "ear order" in which all digits presented to one ear are repeated before digits from the other ear, and "temporal order", in which both digits of the first pair are reported prior to the second and third pairs. Digits given in either of these orders were scored as correct. In addition, where neither of these orders was used, a digit was scored as correct only if it retained its sequential position relative to other digits presented to the same ear.

In studies by Kimura (1963) and others who were not directly investigating ear order, digits have been scored as correct without regard to order of recall. Where the task is of moderate difficulty for all subjects, scores will be normally distributed. In the present study, however, subjects differed greatly both in age and in auditory proficiency and it was anticipated that the scores of the older normal-hearing subjects might approach a ceiling so that a laterality effect might not be observed (Kimura, 1963; Satz, Achenbach, Pattishall & Fennell, 1965).

Hand Proficiency Tests

The hand proficiency tests were drawn up by Barnsley (Ph.D. thesis in preparation) following a factor analysis of hand performance in Grade I children. For each test two trials were given for the preferred, and two for the non-preferred hand. The hand used for writing was taken as the preferred hand. The tests were as follows:

a) Tapping Small-speed. The number of seconds required to make a pencil dot in each of a series of 20 small circles.

b) Tapping Small-error. The number of dots marked on, or outside the circles in the above task.

c) Finger Tapping. The number of taps made with the forefinger on a mechanical hand tally counter in 30 seconds.

d) Vertical Arm Movement Steadiness. The amount of time during which the stylus rested on the side of a vertically mounted track, with the arm held out (i.e. not resting on the table). One trial consisted of moving the stylus from the bottom of the track to the top and returning to the bottom.

e) Dynamometer. The strength of grip was measured in kilograms.

f) Hand Steadiness. The amount of time during which the stylus rested on the side of hole number 6, during a 10 second trial.

Procedure

The hand proficiency tests were given on a different day from the digits tests in a session lasting about half an hour. For all tests except the dynamometer, the child was seated at a table on a chair of appropriate height. As recommended by Barnsley, the tests were given in a different order to each subject. Explanation and demonstration preceded each test. Particular care was taken to ensure that the hearing-impaired subjects understood what they had to do. Practice with each hand was allowed for tests a, b and c. The trials for hole 5 were counted as practice since a number of subjects failed to follow the instruction to hold the stylus in the hole until told to stop.

The order of trials was preferred hand, non-preferred, non-preferred, preferred for Tapping Small, Vertical Arm Movement Steadiness and Hand Steadiness. For the Finger Tapping and Dynamometer tests, the order was preferred, non-preferred followed by a brief rest, then preferred, non-preferred.

Scoring

Since Barnsley's method did not provide preferred and non-preferred hand scores which could be used in studying the correlation of ear and hand proficiency, the following scoring system was adopted. Scores for each of the six measures were converted to ratios of right minus left to right plus left-hand scores as recommended by Satz, Achenbach

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and Fennell (1967) to ensure that differences in performance related to age and sex would not obscure laterality findings. Positive ratios indicate greater right-hand and negative ratios greater left-hand proficiency. For measures (b), (d) and (f) where high scores indicate low performance, the ratios were multiplied by minus one.

RESULTS

Digits Tests

Monaural Test

The number of digits correctly reported for right and left-ear presentations of 2, 4 and 6 digit sequences are shown along with totals and right minus left-ear difference scores for normal-hearing and for hearing-impaired subjects in Tables 4 and 5, respectively. The mean number of digits correct for each ear and at each level of difficulty is presented, along with mean totals, difference scores and percentages correct. Of the 19 normal-hearing subjects, 14 attempted the 6-digit sequences, and of these, only 9 children had a memory span for 6 digits. Not one of the hearing-impaired subjects could recall a sequence of 6 digits and some had difficulty even at a 2-digit level.

Normal-hearing subjects. The mean right-ear score on the test as a whole was 48.3 (80.5%) and the left, 46.5

Table 4.

Monaural Test: Number of Digits Correctly Reported for Each Ear, together with Totals and Difference Scores for the 19 Normally-Hearing Subjects

	MONAURAL SEQUENCES									
	2-Digit		4-Digit		6-Digit		Totals			Difference
Ear	R	L	R	L	R	L	R	L	R + L	Score
Maximum Score	10	10	20	20	30	30	60	60	120	R - L
Subject										
H 1	10	10	20	20	27	23	57	53	110	+ 4
H 2	10	10	20	20	18	20	48	50	98	- 2
H 3	10	10	20	20	30	29	60	59	119	+ 1
H 4	10	10	18	20	18	11	46	41	87	+ 5
H 5	10	10	20	20	28	30	58	60	118	- 2
H 6	10	10	20	20	30	28	60	58	118	+ 2
H 7	10	10	20	20	23	28	53	58	111	- 5
H 8	10	10	20	20	23	15	53	45	98	+ 8
H 9	10	10	20	20	28	25	58	55	113	+ 3
H 10	10	10	20	20	23	18	53	48	101	+ 5
H 11	10	10	20	20	29	21	59	51	110	+ 8
H 12	10	10	18	20	26	27	54	57	111	- 3
H 13	10	10	20	20	-	-	30	30	60	0
H 14	10	10	20	20	22	12	52	42	94	+10
H 15	10	10	20	20	28	30	58	60	118	- 2
H 16	10	10	20	20	-	-	30	30	60	0
H 17	10	10	20	20	-	-	30	30	60	0
H 18	10	10	18	18	-	-	28	28	56	0
H 19	10	10	20	20	-	-	30	30	60	0
Mean	10	10	19.7	19.9	25.2	22.6	48.3	46.5	94.8	+1.7
	100%	100%	98.5%	99.5%	84.0%	75.5%	80.5%	77.5%	79.0%	

- Subjects unable to complete the task

Table 5.

Monaural Test: Number of Digits Correctly Reported for Each Ear, together with Totals and Difference Scores for the 19 Hearing-Impaired Subjects

	MONAURAL SEQUENCES							
	2-Digit		4-Digit		Totals			Difference
Ear	R	L	R	L	R	L	R + L	Score
Maximum Score	10	10	20	20	60	60	120	R - L
Subject								
D 1	10	9	19	12	29	21	50	+ 8
D 2	8	10	19	20	27	30	57	- 3
D 3	8	7	14	10	22	17	39	+ 5
D 4	8	6	8	13	16	19	35	- 3
D 5	7	6	14	15	21	21	42	0
D 6	7	5	7	10	14	15	29	- 1
D 7	10	9	20	19	30	28	58	+ 2
D 8	5	5	8	5	13	10	23	+ 3
D 9	8	8	10	12	18	20	38	- 2
D 10	5	4	7	7	12	11	23	+ 1
D 11	7	8	16	16	23	24	47	- 1
D 12	7	7	7	8	14	15	29	- 1
D 13	10	10	20	20	30	30	60	0
D 14	10	10	20	20	30	30	60	0
D 15	10	8	12	12	22	20	42	+ 2
D 16	10	10	20	20	30	30	60	0
D 17	9	8	20	15	29	23	52	+ 6
D 18	7	7	8	6	15	13	28	+ 2
D 19	8	7	8	7	16	14	30	+ 2
Mean	8.1*	7.6	13.5	13.0	21.6	20.6	42.2	+ 1.1
	81.0%	76.0%	67.5%	65.0%	36.0%	34.3%	35.3%	

* Right ear superiority significant at the .05 level

Note: None of the hearing-impaired subjects was able to complete the 6-digit sequences.

(77.5%). The t-test for paired measures indicated that the difference between means for the two ears was not significant ($t = 1.79$). Neither was there significant difference between ears at a 2, 4 or 6-digit level.

Hearing-impaired subjects. On the test as a whole, the mean right-ear score was 21.6 (36.1%) and the left-ear score was 20.6 (34.3%). This difference was not significant ($t = 1.56$). However, for the 2-digit sequences the right ear was superior ($t = 2.248$, $p < .05$).

Dichotic Test

The number of digits correctly reported for right and left-ear presentations of single-digit, 2-digit and 3-digit pairs are shown, along with totals and difference scores for normal-hearing and hearing-impaired subjects in Tables 6 and 7 respectively. The mean number of digits correct is shown for each ear at each level of difficulty. Mean totals, difference scores and percentages correct are also included.

Table 6.

Dichotic Test: Number of Digits Correctly Reported for Each Ear, together with Totals and Difference Scores for the 19 Normally-Hearing Subjects

	DICHOTIC PAIRS									
	1-Digit		2-Digit		3-Digit		Totals			Difference
Ear	R	L	R	L	R	L	R	L	R + L	Score
Maximum Score	10	10	20	20	30	30	60	60	120	R - L
Subject										
H 1	10	10	19	19	22	25	51	54	105	- 3
H 2	10	10	20	16	25	19	55	45	100	+10
H 3#	10	10	20	20	30	28	60	58	118	+ 2
H 4	10	10	19	18	21	19	50	47	97	+ 3
H 5	10	10	20	18	25	27	55	55	110	0
H 6	10	8	20	17	23	20	53	45	98	+ 8
H 7#	10	10	20	18	22	24	52	52	104	0
H 8	9	10	16	15	20	20	45	45	90	0
H 9	10	10	17	15	24	16	51	41	92	+10
H 10	9	8	18	19	21	21	48	48	96	0
H 11	10	10	15	16	21	18	46	44	90	+ 2
H 12	10	10	19	18	27	15	56	43	99	+13
H 13	10	10	17	15	13	16	40	41	81	- 1
H 14	10	10	20	15	26	22	56	47	103	+ 9
H 15	10	8	18	12	22	18	50	38	88	+12
H 16	10	10	18	12	15	23	43	45	88	- 2
H 17	10	10	17	18	14	21	41	49	90	- 8
H 18	10	10	19	17	22	20	51	47	98	+ 4
H 19	10	9	13	7	14	10	37	26	63	+11
Mean	9.9	9.6	18.2**	16.1	21.4	20.1	49.5*	45.8	95.3	+3.7*
	98.9%	96.3%	90.8%	80.3%	71.4%	67.0%	82.5%	76.3%	79.4%	

Subjects whose left hand was the preferred hand
* Right ear superiority significant at the .05 level
** Right ear superiority significant at the .01 level

Table 7.

Dichotic Test: Number of Digits Correctly Reported for Each Ear, together with Totals and Difference Scores for the 19 Hearing-Impaired Subjects

	DICHOTIC PAIRS									
	1-Digit		2-Digit		3-Digit		Totals			Difference
Ear	R	L	R	L	R	L	R	L	R + L	Score
Maximum Score	10	10	20	20	30	30	60	60	120	R - L
Subject										
D 1	6	5	6	11	13	13	25	29	54	- 4
D 2	2	5	0	12	10	16	12	33	45	-21
D 3	7	1	3	2	14	8	24	11	35	+13
D 4	6	3	13	4	21	3	40	10	50	+30
D 5	5	0	7	1	9	4	21	5	26	+16
D 6	2	3	5	10	16	10	23	23	46	0
D 7#	8	5	19	5	24	8	51	18	69	+33
D 8	3	2	5	7	13	10	21	19	40	+ 2
D 9#	4	0	11	3	14	4	29	7	36	+22
D 10	4	2	6	5	4	6	14	13	27	+ 1
D 11	0	6	3	12	3	25	6	43	49	-37
D 12	6	0	2	6	9	6	17	12	29	+ 5
D 13	0	6	3	14	2	22	5	42	47	-37
D 14	5	1	12	6	14	9	31	16	47	+15
D 15	5	3	18	1	22	6	45	10	55	+35
D 16	5	3	14	4	18	13	37	20	57	+17
D 17	4	5	10	7	12	13	26	25	51	+ 1
D 18	7	0	12	0	16	4	35	4	39	+31
D 19	3	2	10	2	11	6	24	10	34	+14
Mean	4.3	2.7	8.4	5.9	12.9	9.8	25.6	18.4	44.0	+7.2
	43.0%	27.0%	42.0%	29.5%	43.0%	32.6%	42.7%	30.7%	36.7%	

Subjects whose left hand was the preferred hand

Normal-hearing subjects. Significant right-ear superiority was found on the dichotic test as a whole ($t = 2.710$, $p < .05$), the mean for the right ear being 49.5 (82.5%) and for the left, 45.8 (76.3%). For the 2-digit pairs, scores for the right ear were also significantly greater than for the left ($t = 3.898$, $p < .01$) but no significant difference was found for single-digit ($t = 1.56$) or 3-digit pairs ($t = 1.176$). On the test as a whole the mean difference score was +3.7 and the range was from -8 to +13.

Hearing-impaired subjects. For this group as a whole, neither ear was superior on the dichotic listening task. The mean score for the right ear was 25.6 (42.7%) and for the left, 18.4 (30.7%). The mean right-left ear difference score was +7.2, with scores ranging from -37 to +35. This difference was not significant ($t = 1.475$). For single-digit pairs, the mean right-ear score was 4.3 (43%) and the left, 2.7 (27%) with $t = 1.859$. For 2-digit pairs, the mean right-ear score was 8.4 (42.0%), and the left, 5.9 (29.5%) with $t = 1.259$. For 3-digit pairs, the mean right-ear score was 12.9 (43.0%) and the left-ear, 9.8 (32.6%)

with t = 1.280. Nor were the right-ear effects significant using a non-parametric measure, the Signed Rank Test for Paired Observations.

Although the mean difference score for the hearing-impaired subjects at each level of difficulty was of greater magnitude favoring the right ear than the equivalent difference score for the normal-hearing group, none of these differences was significant. This was because of the greater variability among the hearing-impaired subjects. In particular, subjects D 2, D 11 and D 13 had very large difference scores favoring the left ear.

Whereas the normal-hearing subjects generally reported both members of the dichotic single-digit and 2-digit pairs, as indicated by their relatively high dichotic scores (Table 6), the hearing-impaired subjects rarely reported both members of a pair. The number of dichotic pairs correctly reported by each hearing-impaired subject is shown in Table 8.

Table 8.

Number of Dichotic Pairs with both Members Correctly Reported by the 19 Hearing-Impaired Subjects

No. of Pairs	Single Digit 10	2 Digit 20	3 Digit 30	Total 60
Subject				
D 1	2	-	1	3
D 2	1	-	1	2
D 3	-	-	3	3
D 4	-	-	1	1
D 5	-	-	1	1
D 6	-	2	4	6
D 7	4	5	5	14
D 8	-	-	3	3
D 9	-	-	2	2
D 10	-	-	1	1
D 11	-	-	1	1
D 12	-	-	2	2
D 13	-	1	-	1
D 14	-	-	-	-
D 15	-	-	1	1
D 16	-	-	4	4
D 17	-	-	-	-
D 18	-	-	1	1
D 19	-	1	-	1

Ear preferred for first report. The frequency with which the digit first reported from a dichotic set was a right or left-ear presentation is shown for both groups in Table 9. Out of 30 dichotic presentations, subjects with normal hearing began their recall with a digit presented to the right ear a mean number of 16.0 times, and to the left ear a mean of 13.8 times. This difference was not significant ($t = 1.056$). Although, as a group, subjects did not consistently prefer one ear to the other as the ear of first report, there was a significant correlation between the frequency with which an ear was used for first report and ear asymmetry on the dichotic task ($r = 0.59$, $p < .01$).

For hearing-impaired subjects, the right ear was preferred as the ear of first report a mean of 13.05 times and the left ear, a mean of 8.0 times. These means did not differ significantly ($t = 1.673$) probably due to the strong tendency of subjects D 2, D 11 and D 13 to report left-ear presentations first. A correlation of $r = 0.91$, significant at the .001 level indicated that the ear preferred for first report would be a good predictor of ear asymmetry on a

Table 9.

Frequency with which the Digit First Reported from a Dichotic Set was a Right-Ear or Left-Ear Presentation, for Normal-Hearing and Hearing-Impaired Subjects

	Ear of First Report in 30 Dichotic Presentations				
	Normal-Hearing			Hearing-Impaired	
Ear	R	L		R	L
Subject			Subject		
H 1	16	14	D 1	13	13
H 2	22	8	D 2	7	13
H 3	17	13	D 3	13	6
H 4	14	16	D 4	23	5
H 5	16	14	D 5	13	1
H 6	18	12	D 6	11	11
H 7	13	17	D 7	25	4
H 8	17	13	D 8	12	5
H 9	17	13	D 9	18	1
H 10	13	17	D 10	6	8
H 11	11	19	D 11	1	23
H 12	19	11	D 12	12	5
H 13	18	11	D 13	2	20
H 14	14	15	D 14	19	4
H 15	22	8	D 15	17	10
H 16	18	12	D 16	15	11
H 17	9	21	D 17	10	16
H 18	14	16	D 18	17	2
H 19	15	12	D 19	14	5
Mean	16.0	13.8		13.05	8.0

dichotic digits task for this group of hearing-impaired subjects.

Comparison of Normal-Hearing and Hearing-Impaired Subjects

Since the distributions of scores of the two groups were markedly different both on the monaural and on the dichotic digits tests, the Mann-Whitney Sum of Ranks test was used to evaluate the results, with correction for ties as recommended by Siegel (1956, p. 123).

Monaural test. The mean total number of digits correctly reported for right and left-ear presentations was 94.8 (79.0%) for the normal-hearing, with scores ranging from 58 to 119, and for the hearing-impaired, the mean total was 42.2 (35.3%) with scores ranging from 23 to 60. The maximum score was 120. The groups differed significantly both with respect to means ($z = 4.93$, $p < .0001$) and variance ($F = 3.11$, $p < .05$).

Dichotic test. The mean total score for normal-hearing subjects was 95.3 (79.4%) and for the hearing-impaired, 44.0 (36.7%). Thus the hearing-impaired children reported less than half as many digits as the normal-hearing children. While the variance was minimal ($F = 1.1$), the difference between mean scores was significant beyond the .001 level ($z = 5.207$).

The older normal-hearing subjects tended to obtain higher scores on the dichotic test than younger subjects ($r = 0.723$, $p < .01$), but no such relationship was observed among hearing-impaired subjects ($r = 0.052$).

Since the right minus left-ear difference scores on the dichotic test provide a measure of ear asymmetry and possibly an index of cerebral laterality, they are of major importance in this study. The frequency distributions of the difference scores for the two groups are presented in Table 10. A comparison of the two groups showed that they did not differ significantly with respect to mean asymmetry but the hearing-impaired group showed significantly greater variance ($F = 5.02$, $p < .01$).

No significant correlation was found between degree of asymmetry and total score on the dichotic test, either for normal-hearing ($r = 0.165$) or for hearing-impaired

Table 10.

Frequency Distribution of Dichotic Difference Scores for Normal-Hearing and for Hearing-Impaired Subjects

Right Minus Left Ear Scores	Number of Subjects Normal-Hearing	Hearing-Impaired
30 to 39	0	4
20 to 29	0	1
10 to 19	5	5
1 to 9	6	4
0	4	1
-1 to -9	4	1
-10 to -19	0	0
-20 to -29	0	1
-30 to -39	0	2

subjects (r = 0.343). In other words, there was no tendency in either group, for those with higher total scores to show less ear asymmetry.

Nor was there a significant difference between the two groups with respect to the frequency with which either ear was preferred for first report (z = 1.308) although individual hearing-impaired subjects tended to have very strong preferences for one or other ear.

Correlations between the Monaural and Dichotic Tests

The total scores obtained on the dichotic test were found to be significantly correlated with those obtained under the monaural condition, both for the normal-hearing ($r = 0.588$, $p < .01$) and for the hearing-impaired subjects ($r = 0.642$, $p < .01$). Thus, subjects who had high monaural scores tended to have high scores on the dichotic test. However, there was no correlation between ear difference scores on the two tests, either for the normal-hearing ($r = -0.101$) or for the hearing-impaired ($r = 0.080$). Thus, ear asymmetry on the monaural test was not a good predictor of asymmetry on the dichotic test.

Hand Proficiency Tests

The ratios of right minus left to right plus left-hand scores for the six measures of hand proficiency are presented in Tables 11 and 12 for the normal-hearing and hearing-impaired subjects respectively. The greater the positive ratio, the greater is the proficiency of the right hand. The greater the negative ratio, the greater is the proficiency of the left hand. The mean ratios and variances for the two groups are shown in Table 13.

Since the groups were matched by pairs for age but not for hand preference, the test of significance between means for independent samples was used. The two groups did not differ significantly on any of the six measures.

Relative Ear and Hand Proficiency

To permit comparison of right-left ear proficiency with right-left hand proficiency, ratios of right minus left to right plus left ear scores on the Dichotic test were

Table 11.

Ratios for Right Hand Minus Left Hand to Right Hand Plus Left Hand Scores for Normally-Hearing Subjects on the Six Measures of Hand Proficiency

Measure / Subject	Tapping Small-Speed a	Tapping Small-Accuracy b	Finger Tapping c	Vertical Steadiness d	Dynamo-meter e	Hand Steadiness f
H 1	+0.08	+0.50	0.00	+0.82	+0.15	-0.47
H 2	+0.06	+0.50	+0.10	+1.00	+0.13	+0.85
H 3#	-0.17	-0.73	-0.03	-0.43	+0.03	+0.13
H 4	+0.26	+1.00	+0.09	+0.38	+0.01	+0.22
H 5	+0.30	+1.00	+0.05	+0.46	+0.07	+0.52
H 6	+0.23	+1.00	+0.06	+0.86	0.00	+0.39
H 7#	-0.14	-0.25	-0.06	-0.58	0.00	-0.36
H 8	+0.29	+0.06	+0.11	-0.10	+0.07	+0.71
H 9	+0.42	+1.00	+0.09	+0.56	+0.05	+0.46
H 10	+0.18	+0.19	+0.06	+0.62	+0.02	+0.80
H 11	+0.34	+1.00	+0.06	+0.80	+0.06	+0.08
H 12	+0.21	+0.75	+0.12	+0.54	+0.00	+1.00
H 13	+0.13	+1.00	+0.04	-0.09	+0.14	+1.00
H 14	+0.29	+0.08	+0.07	+0.28	+0.06	+0.52
H 15	+0.33	+0.20	+0.01	+0.61	+0.12	-0.18
H 16	+0.38	+0.60	+0.08	+0.33	-0.02	+0.19
H 17	+0.20	+1.00	+0.09	+0.60	-0.05	+0.63
H 18	+0.36	+1.00	+0.05	+0.83	+0.12	+0.06
H 19	+0.09	+0.39	+0.04	+0.37	+0.03	-0.59

\# Subject whose left hand was the preferred hand.
Positive scores (+) indicate greater right hand proficiency.
Negative scores (-) indicate greater left hand proficiency

Table 12.

Ratios for Right Hand Minus Left Hand to Right Hand Plus Left Hand Scores for Hearing-Impaired Subjects on the Six Measures of Hand Proficiency

Measure	Tapping Small-Speed a	Tapping Small-Accuracy b	Finger Tapping c	Vertical Steadiness d	Dynamo-meter e	Hand Steadiness f
Subject						
D 1	+0.24	+0.47	+0.05	+0.92	+0.27	+0.87
D 2	+0.08	+0.80	+0.06	+1.00	+0.12	+0.71
D 3	+0.24	+1.00	+0.10	+1.00	+0.07	+0.92
D 4	+0.20	+0.54	-0.04	-0.07	-0.03	-0.23
D 5	+0.36	+0.93	+0.02	+1.00	+0.07	+0.92
D 6	+0.13	+0.82	+0.02	+0.81	-0.03	+0.22
D 7#	-0.03	-0.40	-0.03	+0.26	-0.02	-0.54
D 8	+0.25	+0.71	+0.14	+1.00	+0.02	+0.51
D 9#	-0.22	-0.73	+0.01	+0.62	0.00	-0.12
D 10	-0.02	+0.26	+0.07	+0.53	-0.02	+0.03
D 11	+0.32	+1.00	+0.06	+0.60	+0.06	-0.27
D 12	+0.29	+0.71	-0.01	+0.55	-0.04	+0.75
D 13	+0.28	+0.60	+0.04	-0.25	+0.02	+1.00
D 14	+0.11	+0.75	+0.05	-0.89	+0.07	-0.08
D 15	+0.15	+0.57	0.00	+0.26	0.00	+0.74
D 16	+0.13	+0.75	-0.03	+1.00	+0.02	+0.97
D 17	+0.25	+0.75	+0.10	+0.77	-0.04	+0.61
D 18	+0.01	+0.36	0.00	+0.21	+0.05	+0.35
D 19	+0.32	+0.88	+0.10	-0.54	0.00	+0.41

Subjects whose left hand was the preferred hand
Positive Scores (+) indicate greater right hand proficiency
Negative Scores (-) indicate greater left hand proficiency

Table 13.

Hand Proficiency: Mean Ratios and Variance of the Normal-Hearing and Hearing-Impaired Groups on the Six Measures

Test	Mean Ratio		Variance	
	N - H	H - I	N - H	H - I
a) Tapping small-speed	0.202	0.163	0.0265	0.0221
b) Tapping small-accuracy	0.542	0.567	0.2601	0.5123
c) Finger Tapping	0.054	0.037	0.0022	0.0025
d) Vertical steadiness	0.414	0.435	0.1905	0.3423
e) Dynamometer	0.052	0.031	0.0033	0.0053
f) Hand steadiness	0.314	0.409	0.2333	0.2354

calculated for all subjects. From these ratios and from those obtained on the Hand Proficiency tests, standard scores were calculated for each group separately. No significant correlation was found between relative right-left ear and right-left hand proficiency among the normal-hearing ($r = 0.075$) nor among the hearing-impaired children ($r = -0.242$).

Additional Correlations for Hearing-Impaired Subjects

Additional correlations were calculated between a number of variables in order to provide further information about the performance of the hearing-impaired subjects. Results are presented in Table 14. Five comparisons were significant:

a) pure tone hearing level for the better ear and total score on the dichotic test,

b) pure tone hearing level for the right ear and the right-ear score on the dichotic test,

c) vocabulary score and the total score on the monaural test,

Table 14

Additional Correlations for Hearing-Impaired Subjects

Measures Compared		Results
Pure tone (better ear)	Dichotic total	rho= 0.639 **
Pure tone (right ear)	Monaural (right ear)	rho= 0.43
Pure tone (left ear)	Monaural (left ear)	rho= 0.367
Pure tone (right ear)	Dichotic (right ear)	rho= 0.704 **
Pure tone (left ear)	Dichotic (left ear)	rho= 0.109
Pure tone (difference)	Monaural (difference)	r= -0.36
Pure tone (difference)	Dichotic (difference)	r= 0.402
Vocabulary	Pure tone (better ear)	rho= -0.03
Vocabulary	Monaural total	rho= 0.687 **
Vocabulary	Dichotic total	rho= 0.28
Vocabulary	Dichotic difference (ignoring sign)	rho= 0.097
Vocabulary	Hand proficiency (ignoring sign)	rho= 0.501 *
Years use of aid	Monaural total	r= 0.21
Years use of aid	Dichotic total	r= -0.07
Years use of aid	Vocabulary	r= 0.504 *

* Significant at the .05 level with 17 degrees of freedom
** Significant at the .01 level with 17 degrees of freedom

d) vocabulary score and the degree of (right or left) hand proficiency, and

e) vocabulary score and years of hearing aid use.

Thus, children with better hearing for pure tones were better able to discriminate dichotic digits. Verbal skill was found to be positively associated with handedness, the ability to recall auditory sequences, and the period over which residual hearing had been used.

DISCUSSION

The purpose of the study was to determine whether speech lateralization, as evaluated by ear asymmetry on a dichotic digits task, could be shown to occur in hearing-impaired children. Digits were also presented monaurally primarily to ensure that any ear asymmetry found on the dichotic task was not simply a reflection of ear asymmetry under monaural conditions. Information was also sought with respect to the correlation between language proficiency and speech lateralization, and between hand and ear laterality.

As a group, the normal-hearing children showed right-ear superiority in reporting dichotic digits. While the trend towards right-ear advantage was not significant among the hearing-impaired children, individual subjects showed marked right or left ear preference. Apart from one subject, the hearing-impaired group were unable to process the two competing digits. They consistently reported no more than one member of each dichotic pair. The groups did not differ with respect to relative right-left hand proficiency. No significant correlation was found between the degree of ear asymmetry and vocabulary scores among the hearing-impaired children, nor between hand and ear proficiency in either group. Hearing-impaired subjects were found to be strikingly deficient in the recall of auditory sequences, as shown by their performance on the monaural test.

Digits Tests

Monaural Test

Normal-hearing subjects. Significant ear asymmetry was not observed for the normal-hearing subjects either on the monaural test as a whole or for the sequences of 2, 4 or 6 digits separately. These findings provide no support for those of Bakker (1969) who used letters of the alphabet with normal children, but are in accord with results obtained for a variety of monaural tests by Berlin, Willett, Thompson, Cullen, & Lowe (1969), Bryden (1969), Calearo & Antonelli (1963), Dirks (1964), Jones & Spreen (1967), Kimura (1967), and Palmer (1964).

<u>Hearing-impaired subjects</u>. The performance of hearing-impaired subjects on the monaural test was significantly poorer than that of the normal-hearing children. Ear asymmetry was not observed on the task as a whole. The right-ear advantage found for recall of the 2-digit sequences was relatively small. The right minus left ear scores on the monaural test were not significantly correlated with right-left differences in pure tone threshold. Thus the differences between ears on the monaural test could not be accounted for by a similar difference in hearing level for pure tones.

Correct repetition of the 2-digit sequences mainly depends on the subject's ability to make simple auditory discriminations. At a 4-digit level, the task is more complex, since it involves not only the discrimination of each item, but also the recall of the items correctly ordered in a longer sequence.

The difficulty experienced by the hearing-impaired children in recalling sequences cannot be explained solely in terms of difficulty in discriminating or in repeating (i.e., articulating) the spoken digits, since Pintner &

Paterson (1917) and Blair (1957) have reported similar deficiencies when digit sequences are presented visually. In the study by Pintner & Paterson (1917) the normal-hearing subjects had a digit span of five by age 7. This level was not attained by any of their deaf subjects, even by age 14. In the present study, four digits was the maximum span achieved by hearing-impaired subjects, as compared with a 6-digit span for some normal-hearing subjects.

According to Conrad & Rush (1965), efficient recall of a series of letters of the alphabet is normally based on an acoustic/articulatory code, even when a visual mode of presentation is used. Presumably the same type of cues would be used in recalling auditory sequences of digits. The poor performance of the hearing-impaired subjects in repeating the monaural digits indicates that they have not learned to use these acoustic and articulatory cues to a sufficient extent.

Auditory-vocal recall of digit sequences appeared to be an unfamiliar task for the hearing-impaired children, indicating that they had received little or no training in this type of activity. In addition, they lacked the early childhood experiences of chanting rhymes and digits. Such repetitive activity presumably leads to a considerable degree of automatic skill in the sequencing of auditory events, a skill which is fundamental to the acquisition of spoken language (Hirsh, 1967). The significant correlation found between the total score achieved by hearing-impaired subjects on the monaural test (recall of auditory sequences) and their vocabulary scores suggests that a higher level of language is likely to be attained by children with better auditory memory. This, in turn, suggests an important area for training.

Dichotic Test

Normal-hearing subjects. Right-ear advantage was observed for 11 normal-hearing subjects, and left-ear advantage for four. The remaining four subjects showed no difference between ears. Significant right-ear superiority in the recall of dichotic digits was found for the group as a whole. A similar finding for normal children was obtained by Kimura (1963, 1967) and Taylor (1962). Inglis & Sykes (1967) postulated that right-ear superiority could probably be accounted for by a tendency on the part of subjects to report material from the right ear first. In the present study, neither ear was consistently used for first report, although a significant correlation was observed between the ear used for first report and ear asymmetry.

The degree of right-ear superiority was somewhat less than that reported by Kimura (1963), who pointed that a very high level of accuracy would tend to reduce the possibility for ear asymmetry to occur. Thus, if a subject has a total score of 118 out of 120, there is less chance of demonstrating ear asymmetry than if his score is 90 out of 120. While total scores of the normal-hearing subjects in the present study were found to increase with age, the degree of asymmetry was not significantly correlated with the total score on the dichotic task.

Hearing-impaired subjects. No significant ear asymmetry was found for the group of hearing-impaired subjects on the dichotic test in spite of a greater mean difference score favoring the right ear. Right-ear superiority was observed in 14 subjects, left-ear advantage in 4 subjects, and for the remaining subject, there was no difference between ears.

The most notable finding for the hearing-impaired subjects was the few occasions on which they reported both members of a dichotic pair. Apart from subject D 7, who reported 14 dichotic pairs, subjects reported only from one to six pairs out of a possible 60, some of which were probably discrimination errors (e.g. 'one' for 'nine') since they were mainly from the most difficult 3-digit pair condition, rather than from the single-digit pairs. In general, subjects reported half of the digits presented. Thus, one digit was reported from a single-digit pair, two digits from a 2-digit pair, and three digits from a 3-digit pair. Some subjects mainly reported digits from one ear, while others reported the first digit from one ear and the next from the other ear, apparently switching at random from one ear to the other. There was no tendency for older hearing-impaired subjects to achieve higher total scores on the dichotic test than younger subjects, nor were total scores related to the period of hearing aid use.

Reliability. The factor most likely to affect the reliability of the results was the relative listening levels established for the two ears. The procedure used to ascertain listening levels was carefully followed to ensure that, as far as possible, the subjects heard the digits at equivalent loudness levels in the two ears. For greater precision, it would be necessary to train subjects to perform loudness balance tests. To estimate the reliability of the results, the same digits tests were administered again at a later date to four subjects, two of whom had extreme right-ear and two, extreme left-ear scores, with almost identical findings.

Discrimination of Competing Auditory Stimuli

Dichotic listening was a new experience for all subjects, normal-hearing and hearing-impaired alike. No practice is required by children with normal hearing to produce correct repetition of both members of a single pair of dichotic digits, as evidenced by the almost-perfect scores achieved at this level (right-ear, 99% and left-ear, 96%). The two competing digits were distinctly perceived, even by the younger subjects in the present study.

Findings were very different for the hearing-impaired subjects. Apart from the one subject mentioned, even the most competent listeners, as judged by monaural scores, were unable to perceive both members of a dichotic pair. When questioned at the end of test, most subjects insisted that they could hear one digit only and that they heard it in both ears. Although many subjects repeated one digit from one ear, followed by a second digit from the opposite ear, only one subject reported that he heard them 'Now in this ear, now in that ear'. Others complained that they 'could not make out the numbers', that they ' could not hear clearly' or that the sound was 'quavering'. Thus, for some subjects, the digit presented to one ear had the effect of masking or distorting the stimulus presented to the other ear. Other subjects reacted by responding mainly, but not exclusively, to digits presented to a particular ear while apparently suppressing those arriving at the other ear. It would seem reasonable, in such cases, to speak of a "dominant" ear.

The profoundly deaf subjects of Ling and Maretic (In press) were found to discriminate vowels better when coded speech was presented to the right ear and conventionally amplified speech to the left, than under the reverse condition. The optimal condition, however, was conventional amplification to both ears. As with subjects in the present study, those of Ling and Maretic were apparently unable to integrate the two different acoustic stimuli, in their case two different acoustic versions of the same syllable. They may have suppressed the coded information while processing the syllable in its uncoded form.

The findings of both studies suggest that hearing-impaired subjects are likely to have difficulty in processing the slightly different patterns of speech which arrive at the two ears when binaural aids are being used.

All of the hearing-impaired subjects in the present study wore hearing aids which provided them with stimulation in both ears, either by means of a Y cord connected from a single hearing aid leading to both ears, or by means of two separate hearing aids.

Subjects in the present study who had experience in everyday listening using binaural hearing demonstrated no greater ability to perceive dichotic digits than those who wore one hearing aid with a Y cord. Present results suggest that subjects who have a "dominant" ear are likely to suppress sounds arriving at the other ear rather than integrate them as do normal listeners. It would be interesting to discover whether training in the use of binaural cues would be effective. The recommendation of binaural aids and also the choice of ear if only one aid is being purchased is at present based on very limited knowledge of the auditory processing abilities of hearing-impaired children.

Ear Asymmetry in the Hearing-Impaired Subjects

The patterns of ear asymmetry differed markedly between groups, with the hearing-impaired subjects showing much greater variability. Marked right-ear superiority was observed for 11 subjects, marked left-ear advantage for four subjects and little or no asymmetry for the remaining four subjects.

The subjects who showed least evidence of lateralization were, with one exception, those with greater hearing loss, those with low scores on the monaural test and those with poor vocabulary. The speech discrimination ability of these three subjects was probably too poor for the dichotic test to be a valid predictor of cerebral laterality.

The marked ear asymmetry of the 15 hearing-impaired subjects is a reflection neither of any difference between right and left ears with respect to hearing levels for pure tones, nor with respect to speech discrimination ability at above-threshold levels, as indicated by the monaural test.

The findings relating to ear asymmetry in the hearing-impaired subjects in the present study are somewhat similar to those reported by Goodglass (1967) in young people who had suffered cerebral lesions in infancy or early childhood. He found that while scores on monaural tests were equal for both ears, the ear ipsilateral to the damaged hemisphere was superior on a dichotic digits test, with striking suppression of material presented simultaneously to the contralateral ear. Kløve (1963) has also reported cases with left hemisphere damage who showed consistent auditory imperception of stimuli presented to the right ear for dichotic but not for monaural conditions.

It would, therefore, seem possible that speech lateralization in the hearing-impaired subjects might have been determined by early brain damage, since Chase (1968) points out that damage to the central auditory system is likely to occur following such insults as viral infection at birth, maternal rubella, anoxia and hyperbilirubenemia. Such etiological factors have been noted for many of the subjects in the present study. Indeed, it would be very difficult to find many hearing-impaired children who had definitively suffered no cortical damage. Only cases of familial deafness would be available as subjects.

If ear asymmetry on the dichotic digits test were used to predict contralateral representation of speech processes, 11 hearing-impaired subjects would be considered to have speech lateralized in the left hemisphere, while for four subjects the right hemisphere would appear to be dominant. Little or no evidence of laterality is available for the remaining four subjects. There is, however, no supporting evidence to permit prediction of speech laterality in these hearing-impaired subjects. Information would be required relating to ear asymmetry on other verbal tests and on some non-verbal dichotic tasks. It is unfortunate that procedures of lateralization such as sodium amytal tests are too hazardous for normal use.

Hand Proficiency

The two groups did not differ significantly in relative right-left hand proficiency as measured by a range of hand performance tasks. Each task was chosen to measure a factor of manual skill such as finger dexterity, hand steadiness or strength of grip.

Ambilaterality, measured in terms of hand proficiency, did not occur to a greater extent among the hearing-impaired than among the normal-hearing subjects. This finding should not be generalized beyond children able to meet the selection criteria of the present study. Ambilaterality might be expected to occur more frequently in a random sample of hearing-impaired children, since this would include children with disorders of the central nervous system in whom confusions of laterality have been reported (Myklebust, 1960).

Relative Ear and Hand Proficiency

Relative right-left ear and right-left hand proficiency were not found to be significantly correlated in either group of subjects. For normal-hearing subjects, this might be because the dichotic test was not adequately sensitive, since ear asymmetry was not observed in four cases and only marginally in another four. Also, the number of subjects with greater left-hand proficiency was small. One showed right ear superiority and the other no asymmetry, thus reducing the correlation. There were however four normal-hearing subjects who showed left-ear superiority even though they were right-handed with respect to proficiency as measured by the six tests.

Both of the left-handed hearing-impaired children showed right-ear advantage on the dichotic test. All four hearing-impaired children who showed left-ear superiority were right-handed both with respect to preference and proficiency. This could be interpreted as an indication that they had suffered damage to the left hemisphere, probably at birth with the result that speech processes became lateralized in the right hemisphere as in cases reported by Basser (1962), Rasmussen (in Zangwill, 1964) and Goodglass (1967).

Ear Asymmetry and Language Proficiency

The hearing-impaired children in the present study did not receive training in speech and language until they were three years of age or older. Their vocabulary ages on the Peabody Picture Vocabulary Test ranged from 2 years 2 months to 10 years 10 months as compared with a chronological age range from 6 years 3 months to 14 years 7 months.

No significant correlation was observed between degree of ear asymmetry on the dichotic test and vocabulary score on the Peabody test. If ear asymmetry for dichotic digits can be used to indicate cerebral laterality for hearing-impaired subjects, it does not appear that speech is better lateralized in children with better language skill, nor is poor lateralization associated with limited language skill. Thus cerebral lateralization for speech and language functions may occur independently of the development of language. This in turn could suggest that specialization of hemispheric function may be genetically determined, though with a certain flexibility in early childhood.

Conclusions

While the dichotic digits task may be a reliable predictor of speech laterality in normal-hearing subjects, the findings of the present study indicate that it would be less reliable with hearing-impaired subjects. The lack of significant correlation between ear asymmetry and vocabulary scores may indicate that specialization of hemispheric function is not dependent on presence of verbal skill.

The discrimination of the competing digits was beyond the capability of all but one of the hearing-impaired group. In general, subjects reported only one digit from a dichotic pair, claiming that they had heard the same digit in both ears. In some cases it appeared that a digit presented to one ear created a masking effect, making discrimination difficult. In other cases, digits arriving at one ear were reported while those presented to the other ear were apparently suppressed. The majority of subjects were observed to have a "dominant" ear, reporting mainly either left or right-ear stimuli.

Supporting evidence from further dichotic testing, using verbal and non-verbal stimuli is required before cerebral laterality can be determined in hearing-impaired children.

Suggestions for further study with hearing-impaired children include;

a) The effect of varying the intensity of the signal to one ear while holding constant the intensity of a contralateral competing signal (Tolhurst & Peters, 1956).

b) The effect of varying onset-time of two competing stimuli on their perception (Cooper-Mehlman, Satz & Tyson, 1969; Satz, Levy & Tyson, 1970; Lowe, S.S., Cullen, J.K., Thompson, C., Berlin, C.I., Kirkpatrick, L. & Ryan, J.T., 1969).

c) The training of hearing-impaired children to perform loudness balance tests (cf. training in frequency discrimination reported by Gengel, 1969).

d) The training of hearing-impaired children in the recall of auditory sequences, both monaural and binaural.

e) The relationship of manual and language proficiency to ear asymmetry deserves further study.

Summary

The purpose of the study was to determine whether speech lateralization, as evaluated by ear asymmetry on a dichotic digits task, could be shown to occur in hearing-impaired children. The correlations between language proficiency and speech lateralization, and between hand and ear laterality were also studied.

Significant right-ear superiority in reporting dichotic digits was found for the group of normal-hearing subjects. While a trend towards right-ear advantage did not reach a significant level with the hearing-impaired subjects, individuals showed marked right-ear or left-ear preference. The groups did not differ in hand proficiency. No correlation was found between the degree of ear asymmetry for dichotic digits and vocabulary scores for hearing-impaired subjects, nor between hand and ear proficiency in either group.

Hearing-impaired subjects were found to be strikingly deficient in the recall of auditory sequences even for monaurally-presented digits.

It was concluded that while the dichotic digits task might confidently be used to predict speech laterality in normal-hearing subjects, it may be considerably less reliable for hearing-impaired children.

The discrimination of pairs of dichotic digits was found to be beyond the capability of all but one of the hearing-impaired group. It appeared that only one member of a digit-pair was heard and that masking or suppression of the other digit occurred. The dichotic digits task was thus not found to be adequate in predicting the cerebral lateralization of speech and language mechanisms in hearing-impaired children.

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