DEVELOPMENT OF ASYMMETRY OF BRAIN FUNCTION FOR LANGUAGE ACTIVITY IN CHILDREN AS REFLECTED BY PERFORMANCES ON A LISTENING AND A VIEWING TASK

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A total of 80 subjects, 40 boys and 40 girls, aged 3, 6, 9 and 12 years, were tested under dichotic listening (simultaneous binaural presentation of pairs of words) and dichoptic viewing (simultaneous loading of both visual fields with pictures under minimal perceptual durations) to investigate cerebral lateralization of language in normal children. Results supported a progressive increase in the degree of hemispheric asymmetry for language fuction over age, as determined by both tasks.

Demonstrations of functional hemispheric asymmetry of the human brain have multiplied in the recent years: the left hemisphere appears to include centers for verbal analytic, temporal activities, while the right hemisphere is specialized in visual configurational, spatial and body scheme functions. Evidence from brain-damaged patients also indicates that in most people one hemisphere governs language, while the other regulates nonverbal, perceptual performances (Milner, 1954).

Handedness is probably the oldest method of inferring the dominant hemisphere for speech and language function. However, current research indicates that handedness is not a consistently valid measure from which to infer the major speech brain. Handedness is a form of behavior in a particular individual which may be influenced by psychological, hereditary, environmental, neurophysiological and perhaps a multiplicity of other factors. With the exception of the individuals who incurred left cerebral damage early in life, the left hemisphere is usually dominant for speech and language function, irrespective of handedness.

A technique that has added much information to localization of the major speech brain is the wada sodium amytal speech test (Wada, 1949; Wada and Rasmussen, 1960). Following the injection of sodium amytal into one carotid artery, contralateral hemiplegia develops with or without dysphasia, for five or ten minutes. The appearance of dysphasia following the injection indicates that the tested hemisphere is dominant for speech and language. Although this method yields reliable information regarding the localization of the major speech brain, it is not a procedurally available method of studying hemispheric specialization for language activity in normal children.

Broadbent (1954) introduced a technique known as dichotic listening, where different auditory stimuli are simultaneously introduced to both ears. Traditional auditory stimuli used in dichotic listening tasks have been pairs of digits, presented as three digits to the right and three digits to the left ear. Kimura (1961) reported early evidence that in normal subjects, more digits were accurately reported from the right than the left ear. The explanation of right-ear superiority was that the right ear had more numerous connections with the left hemisphere, and since the left hemisphere was the one in which speech signals were presumably analyzed, the right-ear sounds had better access to the speech areas. In the same study, Kimura also investigated subjects who had right hemisphere speech representation, as determined by the Wada sodium amytal technique; the expectation that left-ear superiority should occur, was, in fact, confirmed. In another study by Kimura (1963), a right-ear effect was found in normal boys and girls as early as five years of age. The data also suggested that boys may lag behind girls in the development of left hemisphere dominance for speech and language.

Tachistoscopic presentation of visual stimuli to selected visual fields has also opened up new avenues of exploring the functional asymmetry of the brain. Afferent fibers from the nasal retinal field of the left eye and the temporal retinal field of the right eye, corresponding to the left visual field of both eyes, reach the right visual cortex, while the temporal retinal field of the left eye and the nasal retinal field of the right eye, corresponding to the right visual field of both eyes, is represented in the left visual cortex. The visual cortices can communicate via the massive fiber system that connects the two hemispheres, the corpus callosum. The sharing of the visual information in one visual cortex by the neighboring corresponding area may be hindered, if that cortex has barely time to analyze the tachistoscopically presented visual stimulus. Furthermore, the visual cortex that has intrahemispheric connections with the speech areas will have the advantage of verbalizing the flashed visual material. Most adult subjects identify tachistoscopically presented words (Mishkin and Forgays, 1952) and letters (Heron, 1957; Bryden and Rainey, 1963) more readily when such alphabetical material appears in the right visual field than the left.

Surgical disconnection of the two hemispheres eliminates direct crosscommunication between them, leaving the hemispheres otherwise intact, but functionally independent of one another. With specific reference to the verbalization process of the patients who have undergone midline cerebral commisurotomy, Sperry and Gazzaniga (1967) report that these patients are unable to name or describe verbally, objects seen in the left visual field under tachistoscopic viewing conditions, objects felt with the left hand or foot, odors smelled through the right nostril or sounds heard by the right hemisphere. Thus, simultaneous tachistoscopic presentation of verbal material to both visual fields, or dichoptic viewing (Şenkal, 1975) done at minimal perceptual durations, so as to reduce the chances of sharing of the visual information by the right and the left visual cortices via the intact corpus callosum, would be expected to result in a right visual field, left hemisphere advantage.

Development of hemispheric specialization for language activity in children appears to be a complex issue. With reference to neural substrates of language acquisition in children, Ajuriaguerra (1966) states that there are no preformed language centers, but rather, preformed mechanisms that become operational as the general maturation of the nervous system proceeds. Lenneberg (1966), relating language development to universal developmental factors, says that the anatomical, biochemical, and electrophysical events that characterize the maturation process conform to a biological timetable; such orderly acquisition is also observed in language acquisition. He claims that cerebral lateralization of linguistic function is a «plastic phenomenon» and that «no lateralization seems to be present before ages 2 or 3; then there is a period that lasts to about 10 to 12, during which, cerebral lateralization of speech is gradually established, but may still be pushed back to the right hemisphere if the left hemisphere is disturbed.» Thus, in the average child, progressive lateralization of language function, usually to the left hemisphere, seems to begin as language develops-about two years. Obrodor (1964) maintains that elementary stages of lateralization may be completed by five to six years of age, but the higher nervous integrative activity is evidenced up until twelfth or thirteenth year of life. Kimura (1967) refers to the dominant speech hemisphere as «prepotent» in five-year-old children, after which time the child's ability to utilize the minor hemisphere in linguistic functions probably diminishes.

Thus, while continual reference is made to the gradual lessening of equipotentiality of brain function for language activity in children as they approach puberty, no systematic or comprehensive investigation of a progressive strengthening of hemispheric specialization, a more feasible way of studying gradual lessening of equipotentiality, has been reported. Two procedurally available means of studying such hemispheric specialization are by tasks requiring dichotic listening and dichoptic viewing. While dichotic listening studies have been almost entirely confined to adult populations, dichoptic viewing studies have only been utilized with commisurotomized patients. Also, the dichoptic viewing technique is believed to be an even stronger indicator of brain asymmetry for speech and language, since the visual presentation of an object has to be translated into linguistic symbols, where as in dichotic listening, auditory stimuli are only expected to be repeated orally or produced in writing.

Hence, the purpose of the present investigation was to study the progressive development of asmmetry of brain function for certain verbal activity in normal boys and girls aged three, six, nine, and twelve years, as reflected by their performances on dichotic listening and dichoptic viewing tasks.

METHOD

Subjects

A total of 80 children, 40 boys and 40 girls, were studied in four categories: three, six, nine and twelve. Each age group contained 20 children, of which 10 were girls and 10 were boys. The subjects were considered normal by parents and teachers, showed no medical or psychiatric histories that would contraindicate inclusion, had no known hearing or visual field impairments, used English as their native language and had average cognitive capacities and age-appropriante verbal output. The subjects had to be within three months of their birthdays. The three-year-old group however, had the six month spread from their birthday to three years, six months of age.

Materials and Equipment

The dichotic listening (DL) tapes were prepared at Haskins Laboratories, New Haven, Connecticut, by computer assistance to ensure precision of simultaneous presentation of the auditory materials. Such material consisted of 20 pairs of familiar words, which were also pictorially representable. The tape included five pairs of practice items, each pair separated from the next by five second der. Also, there were two items dispersed randomly into the 20 experimental items. The dichotic materials were presented binaurally via stereophonic headphones, from a stereo cassette recorder. Also, there were two items dispersed randomly into the experimental tape, that contained the same stimulus for both ears. The inclusion of these items was for the purpose of holding the attention of particularly the younger subjects, as well as for checking the reliability of their responses.

The dichoptic viewing (DV) material was prepared as slides from three by five-inch picture cards which contained the visual representations of the DL words. These cards contained pictures of items such as apple, cow, train, plate, shirt etc. These cards were also used in pretesting reviews with each subject. Positioning of the visual stimuli on the slides was such that, of the two pictures, the same picture appeared in each visual half-field; i.e., horse and horse for the left temporal and right nasal retinal half-fields (right visual field) and chair and chair for the left nasal and right temporal retinal half-fields (left visual field).

Although the same stimuli were used in the DV tape and on the DV slides, they were paired differently, on a random basis, for each task. Similar to the dichotic items, the first five slides of the DV materials were the practice items, followed by the 20 experimental items. Two additional items dispersed into the experimental set, contained the same stimulus for both visual fields and were included as a means of checking the reliability of subjects' responses. Four other slides were prepared to contain only one picture for both halves of one visual field and were used in screening the subjects for visual field and were used in screening the subjects for visual field defects.

The basıc unit of the DV apparatus was a slide projector that had been modified into a tachistoscope, with a timer that could be set at 500, 100, 40 or 20 msec.

Procedure

Prior to the collection of the experimental data, subjects were screened for auditory and visual functioning. In auditory testing, both ears of each subject were tested at 500, 1000 or 2000 Hz. for threshold sensitivity. Subjects who seemed to have an ear advantage of more than five dB were excluded from the study so as not to confound the findings of the DL task. Similarly, visual field screening was done for the purpose of eliminating those subjecte with visual field defects which could bias the results of the DV task, using the four slides which contained only one item for selective visual fields, as described earlier.

After the subject passed both the auditory test and the visual field screening, the 40 picture cards were reviewed one by one with each subject. The rationale for this procedure was to familiarize the subjects, especially the youngest group, with all the stimuli, such that word knowledge would not bias ear or visual field preference.

During the DL task, the intensity of the auditory stimuli was set at about 45 dB. After the five pairs of practice items, during the 30 sec. interval, the investigator reminded the subjects of the instructions to repeat what they hear, as soon as they hear it. The experimental items were 20 pairs of words, presented at five-second intervals. As the test proceeded, subjects' responses were reinforced with a smile or nod, regardless of the content of a particular response.

Next, during the DV task, the subjects were first familiarized to the task by the five practice items. The instructions were reinforced before the 20 pairs of experimental items weie presented on the screen, each flashed subsequent to the subjects' response. As determined from the pilot investigation, appropriate exposure time was 100 msec. for the three-year-old subjects and 40 msec. for the subject population. Having the subject focus on the pilot lights which were placed at midpoints from the central dividing panel, ensured the stabilization of his ocular movements and adjusted his vision to the same distance as the presented pictures. During the course of the task, the investigator switched the lights off once or twice and reinstructed the subject to focus on them if he failed to report this event.

RESULTS AND CONCLUSIONS

Three different measures of the results of the DL task were made in order to answer the first research question: Is there a progressive increase in the degree of asymmetry of brain function for certain verbal activity in normal children aged three, six, nine and twelve years, as reflected by their performances on a DL task? Is such a performance sex-related? A two-way analysis of variance, which tested for age and/or sex as significant factors affecting differences in mean performances, and Scheffé test, to compare mean performances between age groups, were used. The three measures and their results were the following :

a) Right-ear scores, which included the total number of only right-sided responses : mean right-ear scores showed a trend toward a progressive increase over age. Analysis of variance showed that the mean right-ear scores were significantly different with respect to age, but not sex. A significant difference was found between 3 and 12 year-old groups, only.

b) Percentage of right-ear scores, which was obtained by dividing the right-ear scores by the total number of acceptable (the sum of only right- and only left-sided) responses: the mean percentage of right-ear scores showed a trend for a progressive increase over age. Similar to mean right-ear scores, analysis of variance showed that mean percentage of right-ear scores were significantly different with respect to age, but not sex. A significant difference was observed between 3 and 12-year-old groups, only.

c) Absolute ear-difference scores, which reflected the difference between right-ear and left-ear scores, without indicating which side was favored: mean scores of absolute ear-differences showed a trend toward a progressive increase over age. Analysis of variance showed that mean absolute ear-difference scores were significantly different with respect to age, but not sex. Significant differences were observed in the comparisons of 6 and 12-year-olds, as well as 3 and 12-year-old groups. Please see Table 1 for mean values of DL measures.

Thus, results on DL performances supported the concept of a trend toward a progressive increase in the degree of asymmetry of brain function in normal children aged three, six, nine and twelve showed that mean absolute ear-difference scores were significantly No sex-related differences were observed.

Similarly, three different measures of the results of the DV task were made in order to answer the second research question: Is there a progressive increase in the degree of asymmetry of brain function for ceıtain verbal activity in normal children aged three, six, nine and twelve years, as reflected by their performances on a DV task?

Table 1

Mean Values and Standard Deviations of the Dichotic Listening Measures (n=80)

	Right - Ear Scores		% of Right - Ear Scores		Absoulte Ear - Difference Scores	
Age	Mean	SD	Mean	SD	Mean	SD
3	8.400	2.349	60.732	13.765	3.700	2.830
Girls	8.500	2.461	59.644	15.175	3.500	3.206
Boys	8.300	2.359	61.819	12.927	3.900	2.558
6	9.050	3.634	66.379	16.674	5.550	2.819
Girls	8.800	3.910	62.305	19.596	5.300	2.359
Boys	9.300	3.529	70.354	12.886	5.800	3.327
9	9.250	2.881	73.291	16.652	5.800	2.858
Girls	9.800	2.530	76.785	13.722	6.300	2.627
Boys	8.700	3.233	69.798	19.234	5.300	3.129
12	11.300	3.230	75.845	17.750	8.350	3.514
Girls	12.400	3.748	73.039	18.873	8.800	4.341
Boys	10.200	2.300	78.652	17.071	7.900	2.601

Is such performance sex-related? The same statistical means of analysis were utilized. The three measures and their results were the following :

a) Right visual field scores, which included the total number of only right-sided responses: mean right-visual field scores showed a trend toward a progressive increase over age. Analysis of variance showed that right-visual field scores were significantly different with respect to age, but not sex. A significant difference was found between 3 and 12-year-old groups, only.

b) Percentage of right-visual field difference scores, which was obtained by dividing the right-visual field scores by the total number of acceptable (the sum of only right- and only left-sided) responses: the mean percentage of right- visual field scores showed a trend toward a progressive increase over age. Analysis of variance showed that the mean percentage of right-visual field scores were significantly different with respect to age, but not sex. Significant differences were observed between 3 and 9-year-old, as well as 3 and 12-year-old groups.

c) Absolute visual field-difference scores, which reflected the difference between right-visual field and left-visual field scores, without indicating which side was favored: mean scores of absolute visual-field differences similarly showed a trend toward a progressive increase over age. Analysis of variance showed that mean absolute visual field-difference scores were significantly different with respect to age, but not sex; significant differences were observed between the 3 and 12-year-old, 6 and 12-year-old, and 9 and 12-year-old groups.

Thus, in conclusion, results on DV performances supported the concept of a trend toward a progressive increase in the degree of asymmetry of brain function in normal children of the studied age groups, although such trends were not always statistically significant. However, comparisons of 3 and 12-year-old children consistently yielded significant differences, and some other inter-group differences were also found significant. No sex-related differences were observed.

Two pairs of analogous measures were correlated (Pearson product-moment coefficients of correlation) in order to answer the third research question: Is there a relationship between the DL and DV performances of three, six, nine and twelve-year-old children? The correlation between absolute ear-difference and absolute visual-field difference scores was. 32, indicating a significant but mild relationship. The correlation between the right-ear and right visual-field scores was. 40, indicating a moderate and significant relationship. Crosstabulation of the DL and DV scores, indicating sidedness revealed that 81.2 % of all subjects demonstrated a right visual-field advantage, as shown in Table 2. Crosstabulation of the DL and DV scores indicating sidedness over the studied age groups, showed that most of the children exhibited a right-sided preference on both tasks. Further, the number of subjects that showed a right-sided preference increased over age.

Thus, based on the correlations and crosstabulations, a relationship was found to exist between the DL and DV performances of the studied age groups. Also, the tendency for the subjects to show a right-sided prefence on both tasks, seemed to strengthen as a function of age.

Table 2

Crosstabulation of the Dichotic Listening and Dichoptic Viewing Scores, Indicating Sidedness (N=80)

Visual field sidedness ↓		Ear sidedness →			
		Left	Zero*	Right	Total
Left	n	4	0	8	12
	%	5	0	10	15
Zero	n	0	0	5	5
	%	0	0	6.3	6.3
Right	n	10	1	52	63
	%	12.5	1.2	65	79
Total	n	14	1	65	80
	%	17.5	1.2	81.2	100

DISCUSSION

Among the limitations of the study, reliability of subject responses using repeated measures was not tested. However, two check stimuli in each of the tasks, which contained the same stimuli for both ears and both visual fields, served as the reliability indicator On the DL task, 94 % of all subjects reported both check stimuli, while on the DV task, 64 % of all subjects reported both of these items. The number of subjects identifying both check stimuli appeared to increase over age on both tasks. On the DL task, no subject failed to report at least one of the check stimuli. On the DV task, three subjects failed to respond to either of the check stimuli; however, these subjects had a total number of acceptable responses that were similar to the mean response rate for their age group. Qualitative analysis of the responses in DL, and 5.2 % of all responses in DV were idiosyncratic, that is, they did not seem to be related to the given stimuli. Such a low idiosyncratic response ratio also suggests that the subjects generally responded reliably.

All of the subjects were dawn from New York City. These subjects might not have been representative of nursery and primary school systems in general.

The DV test was developed by the investigator and was a novel experimental setting. Under carefully controlled conditions, dichoptic testing is considered a sound method of assessing hemispheric asymmetry for language function. However, valid responses are dependent on the subjects' proper focusing on the macular points, which were the pilot lights. A shift in focus from these points, favoring the right or the left side, may result in biased or invalid responses. In this investigation, subjects' ocular movements were carefully monitored, but could not be strictly controlled. Another source of variability in the DV task was the exposure time: the durations of the pictorial stimuli were 100 msec. for the three-year-olds, and 40 msec. for the rest of the subject population. Although the youngest subjects failed to respond to the visual stimuli when they were presented at 40 msec., the instrumentation did not have the gradations between 40 and 100 msec. Such gradations might have enabled the use of an exposure duration longer than 40, but shorter than 100 msec., still adequate exposure duration for the youngest subjects. As a result of the longer viewing time, the three-year-old children might have had an advantage in processing and verbalizing the visual input as compared to the rest of the subjects, thus obscuring possible differences between three and six and nine-year-old subjects.

Further, the number of subjects tested is not large enough to draw universal conclusions from. Since there were only 10 boys and 10 girls in each of the four age groups, subtle age or sex differences might have been called insignificant.

In the present investigation, an ear preference was observed in children as young as three years of age on DL. Kimura (1963) studied five, six, seven and eight-year-old normal boys and girls under DL conditions and reported a right-ear advantage in the five-year-old group. However, while Kimura reported sex differences on right-ear scores favoring girls, no significant sex differences were observed in the present study.

Sperry and Gazzaniga (1967), studying the performances of commisurotomized patients under tachistoscopic conditions, reported 100 % correct verbal response to the right-visual field stimuli, and no correct response to the left-visual field stimuli. This study also attempted to produce a functional hemispheric independence in normal children through the use of the DV technique. However, the findings of the study did not reveal an all-or-none response pattern from the right and left visual fields as described by the above researchers. Nevertheless, the responses obtained from the subjects did generally indicate a preference toward verbalization of the right-visual field stimuli.

Penfield and Roberts (1959) reported that 73 % of the right-handed and 72 % of the left-handed patients had transient dysphasias following left hemisphere operations. Handedness was not controlled in this study, since its major focus was to explore the patterns of developing brain asymmetry for language function in normal children, without attempting to postulate a relationship between handedness and speech brainedness, two functions that appear to exist independently of each other. However, the findings did indicate that the left hemisphere was the major speech brain in most of the subjects: 65 % of all children exhibited right-ear and right-visual field advantages in both tasks, indicating the specialization of the left hemisphere for speech and language functions.

Findings of the present investigation do not generate a new or a different theory regarding the neurophysiological basis of language development; rather, they supply experimental evidence to support the theory of a progressive, but not necessarily a linear development of hemispheric asymmetry for language function in normal children.

Three-year-old children performed significantly differently than the twelve-year-old children on both tasks. A progressive increase in the degree of asymmetry was observed as a trend with respect to the intervening age groups, but differences between these groups were not found to be statistically significant. Furthermore, differences in performance of six and nine-year-old children were relatively small. The plateau observed in the performances of six and nine-year-olds suggests that the establishment of hemispheric asymmetry for language function in children is not a linearly progressive function, with similar increments of development. Although the developmental patterns in age groups that were not studied in this investigation cannot be ascertained, observed trends in those that were studied are rather similar to growth curves for neural maturation. Brain weight nearly quadruples in the first three years of life, then continues to grow, but at a considerably slower pace, until it reaches an asymptote around puberty. It may be that specialization of one hemisphere for one hemisphere for language function becomes evident by three years of age, and the rate of development during midchildhood years is slower compared to the rate during the first three years of life.

The performance characteristics of 12 year-old boys and girls seemed different: the girls scored higher on the right-ear and right-visual field, and showed greater ear and visual field-difference scores. Such difference may be attributable to the difference in the maturation profiles of boys and girls during early puberty years. The variability of the scores generally increased over age. The enlarged receptive and expressive language repertoire of children as they get older may account for the increasing variability of DL and DV scores, since these tasks also reflect language function. Also, more instances of significant differences were observed between the age groups in the DV, than the DL task. This finding may imply that DV provides, as predicted, a more sensitive measure of assessing developing hemispheric specialization for language function in children. It is also hypothesized that the single measure that best reflects the functional asymmetry of the brain for language activity on both tasks, is the absolute difference score, which was also found to yield a greater number of significant differences between age groups.

The preliminary experimental evidence presented in this investigation may be used as an additional tool in studying children who suffer from delay or retardation of language development. This information may be of diagnostic value, indicating a possible neurological immaturity of the child, comparing the child to the values obtained in this study may give information, in terms of how different the child is from the group of normal children studied. Also, tasks that require DL and DV in therapy may be used to attempt to facilitate the establishment of speech brainedness. Performance on these tasks could also be used to evaluate the progress of therapy.

These findings also suggest some fruitful avenues of future research. Similar investigations with larger sample sizes that include all age groups from three up to thirteen or fourteen years would supply data which may shed more light on the upper limits of developing asymmetry of the brain for language function and may identify significant intervening age levels. Patterns of development of hemispheric specialization for language activity should also be explored with speech, language and learning impaired populations.

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