Inter- and Intramodality Matching Deficits in a Dysphasic Youth

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The subject of this report suffered a stroke at the age of 14, and the available evidence suggests extensive damage to the left (dominant) cerebral hemisphere. During the two years since onset of his illness we have carried out a series of behavioral studies relevant to the general problem of interhemispheric relations, with particular reference to language function.

Clinical tests indicated that the patient was unable to write single letters to dictation, or even to select a dictated letter from several available visual choices. He was, however, able to deal fairly effectively with simple words on these tasks. It was this apparent discrepancy which prompted us to seek through special testing techniques a more precise delineation of his behavioral deficits.

An additional, although not secondary, purpose of this report is to describe an investigative methodology. As is so often the case, our patient's almost complete lack of oral speech rendered conventional techniques of verbal communication nearly useless to our study of his language deficits. It occurred to us that the facilities of a laboratory which is using nonverbal techniques extensively in the study of the behavior of animals and subnormal human subjects (Sidman and Stoddard) might profitably be applied to the exploration of verbal deficits. Specifically, we adopted a sample-matching technique which permitted the subject to indicate his selection of choices by nonverbal responses even when stimulus materials were verbal in nature. This method has the additional virtue of applicability to verbal and nonverbal deficits interchangeably. In addition, a reinforcing consequence (in this instance, money) was provided to the subject following each correct response. The reinforcement not only insured stable performance and cooperation, but served to instruct the subject in the nature of each task. This instruction provided an effective form of communication between subject and experimenter. Automation of the procedures ensured reliable stimulus presentation and accurate recording of responses, kept interactions between subject and experimenter to a minimum, and made it possible to secure large amounts of information relatively rapidly.

Geschwind and others have emphasized the need in studies of language deficits for precision in specifying both the stimuli presented and the subject's mode of responding. Birch and Belmont, Geschwind, and others have stressed the importance to language of deficits in the handling of information within and across sensory modalities (inter- and intramodality deficits). Sample-matching techniques lend themselves particularly well to such specification, and cross-modality comparisons are easily accomplished by varying the sensory modality through which the samples, choices, or both are presented.

The substance of this report, then, is the description of our subject's verbal deficits as a series of relatively specific inter- and intramodality sample-matching deficits. Analysis of these deficits in the light of previous studies has permitted not only some inferences concerning the cerebral lateralization of various verbal and nonverbal behaviors, but also speculations about what constitutes the "verbality" of verbal behavior.

Report of a Case

A 14-year-old boy, in excellent health, was doing generally satisfactory work in school (with some exceptions detailed below), until May 15, 1964, when in the late afternoon just after finishing a foot race he sat down, clapped his
hand to the left side of his forehead, collapsed, and had a grand mal seizure. He was taken to a local hospital, and four hours later transferred to the Massachusetts General Hospital. Examination in the emergency ward showed him to be slightly stuporous, confused, and globally aphasic. The eyes were conjugately deviated to the left. A right central facial weakness, flaccid right hemiparesis, and bilateral extensor plantar responses were noted. An immediate lumbar puncture revealed grossly clear fluid under slightly elevated pressure. Microscopic examination of the cerebrospinal fluid (CSF) revealed 400 erythrocytes/cu mm in the first tube (approximately 4 cc), and 80 in the third tube. The supernatant fluid was not xanthochromic. Skull x-rays showed a shift of what was thought to be a calcified pineal gland to the right, approximately 3 mm. An echoencephalogram also suggested a shift of midline structures to the right.

Two hours after admission to the emergency ward, a left common carotid arteriogram was performed; this showed complete occlusion of the left middle cerebral artery just distal to the point of departure of the main temporal branch, which appeared to supply the temporal pole and part of the middle temporal gyrus (Fig 1). A right carotid arteriogram performed at the same time was normal.

On the fourth hospital day, an episode of acute increased intracranial pressure was thought to represent postischemic cerebral edema. The patient developed decerebrate rigidity, slowing of the pulse, and a dilated left pupil, and was given hypertonic urea solution intravenously. Within two hours he was back to his
hand to the left side of his forehead, collapsed, and had a grand mal seizure. He was taken to a local hospital, and four hours later transferred to the Massachusetts General Hospital. Examination in the emergency ward showed him to be slightly stuporous, confused, and globally aphasic. The eyes were conjugately deviated to the left. A right central facial weakness, flaccid right hemiparesis, and bilateral extensor plantar responses were noted. An immediate lumbar puncture revealed grossly clear fluid under slightly elevated pressure. Microscopic examination of the cerebrospinal fluid (CSF) revealed 400 erythrocytes/cu mm in the first tube (approximately 4 cc), and 80 in the third tube. The supernatant fluid was not xanthochromic. Skull x-rays showed a shift of what was thought to be a calcified pineal gland to the right, approximately 3 mm. An encephalogram also suggested a shift of midline structures to the right.

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Fig 1.—Left carotid arteriogram of our subject (top, lateral view; bottom, frontal view). (Left anterior cerebral artery filled normally from right carotid artery.)
status of the day before. The patient then gradually improved and had an uneventful hospital course. He was discharged three weeks later. Follow-up neurological examination in the outpatient department two months after discharge by one of us (P.B.R.) revealed neurological deficits which were to remain essentially unchanged for the next 12 months. Speech was limited to "yeah," "no," and grunts indicating approval or disapproval. He could make only a feeble attempt to oral imitation of simple vowel and consonant sounds. Mental status examination using written or multiple-choice responses revealed that he was well oriented to person and place, and approximately to time. He pointed to each of ten simple picture cards upon hearing their spoken names, and was able to associate "meow" with the cat picture and "moo" with the cow picture.

Performance in following auditory commands was uneven. When asked to "put the bell picture under the cow picture," he chose the proper pictures, but the word "under" had to be repeated several times. When asked to draw a square he drew a single right angle, and then when asked to draw a circle he drew a square, although he was able to copy both figures accurately from a stylus tracing. He

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Fig 2.—Diagrammatic representation of display and response panel, under the various test conditions.

Fig 3.—Sample-matching performances with single letters presented in visual and auditory modalities. (Sessions were not equally spaced in time.)
pointed to his ears on spoken command, but not to his eyes, nose, mouth, or thumbs. He associated each of the ten picture cards with its written name accurately, but followed no simple written commands. He was unable to identify any body parts upon seeing their written names. He was unable to answer by single written words simple questions regarding the actions described in paragraphs 1 through 4 of the Gray Oral Reading Test. He drew a union jack figure accurately from visual sample, and a picture of a clock from memory on auditory command. He distinguished left from right on auditory command. Simple written addition and multiplication problems were solved accurately.

The clue to an important aspect of the patient's deficit was given in clinical tests of his writing. He was able to write a few words spontaneously and to write simple three-letter words to dictation. However, he was unable to write single letters accurately to dictation, or to pick out on spoken command single letters which he had just written. When asked to "write the alphabet," he lost the correct order after "F," and wrote only random letters after "J."

Cranial nerve examination revealed only a right central facial weakness. The visual fields were intact to confrontation. There was a moderately severe right spastic hemiparesis, affecting the upper more than the lower extremity, and the tendon reflexes were uniformly increased on the right. He was able to walk well assisted by a leg brace, with minimal circumduction of the right leg, marked right limp, and right shoulder droop. Motor coordination was unimpaired within the limits of strength; ataxia and dysmetria were not demonstrable. Sensation to touch, pain, vibration, and position was intact in all extremities; a moderate impairment of stereognosis was present on the right.

The subject's school records did not give an entirely consistent picture of his premorbid language abilities. Grade scores suggested a slight decline in the performance of language-related subjects during the school year before his strike. Scores on standard achievement tests, however, showed no consistent trend. His grade-equivalent score on the language section of the Stanford Achievement Test was 3.8 at grade 3.6, only 3.3 at grade 6.7, and 7.3 at grade 8.5. His standard achievement scores in spell-

Fig 4.—Our subject's performance in writing single letters in response to samples presented in various modalities.
In October 1964, the subject achieved an intelligence quotient score of 69 on the Wechsler Intelligence Scale for Children (WISC) Performance Scale, with his best performance on block designs and object assembly. He was followed in weekly speech therapy for approximately a year, with many missed appointments noted, and little progress recorded. Although pleasant and cooperative, he was noted by several observers to give up readily any task in which he encountered severe difficulty. At one time he was transferred for psychiatric consultation after striking his mother and sister several times. He has not returned to school nor shown any desire to do so, despite a generally successful readjustment to his community and peer groups.

Materials and Methods

Over a period of one year the patient was subject during a large number of separate sessions to various sample-matching tasks, usually in sets of 20 trials each. He worked in a well-ventilated room approximately 5 feet square, with sound-resistant walls and door. An electric fan aided in dampening incidental noises. The subject sat facing a wall on which was mounted a display and response panel consisting of a square matrix of nine translucent windows, each 2 inches square, and arranged in three rows of three, each separated from the other by three-fourth-inch barriers. Touching a window with light pressure activated a micro-switch mounted behind it, delivering a signal to electronic programming and recording devices. Visual stimuli to be presented on the windows were photographed on 35 mm color film and projected as slides from the rear. Motor-driven shutters behind the keys and in front of the projector lens controlled the presentation and removal of stimuli. Sidman and Stoddard have described this apparatus in detail.

The basic experimental procedure was a matching-to-sample task, either within one or between two primary sensory modalities. The procedural variations are summarized as follows (the actual stimuli, letters, words, colors, etc., will be described in conjunction with the results):

![Sample-matching performances with various materials. Auditory samples and visual choices. (Color series contained 18 rather than 20 trials per session.)](image-url)

**Fig 5.**
A sample stimulus was first projected onto the center window of the matrix, the outer windows remaining dark (stage I, Fig 2a). When the subject pressed the center window, stimuli (choices) appeared on the outer windows, giving a total of eight choices per trial except where noted otherwise (stage II, Fig 2b). The subject’s task was then to press the outer window that contained the same stimulus as the center. Correct choice responses (in all procedures) were followed by the sounding of chimes and the delivery of a penny (reinforcement) into a tray situated next to the matrix. Incorrect responses produced no reinforcement. A new sample was presented 1.5 seconds after the subject made his choice.

Auditory Sample and Visual Choices (Auditory-Visual Matching).—Auditory samples were spoken by the experimenter (seated behind the subject) and were repeated at one-second intervals with all windows dark (stage I, Fig 2b). The subject pressed the dark center window, exposing the visual choice stimuli, one of which corresponded to the auditory sample (stage II, Fig 2b). The experimenter continued to repeat the sample until the subject pressed his choice. A new trial started 1.5 seconds later.

Tactile Sample and Visual Choices (Tactile-Visual Matching).—Tactile samples consisted either of small objects placed unseen in the subject’s left hand (right never used because of paraparesis), or of 1-inch high plastic block letters affixed to cardboard backing, which the subject could touch with his fingers but not view. When the subject completed his tactile examination of the sample, he pressed the dark center window, exposing the choices, and made his selection of the appropriate visual stimulus. Where simultaneous match was called for, he was free to make repeated tactile examinations of the sample if he wished.
Auditory Sample and Auditory Choices (Auditory-Auditory Matching).—One experimenter spoke the sample and another experimenter spoke the choices, the sample being repeated before each successive choice. The subject rang a bell to indicate that the two auditory stimuli were identical. Because the auditory-auditory matching involved a radical procedural change, the same method and materials were used to check our findings with visual-visual, auditory-visual, and visual-auditory matching. The procedural variations did not alter the findings.

Tactile Sample and Auditory Choices (Tactile-Auditory Matching).—The tactile samples were presented as described above, and the auditory choices were spoken aloud to the subject. He signified identity by nodding or making a sound.

Written Responses.—Visual, auditory, or tactile stimuli were presented to the subject, who was required to copy them on paper.

Delayed Matching.—In simultaneous matching, the sample remained available (visible, spoken at one-second intervals, or accessible to touch, depending on the modality being tested) after the choices had been presented. In delayed matching, the sample was no longer available after the choices had appeared (Fig 2c).

Zero-Delay Matching.—When the subject pressed the sample window, the sample disappeared and the choices were presented immediately.

Adjusting-Delay Matching.—This procedure started with zero delay. Each time the subject chose correctly, a progressively longer delay (stage II, Fig 2c) was imposed between the removal of the sample and the presentation of the choices on the next trial. If the subject made an error, a shorter time interval intervened between sample and choice stimuli on the next trial. With this procedure, the subject's level of accuracy adjusted the duration of time over which he had to remember the sample.

For a given task, 20 trials (except as noted below) were used to assess the subject's performance. The time required to complete a set of 20 trials varied from two to ten minutes, and a given session usually included from 6 to 12 sets. In order to control for the variables of practice and fatigue, each session began and ended with a set on which the subject normally performed well. Poor performance on a given set was not included in the reported data unless a good performance was obtained on a set following.

The data to be presented below were shown to be uninfluenced by the time of day of the tests, by testing site in the experimental chamber or with similar materials outside the chamber, by who the specific experimenter was (different personalities and manners of speech), or by the size of the reinforcement (1 vs 10 cents) for correct choices.

Results

Deficits Across Modalities.—Single-Letter Matching.—In clinical tests, the subject was able to write a few words spontaneously and to write three-letter words to dictation, but he was unable to write the complete alphabet on command, or to pick out given letters in response to their spoken names from those he had just written. The first sample-matching tasks followed up this clue.

The subject made large numbers of errors in matching single letters when auditory samples and visual choices were offered (auditory-visual match), even though he was consistently accurate in matching the letters when they were presented as visual samples (visual-visual match). Error rates on these two tasks over a 30-week period appear in Fig 3. Sessions 27 and 28, in which the auditory-visual error rate was low, occurred on the same day. Tests given immediately afterward, requiring choices to be made with no sample given, indicated that he had...
learned something about the stimuli besides what the task was calling for. New sets were constructed with choices and patterns rearranged, and in the following sessions, error rates were once again high.

The auditory-visual deficit was equally demonstrable with capital and lower-case letters, occurred with delayed as well as simultaneous matching, and was independent of the order of presentation of the various modality combinations. The subject showed no propensity for selecting particular positions on the matrix of windows, or for selections based on reversals or other similarities between the correct and incorrect choices.

Figure 3 also shows that his error rate was high in matching visual samples to auditory choices; the auditory-auditory error rate was low, however. His deficit was not in the auditory modality alone, nor in the visual modality alone, but was truly one of intermodality transfer.

The question of whether the deficit involved the specific modalities of audition and vision, or intermodality transfer per se, was approached by adding still another modality of presentation. Tactile samples, single uppercase letters, were presented for the subject to match with visual or auditory choices. The subject made nine errors in 20 trials of tactile-auditory match, compared with only one error on tactile-visual match. Tactile-auditory match was thus significantly and nearly as defective as auditory-visual match, while tactile-visual match was as intact as visual-visual match. This fact suggested that the matching deficit, as tested by single letters, was specifically an “auditory-other modality” deficit.

It was possible to vary not only modalities of sample and choice presentation, but also modes of response, to the extent that the subject could be required to respond by writing rather than picking out a choice from a number of alternatives. His writing performance is shown in Fig 4. Here again it can be seen that performance was nearly perfect with visual and tactile samples (allowing for some awkwardness in writing with the left hand), but significantly defective with auditory samples.

Other Materials.—It was noted earlier that the subject dealt with the spoken names of simple words better than with those of single letters. This finding was confirmed in the laboratory tests.

Our experience with auditory-visual matching of several different types of words and other materials is presented in Fig 5. All error data presented on the figure were controlled on at least one occasion by errorless visual-visual match with the same materials during the same session. Again, visual-visual tests were usually presented before auditory-visual tests. This gave the intermodality tasks the benefit of any possible practice effect. The incorrect alternatives on each trial consisted of items that were correct on other trials.

The open circles connected by solid lines on Fig 5 demonstrate that auditory-visual matching with two sets of three-letter “representative” nouns (representing pictureable objects) was errorless or nearly so on ten different occasions. The two different sets of nouns are listed as A and B in Table 1. Set A was also given in two different sequences. The subject also performed without error when he had to match the spoken word samples of set A with picture choices (open squares). When the sample words of set A were spelled, however, rather than being pronounced as words, error rates were as high as they had been with single letters (open circles connected with dotted lines).

The question of what accounted for the differences between words and letters in his sample-matching performance was further explored by constructing other sets of words, syllables, and letter combinations. List C in Table 1 consists of “nonrepresentative” nouns (not representing pictureable objects); list D is composed of non-nouns; list E contains pronounceable “nonsense syllables,” selected from those found by Glaze and corroborated by Noble to have low association value for normal subjects; list F contains unpronounceable nonsense trigrams.

As can be seen from Fig 5 (sessions 18 and 21, dotted and bisected circles) the nonpictureable nouns and non-nouns increased the subject’s error rate. The pronounceable nonsense syllables (sessions 13 and 14, cross-hatched circles) produced extremely high numbers of errors. Auditory-visual matching of three-letter unpronounceable nonsense trigrams (sessions 13 and 16,
Tasks involving color names also yielded higher error rates than did noun lists A and B, but all the color names except "red" contain more than three letters. He was subjected on several occasions to an 18-trial set in which six color names were each given three times as samples. All six colors or names appeared as alternatives on each trial.

There were two types of auditory-visual matching: auditory (spoken) color names and visual (projected) colors; auditory (spoken) color names and visual (projected) color names.

The second of these is, of course, a word choice matching task, with non-nouns (color names) as materials; the error rate (Fig 5, cross-hatched hexagons) is comparable to that on the non-noun list. Error rates for name-color matching (Fig 5, striped hexagons) were consistently higher than in the nearly errorless visual-visual match with the same materials, but the performance with this material improved considerably.

Auditory-visual matching of numbers (single digits) with their names was error-free. Also, the subject made no errors in selecting the pictures of common objects that were placed as unseen samples, in his left hand. The right hand was not tested because of its motor and sensory deficit.

As had been the case with single letters, the word matching data were further corroborated by tests requiring a writing response (Fig 6). When the auditory sample was pronounced as a word (auditory syllable), or even when a picture of the object was given as a sample, he had no difficulty writing the correct word. He was even able to rearrange scrambled visual samples to write the required words. Only when the auditory samples were spelled was he unable to respond correctly.

Since spoken words are made up of the

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Table 1.—Lists of Words, Nonsense Syllables, and Trigrams

<table>
<thead>
<tr>
<th>Representative Nouns</th>
<th>Nonrepresentative Nouns</th>
<th>Nonsense Syllables</th>
<th>Trigrams</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
</tr>
<tr>
<td>car</td>
<td>jug</td>
<td>nap</td>
<td>ago</td>
</tr>
<tr>
<td>bee</td>
<td>egg</td>
<td>loy</td>
<td>yes</td>
</tr>
<tr>
<td>man</td>
<td>bag</td>
<td>one</td>
<td>but</td>
</tr>
<tr>
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<td>dip</td>
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</tr>
<tr>
<td>bed</td>
<td>wig</td>
<td>zip</td>
<td>low</td>
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</table>

Table 2.—Sample-Matching, Control Subjects

<table>
<thead>
<tr>
<th>Samples</th>
<th>Choices</th>
<th>Controls</th>
<th>Our Subject (Mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital letters, visual</td>
<td>Capital letters, visual</td>
<td>0/20</td>
<td>0/20</td>
</tr>
<tr>
<td>Capital letters, auditory</td>
<td>Capital letters, visual</td>
<td>1/20</td>
<td>1/20</td>
</tr>
<tr>
<td>Nonsense syllables, visual</td>
<td>Nonsense syllables, visual</td>
<td>0/20</td>
<td>0/20</td>
</tr>
<tr>
<td>Nonsense syllables, auditory</td>
<td>Nonsense syllables, visual</td>
<td>0/20</td>
<td>0/20</td>
</tr>
<tr>
<td>Words (non-nouns), auditory</td>
<td>Words (non-nouns), visual</td>
<td>0/20</td>
<td>0/20</td>
</tr>
<tr>
<td>Names of colors, auditory</td>
<td>Colors, visual</td>
<td>0/18</td>
<td>0/18</td>
</tr>
<tr>
<td>Letters, visual</td>
<td>Names of letters, visual</td>
<td>0/8</td>
<td>0/8</td>
</tr>
<tr>
<td>Names of letters, visual</td>
<td>Letters, visual</td>
<td>0/8</td>
<td>0/8</td>
</tr>
</tbody>
</table>

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sound rather than the names of individual letters, the question presented itself: Are the phonetic sounds of letters more useful to this patient than the names of letters as auditory samples? This question was pursued by presenting the subject with the phonetic sounds of letters and requiring him to match these sounds with the visual letters themselves. He made 14 errors in 20 trials, a deficit comparable to that with auditory-visual matching of letter names and letters (Fig 3).

**Deficits Within the Visual Modality.**—**Homonymous Letter-Syllable Matching.**—A set of stimuli was constructed in which visual letters were to be matched with visual words or syllables sounding like the names of those letters but not containing them: c-see, q-cue, i-eye, u-yew, k-cay, f-eph, x-eks, g-gee. On each trial, one of these pairs was the sample and correct choice; the remaining ones were the incorrect choices. The “similarity” between the members of each visual pair could only be mediated by their common sounds.

With the visual letters, eg, “i,” as samples, and the visual letter-names, eg, “eye,” as choices, the subject made seven errors in eight trials. Similarly, he made seven errors with the names as visual samples and the single letters as visual choices.

However, an additional finding makes the correct interpretation of these data difficult: the subject also made seven errors when the names of the letters were spoken to him as auditory samples to be matched with the visual names, ie, “q” auditory-“cue” visual. The task was, perhaps, no different for the subject than auditory-visual matching of pronounceable nonsense syllables on which he had already demonstrated a large deficit (Table 1-E and Fig 4).

Nevertheless, in contrast to all previous data presented, here it is not possible to be certain that he understood the nature of the task: control subjects, however (see below), had no difficulty.

**Delayed Matching of Letter Combinations.**—An adjusting delay of 1 second (see Materials and Methods) was used for each of three sets, wholly within the visual modality: three-letter words, pronounceable nonsense syllables, and unpronounceable trigrams. The words, syllables, and trigrams are listed in Table 1. Incorrect choices in the last two sets consisted of all possible reversals of the sample (eg, zoj: jzo, ozj, ojz, zoj, jzo, joz; pfz: pfz, zpf, zfp, pfp, zfp, zfp).

The data appear in Fig 7. With words and syllables, the subject made few errors and quickly ran the delay up to 15 and 17 seconds respectively. However, with the trigrams, he did not match the sample correctly after delays as short as 3 seconds and experienced great difficulty even at zero delay. It will be remembered that in simultaneous visual-visual matching, his performance with the trigrams was virtually error-free.

**Delayed Matching of Ellipses.**—In this visual-visual task, the choices were a graded series of horizontal ellipses (ratios of minor/major axis: 0.17, 0.31, 0.39, 0.46, 0.61, 0.77, 0.89, and 1.00). The sample on each trial was one ellipse from this series, with the exception that the smallest and largest ellipses were never used as samples. The relative discriminability of the ellipses was demonstrated by the subject's nearly errorless performance on simultaneous matching. However, with the adjusting-delay procedure, he tolerated a delay no greater than that with trigrams.

The graded series of ellipses permits a quantification of the data not possible with the verbal material. Each ellipse the subject actually chose could be classified with respect to its degree of similarity to the sample. Inspection of his adjusting-delay data indicated that most of his wrong choices were still relatively close in size to the samples. Therefore, he was given a series of 48 trials each at delays of 0, 8, 16, 32, and 40 seconds.

In order to summarize the data, the ellipse the subject chose on each trial was ranked with respect to its ordinal deviation from the sample, in terms of the above series of axis ratios. Since the number of opportunities for the subject to deviate a given number of steps from the sample ellipse depended on the size of the sample, the number of times he selected each deviation was divided by the number of opportunities he had to make each selection. This yielded the ratios scaled on the ordinates of Fig 8. His performance in simultaneous ellipse-matching was quite precise; the few errors were selections of ellipses closest in size to the
sample. There was some loss of accuracy at delays of 0, 8, and 16 seconds, but the choices were still clearly related to the samples. At delays of 24, 32, and 40 seconds, his accuracy diminished considerably.

Normal subjects, including children of our subject’s age and younger, show no evidence of deterioration at delays up to 40 seconds.

Control Series.—Five male students, who had attended the same eighth grade classes as our subject at the time of onset of his illness, were chosen on the basis of the teacher’s report that they were maintaining a low “C” average in English and Social Studies. Each was subjected to visual—visual and auditory—visual matching procedures with five sets of materials which gave our subject great difficulty. With the exception of one subject, performances on all tasks were nearly error-free (Table 2). This control subject’s error rate on first exposure to auditory—visual matching of pronounceable nonsense syllables (four errors in 20 trials) was significantly lower than that of our subject, and on repeat testing immediately thereafter he reduced his errors to one in 20 trials.

Comment

Recognition of Single Letters.—Specific deficits in recognition of single letters have rarely been reported. Bramwell remarks that “some word-blind patients can read words (combination of letters) and yet are unable to read the individual letters of which those words are composed.” In his report of the case of a 60-year-old man with paralysis of the right arm, aphasia, and partial right homonymous hemianopia, he notes that although the patient was able to write some single letters spontaneously and to copy all single letters from visual sample, he was unable either to write single letters to dictation or to match single-letter visual samples to auditory choices (see Fig 3 and 4, our subject). However, he was able to point to pictures upon hearing their spoken names (Fig 5, our subject), and during his recovery learned to read several simple words aloud, although remaining “blind” to single letters. In contrast to our subject, Bramwell’s patient was not able to write words to oral dictation, nor in the early stages of his recovery to pick out spoken numbers from a visual assortment (auditory—visual).

Trescher and Ford in their report of a patient with surgical section of the posterior half of the corpus callosum, point out that the patient was able to name familiar objects placed in the left hand, but was unable to perform the same task with single letters. Similar tests of simple words were not reported, but the authors state that, “The tactile defect was limited to inability to recognize letters of the alphabet and was absolute in this regard.” There was, however, a deficit in naming familiar objects as well as letters presented in the left visual field. The case is noted here simply to document the observation that recognition of letters may be selectively impaired.

Right vs Left Hemisphere.—Another matter for consideration is the cerebral localization of those functions left intact. Our patient sustained damage to the left hemisphere of uncertain extent and location. Although some of the left hemisphere may have continued to function, it is of interest to discuss whether the sample matching tasks which our subject performed well might have been accomplished with the right hemisphere alone. Information on this matter is available from two sources: left hemispherectomies, and sections or disease of the corpus callosum.

Unfortunately, the few reported cases of left hemispherectomy for reasons other than infantile hemiplegia (Zollinger; Crockett and Etridge; Hillier; Smith) were studied largely in different contexts. Zollinger’s patient lived only 17 days postoperatively; during that time speech progressed to the point of “please” and “thank you.” Crockett and Etridge’s patient survived four months. Very shortly after the operation this patient was speaking phrases such as “No, I don’t want any,” and “Put me back to bed.” One month postoperatively his speech suddenly regressed to a single nonsense sound, and remained so until his death. Necropsy showed the right hemisphere to be entirely normal, and tumor invasion of the left thalamus was found. Hillier’s patient, a 14-year-old Indian boy, was last examined 27 months postoperatively, at which time he “was able to read individual letters, but not form words.” Comprehension of the spoken word was said to be “accurate.”
Smith's\textsuperscript{15} case of a 47-year-old man offers more relevant comparisons. Postoperatively, the patient was able to get 85 out of 112 trials correct on the Peabody Picture Vocabulary Test (analogous to word-picture, auditory-visual, Fig 5), a score to which the test norms assign a mental age of approximately 12 years. He "showed more frequent errors in identifying pictures of activities than of objects,"\textsuperscript{15(p469)} Our patient had no difficulty with auditory-visual matching of pictureable nouns but had difficulty with non-nouns (Table 1 and Fig 5). If we can accept an analogy between object-pictures and pictureable nouns on the one hand, and between activity-pictures and non-nouns on the other, these two sets of data would appear consistent. They suggest that auditory-visual, word-word, and word-picture, Fig 5).

The following deficits shown by these callosal-section patients are of interest in the present context:

1. Failure of verbal recognition (naming) of stimuli presented in the left visual field or manipulated with the left hand.
2. Failure to copy, with either hand, letters, numbers, and single words presented as samples to the left visual field. (These skills may have been affected by preexisting apraxias, however, the authors suggest).
3. "Inferior performance" in drawing with the left hand simple figures presented to the left visual field.
4. Failure to spell by tactile manipulation words presented as auditory samples.

Similar information is available from the report of Geschwind and Kaplan\textsuperscript{19} of a case of infarction of the anterior two thirds of the corpus callosum and massive tumor involvement of the left hemisphere. This patient was able, with his left hand, to match objects or letters by touch or vision, to draw pictures of objects felt with the left hand, and to trace with the left hand and even on the ground with the left foot letters traced on the left hand (Geschwind, communication). He was unable to match objects or letters with his right hand after feeling them with his left hand. Also, he could copy printed, written, or dictated letters, numbers, and words with his right hand; with the left hand, he could copy these materials when they were printed or written, but not when they were dictated.
Although the incomplete callosal involvement in this patient makes it impossible to draw definite conclusions concerning tasks of which the isolated right hemisphere is capable, the changes from intact to deficient performance when the task involved the left hemisphere provide presumptive evidence. Also, a normal right hemisphere was definitely not capable of naming tactually appreciated objects or letters, or of writing or typing letters of words to dictation.

This brief review suggests that two of our subject's most striking deficits were in tasks for which other investigators have found involvement of the dominant hemisphere: writing dictated letters, and auditory-visual matching of words other than nouns. On the other hand, the following control performances which were intact in our subject may apparently be accomplished by the right hemisphere alone: visual-visual matching of letters, numbers, and words; auditory-visual matching of pictureable nouns, and of these words with their pictures; copying visually-presented letters, numbers, and words; and tactile-visual matching of objects, words, and letters.

We found no reported data on hemispheric dominance with respect to auditory-visual matching of letters, in which our subject made many errors. Smith found the right hemisphere to be sufficient for visual-visual and auditory-visual matching of color names with colors; our subject initially had difficulty with the latter task, but he showed rapid improvement. An unresolved difference between our subject and the one described by Smith was our subject's intact performance in printing the names of pictured objects.

Relation of the Deficits to Impaired Functions of the Major Hemispheres.—Our subject's intermodality (auditory vs tactile or visual) deficits were relatively specific to certain materials. He also displayed delayed-matching deficits for certain materials entirely within the visual modality. These observations, together with his almost complete lack of oral speech, allow some speculations concerning the relations among intermodality transfer, verbal "coding," the relative "verbality" of various types of information, and language functions of the major hemisphere.

Visual-visual and tactile-visual matching of single letters can be accomplished on the basis of identity of form, without reference to the language functions of the letters. However, auditory-visual and auditory-tactile matching of letters may be considered an almost purely verbal task. There is no common identity between the names or sounds of letters and their shapes except via the mediation of common verbal responses to each. The same consideration would apply to nonsense syllables and trigrams, and to the homonymous visual counterparts of letters (ie, q-cue).

What of words, pictures, and numbers, all of which our subject handled well in an auditory-visual match? Geschwind has suggested that objects and numbers "have rich association values in other modalities, eg, we can recognize an apple by vision, touch, taste, smell, even by its texture on being bitten." We might expect the names of common objects to share these nonverbal associations, and to be mediated, in intermodality matching, perhaps by the minor hemisphere alone. Our subject's partial deficits with auditory-visual matching of "nonrepresentative" nouns and non-nouns would be consistent with this interpretation. Geschwind made the opposite assumption about names of colors, which might be consistent with our subject's initial difficulties in handling these in auditory-visual matching. We would suggest, however, that it is not self-evident that "the only association unique to the color is its name."

The deficit in visual-visual delayed matching of nonsense trigrams may fit this conception in a quantitative sense. The delayed matching of letters and short letter combinations within the visual modality should be possible on the basis of form alone. However, as a combination of letters becomes longer, its form becomes complex, and some kind of verbal labelling ("reading?") is required to retain the group over an interval of time. The pronounceable nonsense syllables, although containing three letters, require only a single coding label for their retention. Trigrams which are not pronounceable may require three separate labels, however, and thus the failure to retain them may quantitatively reflect impaired verbal function of the dominant hemisphere. Similar considerations apply to the de-
layed ellipse-matching. The ellipses are non-verbal stimuli, but to retain the sample and select it from eight different ellipses after an interval as long as 40 seconds requires that the series of ellipses be "coded" in some manner along a relative size dimension. All normal subjects do this verbally; and it may be that whatever verbal capacity remain in our subject is insufficient to generate such a long sequence of verbal labels.

Summary

Behavioral experiments are reported in the case of a 14-year-old boy with occlusion of the left middle cerebral artery, who showed a nearly complete loss of oral speech. Automated sample-matching techniques were used which did not demand vocal communication between patient and experimenter. The techniques also permitted samples and choices to be presented to the patient through different sensory modalities without changing experimental conditions.

The findings demonstrated the importance of both inter- and intramodality testing with both similar and varying stimulus materials.

The patient demonstrated a severe deficit in matching auditory (spoken) single letters of the alphabet with both their visual and tactile counterparts. The deficit appeared whenever the auditory modality was involved in an intermodality match, whether in the samples or the choices. No such deficit appeared in matching single letters wholly within a given modality, including the auditory. Simple three-letters words, pictures, and numbers were well handled across modalities—names of colors and "nonrepresentative" nouns only partially so. In addition, when matching of letters with their homonymous word counterparts (i.e., q-cue) and delayed matching of nonsense trigrams and certain nonverbal materials were required within the visual modality, intramodality deficits were demonstrated.

Comparisons are made with reports of related experiments in the literature, and an interpretation of the relatively specific inter- and intramodality deficits demonstrated is suggested which may contribute to a more precise behavioral definition of the language functions of the major hemisphere.

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