

CROSS-MODAL MATCHING AND ASSOCIATION ABILITIES OF THE
LEFT AND RIGHT HEMISPHERES TESTED UNDER
INTRACAROTID SODIUM AMYTAL

by

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A THESIS SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

in the Department

of

Paediatrics

Division of Audiology and Speech Sciences

We accept this thesis as conforming
to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

April, 1975

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Abstract

Anatomical and theoretical considerations, as well as experimental findings, have yielded conflicting points of view regarding the abilities of the right hemisphere in man to accomplish cross-modal transfer of information. Auditory-visual cross-modal matching (CMM) and association (CMA) abilities of the left and right hemispheres (LH and RH) were tested, utilizing the Wada intracarotid sodium amytal technique.

It was found that the RH performed slightly better on these tasks than the LH. Possible reasons for this RH advantage are discussed. These findings contrast with results of other techniques which indicate that the RH cannot perform CMM and CMA. The hypothesis that damage to one hemisphere interferes with the normal operations of the other hemisphere is discussed.

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ACKNOWLEDGEMENT

I wish to thank Dr. J. Wada and Dr. J. Gilbert for their support of this work; Sylvia Willis and Sharon Adelman for invaluable help as testing assistants; Lars Eastholm of C.B.C. for supplying the magnificent foghorn, and Donald McLeod, who didn't know what he was getting into.

INTRODUCTION

The relationship between language and "thinking" has been a subject for speculation and investigation by a variety of disciplines. On both practical and theoretical levels, this problem is of interest to linguists, psychologists, educators of the deaf, aphasiologists and neuropsychologists. While it would be inconvenient here (though certainly not inappropriate) to review the literature devoted to this problem, there emerges a clear tendency to associate thinking with verbal or other symbolic activity (e.g. mathematics) (Bogen, 1969; Bogen & Bogen, 1969). But "thinking", whether verbal, mathematical or artistic, etc., must be based on less sophisticated processes of the brain. It is one of these more basic processes (which will be presumed to subserve "thought") which is to be investigated in this research.

One important aspect of "thinking" or "reasoning" involves the ability to make a connection, or to "see" a relationship, between different elements in a given situation or problem. We make such connections every time we relate a piece of information received through one sense modality with information received through a second, different sense modality. For example, when driving a car, through our senses of touch and pressure we are aware of how hard we are pushing on the brake, and when our eyes tell us we are not stopping fast enough, we respond by pushing harder ("fast thinking"). In neuropsychological terminology, this process is called cross-modal transfer of information (Ettlinger, 1973; see Zippel, 1973, for a broader survey). Since there is no clear delineation of "thought" and lower level psycho-perceptual abilities,

one approach to examining the relationship of language to thought is by observation of the role that the language areas of the brain serve in the utilization and integration of information received by the separate sensory cortical areas. I.e., the role of the language area(s) of the brain in cross-modal transfer of information.

Geschwind (1965, 1967) has proposed that the angular gyrus (Brodmann area 39 in the inferior parietal lobe) of the language dominant hemisphere represents a neuroanatomical advance not found in sub-human primates (see also Von Bonin, 1962). The angular gyrus lies just posterior to Wernicke's area (the auditory association area) and appears to receive most of its afferents from the surrounding auditory, visual and somesthetic association areas. The location of the angular gyrus and its connections with the rest of the left hemisphere (see Fig. 1) led Geschwind to propose that it is an "association area of association areas". Its function being to allow cross-connections between the non-limbic sensory areas of the brain; such connections, provide a possible mechanism for inter- or cross-modal transfer. The relationship of the angular gyrus to the sensory association areas is presumed to provide language with its capacity to act as a "supra-modal symbol of an object" (Ettlinger, 1967, P. 53) and hence with the means to generalize about the relations between objects (or stimuli) and build concepts upon these relations. (This is seen most clearly in our ability to identify by name any known object, regardless of the sense modality by which it is perceived. Reading, as well as object-naming, is seen to depend on visual-auditory associations.)

Thus Geschwind argues: "The ability to acquire speech

Figure 1. Language and other areas of the left hemisphere.

Angular gyrus: "Association area of association areas" (Geschwind). Believed to integrate functions of various areas of the hemisphere. Roughly corresponds to Brodman area 39.

Broca's area: involved with the motor (articulatory) aspects of speech.

Writing centre: also known as Exner's area. Involved in the writing of language.

Heschle's gyrus: on the posterior superior temporal gyrus, lying on the floor of the sylvian fissure. Wernicke's area forms its outer border. The primary auditory projection area.

Wernicke's area: considered an auditory association area concerned with the comprehension of spoken language.

Supramarginal gyrus: adjacent to Wernicke's area; little more known about it than what applies to Wernicke's area. Contained in Brodman area 40.

Naming centre: Its functions are not well defined, but lesions here cause word finding difficulties, syntactic errors, etc.

Arcuate fasciculus: bundle of association fibres connecting parts of the frontal, parietal and temporal lobes. Roughly outlined above as == == == == ==

(after Whitaker, 1969; modified from Truex & Carpenter, 1969, and Geschwind, 1969)

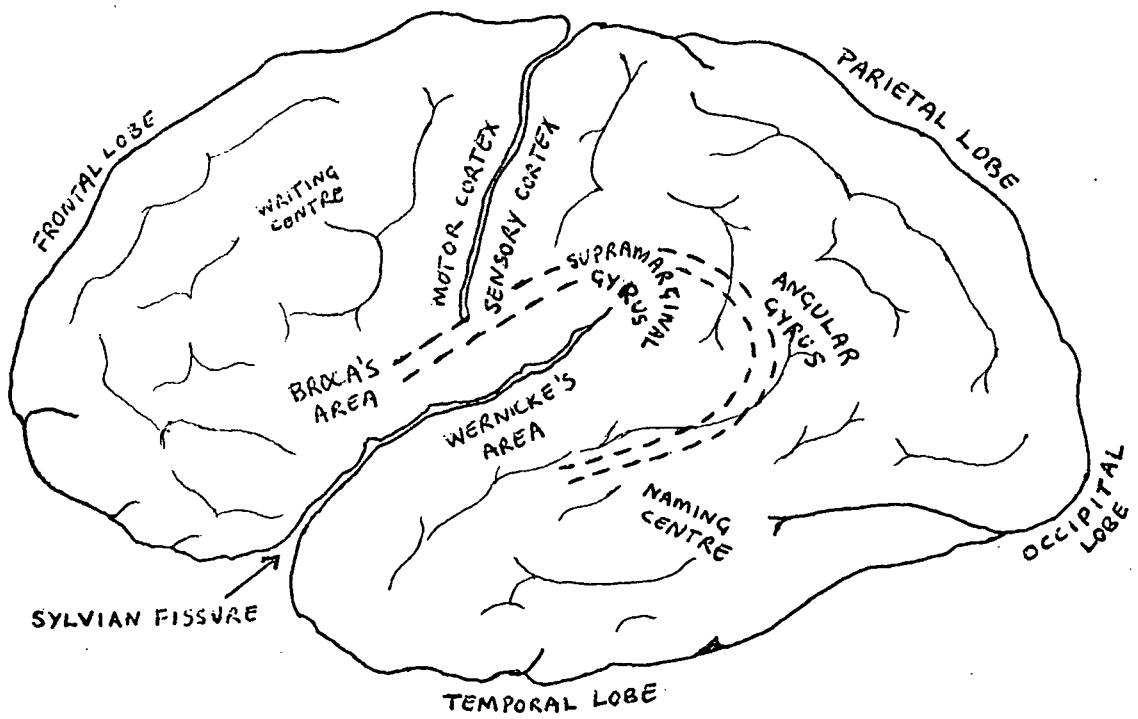


Figure 1.

has as a prerequisite the ability to form cross-modal association" (Geschwind, 1965, p. 275). The implications of this statement have led to many investigations with non-human primates and pre-verbal children to determine whether they can perform cross-modal tasks, since non-human primates lack the "neuroanatomically advanced" angular gyrus presumed necessary for cross-modal transfer of information, and while pre-verbal children possess an angular gyrus, by definition they demonstrate no verbal language abilities.

It is very difficult to interrelate the results of such heterogeneous research, representing non-comparable subjects (including the deaf, and brain-damaged humans), non-equivolent tasks, non-equivalent use of similar terminology, and different criteria for evaluating results. For example, often a distinction is not made between the ability to verbalize (which is of course a function of the language areas, per se) and the associative functions of the angular gyrus which are presumably functioning before language becomes evident (as in young children) or may still be functioning when speech is disrupted (as in aphasics). Much of this sort of confused work appears to be based on a converse interpretation of Geschwind's statement, i.e. that language may be necessary to form cross-modal associations. (For such an example, see Blank and Bridger, 1964.) The need to distinguish between the two (language, per se and ability to do cross-modal associations) is clearly perceived by Drewe, et al (1970). Referring to dysphasic patients who perform poorly on the Weigl block sorting test they state:

it is

not clear whether the deficit is secondary to dysphasia or whether it results from an over-lapping of those areas concerned with language and concept-formation...this finding could be taken as support

for the idea that language is itself dependent on a more basic ability related to concept formation (Op. cit., pp 133 - 134).

Because of their close physical proximity, it is usually neither experimentally nor diagnostically possible to separate the angular gyrus and language areas of the left hemisphere.

Since the present research is concerned with possible left-right differences in man's ability to make cross-modal integration, a brief review of some of the organizational, and functional, differences of the right hemisphere, is in order. It is not at all clear whether the presumed cross-modal functions of the left angular gyrus are in fact unique to the left side. That is, since the right hemisphere demonstrates limited capacity for language comprehension and production, are we to assume that it does not possess a structural basis which allows cross-modal connections similar to those made by the left angular gyrus? The right hemisphere (RH) has not only been studied less extensively than the left, but clear-cut localization and/or descriptions of functions on the right have been harder to show. (For a comprehensive review of the problems see Bogen 1969 and Bogen & Bogen, 1969). The basic organization of the right hemisphere, according to Semmes (1968), may be quite different from that of the left. She has amassed considerable evidence that the left hemisphere (LH) is focally organized, i.e., specific functions can be localized to relatively discrete areas. The RH appears to be diffusely organized and thus its functions cannot be discretely localized. If this interpretation is the case, then we cannot ask "does the right angular gyrus subserve cross-modal functions, in a manner similar to the left angular gyrus?",

but rather, "can the right hemisphere carry out cross-modal functions at all? If so, are these right and left cross-modal functions similar or different?" Semmes feels that given diffuse organization of the RH:

one might predict heteromodal integration to an extent surpassing that possible in a focally-organized hemisphere... Spatial function [the major known function of the right hemisphere] might depend instead on convergence of unlike elements-visual, kinesthetic, vestibular, and perhaps others - combining in such a way as to create through experience a single supramodal space.

(Semmes, 1968, p. 23-24)

Critchley, (1953) states that the RH area linking the parietal, occipital and temporal lobes was the chief suspect in marked disorders of spatial thought. This view is supported by Warrington & Taylor's (1973) work on object recognition in which they found a "failure of perceptual classification, that mechanism whereby two or more stimulus inputs [in this case uni-modal] are allocated to the same class" (op cit., p. 162). It is of interest that the lesion producing this failure was located to the RH, Brodman areas 39 and 40. Warrington & Taylor suggest that these areas are concerned with "integration of sensory data" (op.cit., p. 163). While Critchley's, and Warrington & Taylor's findings conflict with Semmes' hypothesis of diffuse organization, all offer results which indicate that the RH does possess an integrating function similar to that of the left angular gyrus.

In addition to its spatial functions, the RH is definately involved with musical abilities (Bogan, 1969b). Such an involvement is relevant to our question of RH cross-modal abilities, in that correct musical expression on the piano, (as observed in Ravel after his stroke and subsequent aphasia), implies auditory-

somesthetic feedback.

On theoretical and anatomical grounds it may be observed that the LH is organized to allow cross-modal integration (CMI). There is also some evidence that the RH's organization, while possibly different from the left's, should also allow some form of CMI.

Investigations of cross-modal integration have failed to arrive at a common terminology for the types of functions tested. For the purposes of this paper the following definitions will be used:

Cross-modal integration (CMI): the ability of the brain which allows information received through one sense modality to be utilized by another sense modality.

Cross-modal matching (CMM): the ability to recognize the source of a sensory stimulus as identical to the source of a different sensory stimulus (e.g., to hear a cat's miaow and identify its source with the model for a picture of a cat).

Cross-modal association (CMA): the ability to recognize a stimulus in one modality and relate it appropriately to a different stimulus presented via a different modality. The relationship between the sources of the two different stimuli is based on commonly accepted association (e.g., cat miaow and mouse). In the following literature review, discussion has been restricted to work relating to the foregoing terms and definitions; for the sake of consistency and clarity, these terms have been substituted for those used by the various researchers. First those experiments pertaining to CMM will be discussed, followed by the CMA experiments.

Cross-modal matching

In experiments designed to evaluate the role of the left and right parietal lobes in the mediation of intra- and cross-modal matching, Butters and Brody (1968) and Butters, Barton and Brody (1970) compared the effect of lesions, in various areas of the brain, on three cross-modal matching tasks: tactile-visual, visual-tactile, and auditory-visual. (The ordering of the modalities, e.g. tactile-visual, indicates that a single stimulus presented tactually is the one to be chose from an assortment of objects presented visually.) Intra-modal matching tasks were given to ensure that possible perceptual impairments were not affecting cross-modal results. The authors found that Ss with severe parietal damage on the left (LSP) had significantly more errors on the tactile-visual tasks than the other experimental groups; also, the difference in their scores approached significance on the visual-tactile task.

Asking essentially the same question as Butters and his colleagues, i.e. "whether complex visual and tactile performance are independently susceptible to injury in different regions of the brain" Semmes, et al. (1954) tested a different and more complex form of cross-modal matching. They gave a series of tasks involving direct visual matching, but the Ss were expected to find out for themselves that it was a simple match, and not some other pairing of stimulus and choices, that was required. After an established number of correct trials the Ss were given the same tasks tactually. Ss were judged to show positive transfer of information if they had fewer errors to criterion (i.e., an established number of correct responses) on the second task. All groups tested, with the notable exception of those with posterior

parietal lesions, showed positive transfer. (It is assumed that on an anterior-posterior basis, the angular gyrus would fall posterior.) As a group the severely damaged left parietals did worse than severely damaged right parietals, but the right parietals were still worse than all other non-parietal groups. The lack of transfer was shown not to be due to any problems on the tactile task itself. While this is not strictly an example of CMM, it does support the hypothesis that an intact parietal region is necessary for transfer of information from one sense modality to another.

Studies conducted on patients who have undergone callosal commissurectomies (split-brain Ss) seem to indicate that the RH, when deprived of access to the language areas of the LH, can recognize, but not name, stimuli presented to it via any modality. The isolated RH can also carry out visual-tactile and tactile-visual matching of common objects, and of geometric forms (Sperry & Gazzaniga, 1967; Sperry, 1968; Gazzaniga, Bogen & Sperry, 1965). In an experiment conducted by Levy-Agresti & Sperry (1968) the isolated RH was able to match 3-D shapes presented tactily with their unfolded representations presented visually, and as might be expected was superior in this translation-in-space task to the LH. These results, Gazzaniga feels, imply that the right hemisphere is attending to "certain broad and universal features of a stimulus", rather than to purely perceptual aspects;

clearly, language greatly facilitates intermodal responses in man. On the other hand, a feature-abstracting system of this type may be the kind of information-handling system that is active prior to the linguistic encoding procedure in humans.

(Gazzaniga, 1970, p. 30)

In an experiment (very similar to the matching test used in our research) which required brain-damaged Ss to match non-verbal meaningful sounds with the appropriate picture (e.g. cat's miaow to picture of a cat) Spinnler & Vignolo (1966), and Faglioni, Spinnler & Vignolo (1969) found that of all groups, only the left-damaged aphasic group showed significantly poorer performance than controls. These results imply that an intact language area (and in aphasia the angular gyrus may or may not be intact) is necessary for audio-visual CMM of non-verbal meaningful sounds to their corresponding pictures. However, their test was designed to be linguistically confusing, since the non-correct choices were designed to include pictures semantically and phonemically related to the correct choice.

Dee & Benton (1970) found no significant differences between their left and right brain-damaged groups (excluding the apraxics) to whom they gave a tactile-visual matching test using simple non-geometric forms. Both groups (left and right damaged) performed below normal control levels. In summary, the CMM experiments described above indicate that except where the RH is isolated from the LH (split-brain Ss), it cannot perform CMM tasks, at least not in the form such tasks have taken in the experiments reported.

Cross-modal association

Matching of equivalent stimuli (e.g. presenting a real apple to both eye and hand) is the simplest of cross-modal tasks. What of more complex cross-modal relationships? These include transfer of a learned principle, transfer of a specific discrimination habit, the ability to make associations, and cross-modal matching of analogous, but not equivalent, stimuli.

Ettlinger (1967) feels that on theoretical grounds:

the ability to transfer across modalities (whether this be transfer of a specific habit or of a principle) presupposes an ability to match (either stimuli or principles of response) across modalities; whereas cross-modal matching performance does not presuppose an ability to show transfer across modalities.

(op.cit., p. 58)

These different types of tasks should not be confused.

Butters and Brody (1968), reported above, presented their Ss with three CMM tasks, but in only two of the tasks were the stimuli equivalent. In the auditory-visual task the stimuli, a tapped sequence of sounds and a linear pattern of dots and spaces, are not equivalent, they are analogous, in the sense that duration and distance are conceptually equivalent (linguistic ("long", "short") and mathematical symbols link them) but not perceptually equivalent (i.e. perceptually we must wait a long time for a long time to pass, but perceive a long line instantaneously). Furthermore, the task required retention, (not just perception) of the initial auditory stimulus. They found that left or right severe parietal damage produced the same degree of impairment on this audio-visual CMA task.

Sperry and his colleagues demonstrated CMM in their split-brain Ss. They went on to demonstrate the ability of the isolated right hemisphere to make less obvious cross-modal associations (CMA). The patients read a printed (flashed tachistoscopically) word and selected tactilely the corresponding object from an assortment hidden from view. Shown a dollar sign (\$) they would pick a coin from the pile, shown a hammer, a nail was selected (Sperry, 1968). These results, however, may not be too reliable,

since later work by Sperry and his colleagues was better controlled for interhemispheric cueing, and these previous results are not mentioned in the later work. It is not clear if the authors still stand by them.

The results of Semmes et al. (1954) CMM task were presented earlier. In addition to the matching task, they presented their brain-injured Ss with 4 more cross-modal tasks, of varying degrees of abstraction such as a conditioned reaction in which the correct choice was dependent on alignment of the slot through which the S reaches to feel (or looks to see) the choices. As with the CM "matching" task, this is not an association task as defined under CMA, but rather a learning task, where the correct response must be reasoned out based on E feedback as to whether the S has guessed correctly (serial learning). The specific tasks are not relevant to this discussion. (If one accepts Ettlinger's assumption that CM transfer of a principle or specific habit presupposes an ability for CMM, the fact that the "CMM" task was not the easiest for any group is of interest.) The visual form was given first; when tested on the tactile form, significant improvement (positive transfer) was shown on all tasks, by all groups except by the left and right parietally injured groups. Most of the Ss had sustained multiple brain lesions. Of all the subgroups with unilateral lesions, only the left parietals did significantly worse than the control (non-brain damaged) group.

While the last experiment to be described is not cross-modal, it does reveal something about the association abilities of the L and RHs. De Renzi, et al., (1972) designed an intra-modal (visual) test of ability to associate color with form

(i.e., yellow with outline of a banana). The only group of brain-damaged Ss which performed significantly worse than the control group was the severe (Wernicke's) aphasics. However, half of these severe aphasics performed normally, suggesting that " the relationship occurring between the two orders of symptoms [language comprehension disability and association disability] results from overlapping anatomical representation of functions" (op.cit., p. 303).

A summary of the experimental findings reviewed in this chapter is shown in Table 1. Two results are of particular relevance to the research which will be described in this paper. The first, is that the only experiments which indicate CMI to be possible in the RH utilized split-brain subjects. In such subjects and experiments the RH cannot be influenced by functioning of the LH. All other experiments reviewed here indicated that the RH could not do CMI tasks, while the left could. Several experiments demonstrated that neither LH nor RH could perform these tasks in the presence of damage to the opposite hemisphere.

The second point of interest involves those experiments which seek to test auditory-visual CMI, since these are the modalities utilized in our experiments. Butters, Barton & Brody found that neither the left nor right uninjured hemispheres of their brain-damaged Ss could perform CMA of analogous auditory-visual stimuli. Faglioni, Spinnler & Vignolo, using stimuli similar to, and sometimes identical with, those used in our experiment, found that in the presence of left damage the RH could not perform CMM, whereas the left could, even though the right was damaged.

Table 1. Summary of left-right hemisphere (H) differences on CMM and CMA tasks reviewed in the Introduction.

	Right H cannot (in presence of damaged left H).	Neither right nor left H can (when opposite H damaged).	Right can.
<u>CMM</u>	<p>Butters & Brody, 1968. (tactile ↔ visual)</p> <p>Butters, Barton & Brody, 1970. (tactile ↔ visual)</p> <p>Spinnler & Vignolo, 1966. (auditory - visual)</p> <p>Faglioni, Spinnler & Vignolo, 1969. (auditory - visual)</p>	<p>Semmes, et al., 1954. (visual - tactile)</p> <p>Dee & Benton, 1970. (tactile - visual)</p>	<p>Levy-Agresti & Sperry, 1968. (tactile - visual)</p> <p>Sperry & Gazzaniga, 1967. (visual ↔ tactile)</p> <p>Sperry, 1968. (visual ↔ tactile)</p>
<u>CMA</u>	<p>De Renzi, et al., 1972. (intramodal, vision)</p>	<p>Butters, Barton & Brody, 1970. (audio - visual)</p> <p>Semmes, 1954. (visual - tactile)</p>	<p>Sperry, 1968. (visual - tactile)</p>

The overall impression to be gained from the experiments reviewed above, is that: 1) the only evidence for RH capacity in CMI comes from split-brain Ss, and 2) in brain-injured Ss, (a) audio-visual CMM can be performed by the LH, but not the right, and (b) neither hemisphere can do audio-visual CMA.

Statement of the problem

There is no preponderance of clinical evidence that the LH is uniquely responsible for CMI in humans, as Geschwind and Ettlinger propose, despite its overwhelming importance in language and the suggested role of the left angular gyrus in facilitating the CMI necessary for language. On the other hand, the work reported by Semmes and her colleagues suggests that both hemispheres play an important role in CMI and/or that neither hemisphere can perform these tasks well if the other is damaged. Semmes' results have led her to suggest that the organization of the RH should allow a greater degree of CMI than that possible in the left.

EXPERIMENTAL RATIONALE

The present experiment was designed to investigate CMM and CMA abilities of the left and right hemispheres. Each hemisphere was tested independently, utilizing the Wada sodium amytal technique for establishing language lateralization (Wada & Rasmussen, 1960). This technique allows us to produce in our Ss the otherwise unique neurological condition produced by callosal commissurectomy, that is, a situation of interhemispheric non-interference, thus maximizing RH chances for success on these tasks. Auditory and visual stimuli were used, and this choice of modalities should, if anything, give an advantage to the LH.

In addition to mimicking split-brain testing conditions in our Ss, the sodium amytal technique helps us avoid several problems inherent in other experimental procedures:

- 1) matched groups for controls. Each S will serve as his own control, and as a right and left experimental subject, avoiding problems of age, educational, pathological and other differences between Ss.
- 2) auditory input can be localized to just one hemisphere.
- 3) the amytal should produce more consistent aphasic effects between Ss than comparison and grouping of Ss by Aphasic types caused by different cerebral traumas (e.g. CVA's, penetrating brain wounds).
- 4) the possibility of an intact left angular gyrus concomitant with aphasia in brain-damaged Ss is eliminated.

Problems inherent in this technique:

- 1) we cannot distinguish between the respective roles of

the left angular gyrus and the language areas per se. in CMI.

2) the limited time available to test each hemisphere will not allow thorough enough testing to provide a complete picture of what each isolated hemisphere can do under these conditions.

Effects of sodium amytal administered unilaterally:

(For details on administration see Methods section.) In the Wada test, sodium amytal is injected into either the right or left internal carotid artery. Within 30 sec. after injection the following major effects are noted:

- i) clear-cut hemiparesis of both limbs on the side of the body contralateral to the injection;
- ii) contralateral homonymous hemianopsia
- iii) contralateral hemiaesthesia
- iv) speech and language:
 - a) non-dominant hemisphere injected: patient frequently stops counting and shows momentary confusion, but then resumes counting, can name objects on request, obeys commands, and engages in normal spontaneous speech.
 - b) dominant hemisphere: counting ceases and does not resume. Patient cannot name objects or respond verbally to questions, but will carry out commands with the ipsilateral extremities indicating consciousness is not disturbed. Language if present is markedly dysphasic.

With a 100 mg. dose, these effects last from 4 - 5 min. Limitation of the drug to one hemisphere can be verified by: concurrent

angiography, the EEG, and checking motor responses (Wada & 18
Rasmussen, 1960; Branch, Milner & Rasmussen, 1964; Rossi &
Rosadini, 1967; Blume, et al., 1973)

Memory for stimuli seen before or during injection appears to be relatively unaffected. While recall for verbal material was decreased when the language-dominant hemisphere was injected, memory for visually presented objects, pictures and geometric shapes was close to 100% for either hemisphere (Milner, Branch & Rasmussen, 1962; Serafetinedes, 1966; Blume, et al., 1973).

Anatomical considerations

Given that we know or can monitor the effects of sodium amytal on the treated hemisphere, it is essential that we also know the capacities and functions of the non-treated hemisphere which is being tested. The basic, generally agreed upon differences between the two hemispheres include:

Left hemisphere: in right-handed people, the left hemisphere is dominant for speech and language in 90% of all Ss tested. In left-handed persons, 43% are left dominant for language; in ambidextrous person, 60% have language on the left. Some left-handers and ambidextrous (11-16%) demonstrated bilateral speech representation. (Branch, Milner & Rasmussen, 1964).

Right hemisphere: there is considerable evidence that the right hemisphere (in left language dominant people) is specialized for the recognition and manipulation of spatial relationships, both visual and tactual (Nebes, 1971; Sperry, 1968; Colonna & Faglioni, 1966; Lubin, 1969; Milner & Taylor, 1972; teuber, 1962; Warrington & Taylor, 1973; De Renzi, Faglioni & Scotti, 1970).

There is, however, some evidence for receptive language function in the right hemisphere, even in strongly left-dominant individuals. Working with split-brain Ss, Gazzaniga & Hillyard (1972), and Levy, Nebes, & Sperry (1971) revealed the following upper limits for speech capacity on the right side, as tested by tachistoscopically presented written words to the surgically separated hemisphere. The right side was primarily skilled in recognition of common nouns and could distinguish a negative from an affirmative statement. No comprehension of any verb forms was indicated; neither were singular vs. plural nouns distinguished. An apparent expressive speech capacity noted at first was found to be due to inter-hemispheric cueing.

When normal subjects were tachistoscopically presented with written words, it was found that the left visual field (LVF, represented exclusively in the right hemisphere) could recognize category-ambiguous (noun/verb) words (Caplan, Holmes & Marshall, 1974). However, these Ss were required to report aloud first, a fixation symbol, and second, the word they saw. Thus the LH "reads off" the visual image transferred to it from the RH, but this does not imply that the RH understood the word. The amount and complexity of material that can be tested tachistoscopically is very limited, and we are left with little information about right hemisphere language abilities.

When patients are injected with sodium amytal in the left, language-dominant hemisphere, they are still able to carry out commands (Wada & Rasmussen, 1960; Milner, Branch & Rasmussen, 1964). However, no controlled study of linguistic variables has been carried out, and it is therefore not clear whether the patient is comprehending the verb or the noun, as in "move your

leg". In additon, many of these patients are not completely aphasic, but retain some dysphasic expressive speech.

Auditory processing

Dichotic listening studies indicate a distinct but limited amount of functional asymmetry for auditory recognition between the hemispheres. The left hemisphere (i.e. right ear input) is better at recalling sounds conveying language information, and the right is better at recalling non-language (melodic, environmental) sounds. These differences appear to be due in part to a suppression of the ipsilateral pathway in the presence of competing auditory stimulation. (Spellacy & Blumstein, 1970; Spellacy, 1970; Milner, 1962, 1971; Milner, Taylor & Sperry, 1968; Kimura, 1964, 1967.) The asymmetry revealed under dichotic listening conditions does not appear to be so distinct as to create problems in the amytal testing situation, especially as only one auditory stimulus at a time will be presented.

METHOD AND MATERIALS

Normal Controls

Fifteen university students were used to evaluate the test materials, procedures and instructions. The results from the first 8 controls were used to modify or eliminate stimuli not clearly recognizable, and to simplify instructions. The last 7 served to confirm that all obvious difficulties had been corrected. They were also used to establish an average reaction time for left and right hands. They were given the pre-test form of the test.

Subjects

Subjects were the patients of Dr. J. Wada, hospitalized for neurological investigation of their epileptic seizures. Some Ss were medicated for control of seizures, others not. This, however, is not relevant to the results, as medication (where necessary) was consistent throughout testing, and results were evaluated in terms of left and right hemisphere performances within the same subject. All Ss able to follow instructions and solve the pre-test items were tested under amytal. All appeared to have hearing within normal limits. Those Ss who did not demonstrate clear left dominance for languages by sodium amytal were excluded for the final results.

Table 2. Subjects tested under sodium amytal

Subject	Sex	Age	Time since on-set of seizures	Focus of seizures
P.M.	M	14	13 years	R temporal
J.L.	F	33	2 months	R and L
J.Mc.	M	27	4 years	L
L.E.	F	16	14 years	R and L
J.K.	F	51	26 years	R temporal
B.K.	M	19	1 year	R temporal
D.M.	M	20	19-20 years	R temporal
A.C.	F	21	5 years	R temporal

Each S served as his own control. If the pre- and post-test responses to a given test item were consistent, however divergent from the normal controls', that response was scored as the "correct" one for that particular subject, and isolated left and right hemisphere responses were compared with the pre- and post-test results. (This was relevant only to the association test).

Materials

Table 3. Auditory stimuli with "correct" visual response for matching (CMM) and association (CMA) tests.

Auditory stimulus	Duration (in secs)	Corresponding CMM visual stimulus (picture)	Corresponding CMA visual stimulus (object)
cat miaow	4.0	head of cat	catnip mouse
dog barking	1.8	head of dog	bone
sheep baas	5.0	(1) standing sheep	ball of wool
person sneezing	1.4	torso, person sneezing, hand to mouth, no handkerchief	handkerchief
chicken cackling	5.6	standing chicken	egg
door slamming	1.2	door, partly open	ring of keys
baby crying	6.2	head of crying baby	toy baby bottle
sawing	5.6	saw	large nails
car screeching to stop	3.6	car in motion	the word "STOP"
fog horn	4.5	lighthouse in fog	toy sailboat
typing	5.8	typewriter	book

Auditory stimuli

All sounds were recorded and played back on a Uher 4400 portable tape recorder (with the exception of the fog horn provided by Lars Eastholm, C.B.C.). Editing, and sound-level balancing, were done with a Scully 280 tape recorder. Sound-level balancing between the stimuli was performed by ear and by V-U meter. The stimuli varied in duration from 1.2 - 6.2 sec, and were separated by 2 sec intervals. The differences in stimuli duration had no

apparent influence on results (see Table 4, Results). The order of stimulus presentation was randomized across 8 different lists, and 4 tapes were made (Tape 1: pre-test matching and pre-test association; Tape 2: left hemisphere matching and association; Tape 3: right hemisphere matching and association; Tape 4: post-test matching and association).

Visual stimuli

Pictures: Four heavy cardboard plates were prepared by the Dept. of Biomedical Communications, U.B.C. Each plate was $10\frac{1}{2}$ " high X $8\frac{1}{4}$ " wide and contained 1 picture in each of 4 quadrants. The pictures were hand drawn and painted on a flat-white background; the colors were naturalistic but muted to avoid any one feature from being more obvious than the rest. The choice and arrangement of pictures on the plates was randomized. Since these are only 11 different pictures, and 4 plates with 4 pictures each, 5 of the pictures were reproduced twice. This allowed the E to minimize perseveration effects by ensuring 1) that the same plate was never presented twice in a row, and 2) that a "correct" response for one auditory stimulus was never presented as an alternative ("wrong") choice with the next auditory stimulus.

Object-boxes: Two 9" high X $7\frac{1}{2}$ " wide X $1\frac{3}{4}$ " deep boxes were divided into 4 compartments (2 X 2), each $4\frac{1}{2}$ " X $3\frac{3}{4}$ " X $1\frac{3}{4}$ ". The box, inside and out, was painted flat white and the lower $\frac{1}{3}$ of each compartment covered with a clear plexiglass sheet, allowing maximum visibility while preventing objects from falling out. Thus, the picture plates and object boxes presented roughly the same area to be scanned visually.

Objects: Common, everyday examples of the object stimuli were used, with the exception of a miniature (toy) sailboat and baby bottle. The word "STOP" was block printed in black ink, and measured $2\frac{1}{4}$ " X $3/4$ ". The choice and arrangement of the objects was quasi-random to preclude any alternate ("incorrect") choices which the results from normal control had revealed as having (for some people) an associative connection with the auditory stimulus (e.g. ball of wool often chosen instead of the baby bottle, in response to the baby's cry. That item was replaced with the keys). Steps to minimize perseverative responses, as for pictorial stimuli, were taken.

Procedure

The test was given in two sections, 1) matching and 2) association. Matching involved choosing one picture out of 4 which matched (i.e. was the visible source of) the auditory stimulus. Association involved choosing one object out of 4 which was best associated with the auditory stimulus. The first 3 Ss were given procedure 1, the last 5 Ss were given procedure 2.

Procedure 1: The S was told to "Listen", and the sound was then played. The visual stimulus was presented, and if necessary, the S reminded to "Point to the picture/object that goes best with the sound". Reaction time was measured from the moment the S appeared to focus on the visual display until he pointed to one item. After testing 3 subjects, the testing procedure was changed, for the following reasons:

- 1) on the association test, Ss often remarked after hearing the sound that they expected to find a particular object; when it was not there they had to "re-think" the problem.

ii) the memory component involved in playing the sound before presenting the visual display was felt to be an unnecessary complication.

iii) reaction times were noted to include scanning the visual display. This varied from subject to subject.

Procedure 2: The visual display was presented with the following instruction: "Look at all 4 pictures (objects)". Four (4) seconds were given for the S to scan the display. Then the S was instructed "Listen", and a sound was played. Reaction time was measured from the start of the sound until the S pointed to one item.

Controls (pre-test and post-test)

At the time of the pre-test (1 - 2 days before amytal testing) the S was visited in his hospital room. The form of the test was explained, and it was emphasized that he was required only to listen carefully and point to the picture (object) of his choice; verbalization during testing was discouraged. He was briefed on what to expect in the actual testing situation. The 11 matching stimuli were given consecutively, followed by the 11 association stimuli. The post-test (1 - 2 days after amytal testing completed) followed the form of the pre-test. In addition Ss were asked for recollections and comments about testing.

Testing of left and right hemispheres

The left hemisphere was always tested first by injection of sodium amytal into the right hemisphere. The procedure is followed by Dr. Wada in order to maximize comprehension of the situation, and minimize distress (aphasia). The right hemisphere

is tested 2 - 3 days later. Testing took place in the radiology room at Vancouver General Hospital. Six to 10 staff were present. To conduct the sodium amytal procedure the S lies on his back, with head connections to the EEG. Wada and Rasmussen's 1960 technique has been modified such that the sodium amytal was administered to the internal carotid artery, via the femoral artery. 75 - 100 mg. of amytal, in 3 or 4 cc respectively, are injected at one time. (For more details on this testing procedure see Blume, et al, 1973).

The effects of amytal are reliable for only $3\frac{1}{2}$ min. The time of injection and the time of each stimulus and response were noted on the electroencephalogram and responses obtained after $3\frac{1}{2}$ min. were not included in the results. Testing began as soon as hemiplegia and loss of grip strength was clearly evident, and temporary confusion, dizziness clears.

The period following the first injection was utilized to determine speech capacities of the non-drugged hemisphere. Counting, singing a song, and naming objects and pictures were tested. Any spontaneous utterances during the testing were noted. Two - 3 more injections were given during which affective time cross-modal testing was done. Since the time limitations of the drug coupled with drowsiness in the Ss rarely allowed testing of all 22 items, the form of the test was modified to ensure inclusion of both matching and association items. Thus 4 matching stimuli were followed by the same 4 auditory stimuli in the association form of the test.

RESULTS

Short and long auditory stimuli

Two of the auditory stimuli were much shorter than the others, i.e. "door-slamming" (1.2 sec), and "sneeze" (1.4 sec). The third short sound, "dog-barking" (1.8 sec) came at the end of the tests and was therefore not reached by any of the Ss. In Table 4, responses evoked by these stimuli on the matching test are compared with those of 3 longer sounds. Left and right hemisphere results are combined.

Table 4. Combined left and right responses to 2 short and 3 long auditory stimuli on the matching test (5 subjects). Ratio correct responses / total # of presentations expressed in decimal form.

Stimulus	No. of presentations of stimuli	No. of correct responses	No. of incorrect responses	No. of "no responses"
door (1.2 sec)	9	5 (0.56)	3	1
sneeze (1.4)	10	5 (0.50)	3	2
baby cry (6.2)	6	3 (0.50)	3	-
chickens (5.6)	8	3 (0.38)	5	-
cat miaow (4.0)	9	6 (0.66)	1	2
Total 2 short	19	10 (0.53)	6	3 (.16)
Total 3 long	23	12 (0.52)	9	2 (.09)

The ratio listed in the "correct responses" column indicates that short and long sounds were correctly recognized equally often. It thus may be assumed that differences in stimuli duration did not present Ss with any particular difficulties. Results under "no response" reveal no apparent difference in the ability of the short stimuli to evoke a response.

Reaction times

The overall RTs, averaged for 7 normal controls and each of the 4 experimental subjects are shown in Table 5. It can be seen that pre- and post-test RTs for Ss are comparable with the averaged RTs of the normal controls. The RTs of the isolated hemispheres correspond with the generally accepted idea that slower RTs reflect general or specific impairment of the C.N.S. (Miller, 1970; De Renzi & Faglioni, 1965; Blackburn & Benton, 1955). It is of interest to note that on the matching test (with one exception, D.M.) left hemisphere RTs were faster than right hemisphere RTs, while on the association test all right hemisphere RTs were faster than those of the left.

Left and right hemisphere responses on matching and association tests.

The results of testing are shown in Table 6. The results of 4 Ss were eliminated from final consideration for reasons given in the table. Pre- and post-test scores are not listed, since all Ss (including those eliminated) responded correctly to all 11 matching items. Almost all Ss responded correctly (consistently) to the 11 association stimuli; a few Ss were not consistent on pre- and post-test responses to 1 item, and therefore that item was

Table 5. Averaged RTs (in seconds) for matching (M) and association (A).

Subject	Hand	Pre-test		Left hemisph.		Right hemisph.		Post-test	
		M(N) [†]	A	M	A	M	A	M	A
7 controls	Right	1.1 ₍₆₎	1.4 ₍₅₎						
	Left	1.9 ₍₅₎	2.3 ₍₆₎						
L.E.	R	2.3 ₍₁₁₎	3.8 ₍₁₁₎	6.8 ₍₇₎	7.7 ₍₃₎			1.1 ₍₁₁₎	2.9 ₍₆₎
	L					9.1 ₍₇₎	5.3 ₍₃₎		1.1 ₍₅₎
B.K.	R	1.9 ₍₅₎	1.3 ₍₆₎	4.9 ₍₄₎	7.0 ₍₄₎			1.2 ₍₅₎	1.3 ₍₆₎
	L	1.5 ₍₆₎	2.6 ₍₅₎			7.2 ₍₅₎	6.2 ₍₅₎	1.2 ₍₆₎	1.1 ₍₅₎
D.M.	R	1.8 ₍₇₎	1.5 ₍₆₎	10.0 ₍₇₎	16.0 ₍₃₎			1.2 ₍₅₎	1.2 ₍₆₎
	L	0.6 ₍₅₎	2.6 ₍₅₎			2.4 ₍₄₎	8.0 ₍₃₎	0.9 ₍₆₎	1.1 ₍₅₎
A.C.	R	1.5 ₍₅₎	1.4 ₍₆₎	2.8 ₍₈₎	10.6 ₍₅₎			1.3 ₍₅₎	1.1 ₍₆₎
	L	1.4 ₍₆₎	2.5 ₍₅₎			6.6 ₍₅₎	6.2 ₍₅₎	1.2 ₍₆₎	2.0 ₍₅₎

[†]: Number in parentheses represents N.

Table 6. Percentage correct responses/total responses (N) for left and right hemisphere testing of cross-modal matching (M) and cross-modal association (A).

Ss eliminated from final results	Lang. dom. hemisphere	Proced.	Left hemisphere		Right hemisphere		Reason not used
			M	A	M	A	
P.M.	L	1	0/1	0	1/3	0	Barely conscious under amytal. Right hemisphere grossly abnormal.
J.K.	L	1	5/6	1/2	1/4	0	Too drowsy, uncooperative testing R hemisphere.
J.L.	L	2	3/4	3/3	0	0/1	Aphasia panicked S, no R responses.
J.Mc.	B	2	2/4	0/3	8/8	3/5	Bilateral speech representation. Had seizure during L testing.
<u>Subjects</u>							
L.E.	L	1	43% N=7	67% N=3	57% N=7	100% N=3	
B.K.	L	2	25% N=4	75% N=4	80% N=5	80% N=5	
D.M.	L	2	57% N=7	33% N=3	100% N=4	100% N=3	
A.C.	L	2	62% N=8	20% N=5	80% N=5	40% N=5	
Combined results, 4 subjects			50% N=26	46% N=15	76% N=21	75% N=16	

Proced.: 1 or 2 refers to the two testing procedures described in Methods.

deleted from their test results. The percent correct scores represent the ratio of number correct / total possible responses obtained from each Ss; non-responses, (however many stimuli were missed) were not included in the denominator.

DISCUSSION

It is apparent from Table 6 that for these left-dominant subjects the RH was able to perform audio-visual cross-modal matching and association tasks. The totalled results for all Ss (bottom line) demonstrates this; each and every individual S performed in a similar manner. It is of interest to compare these totalled results with those of J.Mc. who was rejected because of bilateral speech representation. His RH matching responses are striking in that they represent a very alert mind, although his association responses are no better than those of the 4 left dominant subjects.

Not only could the RH perform cross-modal tasks, but we note that in all Ss the Rh performed much better than the LH. Although there is insufficient data to interpret this finding as characteristic of consistent RH response, several possible reasons for this experimental finding will be considered under the following questions:

1) Was the right hemisphere more alert than the left?

There are several findings that make this unlikely. As indicated earlier, medication (where necessary) and dosage of amytal were consistent throughout testing. Differences in RTs for left and right sides (Table 5) appear to balance out (excluding D.M.): RH matching RTs were about 2.5 sec. slower than LH, while association RTs were on the average 2.8 sec. faster. Total number of responses elicited from the RH (see bottom line, Table 6) was slightly less than the number elicited from the LH; the RH did better only because it gave more correct responses. In addition, the number

of "no responses" (and therefore indication of lack of attention) was slightly larger on the right (Table 7). The question is whether continued testing would have broadened or narrowed this gap.

Table 7. Number of stimuli eliciting no response.

Subject	<u>Left hemisphere</u>		<u>Right hemisphere</u>	
	M	A	M	A
L.E.	1	1	1	0
B.K.	0	0	3	1
D.M.	0	1	0	1
A.C.	0	3	3	0
Totals	1	5	7	2

2) Could the right hemisphere have "learned" from the experiences of the left? This is an intriguing possibility. While short term memory (less than 5 min.) for recall of objects seen before and during amytal injection appears to be good (Milner, Branch & Rasmussen, 1962) we do not know if information can be transferred from the "learning" hemisphere to the drugged one for future use. In addition, although the left hemisphere has been exposed to the test material, it received no feedback as to whether its responses were or were not correct.

Bures and Buresova (1960) have answered this question for rats and rabbits. Using the cortical-spreading-depression (CSD) technique of Leao, they showed that suppression of one entire hemisphere during task training prevents transfer of that information after CSD has worn off; i.e., the untrained hemisphere shows no savings in learning the task, even though commissures are intact.

Whether or not this finding would hold true for humans is open to conjecture. Cursory comparison of RH and LH correct vs. incorrect responses appeared to indicate that as many times as an incorrect LH response became a correct RH response, the correct LH responses were missed by the RH.

3) Possible reduction in anxiety due to familiarization with the surgical procedure? Casual conversation with the Ss prior to testing of both left and right hemispheres supports this idea. The equipment in the radiology room is quite formidable, and the S faces an unknown pain factor. The E feels that familiarity with these conditions did help to decrease anxiety. It is by now well documented (Broadbent, 1971) that anxiety interferes negatively with performance.

Questions 2 (learning) and 3 (anxiety) might be answered by testing the right hemisphere first, followed by the left, to determine whether RH performance would still be superior. A better test would depend on the development of a standardized auditory recognition (matching) and association test of the form used in the present investigation. With this, one could test naive Ss with sodium amytal, $\frac{1}{2}$ RH first, $\frac{1}{2}$ LH first. In this way we could determine if the RH's apparent superiority would obtain if it were the sole respondent to the initial testing. In other words, it is possible that the RH stores associative information better than the LH but requires LH processing to make (or mediate) such connections. (See Bogen, 1969, for a review of the ways in which LH and RH thinking are thought to differ, e.g. digital vs. analogue, analytical vs. synthetic, propositional vs. appositional.)

4) Is the right hemisphere better in recognition of

non-verbal auditory stimuli? As reviewed in the introduction (under "Anatomical considerations"), dichotic listening studies have shown this to be true. However, this superiority does not necessarily convey an advantage on CMI tasks, as shown by Faglioni, Spinnler & Vignolo's (1969) aphasic group. In this experiment, the Ss could not match meaningful non-verbal sounds to the appropriate pictures (although the RH was undamaged). The contrast between Faglioni et al.'s findings, and those reported here, supports the idea that damage to one hemisphere can interfere with non-damaged functions in the other hemisphere.

5) Does the existence of a unilateral epileptic focus produce disfunction in that hemisphere? (When the S is not in seizure.) Blume, et al., (1973), tested memory in epileptic patients using intracarotid sodium amytal to inactivate the suspected epileptic hemisphere. They found a direct relation between memory loss and presence of EEG epileptiform activity in the temporal lobe contralateral to the injection. Where no epileptiform activity was observed, memory was intact. As noted in Table 2, all of our Ss were found to have a right temporal focus for their epileptic seizures. Thus it does not appear that the epileptic focus in our Ss should have interfered with LH performance.

6) Since the right hemisphere is known to be superior to the left in spatial functions, could inactivity of the RH affect accuracy of pointing responses directed by the LH? Semmes (1968) and Teuber (1962) have found that damage to the RH regardless of location, produces a general, rather than a modality-specific, impairment of spatial functions. A similar effect was found by

De Renzi, Faglioni & Scotti (1970) in which left visual field defects (reflecting right visual cortex damage) severely affected performance of a tactilely guided maze test, where no somesthetic defect was evident. This possibility was reflected in 2 of our Ss while their LHs were being tested (i.e. RH injected). B.K., the only S to receive feedback on a response, was played the stimulus: "door slamming", and pointed to the picture of a "dog". It so happened that this S heard the E tell the testing assistant "dog"; the S then responded "I blew it". D.M. heard the "baby crying", said "baby" and pointed, incorrectly, to the picture of the sheep. During association testing, upon hearing the stimulus "baby crying" he said "bottle", and pointed, incorrectly, to "book". These 3 examples would appear to indicate that the Ss knew the correct response, but could not perform that response.

These situations demonstrate the difficulty of evaluating capabilities of 2 sensory modalities by means of a third sensory modality. Except for the questionable anxiety factor (question 3 above), the known importance of the RH in control of spatial functions appears to be the most likely explanation for the RH superiority of CMM and CMA as found in this experiment. Unless, of course, Semmes is correct in predicting RH superiority of CMI.

An additional point of interest regarding right hemisphere function was revealed by this test. It will be recalled that one of the items in the association test was the word "STOP", which corresponded to the auditory stimulus "car-screeching-to-stop". According to the findings of Gazzaniga and his colleagues, the RH is not able to recognize visually presented verbs, or nouns derived from verbs (Gazzaniga, 1970). It was therefore of

considerable interest to find that during left hemisphere testing none of the 4 Ss responded correctly to this item (3 incorrect, 1 no response), whereas all 4 responded correctly with the right hemisphere. The time after injection of amytal when each S responded was: L.E. 3'10"; B.K. 2'20"; D.M. 0'45"; A.C. 3'00". Since stimulus "STOP" was neither in red, nor associated with the traditional hexagonal shape of a stop sign, either the subjects' right hemisphere could read the word, or, remembering the pre-test, Ss chose the only non-3-dimensional, non-object stimulus. Such an explanation does not account for the failure of the left hemisphere to recognize the word. Though tachistoscopic testing of normal (non-split-brain) Ss when they are required to report verbally does not give conclusive evidence of RH language functions, our Ss's RH response to "STOP", without access to the LH, seems to support Caplan, Holmes & Marshall's (1974) finding that the RH did recognize category-ambiguous (noun/verb) words.

It would appear that under test conditions employed in this experiment, Semmes' prediction of RH superiority in hetero-modal integration holds true. Her concept of RH diffuse organization seems closely related to Pribram's (1971) hypothesis of holographic coding in the brain. He states: "One of the attributes of holograms is the facility of associative recall. Accordingly, associations ought to take place within a system, not between systems" (op.cit., p. 362) and cites as an example that single neurons "in the primary projection areas are sensitive to excitation in a modality different from the major sensory mode served by that system (Loc. cit.). These points are reminiscent of Semmes' idea

that spatial function relies on

convergence of unlike elements - visual, kinesthetic, vestibular, and perhaps others - combining in such a way as to create through experience a single supra-modal space.

(Semmes, 1968, p. 24)

Semmes and Pribram imply an interrelationship of all parts of the brain into one smoothly integrated whole. This is reflected in the observations that in the presence of LH damage, the RH could not function as it could when completely isolated from the left (split-brain and intracarotid amytal conditions). Perhaps the LH is not focally organized as Semmes proposes; the repercussions of its disfunctions are certainly not focally localized; "an imbalance of function has been caused by the initial insult to the brain, an imbalance that results in the suppression of a function" (Pribram, 1971, p. 364).

Evidence that a disfunction can be actually the manifestation of a suppressed normal function has been shown in several experiments: 1) Smith (1966) released quite functional language capabilities in the RH of a severely aphasic patient by performing a left hemispherectomy on him. 2) Behavioral deficits resulting from brain lesions have been corrected when additional lesions were made in other areas of the brain (Pribram, 1971). 3) Butler trained monkeys on a conditioned response in which the stimulus was directed to the left visual cortex, and the response controlled by the right motor cortex. Rate of learning this response was normally slow; when the right visual and left motor areas were removed (thus eliminating distracting information) rate of learning was faster than in normals (cited in Bogen & Bogen, 1969). 4) one split-brain patient of Levy, Nebes & Sperry (1971) could

write (copy) with his left hand roughly 1/3 of the printed words presented to his left visual field (RH). 84% of those he could write he could not name correctly. In this, and another, patient there was evidence that the dominant H took over control of the left hand. E.g., the correct word was "sit"; the S would start to write "si-" and finish "simp" as his left hemisphere said "jump".

Based on evidence such as the aforementioned, Moscovitch (1973) hypothesizes that:

the extent to which the minor himisphere's performance on verbal tasks reflects its limited underlying competence...depends on the degree to which the dominant hemisphere can control the verbal behavior of the minor hemisphere via the midline commissures and other pathways... Consequently, the verbal performance of patients with lesions to the dominant hemisphere will usually reflect only the verbal competence of a malfunctioning dominant hemisphere, which, in many instances, will be poorer than the verbal behavior which a healthy minor hemisphere might execute were it not under dominant hemisphere control.

(Op. cit., p. 114-115)

From the evidence presented in this paper, it appears that 1) Moscovitch's hypothesis is true for other functions, in addition to language; 2) the left angular gyrus is not necessary for CMA, as Geschwind and Ettlinger propose, and 3) that Semmes' "diffuse organization" may apply not just to the right hemisphere, but to the brain as an integrated whole, as Pribram suggests.

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