INTRAHEMISPHERIC PROCESSING AND SUBCORTICAL TRANSFER OF NON-VERBAL INFORMATION IN SUBJECTS WITH COMPLETE FOREBRAIN COMMISSUROTOMY

Thesis by

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To my mother

AGNES NELSON CRONIN

and the memory of my grandmother

ALICE J. NELSON

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ABSTRACT

Subjects who had undergone complete surgical division of the forebrain commissures for treatment of intractable epilepsy were tested on a variety of cognitive and perceptual tasks. It was found that the right hemisphere performs as well as the left on a test of abstract concept comprehension when the stimulus materials are presented in a non-verbal format. In light of evidence of a selective right hemisphere deficiency for processing abstract words, this result is taken to imply a dissociation of language and cognition at a high level. A second experiment involved the nature of information which can cross subcortically between the cerebral hemispheres. With stimuli presented to opposite visual hemi-fields for prolonged durations, three commissurotomy subjects were able to make matches which convincingly demonstrated interhemispheric transfer and integration of cognitive information, including concrete and abstract concepts. Transfer between the hemispheres was equally successful in the two directions, though the pathway originating in the right and terminating in the left hemisphere may be more sensitive to some affective and semantic components of the stimulus. The information relayed subcortically is neither verbal nor imagic in nature, but appears to involve contextual or connotative associations of the stimulus. Implications for the evolution and development of non-verbal thought include the possible existence of a common bilateral cognitive system which permits interhemispheric communication of complex, if imprecise, associations that are distinct from the more specific verbal and visuospatial constructs of the left and right hemispheres, respectively. Finally, differences in the ability of the two hemispheres to perceive figure and background were described for four commissurotomy subjects. While the left hemisphere preferentially identified figures from briefly-presented picture compositions, the right hemisphere was equally adept at recognizing both figure and ground. The right hemisphere was also more sensitive to background influences on

object perception, and was furthermore able to use "natural" gradient and perspective cues in evaluating an object's size and position in a field. In sum, the results demonstrate (1) the richness and complexity of non-verbal information and its place in human thought processes, and (2) the sophistication of the right hemisphere as a perceptual and cognitive system.

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GENERAL INTRODUCTION

Non-verbal information provides the best means by which the character of the right cerebral hemisphere may be revealed. In human commissurotomy subjects, for whom the cerebral hemispheres have been surgically divided for treatment of intractable epilepsy, the right hemisphere is cut off from highly-developed language functions, which are the speciality of the left hemisphere. The upper limits of right hemisphere cognition and perception may consequently be understood only by evaluating the nature and extent of the non-verbal information which it can successfully process. Besides its obvious theoretical relevance to issues of brain science, including the relationship of language and cognition, the elucidation of right hemisphere thought processes through non-verbal testing has practical implications for the study of language-impaired individuals, including the development of suitable methods for testing the wide range of psychological capacities that are not directly dependent on language.

The following topics are addressed in the ensuing chapters:

(1) Abstract association in the non-verbal right hemisphere

(2) Subcortical transfer of non-verbal information in the absence of the forebrain commissures

(3) Figure-background perception in the disconnected hemispheres

Each chapter describes in detail the subjects and methods involved in the individual experiments. Discussions of results appear at the end of each section, with a general statement of conclusions following the final chapter.

CHAPTER 1

COMPREHENSION OF ABSTRACT CONCEPTS IN RIGHT AND LEFT HEMISPHERES OF COMPLETE COMMISSUROTOMY SUBJECTS*

* A version of this paper was presented at the annual conference of the Body for the Advancement of Brain, Behavior, and Language Enterprises (BABBLE) on March 17, 1984, in Niagara Falls, Ontario, Canada.

Abstract--The left and right hemispheres of three complete commissurotomy subjects were tested for the ability to comprehend abstract concepts. A technique was used which allows prolonged viewing of stimulus material restricted to a single visual hemi-field. Twenty-three trials involving a sample inspection figure and a three-choice answer array were presented to each hemi-field with instructions to point to the one picture in the choice array related to the sample. As none of the possible choices matched the sample stimulus on any concrete level, correct responses required an abstract mental association. Both the verbal and non-verbal hemispheres performed the task at a high level of proficiency in all subjects. It was further noted that both commissurotomy and normal subjects experienced difficulty in articulating the involved abstract relationship when asked to do so under a free vision condition. The results demonstrate that the right hemisphere, lacking a highly developed language system, can nevertheless support sophisticated cognitive processing at an abstract level, and further suggest that the associative process is not necessarily language-mediated in either hemisphere.

INTRODUCTION

There is general agreement that it is the left, verbal hemisphere which is mainly responsible for the processing of abstract thought in the normal human brain, as supported by evidence from a variety of left hemisphere-intact populations, including commissurotomy [1], right hemispherectomy [16], and right brain damaged groups (e.g., 12, 15). A more recent study of partial commissurotomy subjects [8] in like manner attributes to the left, but not the right hemisphere, the capacity for inferential reasoning. However, the ability of the non-verbal right hemisphere to make abstract associations at a level equivalent to or even superior to that of the left has also been documented, particularly in respect to spatial skills such as concept formation involving the manipulation of objects [10], visual and tactual pattern completion [19, 21] and the appreciation of geometrical relations [6] (see 4, 5, 9, and 11 for more comprehensive reviews of relevant right hemisphere abilities).

In regard to verbal tests, the question may be raised as to what extent the lack of comprehension of abstract words is a matter of vocabulary or a deeper inability to understand the underlying abstract concepts involved. The bulk of the evidence for left hemisphere dominance of abstract thought processes is based on partially or completely verbal test paradigms. At the same time it is widely accepted that the non-verbal right hemisphere is placed at a clear disadvantage relative to the left whenever verbal material is used; moreover, this bias seems to be selectively exaggerated when abstract words are involved [3]. In light of these findings, reports of right hemisphere limitations in appreciating abstract concepts as represented by abstract words may need to be re-evaluated. For example, the reported inability [18] of the right hemisphere after commissurotomy to match abstract words in free vision to related objects identified by the left hand could conceivably be accounted for by a genuine inability to comprehend abstract concepts at a deep level, but might as easily be attributed to a limited vocabulary for abstract words. Results of a more extensive study including hemispherectomy as well as split-brain subjects suggest that the right hemisphere may be able to associate some aurally presented abstract words with pictures lateralized to the left visual hemi-field [20], though the number of trials involved (fewer than 10) was too small to permit an unequivocal assessment of right hemisphere abilities.

The lack of non-verbal formats for standardized tests of abstract conceptualization appears to support the view that this type of mental association is somehow coupled to verbal abilities and is therefore beyond the province of the "minor" hemisphere. Yet, the difficulty one normally experiences in verbally defining "time," "truth," "evil", etc. lends intuitive appeal to the suggestion that non-verbal processing may play a role in the ability to understand these abstract concepts.

The possibility of right hemisphere comprehension of abstract concepts is examined here, using a new, completely non-verbal test of picture associations. The test was designed to preclude the possibility of matches being made on any concrete (e.g., physical or functional) basis, so that successful performance by either of the disconnected hemispheres of complete commissurotomy subjects would necessarily reflect an underlying competence of that hemisphere for abstract association.

METHODS

Subjects

The subjects were three patients of the Vogel-Bogen series (LB, NG, and AA) who had undergone complete surgical division of the forebrain commissures at least 15 years previously. The corpus callosum and the anterior and hippocampal commissures were completely sectioned in all subjects for treatment of intractable epilepsy. The massa intermedia when encountered was also divided. Extra-callosal brain damage is considered to be minimal for LB and NG, while there are some indications of right hemisphere frontal and left hemisphere fronto-parietal damage in AA. All three subjects are right-handed and have left hemisphere speech. Their medical histories are described in detail elsewhere [2]. Six right-handed normal adults served as control subjects.

Stimuli

Stimuli were presented to a single hemisphere by use of the lateral limits technique [14], which allows prolonged hemi-field viewing of lateralized stimuli without attachments to the eye. With the head held in position by use of a standard bite board, the subject moves the eyes horizontally until the limit of rotation in that direction is reached (at approximately 45° off the vertical midline for most subjects). All stimuli which appear in the space lateral to this limit are projected only to the contralateral hemisphere. Through use of this technique, stimulus material may be restricted for prolonged durations to the left or right visual hemi-field while remaining in central vision. Limited vertical scanning of lateralized material is also permitted by this design.

Within a single visual hemi-field, four line drawings of common objects were presented simultaneously in a vertical display (Fig. 1). The top drawing appeared on a slide projection and constituted the sample stimulus, while the three possible answers appeared below on cards arranged in a vertical choice array. The sample stimulus and correct answer were predesigned so as to be related only through a shared abstract association, but not through any common physical or other concrete feature. The abstract concepts represented by a correct match are shown in Table 1. For each trial, the three choices of the answer array were alike in some general way (e.g., all were appliances, or animals, or hand gestures), so that no one choice would be selected or rejected on the basis of its gross dissimilarity to the others. However, none of the three possible matches was related to the sample stimulus on any concrete level. A successful match was possible only if the hemisphere being tested was able to comprehend the appropriate underlying abstract relationship.

Procedure

The subject was instructed to point to the one card of the choice array which was related to the sample, using the hand contralateral to the hemisphere being tested. The ability of the ipsilateral hand was measured by its performance on an additional eight trials, administered in a separate session after the main test had been completed. Because it proved to be difficult to use that hand to reach across the body and into the far opposite hemi-field, the subject was instructed to indicate the position (top, middle, or bottom) of the desired response card of the three-choice vertical array by pointing to the corresponding position on a card comprising three raised, textured squares, placed directly in front of the subject and hidden from view. The contralateral hand was also tested in this manner to ensure that any observed differences in the performance of the two hands reflected more than the relative difficulty of the two modes of response.

The right hemisphere was tested first. Follow-up oral questioning was directed to the verbal hemisphere in order to establish that it had remained uninformed of the test stimuli. The test sequence was repeated to the left hemisphere, and also again in free vision, at least several hours after the right hemisphere testing had been completed. When the stimuli were presented in free vision, the subject was asked to point to the correct answer, and then to verbally explain the basis of the match. If the subject made an incorrect match under both right and left hemi-field conditions and also failed to make and subsequently explain the match in free vision, that trial was excluded from analysis. Two of the original 23 trials were eliminated on this basis for subject LB (T=21), two for NG (T=21), and five for AA (T=18). Two trials were excluded from the analyses of two different subjects' results (NG and AA: "slowness" and "government"), and no one trial was missed by all three subjects.

RESULTS

Both hemispheres of all commissurotomy subjects performed the abstract associations at well above chance level, with the left hemisphere averaging 90% correct across subjects, and the right hemisphere attaining an average of 82% correct. The lowest score which was attained by any subject (71% correct, by NG's right hemisphere) was still well above chance level ($p < 0.01$, one-tailed binomial test). Differences in the performance levels of left and right hemispheres were also analyzed (chi square) and found to be not significant, both for individual subjects and for the combined three subject results. The results are detailed in Table 2.

These results reflect the performance of the hand contralateral to the hemisphere being tested. The ipsilateral hand, in contrast, performed at chance level, indicating that the hemisphere not being tested had remained uninformed of the test material, and was not controlling the responses. For either hand, identical responses were obtained from all subjects for the two modes of manual response, i.e., direct pointing, and pointing to positions on the textured card.

Under the free vision condition, subjects often failed to produce the specific abstract word (or a synonym) which formed the basis for a match, although their comments otherwise indicated that the concepts were well understood. This difficulty in verbally describing the abstract relationship was observed in both the commissurotomy subjects and the normal control group.

DISCUSSION

The foregoing results show that the isolated right hemisphere of these subjects with complete commissurotomy is clearly capable of making mental associations that depend on the comprehension of abstract relationships. The possibility that the left hemisphere might have used subvocal signals to help direct the responses, as suggested by SUGISHITA [18], is not a viable explanation of the present results, since control measures ensured that the verbal hemisphere had remained uninformed of the nature of the input while the right hemisphere was being tested. Infrequent associated responses which accompanied the manual selection of the answer included simple evaluative comments (good/bad), and, occasionally, an appropriate motor display (e.g., subject NG "made horns" on her head after having seen a picture of a devil with her right hemisphere). These associated responses are consistent in the former case with evidence of subcortical crossing of cognitive and affective information [17] and in the latter with right hemisphere control of motor output. In neither instance was the observed response sufficient to provide the subject's left hemisphere with the identity of the right hemisphere stimuli or associations, as was revealed by follow-up questioning.

In light of the reported absence of abstract words from the right hemisphere's vocabulary [3], these findings are taken to indicate that abstract association can be mediated by a non-verbal process. Indeed, considering the difficulty experienced by both normal control subjects and commissurotomy subjects in articulating the appropriate abstract concepts when the task was performed in free vision, it may be suggested that the associative process is not necessarily mediated by language in either the right or the left hemisphere.

These results demonstrate the comprehension in the right hemisphere of high-order abstract relations and at the same time challenge assumptions that sophisticated cognitive processes are dependent on an intimate, and perhaps causal, relationship with verbal abilities. These findings strongly contradict the view that right hemisphere cognition is grossly impoverished relative to that of the left (GAZZANIGA, [7]; but see [13] for relevant comments on Gazzaniga's position). The demonstration of high-order cognition without language in commissurotomy subjects has recently been replicated in tests of adults with unilateral brain damage. Preliminary results indicate that even severe aphasics are capable of performing the current non-verbal test of abstract concept comprehension at a level of 70% correct or better (CRONIN-GOLOMB, in progress). The essential outcome of the present findings is an enhanced view of the intact right hemisphere as a highly developed cognitive system, capable of supporting even abstract thought without correspondingly sophisticated language skills.

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Table 1. Concepts and stimuli

	Abstract concept	Sample stimulus	Correct answer	Other two choices	
	1) Time	Calendar	Clock	Blender	Saw
	2) Communication	Envelope	Telephone	Alarm clock	Doorbell
	3) Evil	Devil	Snake	Turtle	Frog
0	4) Disability	Wheelchair	Hearing aid	Earring	Headphone
	5) Art	Music stand	Palette	Plunger	Stethoscope
	6) Prohibition	(no right turn)	Barbed wire fence	Calf	Barn
	7) Darkness	Moon	Owl	Songbird	Penguin
	8) Lack	Man, empty pockets	Car, out of gas	Car, flat tire	Car, wipers on
0	9) Patriotism	Eagle	Man, hand over heart	Man, hand extended	Man, hand on hip
ΔO	10) Slowness	Snail	Molasses*	Soy sauce*	Salad dressing*
0	11) Silence	Library	Child, hands over mouth	Child, hands on head	Child, hand raised
	12) Negligence	Paint bucket, kicked over	Wrong way on one way street	Traffic jam	Car at parking meter
	13) Military	Tank	Army boots	Ballet shoes	Sandals
	14) Music	Flute	Phonograph	Vacuum cleaner	Toaster
	15) Nationality	Kangaroo	Boomerang	Ball	Frisbee
	16) Danger	Dynamite	Thin ice	Ice skate	Snowman
ΔO	17) Government	Queen	U.S. Capitol	Church	Skyscraper
	18) Goodness	Angel	Good test paper	Books	Pencil box

	19) Violence	Gun	Black eye	Scraped knee	Bandaged finger
	20) Truth/honesty	Woman taking oath	George Washington & cherry tree	Ben Franklin & kite	Davy Crockett & musket
	21) Chance	Slot machine	Car accident	Car being repaired	Car at stop sign
□	22) Necessity	Automobile jack	Life preserver	Canoe	Pond
□	23) Freedom	Ball & chain (broken)	Voting booth	Telephone booth	Shower stall

O: AA excluded

Δ: NG excluded

□: LB excluded

*: Bottles with names on labels, as well as distinction by shape

Table 2. Scores on test of abstract concept comprehension. Chance level = 33 1/3% correct

			# Trials/	Left hemi-field/Right hemisphere		Right hemi-field/Left hemisphere	
Subject	Age	Sex	hemi-field	# Correct	% Correct	# Correct	% Correct
L.B.	31	M	21	19	90**	20	95**
N.G.	50	F	21	15	71**	19	90**
A.A.	32	M	18	15	83**	15	83**
Three subject average					82		90

**$p < 0.01$, one-tailed binomial test.

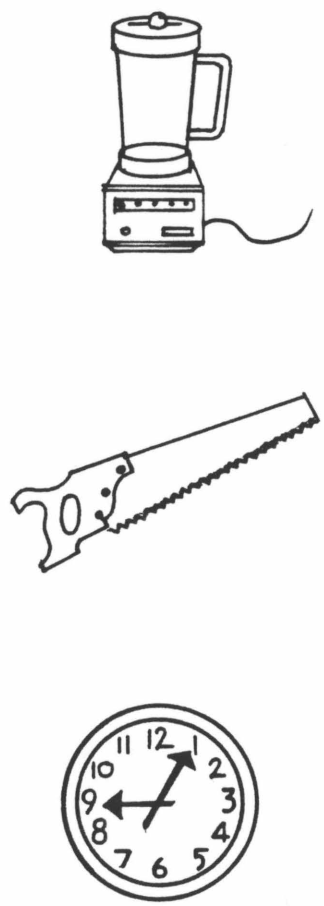

Fig. 1

FIGURE LEGEND

Fig. 1 Abstract concept: 'time'. Correct match: 'calendar'/'clock'.

CHAPTER 2

SUBCORTICAL TRANSFER OF COGNITIVE INFORMATION IN SUBJECTS WITH COMPLETE FOREBRAIN COMMISSUROTOMY

Abstract—Three complete commissurotomy subjects were tested for the ability to integrate cognitive information presented to opposite visual hemi-fields. A technique was employed which permits prolonged viewing of lateralized stimulus materials, and stimulus variables included affective component and concept complexity. Stimuli consisted of line drawings of common objects, with the sample presented to one hemi-field and a three-choice array to the other. The sample and one answer of the choice array were related on an abstract or concrete basis. A correct match thus indicated subcortical transfer and subsequent integration of the conceptual information provided by the stimuli in opposite hemi-fields. All subjects performed the test at well above chance level, with scores comparable to those attained when the task was performed completely within one or the other hemisphere. Analysis of pointing and verbal responses implicated "disembodied" associations, and not raw visual images or verbal labels, as the stimulus elements which cross subcortically. Crossing success was equal in both directions, except that affect-laden stimuli elicited more verbal report for right hemisphere (sample) to left (response) trials than for trials run in the opposite direction. The former direction may also be more sensitive to the meaningfulness of associations. The results are discussed in terms of a cognitive system common to the two hemispheres, involving associational networks but not lateralized functions such as language and complex visuospatial processes. Consequences for brain development and evolution are considered.

INTRODUCTION

There has in recent years been increasing interest in the possible contributions of subcortical brain regions to higher cortical function. Perceptual operations which involve midbrain tectal regions have been described for at least two sensory modalities [24, 30, 31]. Specific subcortical brain regions have additionally been implicated in the generation of emotional response, including limbic structures such as the amygdala [13]. The relationship between cortical and subcortical brain areas involved in affect is now beginning to be elucidated: Sensory-limbic connections are proposed to be more extensive within the right than the left half of the brain [1], suggesting an anatomical basis for the leading role of the right hemicortex in emotional function [1, 2, 4, 15, 32]. In regard to language processing, recent evidence of a subcortical contribution includes detailed descriptions of thalamic and basal ganglial aphasias [5, 9, 18, 33] and the presence of specific components of language processing which precede cortical involvement in the normal brain, as demonstrated by physiological measures [19]. Finally, it has been found that certain types of non-linguistic, affect-neutral cognitive information can be transferred by subcortical pathways between the cerebral hemispheres of complete commissurotomy subjects [11, 12, 22].

Individuals who have undergone complete cerebral commissurotomy are ideal subjects for the study of the role of the subcortex in information transfer. Because all the forebrain commissures have been completely severed, one hemicortex's access to information in the opposite hemicortex may be directly attributed to involvement of subcortical pathways, assuming that appropriate controls for behavioral cross-cuing, right hemisphere speech, and use of ipsilateral sensory pathways have been performed [22]. Additionally, since the massa intermedia was either sectioned or absent in the commissurotomy subjects to be discussed in the present study, the mechanism of information transfer can be presumed, at its most specific, to be subthalamic. In light of recent evidence of brain asymmetries even at the level of the subcortex, from variations in anatomical connectivity [1] to differences in neurochemical composition [17, 23] it is especially advantageous to study subjects for whom there does not exist the usual, direct, hemicortex-hemicortex flow of information along the neocommissures which might easily obscure subtle subcortical-cortical interactions in regard to cognitive function.

It is not unreasonable to expect to find evidence of interhemispheric transfer of cognitive information in commissurotomy subjects, given the increasing number of exceptions to the "split-brain syndrome" which have been reported in recent years. Although physiological and behavioral mechanisms may also be involved, it appears that the development of new testing techniques permitting prolonged unilateral presentation of stimuli [21, 35], and of test designs which encourage maximal performance by both hemispheres, is to a large extent responsible for the growth of the pool of observations which constitutes deviations from the split-brain syndrome, as it was described early in the subjects' post-surgical histories [28]. This situation is analogous to the development of the current view of the right hemisphere as a highly complex and human cognitive system, rather than the mute automaton it was presumed to be before appropriate tests and techniques helped to reveal its actual abilities (e.g., 26, 27, 29). The high level at which the disconnected right hemisphere is able to perform certain complex cognitive tasks is comparable to that of severe aphasics whose left hemispheres were damaged well after the onset of adulthood [6, 7]. This example is representative of many reports, involving a variety of subject populations, which support the premise that the high-level cognitive skills of the right hemisphere are inherent, rather than an abnormal sequel to the section of the forebrain commissures (see 4, 8, 10, and 16 for more comprehensive reviews of right hemisphere abilities). In like manner, the ability of subcortical pathways to support the transmission of cognitive information should not *a priori* be considered a result of compensatory mechanisms related to cortical damage, but rather as a possible feature of the normal, intact brain.

The following experiments examine the nature of subcortical transfer of cognitive information in the absence of the forebrain commissures. Specifically, cognitive processes involving non-verbal stimuli are considered, since it is generally agreed that complex linguistic information does not transfer freely from the right to the left hemisphere in commissurotomy subjects (e.g., 28). A recent demonstration that language and cognition are dissociable for both hemispheres of the same subjects to be tested in the present study [6, 7] serves to strengthen the expectation that non-linguistic cognitive elements may transfer subcortically, even if language itself does not. Concept complexity and affective component constituted two of the stimulus variables to be considered in the present experiments. Direction-specificity of information transfer (i.e., the relative success with which stimulus material crosses in the right to left hemisphere *vs* left to right direction) is also examined. It is proposed that analysis of the nature of the information which can transfer and of the relative success of transfer in the two directions will ultimately help to provide some clues as to the organization of cognitive information within as well as between the two hemispheres of the normal brain.

EXPERIMENT I

METHODS

Subjects

The subjects were three patients of the Vogel-Bogen series (LB, NG, and AA) who had undergone complete surgical division of the forebrain commissures at least 15 years previously. The corpus callosum and the anterior and hippocampal commissures were completely sectioned in all subjects for treatment of intractable epilepsy. The massa intermedia when encountered was also divided. Extra-callosal brain damage is considered to be minimal for LB and NG, while there are some indications of right hemisphere frontal and left hemisphere fronto-parietal damage in AA. All three subjects are right-handed and have left hemisphere speech. Their medical histories are described in detail elsewhere [3]. Seven right-handed normal adults served as control subjects.

Stimuli

Stimuli were presented to a single hemisphere by use of the lateral limits technique [21], which allows prolonged hemi-field viewing of lateralized stimuli without attachments to the eye. With the head held in position by use of a standard bite board, the subject moves the eyes horizontally until the limit of rotation in that direction is reached (at approximately 45° off the vertical midline for most subjects). All stimuli which appear in the space lateral to this limit are projected only to the contralateral hemisphere. Through use of this technique, stimulus material may be restricted for prolonged durations to the left or right visual hemi-field while remaining in central vision. Limited vertical scanning of lateralized material is also permitted by this design. The subject may cross-compare stimuli presented bilaterally by rotating the eyes first in one direction, then in the other, with the number and duration of viewings in each hemi-field specified by the particular test design.

Within a single visual hemi-field, three line drawings of common objects were presented simultaneously on cards arranged in a vertical choice array. In the opposite hemi-field, a fourth drawing appeared on a slide projection and constituted the sample stimulus. Under the first condition, "concrete association," the sample was related to one of the three choices in the opposite hemi-field in one of two ways. Either a "coordinate" relationship was represented by the correct match (e.g., 'fish' and 'duck' both belong to the category 'animals that go in the water'; Fig. 1A), or a "contingent" relationship was present (e.g., 'shoe' and 'sock' form a functional unit; Fig. 1B). The stimuli and concepts used in the "concrete" test had been preselected from a larger group by seven normal control subjects, who had judged this set to be "affect-neutral."

In the second condition, "abstract association," the sample and the correct answer were related by virtue of a mutual association with a single abstract concept (e.g., 'envelope' and 'telephone' together indicate the concept of 'communication'; Fig. 1C). A full description of the abstract concepts tested appears elsewhere [7]. The group comprised both affective and affect-neutral stimuli and concepts, which were pre-ranked on a scale of "emotionality" by seven normal control subjects, and also ranked by the commissurotomy subjects after all testing had been completed. There was good overall correspondence between the rankings of the two subject groups. These data were later employed in the analysis of affect as a factor in the success of interhemispheric associations (see Results).

For both the "concrete" and "abstract" tests, the sample stimulus and correct answer were predesigned so as to be related only through their intended association and not through any common physical feature. Care was taken that no concrete (e.g., simple functional) match was possible between the sample and any of the choices for the "abstract" test, and, conversely, that no abstract relationship existed between the sample and choices under the "concrete" test condition. In the "concrete" and "abstract" tests, respectively, only one choice specified any categorical/functional or abstract relationship with the sample. Finally, for each trial, the three choices were alike in some general way (e.g., all were tools, or types of food, or hand gestures) so that no one choice would be selected or rejected on the basis of its gross dissimilarity to the others. Thus, a successful match was possible only if (1) one hemisphere had access to at least some of the information contained in the opposite hemisphere, and also (2) the information from the two hemispheres was integrated, and the related underlying concept understood by the responding hemisphere.

Procedure

Interhemispheric test

The subject was instructed to point to the one card of the choice array which was related to the sample presented in the opposite hemi-field. In half of the trials, the sample was projected to the right visual hemi-field (left hemisphere) and the three choices to the left hemi-field (right hemisphere), with the left hand used for pointing to the chosen answer card. In the remaining trials, the sample was projected to the right hemisphere and the choice array to the left, with the right hand used for pointing. The order of the two blocks of trials was then reversed, so that each trial was presented under both the left (sample) to right (response) hemisphere condition and the right to left hemisphere condition. Thirty-two trials (sixteen each of "contingent" and "coordinate" relationships) were presented in each of the two directions for the "concrete" test (T = 64). Twenty-three trials were administered in each direction under the "abstract" condition (T = 46). After pointing, the subject was asked to relate verbally any information pertaining to the stimuli projected to the non-verbal hemisphere or to the concept implied by the integration of the information in the two hemi-fields. All responses were tape recorded.

Intrahemispheric test

In order to establish baseline measures of hemispheric performance against which to compare the results of the interhemispheric test, the same matching task was repeated, using an intrahemispheric format. Within a single visual hemi-field, the four drawings were presented in a vertical array, with the sample appearing on top, as in Fig. 2. The subject was instructed as before to point to the card which was related to the sample. The test was administered in its entirety first to the right hemisphere, then to the left, and finally in free vision, each in separate testing sessions which occurred several days or weeks after interhemispheric testing had been completed. The procedure, including controls against participation of the uninformed hemisphere, is described in detail elsewhere [7]. Under the free vision condition, the subject was asked, after pointing, to describe verbally the relationship between the sample and the chosen answer. If the subject was unable to make a correct match under both right and left hemisphere conditions, and also failed to make and subsequently explain the match in free vision, then that trial was eliminated from analysis of the intrahemispheric results. No trials were excluded from the "concrete" test results on this basis. Of the original 23 trials included in the "abstract" test, two were eliminated from analysis for LB (T = 21), two for NG (T = 21), and five for AA (T = 18).

Free vision errors were also employed in the exclusion of trials from the interhemispheric results. An incorrect match made in both directions (left to right and right to left) and additionally in free vision resulted in the elimination of three "abstract" trials each for subjects NG (T = 20) and AA (T = 20), and none for LB (T = 23). As in the intrahemispheric test, no "concrete" trials were excluded from analysis on this basis for any subject.

RESULTS

Interhemispheric test

"Concrete association," pointing response: Because no differences were observed in the performance of "coordinate" and "contingent" trials, the data of

these two subgroups have been combined to form a single group of results for the "concrete" trials. All subjects performed the "concrete" test at well above chance level in both directions. When the sample was projected to the left hemi-field (right hemisphere) and the response array to the right hemi-field (left hemisphere), a three-subject average of 94% correct was attained. Testing for crossing in the opposite direction, with the left hemisphere viewing the sample and the right the choice array, resulted in an average of 90% correct. All individual results were significant at a level of $p < .01$ (one-tailed binomial test).

"Abstract association," pointing response: Performances on the "abstract" test, although not as strong as on the "concrete," were still well above chance level. A three-subject average of 79% correct was attained for the right hemisphere (sample) to left hemisphere (response) direction, and 83% correct in the opposite direction. The lowest score achieved by any subject (AA: 70% correct, in the right to left hemisphere direction) was still significantly above chance level ($p < .01$).

Differences in the performance levels in the two directions were analyzed for both the "concrete" and "abstract" tests (chi square) and found to be not significant, either for individuals or for the combined three-subject results. A summary of results is presented in Table 1.

Intrahemispheric test

The results of testing for "concrete" and "abstract" association within the right and left hemispheres are detailed in Table 2. The performance levels are comparable to those obtained under the interhemispheric condition both for individuals and across all subjects. No significant left/right hemisphere differences were observed (chi square) for individual or group results. A discussion of the implications of the results of the "abstract" test in regard to right hemisphere cognition and the dissociation of language and cognition appears elsewhere [7].

Verbal report:

The following excerpts from transcripts of the three subjects' verbal reports reveal the diversity of the associations which can cross subcortically between the hemispheres. Experimenter's comments are enclosed in parentheses.

Right hemisphere (sample); left hemisphere (response):

Subject NG

(1) *sample:* devil; *response:* snake; *concept:* evil

"That reminded me of a desert, and that looked like a snake. Snakes are in the desert. (What did you see there?) Sand, way out there in the Mojave desert. (Was it something you think was nice?) No. Hot. [nervous laughing] The desert's hot. (Is the desert good or bad or...) Hot. Oh God, now you're going to make me sweat, thinking about the desert."

(The impression of "hotness," plus possibly a sense of the initial sound of the word "devil," provided the verbal hemisphere with a basis for guessing "desert." NG appeared uncomfortable and agitated during questioning, probably reflecting the successful transfer of emotional as well as cognitive components of the left hemi-field stimulus.)

(2) *sample:* moon; *response;* owl; *concept:* darkness

"The owl... that one there—the sun! When the owl goes ow-owoo [making a sound similar to a dog or coyote howling]. Or the moon, when the owl goes hoo-hoo [making a sound like an owl hooting]. That's what it was, the moon."

(The immediate verbal response, "the sun," indicates the transfer of a specific and subtle associational set concerning "heavenly bodies." The subsequent howl, presumably provided by the right hemisphere, caused the subject to quickly change the initial response to "moon," of which she then appeared confident.)

Subject AA

(1) *sample:* fish; *response:* duck; *concept:* animals in the water

"Both animals that go in the water. (What was on this side? [left hemi-field]) [No response] (You just know it's an animal that goes in the water?) Yes. What's a duck that goes in water? Mallot? (Mallard?) Yes, on this side. [right hemi-field] And *that's* maybe a wooden duck. [left hemi-field] (A decoy?) Yeah... it *could've* been."

(The concept of "animals that go in the water" was clearly present, though it alone could not provide the verbal hemisphere with enough information for it to correctly name the left hemi-field stimulus. The final guess, "wooden duck," lacked conviction.)

Subject LB

(1) *sample*: candle; *response*: lamp; *concept*: things that light

"Lamp, and that's... Lamp, that's the answer. I couldn't tell you what *that* is. [left hemi-field] (Do you have any idea why you picked the lamp?) They both light. Both made me think of light. [long pause] Candle! That's what it is."

("Illumination" was the concept which transferred to the verbal hemisphere, permitting LB to run through the set of "things that light" until he came upon the correct answer, of which he was confident.)

(2) *sample*: gun; *response*: black eye; *concept*: violence

"He had a black eye. (What's the idea?) Uh-huh. (You look kind of curious.) [pause] I think *that* [left hemi-field] hit *that*." [right hemi-field]

(On this trial, the connotations of "violence" which were expressed by the verbal hemisphere were insufficient to provide the name of the left hemi-field stimulus.)

A similar richness of association was observed when trials were administered in the opposite direction. The following examples, excerpted from LB's transcript, are included for purpose of illustration.

Left hemisphere (sample): right hemisphere (response):

(1) *sample*: music stand; *response*: phonograph; *concept*: music

"I know what it is, I'm trying to think of the words. (Do you know why you picked it?) They're both art forms."

(The response "art forms" reveals how sophisticated and complex, and yet imprecise, the nature of the cognitive information is which crosses subcortically.)

(2) *sample*: gun; *response*: black eye; *concept*: violence

[pause after pointing response] (Do you know what you pointed to?) [no response] (No idea?) "Not really.... War, I think. (War?) Yes."

(Compare this response with LB's comments from the same trial when it was administered in the opposite direction. Both sets of remarks relate to the original concept of "violence," but are different manifestations either of the "clues" relayed by the hemisphere perceiving the sample stimulus, or the interpretation of that information by the responding hemisphere, or both).

During the verbal report, subjects were regularly questioned about features of the cards not chosen as the correct match, when the choice array appeared in the right hemisphere. A general inability to provide information on the alternative choices was noted, demonstrating that the choice array had indeed been projected exclusively to the right hemisphere.

Emotionality

The 23 abstract concepts, ranked by the commissurotomy and normal control subjects for "emotionality," are listed in Table 3. No differences were observed between the "high emotional" and "low emotional" blocks of trials for number of successful pointing matches, in either direction. When verbal report is considered, however, it appears that the "high emotional" group of trials elicits description that is greater in amount and quality of associations than does the "low emotional" group, and this effect is observed only for trials that were run in the right hemisphere (sample) to left hemisphere (response) direction. For example, left visual hemi-field presentation to subject NG of a bald eagle, a music stand, a devil, a gun, and an angel elicited the following respective comments: "good, perfect"; "reminds me of when I was a teenager...record players... jukebox...jazz"; "scared"; "accident, ambulance"; "weddings...high blood pressure...funerals." Most of the comments indicate an affective as well as purely cognitive component of the transferred associational set. In contrast, trials in the left hemisphere (sample) to right hemisphere (response) direction yielded verbal report that was relatively restricted in its extent and affective quality.

EXPERIMENT II

On the basis of the demonstrated inability of complete commisssurotomy subjects to identify verbally stimuli appearing in the left visual hemi-field, we may conclude that what does *not* transfer subcortically includes the name of the stimulus. The status of the raw visual image of the stimulus is not so certain. It seems conceivable that the image might cross but, for some reason possibly involving the degradation of the image, cannot be subsequently described by the verbal hemisphere except in terms of imprecise sensory, emotional, functional, or other associations. To test this hypothesis, a second experiment was designed in which the sample and one of the responses were identical. Of the two remaining choices, at least one was related to the sample on a simple concrete level. Thus, if the image itself was crossing to, but could not be described by, the receiving hemisphere, the presence of the identical image in response array should facilitate a match based on physical and associational identity. If, however, only the associations of the original object crossed, and not its raw image, then the responses should divide between the identical choice and the choice(s) sharing certain salient associational features with the original.

METHODS

The same three complete commissurotomy subjects (LB, NG, and AA) participated in this as in Experiment I, again using the "lateral limits" technique. Three line drawings of common objects were displayed in a vertical array within a single visual hemi-field. A fourth drawing was projected to the opposite hemi-field and constituted the sample stimulus. Of the three drawings in the response array, one was identical to the sample, and one or both of the remaining choices shared a common "concrete" feature with the sample. For example, in one of the trials the sample was a sailboat, and the choices included (a) the same sailboat, (b) an ocean liner, and (c) a rowboat. A match based on visual identity would be expected to result in the choice of (a), while a match based on connotations (e.g., "goes in the water," or even "boat") could result in the choice of either (a), (b), or (c). As in Experiment I, pointing responses were followed by attempts to verbally describe the stimuli and concepts. Eight trials were administered in each direction (left to right, and right to left hemisphere) for each subject.

RESULTS

Since identical stimuli would be expected to give a better "match" of the associations they elicit than would related but non-identical stimuli, it is not surprising that the most frequent response was, in fact, the choice card identical to the one in the opposite field. However, considering the surprising number of responses other than the identical choice, the idea of a visual image (even if degraded) crossing subcortically between the hemispheres is not supported.

Verbal report offers support to the alternative proposal, that matches are made on the basis of non-specific associations linking the stimuli in opposite hemispheres. Subjects could, for example, name a category (e.g., "fruit") appropriate to their chosen response (e.g., "apple") without being able to name the sample object itself (e.g., "pear"). Additionally, even when they did point to the response card that was identical to the sample, they often seemed to be unaware that it was identical, and still could not name the left hemi-field stimulus. The results are detailed in Table 4.

DISCUSSION

The demonstration of subcortical involvement in high-level cognitive processes greatly extends previous findings of interhemispheric integration of symbolic stimuli [11, 12, 22] and transfer of affective and connotative material [29] in the absence of the forebrain commissures. In the present study, the information amenable to subcortical transfer is found to be of an order of complexity comparable to that which can be processed within the individual hemispheres for the same tasks. Further, purely cognitive elements of informational sets may be relayed equally well in the right to left, or left to right hemisphere direction for affect-neutral stimuli and concepts.

When affect is included as a stimulus variable, it is again found that information transfer and integration is equally effective in either direction (as evidenced by the relative number of correct pointing responses), but also that the right hemisphere (sample) to left (response) trials appear to lend themselves better to subsequent verbal description than do the trials run in the opposite direction. The increased risk of information loss that is incurred under conditions of double transfer may partly account for the quantitative and qualitative differences in verbal report observed for trials involving the right hemisphere (sample) to left (pointing and verbal response) direction (an example of single transfer) *vs* the left (sample) to right (pointing response) to left (verbal response) direction (an example of double transfer). An alternative explanation of this direction-specific difference in verbal performance involves the suggestion that sensory-limbic connections are more extensive within the right than the left hemisphere [1]. The right hemisphere, for which a special role in emotional function is generally postulated (e.g., 4), would be expected both to generate more associations of an affective nature than would the left, and to transfer these associations effectively to other brain areas via limbic and other subcortical pathways. The current results do not directly distinguish between these two possible explanations. However, the fact that the verbal description of affect-neutral trials reveals no such direction-specific difference argues against the model which attributes poor verbal description to any loss of information occasioned by double transfer *per se*.

In contrast to the observed complexity of the concepts which may be integrated subcortically, the means by which the information is transferred between the hemispheres does not seem to include highly-developed linguistic or perceptual processes. The inability of split-brain subjects to name stimuli projected to the right hemisphere is well documented (e.g., 28), implying that any verbal label for the information held by the right hemisphere is not transferred to the left. Additionally, in regard to the possible transfer of percepts, it is found that the projection of identical stimuli to each hemisphere does not necessarily elicit the subjective realization of identity in these subjects, and they often make matches based on associational relationships rather than physical resemblance. From these data it appears that it is not the raw visual image—intact or degraded—which can cross subcortically. Rather, it is the associations extracted from the image which successfully employ subcortical channels of interhemispheric relay. These associations may be affective [29], sensory [20], functional, categorical, or even abstract. By themselves, they are insufficiently precise to allow specific identification of a unilaterally presented stimulus by the opposite hemisphere. However, the presence of an entire associational set comprising what might be thought of as the "essence" of the object, divorced from its physical image and its verbal label, can be demonstrated through use of multiple-choice arrays of objects which are related in various ways to the sample in the opposite hemi-field. These associational sets are in themselves richly informational, and are shown to influence the decisions being made by a hemisphere working with an incomplete information base.

Recent observations indicate that there are features of an object besides language and physical image which cannot be transferred interhemispherically except in the presence of the forebrain commissures. For complete commissurotomy subjects, a complex geometric shape cannot be successfully matched with a depiction in the opposite hemisphere of the same object rotated in space, though the same match may be accomplished within either hemisphere

(K. JOHNSON, unpublished data). This observation suggests that spatial orientation may, like language, be dissociable from other perceptual and cognitive aspects of the same object. It also reinforces the finding of the present study, that raw visual images do not themselves transfer subcortically between the cerebral hemispheres. Further support for the idea of purely associational transfer comes from recent evidence that subject LB, for whom either hemisphere easily learns paired-associate tasks involving pairs of affect-neutral, arbitrarily related (i.e., in fact unrelated) pictures, performs the same task at chance level when the sample is presented to the right hemisphere and a three-choice response array to the left (CRONIN-GOLOMB, unpublished data). Performance is, in contrast, well above chance level in the left hemisphere (sample) to right (response) direction. Thus, for the same direction in which subcortical transfer is selectively amplified when affective information is involved, it also appears that objects must be related in some meaningful, rather than arbitrary way in order for the subcortical relay of the association to occur. Whether affect and "meaningfulness" are independent stimulus variables or fundamentally related ones (i.e., emotion imbues an object with meaning or *vice versa*) is not answerable on the basis of the present findings, but it may be noted that work conducted with normal subjects indicates that the two are to some degree dissociable [14, 25, 34].

The classification of an object's features on the basis of how well they transfer between the hemispheres via the subcortex, besides providing a catalogue of possible uses for subcortical pathways, has implications as well for the structure of cognition within each cerebral hemisphere. Verbal identity, visual image, spatial orientation, affective composition, and semantic associations are found to be discrete and dissociable elements of a stimulus. Moreover, those elements which cannot cross subcortically include those that are often considered to involve functions dominated by one or the other hemisphere, e.g., language (left hemisphere) and visuospatial processes such as spatial rotation (right hemisphere). In contrast, the "disembodied" associations which transfer relatively freely through the subcortex are also present in both hemispheres to an equal extent, as indicated by tests of intrahemispheric concept comprehension. The bidirectional success of subcortical transfer of cognitive information, equal under left to right and right to left conditions (though perhaps selectively amplified in one direction by affective components, and also possibly dependent on the meaningfulness of the association) further suggests that there is a subset of cognitive processes common to both hemispheres. This type of cognition would involve semantic and sensory associational networks, but not necessarily include functions which have become specialities of one or the other hemisphere.

One may naturally speculate on the historical relationship between the old (subcortical) brain and those cognitive processes which may predate the evolution both of lateralized functions such as language and high-order visuospatial operations, and of new structures accompanying this development of hemispheric specialization, such as the neocommissures. It is also interesting to consider the possibility that preverbal thought, as in young children, may be characterized by rich though mutable associations between objects, which give way to increasingly specific verbal and perceptual correlates of the object as functional lateralization becomes more complete. Reliance on the common associational nets which can be supported by subcortical pathways is, however, not necessarily eliminated in the adult, as demonstrated in complete commissurotomy subjects. This connotational system may turn out to be the cognitive substrate of, for example, déja vu and tip-of-the-tongue experiences in the normal human. But however intriguing the questions of the evolution and development of thought may be, our present lack of knowledge concerning the contributions of the subcortex to cortical cognitive function underscores the need for more extensive analysis of the basic nature of cognitive information and the mechanics of its transfer in the modern human brain.

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TABLE 1: Scores on interhemispheric test of concept comprehension.

Chance level = 33 1/3% correct.

			LVF[a] (sample) : RVF[b] (response)		RVF (sample) : LVF (response)	
SUBJECT	AGE/SEX	# TRIALS/ DIRECTION	# CORRECT	% CORRECT	# CORRECT	% CORRECT
			Concrete Concepts			
L.B.	31 M	32	31	97**	30	94**
N.G.	50 F	32	32	100**	29	91**
A.A.	32 M	32	27	84**	27	84**
3 subject average				94		90
			Abstract Concepts			
L.B.		23	20	87**	21	91**
N.G.		20	16	80**	16	80**
A.A.		20	14	70**	15	75**
3 subject average				79		83

**p<.01, one-tailed binomial test

a: (LVF) Left visual hemi-field

b: (RVF) Right visual hemi-field

TABLE 2: Scores on intrahemispheric test of concept comprehension.

Chance level = 33 1/3% correct.

SUBJECT	# TRIALS/ HEMI-FIELD	LEFT HEMI-FIELD/RIGHT HEMISPHERE # CORRECT	LEFT HEMI-FIELD/RIGHT HEMISPHERE % CORRECT	RIGHT HEMI-FIELD/LEFT HEMISPHERE # CORRECT	RIGHT HEMI-FIELD/LEFT HEMISPHERE % CORRECT
			Concrete Concepts		
L.B.	32	25	78**	32	100**
N.G.	32	26	81**	29	91**
A.A.	32	29	91**	29	91**
3 subject average			83		94
			Abstract Concepts		
L.B.	21	19	90**	20	95**
N.G.	21	15	71**	19	90**
A.A.	18	15	83**	15	83**
3 subject average			82		90

**p<.01, one-tailed binomial test

TABLE 3: Abstract concepts, ranked by increasing emotionality

(Low)	(Middle)	(High)
1. nationality	10. art	15. chance
2. time	11. disability	16. truth
3. prohibition	12. music	17. freedom
4. negligence	13. darkness	18. evil
5. lack	14. slowness	19. military
6. silence		20. patriotism
7. government		21. goodness
8. communication		22. violence
9. necessity		23. danger

TABLE 4: Scores on interhemispheric test of identical matches.

Chance level = 33 1/3% correct

SUBJECT	# TRIALS/ DIRECTION	LVFa (sample) : RVFb (response) Identical match, aware of identity	Identical match, unaware of identity	Other responses	RVF (sample) : LVF (response) Identical match, aware of identity	Identical match, unaware of identity	Other responses
L.B.	8	1	3	4	2	2	4
N.G.	8	1	4	3	0	7	1
A.A.	8	4	2	2	5	1	2
		-	-	-	-	-	-
3 subject total		6	9	9	7	10	7

a: (LVF) Left visual hemi-field

b: (RVF) Right visual hemi-field

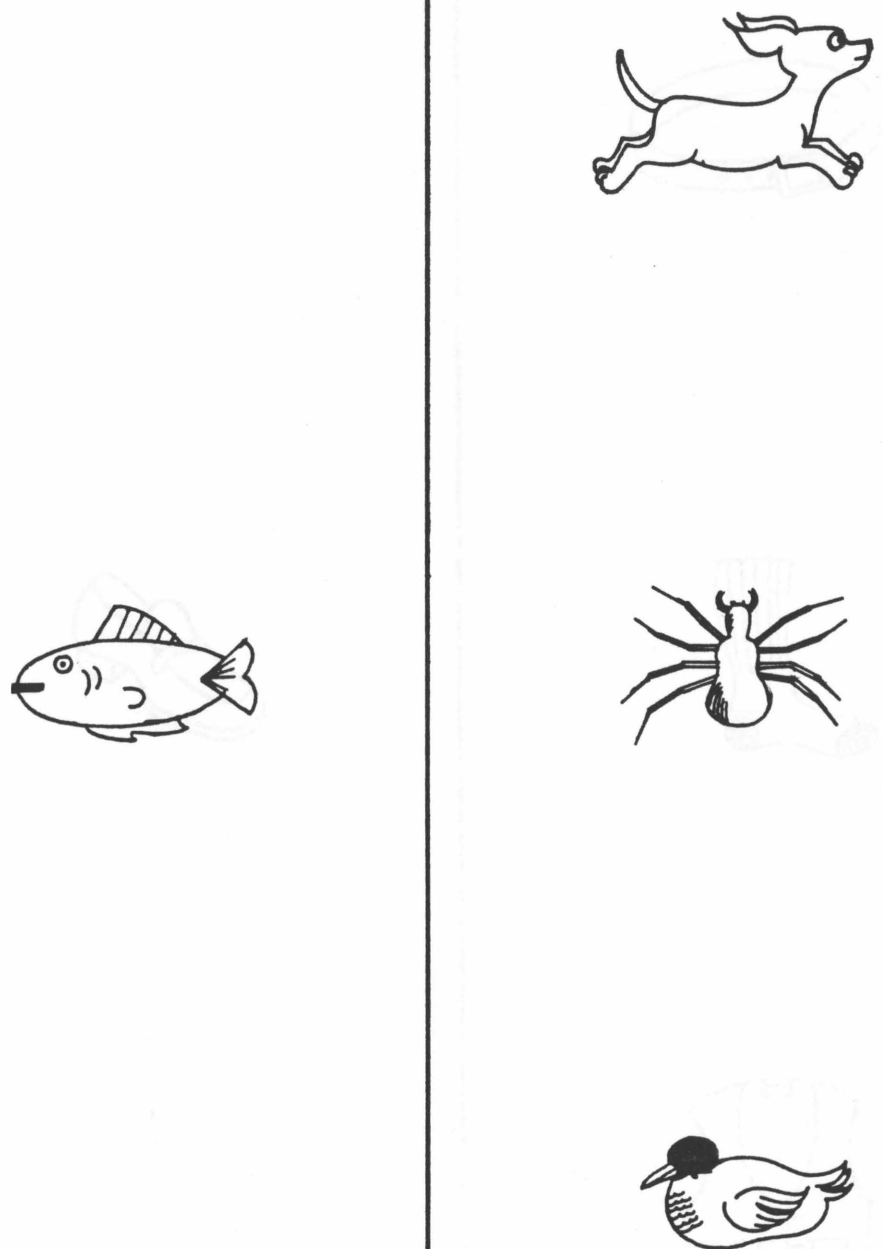

Fig. 1a

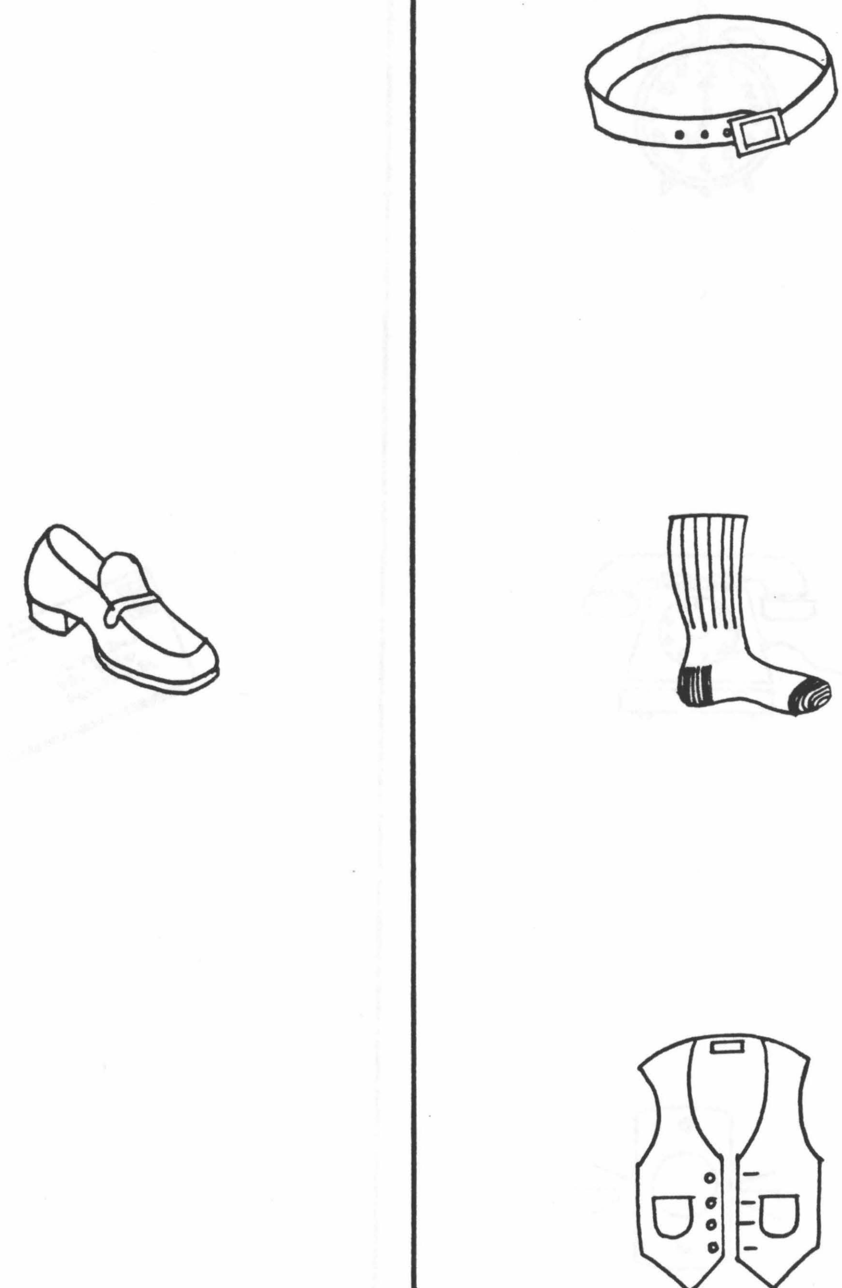

Fig. 1b

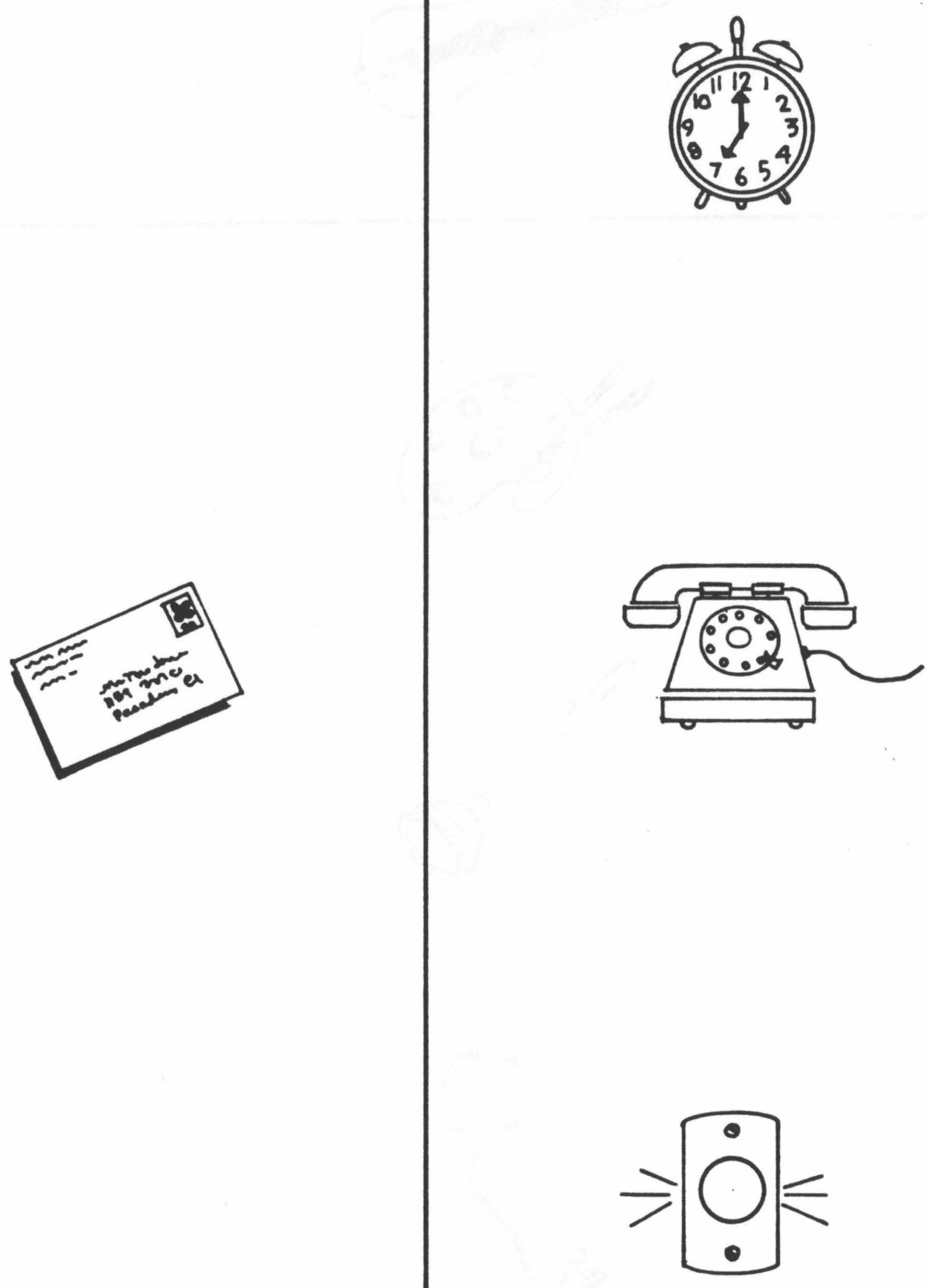

Fig. 1c

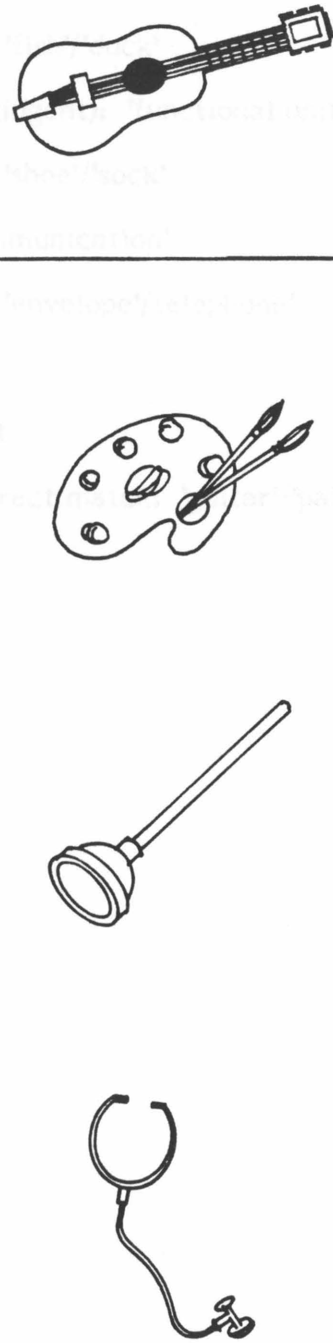

Fig. 2

FIGURE LEGENDS

FIG. 1. Interhemispheric test

a) Concrete concept (coordinate): 'animals that go in the water'

Correct match: 'fish'/'duck'

b) Concrete concept (contingent): 'functional unit'

Correct match: 'shoe'/'sock'

c) Abstract concept: 'communication'

Correct match: 'envelope'/telephone'

FIG. 2. Intrahemispheric test

Abstract concept: 'art'. Correct match: 'guitar'/'pallete'

CHAPTER 3

FIGURE-BACKGROUND PERCEPTION IN RIGHT AND LEFT HEMISPHERES OF HUMAN COMMISSUROTOMY SUBJECTS

Minds that have nothing to confer
Find little to perceive.

Wordsworth

Abstract--The right and left hemispheres of four complete commissurotomy subjects were tested for the ability to recognize and integrate figure and background elements of composite visual stimuli. In the first experiment, the subjects were required to identify from a four-choice array in free vision the stimulus card which matched the briefly lateralized (150 msec) sample. The left hemisphere of each subject performed very well in identifying the figure, but at near-chance level in recognizing the background. In contrast, the right hemisphere was equally adept at identifying figures and grounds. Both hemispheres could easily identify the isolated "figure" or "ground" from a choice array, demonstrating that the observed hemisphere effects were due to figure-ground interactions rather than difficulty in processing specific elements of the composite stimulus. The second experiment involved the determination of the size and position of a dot which appeared against various plain and textured backgrounds. The right hemisphere, but not the left, of two subjects performed with greater accuracy when the background consisted of a "natural" texture gradient, rather than a plain white backing, an inverted gradient, or an evenly spaced grid. Additionally, right hemisphere performance was better on trials in which a relatively "correct" relationship of dot size and position occurred (in terms of constancy scaling) than for trials involving incorrect scaling relations. These results implicate the right hemisphere in (1) the recognition of background components of a whole-field stimulus, (2) sensitivity to the influence of the background on the perception of an object, and (3) the ability to use natural visual cues to assist in the accurate perception of an object.

INTRODUCTION

Beginning with RUBIN'S observations in 1915 [41], there have been a large number of attempts to define and study the separation of the visual world into figure and background. The great interest in this question demonstrated by clinicians and theorists alike can be attributed to the fact that an object's surroundings can influence how that object is perceived by the human visual system. This fundamental principle of perception, developed by the Gestalt psychologists (e.g., [20]) and recently reinforced with psychophysical evidence [52], has been invoked to explain the mechanics of normal perception [7] as well as aberrations in perception such as visual agnosia [46] and impaired performance of brain-damaged children [51] and adults [44] on a variety of visual and tactual tasks.

Over the past several years, experiments on normal subjects and on patients with severed cerebral commissures, with epilepsy, with unilateral lesions, and with other types of brain damage have been conducted with the intention of investigating the lateralization of "Gestalt" processes. Although "Gestalt" in its original sense incorporated the influences of the total field--i.e., ground as well as figure [20]--, much lateralization research has been confined to the study of figure perception, exclusively. The result has been a cataloguing of various right and left hemisphere skills in regard to the processing of form. The right hemisphere has been found to be superior to the left at recognizing unfamiliar objects [19, 26, 29-30, 32-33, 48], overlapping figures [11, 40, 43], geometric shapes [13, 34], and faces [1, 6, 10, 26, 31, 47]. It has also been implicated in the discrimination of stimulus size [50], the performance of visual closure [11-12, 23, 35-36, 48] and the ability to recognize objects viewed at unconventional angles [49]. The left hemisphere, on the other hand, has been found to be superior for form perception chiefly when it involves the recognition of familiar objects [2, 5, 26, 53]. It is proposed that the differential skills of the two hemispheres in regard to form perception are closely related to the ease with which a form may be verbally labeled [19, 30].

The little evidence available which specifically concerns the relationship of an object to its spatial context suggests that it is the right hemisphere which is most sensitive to context effects. For example, damage to the right hemisphere is accompanied by impaired ability to set slanted lines to the vertical or horizontal axis [28]. On the basis of this sort of observation, together with reports of a greater right hemisphere susceptibility to certain optical illusions [16, 21-22], it has been proposed that the right hemisphere is more "field dependent" than the left (e.g., [21-22]).

The purpose of this study is to directly test the hypothesis that the ability to distinguish figure from background is lateralized in the human brain. The following two experiments were designed to establish whether the hemispheres differentially process figure and ground information, and also to what extent various backgrounds may affect perception of a figure for either hemisphere. Besides providing information on the brain correlates of a basic perceptual process, evidence for differential hemisphere perception of a whole visual scene would hold implications for the "cognitive strategies" theory of lateralization, which describes the verbal left hemisphere as focal, sequential, and analytical in its method of information processing, and the right hemisphere as holistic and synthetic in its processing style [3, 27, 35, 37-38].

EXPERIMENT I

METHODS

Subjects

Four patients of the Vogel-Bogen series were tested. All had undergone complete surgical division of the forebrain commissures at least 15 years previously for treatment for intractable epilepsy. In addition to the corpus callosum, the anterior and hippocampal commissures were completely sectioned, as was the massa intermedia when encountered. Extra-callosal brain damage is considered to be minimal for LB and NG, with some indication of right frontal and left fronto-parietal damage in AA. Pre-surgical seizures in RY may have had a right posterior cortical origin. All subjects are right handed and have left hemisphere speech. Their case histories are described in detail elsewhere [4]. Four right-handed normal adults served as control subjects.

Stimuli

Figures: "Figure" stimuli included four amorphous black forms, each measuring approximately 1.6 cm in diameter (Fig. 1A). All control subjects and two commissurotomy patients (LB and NG) provided unsolicited one-word descriptions of the figures after the testing session was over. The other two subjects (RY and AA) likewise readily gave descriptions of the figures when the experimenter asked after testing, "What did you think of that task?" The verbal label assigned to each figure was different for each subject.

Grounds: The "background" stimulus cards consisted of four "Gibson gradients" [14], i.e., regular patterns which appear to recede toward the top of the card (Fig. 1B). These gradients were employed to give the two-dimensional card surface, as much as possible, a "ground-like," three-dimensional character. Neither LB, RY, nor AA assigned a label to any background, even when asked afterwards to give their impressions of the test. Only subject NG provided unsolicited verbal descriptions of the backgrounds (e.g., calling Fig. 1B, d, "raindrops").

Stimulus cards: Each stimulus card measured 6.5 x 6.5 cm, which corresponded to the same number of degrees of visual field when the cards were presented tachistoscopically. For each card, one of the four figures was centered on one of the four backgrounds. All of the 16 possible combinations of four figures and four backgrounds were employed in the test.

Answer arrays: Each figure-ground combination appeared in two of a total of eight choice arrays, each of which consisted of four cards arranged in a 2 x 2 display. In the "Figure" array, the four choice cards consisted of the four different figures, all appearing in combination with a single background (e.g., Fig. 2). Conversely, for the "Ground" array, a single figure was presented against each of the four different backgrounds (e.g., Fig. 3). Two versions of each answer card were alternately employed, with the four choices occupying different quadrants of the answer array for each version. This design variation was employed so that any perseveration effects involving particular quadrant positions could be identified.

Procedure

A Gerbrands two-channel tachistoscope was used for stimulus presentation. The non-dominant left eye was covered with a soft patch for each subject. Stimulus cards were then presented monocularly for 150 msec, immediately preceded by a fixation point ("#"; 0.8° in diameter) of 500 msec duration, which appeared in the center of the field of view. Each card appeared completely within the right or left visual hemi-field, and occupied the area extending between 1.5 and 8.0° lateral of the vertical midline.

The subject was instructed to look into the "box" after hearing a click, which was emitted from a device manipulated by the experimenter. While the subject viewed the sample stimulus, one of the two possible answer arrays that included the card identical to the sample was placed on the table directly in front of the subject. The mode of response involved pointing to the choice in free vision which matched the lateralized sample. The order of presentation on "Figure" and "Ground" arrays was randomized, so that the subjects could not know in advance of the presentation whether they would be expected to recognize the figure or the background of the lateralized combination. The "Figure" task thus involved identification of the correct figure (i.e., the one that matched the figure presented in the lateralized sample) from the four-choice array of answer cards consisting of four different figures, each appearing against the same background as that displayed in the sample. Likewise, for the "Ground" task, the subject was instructed to choose from the answer array the background which matched the one appearing in the sample, while the figure presented in the sample and all four choice cards was held constant. Subjects were encouraged to guess rather than not to respond.

Each of the 16 figure-ground combinations was presented four times to each visual hemi-field (T = 128), during two of which trials it was paired with the appropriate "Figure" answer array, and twice with the "Ground" array. The right hand was used for pointing in half the trials, and the left for the remaining trials, with the order of hand use determined randomly for each subject. Each hand was tested in a separate session. The order of presentation of the sample cards was pseudorandom, with the constraint being that neither hemi-field be tested more than three consecutive times.

RESULTS

The hand used for response was not a factor in the test results, and the data were consequently combined for all analyses.

Combined results

Comparison of the performance of the subjects' two hemispheres on a single task ("Figure" or "Ground"), and of a single hemisphere on the two tasks, gave the results which appear in Table 1. In addition to the single-subject comparisons (measured with chi-square, using Yates' correction for continuity), an analysis of variance was performed on the combined four-subject results. A two-way interaction of (hemisphere x task) was noted ($p < 0.06$), with a simple main effect occurring for (task x left hemisphere) ($p < 0.05$).

The following trends are reflected in the combined four-subject data: (1) the left hemisphere is somewhat better than the right at the "Figure" task; (2) the right hemisphere is better than the left on the "Ground" task (except for subject NG, who presumably used a verbal strategy to code the backgrounds, as she did the figures, in the left hemisphere); (3) the left hemisphere performs the "Figure" task at a high level of competence but the "Ground" task at chance level (again, excepting NG). This differential ability of the left hemisphere to perform the two tasks is the single largest source of variance for the four-subject results. (4) The right hemisphere performs the two tasks equally well. The results indicate a gradient of performance, with the highest score being attained by the left hemisphere on the "Figure" task, followed by good right hemisphere scores on both the "Figure" and "Ground" tasks, and finally the relatively poor showing of the left hemisphere on the "Ground" task.

Individual results

Left hemisphere performance: All four subjects performed the "Figure" task at well above chance level ($p < 0.01$, one-tailed binomial test). Performances on the "Ground" task were generally inferior, with only one subject (NG) demonstrating a high level of proficiency. It will be recalled that NG was the only subject who gave a verbal description of the backgrounds as well as the figures upon completing the test (see *Stimuli*). Subject RY showed perseveration of response, for the "Ground" task only. The general discrepancy between performances on the "Figure" and "Ground" tasks for the commissurotomy subjects is illustrated in Fig. 4. Control subjects made virtually no errors under either the "Figure" or "Ground" condition.

Right hemisphere performance: In contrast to the large difference in ability to perform the two tasks shown by the left hemisphere, the right hemisphere of each of the four subjects was equally proficient at the "Figure" and "Ground" components of the test. Subjects NG, LB, and AA demonstrated a high aptitude on both tasks ($p < 0.01$, one-tailed binomial test), while RY's scores did not exceed chance level as a result of perseveration of response throughout testing of the right hemisphere. The results are depicted in Fig. 5. As before, control subjects performed the test essentially perfectly when the left hemi-field was tested.

"Figure" and "Ground" controls: The large difference in performance on the "Figure" and "Ground" tasks observed only for the left hemisphere indicates its relative difficulty in recognizing the background gradient of the stimulus composition. In order to establish that this result reflects figure-ground dynamics and not some specific inability of the left hemisphere to discriminate pattern gradients, a separate test was run involving unilateral presentation of the four "figures" without the backgrounds (i.e., on plain white backings, as in Fig. 1A), and the four sets of background gradients without figures (Fig. 1B). The procedure was identical to the one already described, with 16 trials administered to each hemi-field. Both hemispheres of three commissurotomy subjects (NG, LB, and AA) and also all control subjects performed the test with virtually no errors, using either hand for pointing. As before, RY showed perseveration of response whenever the right hemisphere was tested, though his left hemisphere performed both the "figure" and "ground" discriminations at a high level of proficiency.

DISCUSSION

The difference in performance on the "Figure" and "Ground" tasks demonstrated by the left hemisphere is the result of its relative inability to identify the background elements of a visual composition. When presented alone instead of simultaneously with a well-differentiated figure, the same "background" is easily discriminated, even for the one subject (RY) who had shown perseveration when the elements were presented together. This result indicates that it is the presence of a figure-ground interaction, and not the basic nature of the isolated "figure" and "ground" elements of the composition, which compels the left hemisphere to preferentially attend to figures rather than backgrounds. This effect is consistent with reports which describe the left hemisphere as the one which analyzes individual details rather than Gestalts [3, 27, 37-38]. Verbal labeling may be involved in the facilitation of figure identification. As noted at the end of testing, all subjects had provided one-word labels for each figure, but only one (NG) volunteered such a description for any background as well. The fact that NG was the one subject who demonstrated a left hemisphere proficiency for identifying backgrounds as well as figures further implicates verbal labeling in the subsequent success of stimulus recognition by the left hemisphere.

Unlike the left, the right hemisphere performed equally well on the two tasks. Because it processes information from both the figure and the background elements of a composition, its somewhat lower overall performance relative to that of the left hemisphere on the "Figure" task alone may reflect capacity effects, rather than an inherent inferiority in processing either figures or backgrounds. Like the left, the right hemispheres of the three subjects who did not show perseveration of response (NG, LB, and AA) were highly competent at discriminating the isolated "figure" and "background" stimuli. The results support earlier descriptions of the right hemisphere as a holistic processor, the domain of which is the comprehension of Gestalts rather than fine detail [3, 27, 35, 37-38]. These findings also suggest a basis for the observed relationship between the cognitive dimension of field dependence and the extent of functional lateralization in an individual [39, 54].

In the following experiment, the results of a more direct examination of the influence of the background on how a figure is actually perceived by the two hemispheres will be described.

EXPERIMENT II

METHODS

The same four complete commissurotomy subjects (NG, LB, RY, and AA) who had participated in Experiment I were included in the present study. Two normal adults served as control subjects. As before, the method involved brief (150 msec) tachistoscopic presentation of lateralized stimuli.

Stimuli

Figures and backgrounds: Solid black dots of three sizes were used, of diameters 0.3, 0.8, and 1.3 cm, which corresponded to the same number of degrees of visual field when presented in the tachistoscope. Each dot appeared on a 6 x 7 cm card, of which the medial edge was located 1.5° left or right of the vertical midline. Two types of background accompanied the dots. For Test A, a plain white background was used. For Test B, a gradient of receding horizontal lines identical to one of those used in the previous experiment was employed as background (Fig. 1B, a). As before, this type of gradient was chosen to simulate, as much as possible on a two-dimensional surface, a three-dimensional background. The dots were located in one of three positions on the background cards. All were horizontally centered. On the vertical axis, one position was located at the card's center, and the upper and lower positions were found 2 cm above and below the vertical center, respectively. Thus, nine combinations of size and position were possible--large, medium and small sizes x top, middle, and bottom positions--for each test condition.

Answer arrays: The nine possible answer cards for any one background condition were arranged in a 3 x 3 display presented in free vision. Dot size increased from left to right for each of the three rows of cards, with position remaining constant within a row. Dot position varied from "high" to "low" with progression from the top to the bottom card of any column. Size was constant within any one column. Thus, the smallest dot in the highest position appeared in the upper left corner of the array, and the largest dot in the lowest position was found in the lower right corner. Earlier pilot work using an alternate 3 x 3 choice array (with changes in dot size a function of location within a column, and changes in dot position related to location within a row) indicated that the specific location of an answer card in the 3 x 3 choice matrix had no effect on performance under either background condition.

For Test A (a plain white background), both the sample stimuli and all possible choice cards of the answer array were composed of a dot against a plain background, while for Test B ("textured" ground), all samples and answer choices included the textured ground.

Procedure

Each of the nine sample cards was presented eight times to each hemisphere under each of the two background conditions. In half the trials, the right hand was used for pointing, with the left hand responding in the remaining trials. Order of stimulus presentation to the two hemi-fields was pseudorandom, such that neither hemisphere was presented with sample cards more than three times in succession. The order of test conditions followed an ABBA design: 36 trials were conducted under condition A, followed by work on some unrelated task, followed by 36 trials under condition B. In the next session, the order of test conditions was reversed (thus, B-A), but the same hand was used for pointing. The other hand was tested in like manner, with order of hand use randomly assigned for each subject.

RESULTS

Results were grouped into four categories: (1) no errors; (2) size alone correct; (3) position alone correct; and (4) both size and position incorrect. The total abilities of the right and left hemispheres to identify dot size and position were compared under each background condition, using a two-tailed chi-square test with Yates' correction for continuity. Additionally, any change in one hemisphere's ability to determine size and position on a particular trial as a result of background condition was analyzed by use of the McNemar test for the significance of changes, a modification of the chi-square (two-tailed) [45].

Neither the order of presentation of background condition (A-B or B-A) nor the hand used for response yielded differences in test results for any subject. All data were therefore combined into two groups, reflecting the responses made under test conditions A and B.

As shown in Table 2, subjects NG and AA demonstrated a general right hemisphere superiority for this size-position task, especially when background B was used. LB performed very well with either hemisphere under either background condition, and RY showed perseveration of response throughout the test. Apart from the overall performance levels attained by each subject, the significance of changes in performance on individual trials as a function of background condition was also measured, and the results are presented in Table 3. Both control subjects performed the test equally well for the two hemi-fields, with scores under condition B being significantly higher than under condition A. For both subjects (NG and AA) who had demonstrated neither perseveration (as did RY) or a ceiling effect (as did LB), improvement of performance was directly related to use of the gradient (as opposed to plain) background. Moreover, this effect was observed only for the right hemisphere. In contrast, left hemisphere performance appeared to be independent of the background used.

The four subjects showed no general propensity to make size *vs* position errors. Additionally, no systematic changes in perceived size or position of dots as a function of background or hemisphere were observed in the four-subject results. That is, subjects did not tend to generally under- or overestimate dot size, or to systematically misjudge the position. However, when the stimulus cards are categorized according to how "correct" the size and position of the dots are, in terms of constancy scaling, additional hemisphere differences in performance are revealed. "Correct" cards have the largest dots at the bottom of the card ("foreground"), medium-sized dots in the middle, and the smallest dots ("farthest away") at the top. Cards designated "-1" displace the correct size and position by one unit; thus, a small dot or large dot in the middle, or a medium-sized dot at the top or bottom of the card. The last group ("-2") contains displacements of two units: a small dot on the bottom, or a large dot on top. Trials in which errors were made in both size and position were small in number, and so were disregarded in this analysis. For comparisons between categories, correction was made for the size of the category. Errors in size or in position are considered together, as no significant differences between them were indicated by the data.

Trials presented to the right hemisphere were more often performed successfully if the size and position of the dot represented a relatively correct constancy-scaling relationship. This effect held for subjects NG ("correct" >"-2," $p < 0.05$, condition A; "-1" >"-2," $p < 0.05$, condition A), LB ("correct" >"-2," p <0.05, combined A + B; "-1" >"-2," p <0.05, combined A + B), and AA ("correct" >"-2," p<0.05, combined A + B). In only one instance did the effect lie in the opposite direction ("-2" > "-1," p <0.05, subject NG, condition B). Interestingly, in all cases where any difference was seen in left hemisphere performance on trials categorized by these same constancy-scaling relations, superior performance was related to the relative <u>incorrectness</u> of the relationship. This result was observed for NG ("-2" >"correct," p <0.01, condition A; "-2" >"-1," p <0.05, condition B; "-2" > "correct" and "-2" >"-1," each p <0.05, combined A + B), and also for RY ("-2" >"-1," p<0.05, condition B). Thus, the relationship between right hemisphere performance and relatively correctly scaled dots is a direct one, while it is inverse for the left hemisphere. Background does not appear to be a systematic influence.

In order to determine whether the nature of the background gradient was important in the establishment of the observed hemisphere effects, the same test was run using (1) the same gradient, inverted; and (2) a grid of equally spaced lines, of the same number as appeared in the original (or inverted) gradient (Fig. 6). The highly-significant improvement in performance which had been observed for the right hemispheres of subjects NG and AA, under the "natural" gradient, relative to the plain background condition, did not occur with either of the new backgrounds. Left hemisphere performance did not vary with the new background conditions.

DISCUSSION

The results of Experiment II indicate that the perception of an object by the right hemisphere of complete commissurotomy subjects is influenced by the composition of the background. The right hemisphere, but not the left, is selectively facilitated in the recognition of perceptual features of a stimulus by the presence of a textured background which simulates a "natural" gradient in depth. "Unnatural" gradients (including evenly-spaced grids, and inverted gradients of lines receding toward the bottom of the card) do not provide this facilitation. This finding supports the notion that the right hemisphere is more field-dependent than the left (e.g., [21-22]), though it appears that there may be restrictions on the type of field which optimally influences object perception in the right hemisphere. (Here, only a "natural" gradient effectively facilitated the perception of the figures.)

Additionally, it has been demonstrated that the right hemisphere is more accurate at perceiving objects of which the size and position in space conform to, rather than contradict, the rules of constancy scaling; i.e., small objects seem to lie high in the visual field, and larger objects appear relatively lower in the same frame. This result directly implicates the right hemisphere in the processing of perspective cues, which may in turn explain the observed right hemisphere susceptibility to those optical illusions such as the Ponzo [16], which have been described in terms of perspective relations [15].

The observed instances of left hemisphere involvement in recognizing relatively incorrect scaling relationships may be a manifestation of that hemisphere's propensity to seek out and process significant details of a field, as was demonstrated in Experiment I. Unusual perspective cues would be expected to elicit the attention of the analytic left hemisphere, while a correct relationship between object and field would not warrant such extraordinary analysis. A similar left hemisphere involvement in "basic" perceptual processes has been observed for the discrimination of "texton" pairs [9], which is proposed to involve a shift in use from a pre-attentive (or "ground") visual system, to an attentive (or "figural") visual system, whenever there is a change in local conspicuous features, or "textons" [17-18].

Taken together, the results of Experiments I and II establish the right hemisphere as the domain of figure-background interactions. It is seen that the left hemisphere specializes in figure perception only, and that the right is competent at perceiving both figures and backgrounds. The present findings differ in this latter respect from those of a recent study of normal females, which assigned figure and ground perception to the left and right hemispheres, respectively [42]. The present results make clear that the right hemisphere perceives figures as well as it does backgrounds, an arrangement which would appear to be more conducive to the observed figure-ground interactions than would the functional separation of figure and background in the respective hemispheres.

The present findings extend the work of perceptualists such as BRAUNSTEIN and GIBSON, who have postulated that all the information necessary for perspective viewing and depth perception, respectively, is contained in the visual stimulus, and does not need to be inferred by the viewer [8, 14]. The differential abilities of the two hemispheres to selectively employ some stimulus material present in the visual field to influence the simultaneous perception of another stimulus would appear to involve cerebral processes of a high order of complexity, especially for the general figure-ground processor, the right hemisphere. As an example of a general visuospatial skill, the demonstrated right hemisphere specialization for figure-ground interaction also acts to supersede claims of a more restricted role for that hemisphere, i.e., in specifically manipulospatial processing [24-25]. Clearly, the present tasks of figure-ground discrimination require no more complex a manual involvement than a simple pointing response. Relevant effects of this specialization in the normal brain may possibly involve the perception of optical illusions and the behavioral correlates of field dependence, neither of which is explainable in terms of manual activity. Finally, the present study indicates that normal adults are influenced by background components of a field in the same way as is the disconnected right hemisphere of individual commissurotomy subjects. This result suggests a direct role for the right hemisphere in specific perceptual processes in the normal, intact brain.

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Table 1. Hemisphere performance on "Figure" and "Ground" recognition tasks.
correct, of 32 trials per (hemisphere x task).
Chance level = 25% correct (= 8)

	Comparison between hemispheres for one task		Comparison between tasks for one hemisphere	
Subject	LH/F:RH/F	LH/G:RH/G	LH/F:LH/G	RH/F:RH/G
LB	32:28 n.s.	13:28 **	32:13 **	28:28 n.s.
AA	21:17 n.s.	9:15 n.s.	21: 9 **	17:15 n.s.
RY	26: 8 **	5: 8 n.s.	26: 5 **	8: 8 n.s.
NG	30:28 n.s.	26:25 n.s.	30:26 n.s.	28:25 n.s.
4-subject totals	109:81	53:76	109:53	81:76

**p <0.01, chi-square

n.s.: not significant

LH: left hemisphere (right visual hemi-field)

RH: right hemisphere (left visual hemi-field)

F: "Figure" task

G: "Ground" task

Table 2. Hemisphere performance on perception of dots, using two backgrounds

T = 144 trials/hemisphere

Subject	Position A	Position B	Size A	Size B	XX A	XX B	Total A	Total B	A:B Comparison of total errors
L.B.									
right hemisphere	4	4	9	7	2	0	11	11	n.s.
left hemisphere	12	9	9	4	2	1	19	12	n.s.
N.G.									
right hemisphere	22	3	22	12	9	0	35	15	**
left hemisphere	31	28	30	29	12	12	49	45	n.s.
R.Y.									
right hemisphere	46	44	21	30	12	20	55	54	n.s.
left hemisphere	42	33	17	25	11	14	48	44	n.s.
A.A.									
right hemisphere	42	21	35	19	19	6	58	34	*
left hemisphere	46	47	45	43	30	29	61	61	n.s.
2 control subjects (average scores)									
right hemisphere	13	2	8	3	3	0	18	5	*
left hemisphere	13	3	6	2	3	0	16	5	*

* $p<0.05$; ** $p<0.01$; A, "plain white" background; B, "natural texture" background

XX: errors in both size and position

Position: includes XX errors

Size: includes XX errors

Table 3. Size and position of dots, intrahemispheric results

Change in performance, (plain white) vs (natural gradient) background

		Left hemisphere				Right hemisphere			
Subjects	Trials hemisphere	A-B ✓✓	A-B XX	A-B ✓X	A-B X✓	A-B ✓✓	A-B XX	A-B ✓X	A-B X✓
NG	72	13	35	10	14 n.s.	30	8	7	27 **
AA	72	3	28	4	1 n.s.	7	14	2	13 **
LB	72	47	6	6	13 n.s.	54	4	7	7 n.s.
RY	72	17	37	7	11 n.s.	9	46	8	9 n.s.
Normal controls									
LM	36	14	4	1	17 **	11	5	2	18 **
EG	36	23	3	1	9 *	23	1	0	12 **

*$p<0.05$; **$p<0.01$, McNemar test of significant changes; n.s., not significant

A: "plain white" background

B: "natural gradient" background

✓X: trial correct under A, incorrect under B

X✓: trial incorrect under A, correct under B

✓✓: trial correct under conditions A and B

XX: trial incorrect under conditions A and B

Fig. 1a

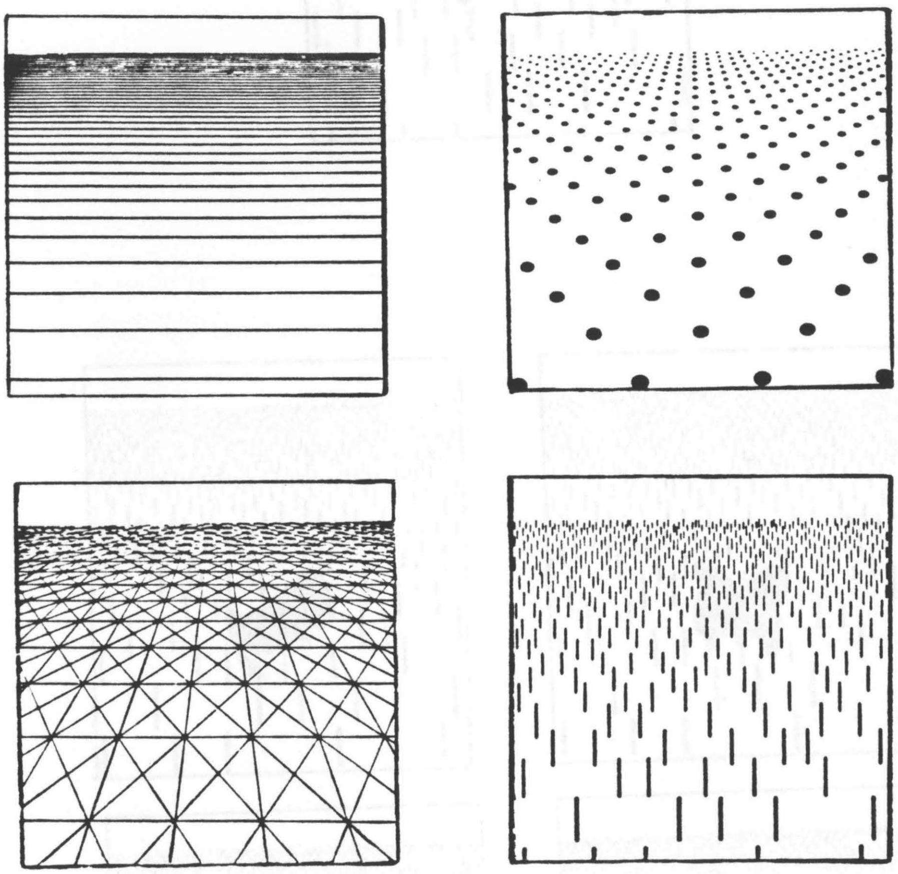


Fig. 1b

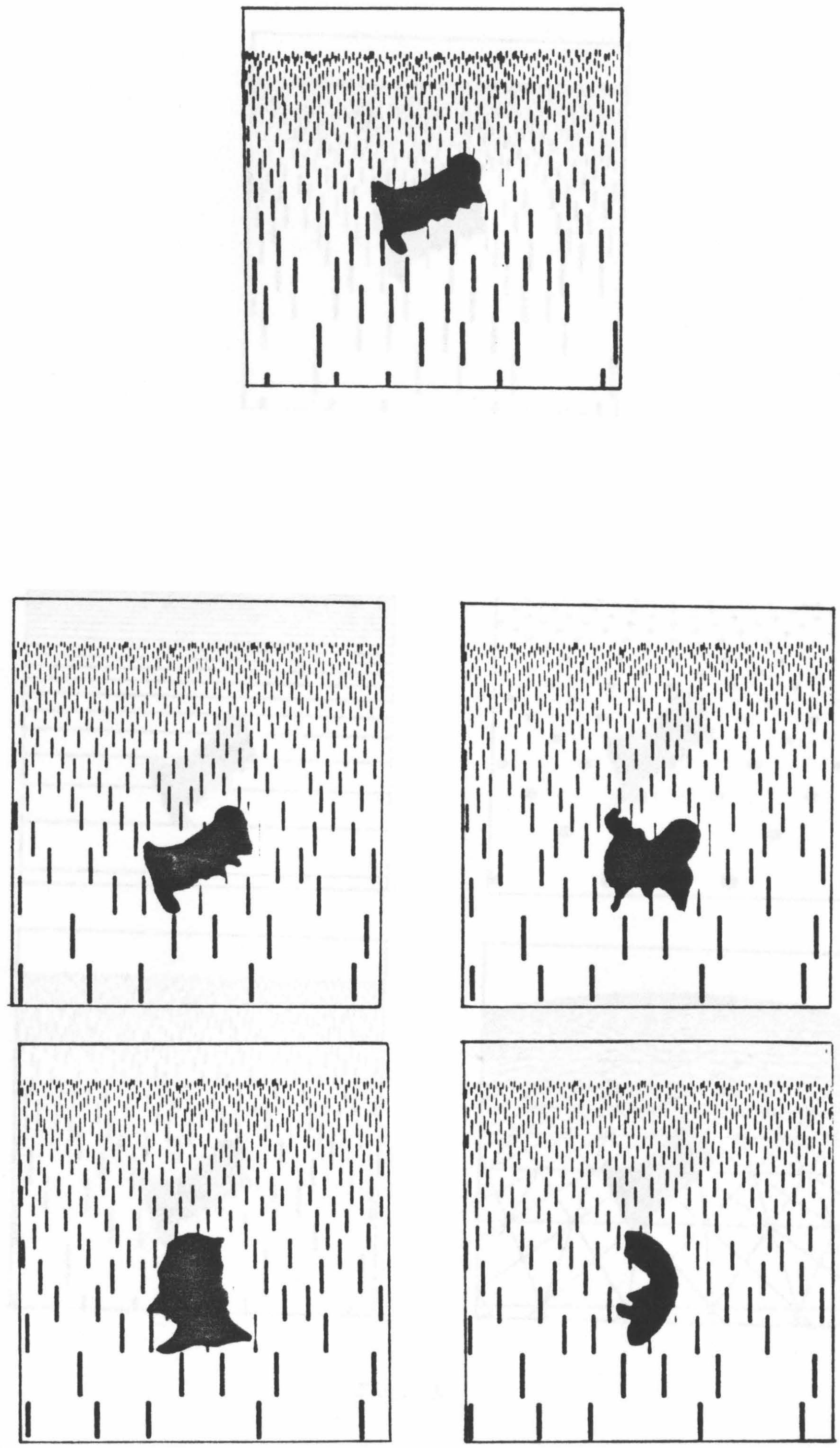


Fig. 2

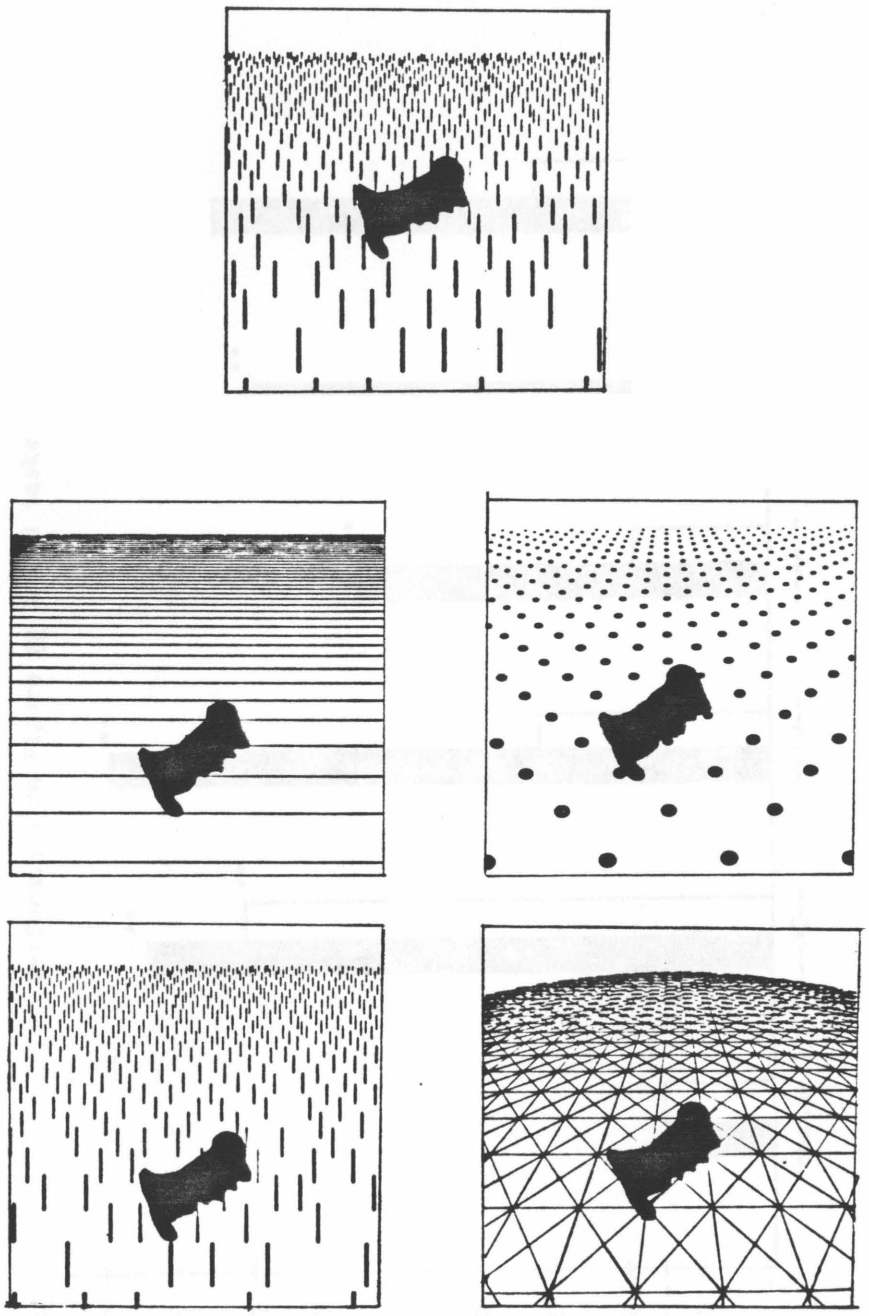


Fig. 3

Intrahemispheric results: Left hemisphere (RVF)

Performance on Figure *vs* Ground tasks

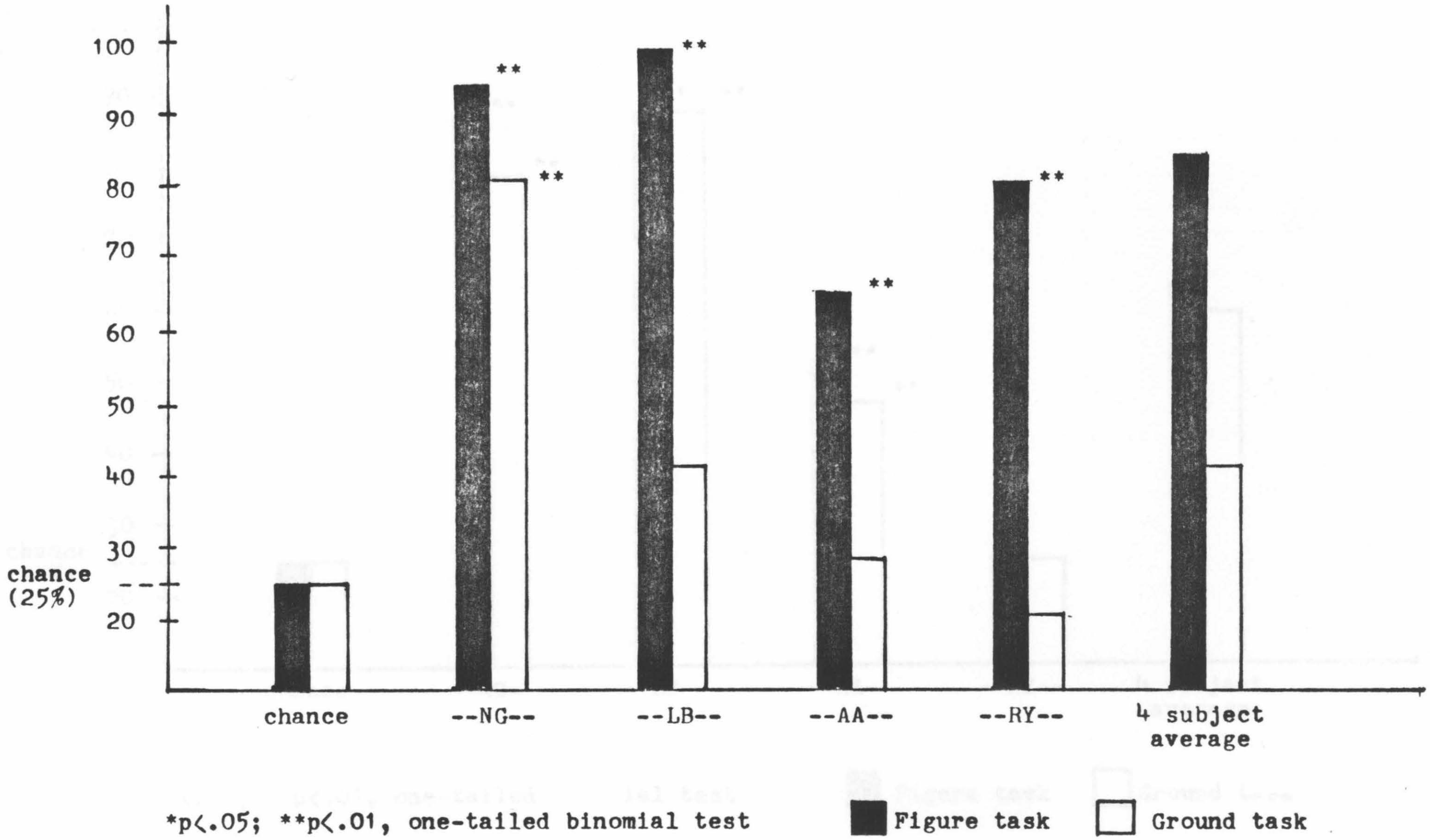
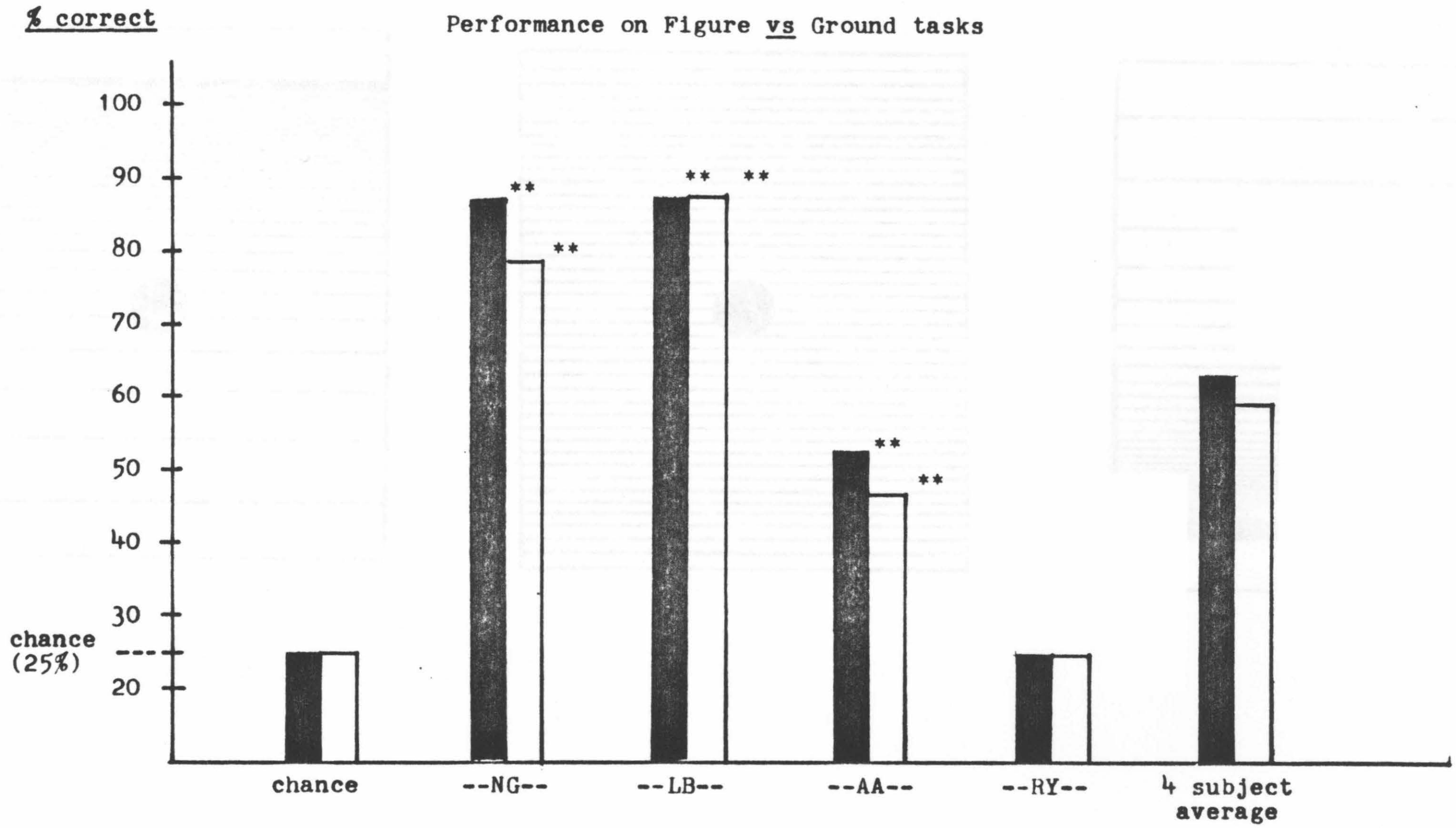


Fig. 4

Intrahemispheric results: Right hemisphere (LVF)

Performance on Figure vs Ground tasks



*p<.05; **p<.01, one-tailed binomial test

Figure task

Ground task

Fig. 5

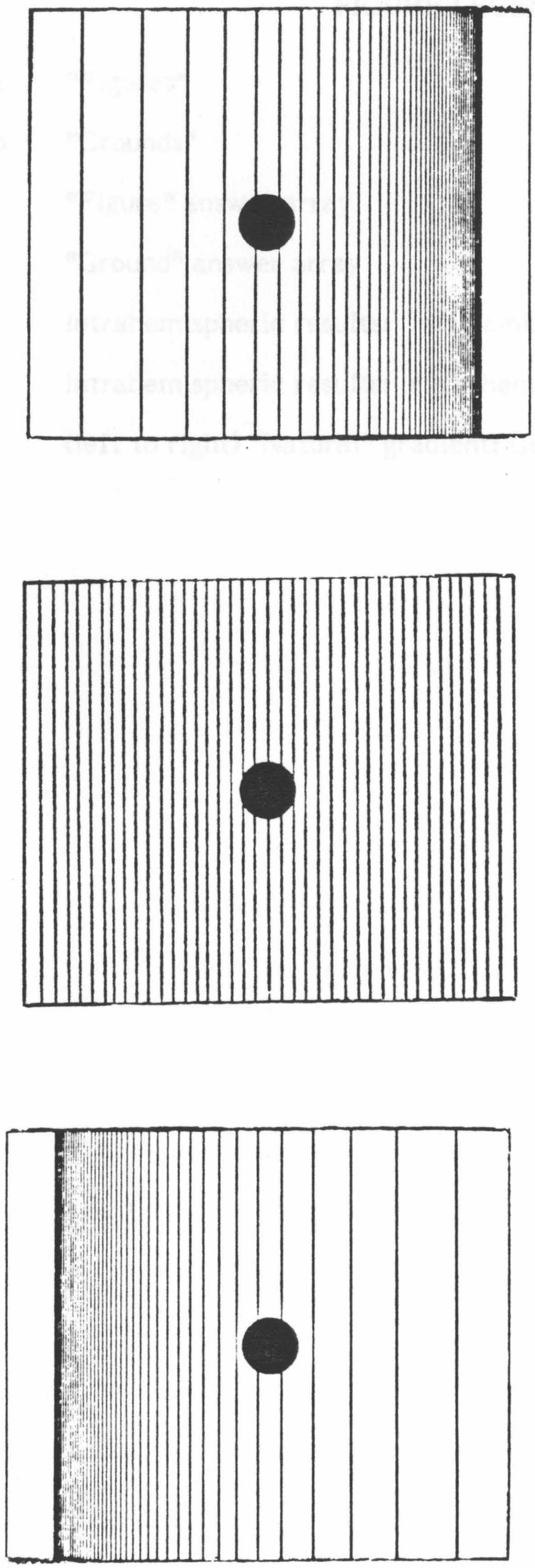


Fig. 6

FIGURE LEGENDS

Fig. 1a	"Figures"
1b	"Grounds"
Fig. 2	"Figure" answer array
Fig. 3	"Ground" answer array
Fig. 4	Intrahemispheric results: left hemisphere (RVF)
Fig. 5	Intrahemispheric results: right hemisphere (LVF)
Fig. 6	(left to right) "Natural" gradient; Grid; Inverted gradient

CONCLUSIONS

The results of the preceding experiments with complete commissurotomy subjects may be summarized as follows:

(1) Both the right and left hemispheres understand abstract concepts, when these are defined in non-verbal terms.

(2) Cognitive information of a high order can be transferred from one hemisphere to the other via subcortical pathways. Affective component may selectively influence the quality and extent of information that crosses from the right hemisphere to the left. Neither verbal labels nor raw visual images transfer through the subcortex, but rather connotative, associative correlates of the original stimulus material.

(3) The right hemisphere processes figure and ground elements of a composite stimulus equally well. It is sensitive to the effects of various backgrounds on the perception of an object, and makes use of texture and perspective cues to assist it in the accurate perception of an object. In contrast, the left hemisphere processes figure information while neglecting the ground component of the whole stimulus.

Taken together, these results characterize the right hemisphere as a sophisticated cognitive system that is fully capable of engaging in abstract thought as well as fundamental perceptual processes. Interfaces of various psychological functions seem to be especially rich in the right, compared to the left hemisphere: the subcortical transfer experiment described the influence of affect on cognition, and the figure-ground experiments revealed the use of inferential cognitive skills on a perceptual task.

The variety of high-order cognitive and perceptual abilities displayed by the right hemisphere serves to underscore the importance of non-verbal processes in human thought in general. Non-verbal information has been shown to be capable of supporting even abstract associations, which had long been assumed to be mediated exclusively by language. Also, like linguistic elements, non-verbal stimuli may be described in terms of more or less discrete and dissociable features, including (for the present visual test) physical image, verbal label, semantic associations, sensory associations, and affective component. Even a subset comprising the last three elements alone can provide sufficient information about the original stimulus to an uninformed observer (or hemisphere) to permit the latter to make decisions about the stimulus' identity and its possible relevance to the observer's own, distinct information base.

Indeed, the subset of sensory, semantic, and affective associations may characterize a cognitive system common to the two hemispheres. Such a system could conceivably pre-date (in a developmental and/or evolutionary sense) the consolidation of cognitive functions such as language and certain visuospatial skills, which are eventually lateralized within the respective cerebral hemispheres. A role for such a system in the modern, intact adult brain, though suggested by the extent of subcortical transfer in commissurotomy subjects and by certain behavioral phenomena (e.g., "déja vu") in normal individuals, remains to be elucidated. In the meantime, one student of the nature of human thought succinctly reiterates the various topics developed in the preceding chapters, including the interrelationship of non-verbal thought, language, and subcortical involvement in cortical processes:

> The tremendous importance of language cannot, in my opinion, be taken to mean necessarily that nothing is back of it, of the nature of what has traditionally been called 'mind.' My own studies suggest to me that language, for all its kingly role, is in some sense a superficial embroidery upon deeper processes of consciousness which are necessary before any communication, signaling, or symbolism whatsoever can occur and which also can at a pinch effect communication.....[1]

[1]Whorf, Benjamin L. *Collected Papers on Metalinguistics*, p. 21. Department of State, Foreign Service Institute, Washington, D.C., 1952.