Worlds apart: Pictorial semantics in the left and right cerebral hemispheres

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Introduction

There are occasions when we do not see things for what they are nor remember specific events that we wish we had remembered. When we acquire new knowledge, it interacts with knowledge already stored in long-term memory, and what was already stored influences how we see and remember things. That is, biases are introduced even while perception occurs[1]. We may posit that the old knowledge is stored as concepts and schemas which in turn help make what we perceive meaningful. We do not know what precise mechanisms are involved in the interaction between the new and the old information in the brain but insights into these mechanisms may be gained by comparing meaning systems in the left and right cerebral hemispheres. This is because there are two semantic memory systems, one in each hemisphere, with some overlapping and other non-overlapping information, and they interact in complex ways to achieve unified perception. This view rests on the assumption that in everyday life the hemispheres are exposed to the same external experiences but those are processed asymmetrically, sorted for storage, and later retrieved in ways characteristic of underlying differences in hemispheric semantic memory. The research in my laboratory has focused on this issue.

Thinking of the right hemisphere as having a meaning system, whence meaning of perceived things may be derived, goes against the standard view in neuropsychology. The dominant view is that meanings of things in the physical world are processed only in the left, language hemisphere[2]. Yet, not all things in the world need necessarily have a linguistic code or language-related meaning (e.g., familiar faces, topography of a neighborhood, musical melodies, all functions specialized in the right hemisphere).

Since the normal right hemisphere is language-poor and since pictures can be processed in both hemispheres, we used pictures to probe the hemispheric conceptual organization, that is, the meaning system in each hemisphere. I will start with experiments that use pictures of single objects, ranging from the special case of the human face to exemplars of natural categories. Pictures of multiple-object scenes will be discussed next. Common, organized scenes will be contrasted with unorganized collections of objects, on the one hand, and with scenes which show violations of physical, biological, or social rules, on the other. The experimental paradigms range from perceptual identification and category decisions to long-term recognition memory. Neurological and neurosurgical brain-damaged patients without clinical visual agnosia as well as or normal subjects participated in the studies. Convergent evidence is crucial in the field of mind-brain interaction. In patients with focal unilateral brain-damage, observed behavior may reflect pathological inhibition of diseased over healthy tissue rather than directly reflecting functions performed by the healthy tissue in the absence of the diseased tissue. Indeed, patients with complete commissurotomy (split-brain) as well as normal subjects have been found to perform hemispheric tasks which could not have been predicted from data obtained on neurological patients with focal unilateral brain-damage. For this reason I attempt to include all three experimental populations in my studies.

Concepts of common objects in the cerebral hemispheres

A. The human Face

The human face is a collection of features (eyes, mouth, etc.) that occur regularly in the same context. The adult right hemisphere is superior to the left in processing and remembering faces. What does this specialization tell us about the conceptual system of the right hemisphere? And, what makes a face a face in the right hemisphere?

To find the answers to these questions, two types of pictures were created. One was of a normal face and another was a face-like picture in which the contour frame of a face was drawn but with systematically rearranged facial features inside the frame. That is, a nose was positioned were lips normally occur, an eye was positioned where the nose normally occurs, and so on. These were presented to the left and right hemispheres of split-brain (complete commissurotomy) patients at Caltech in Pasadena using [3, 4]. The contact lens technique (Z-lens) for continuous lateralized presentations was used instead of quick tachistoscopic flashes. Each picture was presented to one hemisphere at a time (through either the left or right visual half-fields) and the patient pointed with the hand ipsilateral to the exposed visual half field to features named by the examiner (e.g., eye, nose, mouth). In these patients, we can determine which hemisphere gives the response simply by restricting the stimuli to one visual half-field and requiring pointing with the ipsilateral hand. When the left hand points to stimuli in the left visual half-field, the right hemisphere controls the response; when the right hand points to stimuli in the right visual half-field, the left hemisphere is in control. All facial features were correctly recognized in either hemisphere when the normal face was shown. But when the face-like picture with rearranged features was shown, recognition of features was accurate only in the left hemisphere whereas systematic errors were made in the right hemisphere. Instead of pointing to the lips or the nose, say, patients pointed to features which occupied positions of the lips and the nose in a normal face. On the other hand, when a picture of four individual geometrical figures (e.g., circle, triangle) inside a non-face frame such as a square was presented, each hemisphere recognized the individual geometrical figures. The errors were specific to the face, not to any figures enclosed within a larger frame. They revealed a bias derived from a rigid face concept, namely of a straight-on view of a normal face. This bias appears to have interfered with seeing/processing the actual facial features in the face-like picture. (Recent work on normal subjects has confirmed the presence of this hemispheric bias even in the intact brain[5]).

It is tempting to speculate that on those occasions when we do not see things as they are, when we are exposed to new information which appears to violate standard knowledge and we nevertheless apply conventional models, the conceptual system in the right hemisphere is dominant. With the left hemisphere controlling the manual responses, the actual facial features in the face-like configuration were recognized. Whatever the precise nature of the hemispheric conceptual systems may turn out to be, that in the left appears to be "flexible" while that in the right appears to be "rigid".

B. Exemplars of natural categories

To see if this finding can be generalized, normal subjects were asked to decide whether or not line drawings of single objects were members of natural categories such as furniture, weapon, vegetable, and so on. Some of the exemplars were typical and some were atypical members of the categories (as determined independently by Rosch[6]). The pictures were shown in quick flashes in the left or right visual half-fields of normal subjects[7]. The task was to press a button as rapidly as possible to indicate whether or not the seen object was a member of a predesignated category. The results showed different latency patterns in the two visual half-fields (Figure 1). In the left visual half-field (right hemisphere), responses were much faster for typical members than for atypical members; there was no difference between typical and atypical exemplars in the right visual half-field (left hemisphere). Importantly, decisions for typical members were faster in the left visual half-field than in the right visual half-field whereas decisions for atypical members were made faster in the right visual half-field [8].

We see, again, right hemisphere specialization in processing standard or stereotypical concepts whereas there is no effect of typicality in the left. As of now, we do not know how hemispheric control over perception works, that is, how perceptual control is "assigned" to one hemisphere or the other. However, we do know that when the same exemplars were presented in central vision, subjects' decision pattern was identical to the one observed in the left visual half-field. This suggests that the right hemisphere dominated responses in central vision. Note that this is true even for atypical items, where performance in the right visual half-field is actually faster.

Meanings in pictorial scenes

In everyday life, unlike situations encountered in psychology laboratories, we rarely if ever, encounter single objects without a context. Pictorial scenes with common objects may be compared to grammatical sentences where the choice and order of the words in a sentence affects its meaning. The objects in a scene may form a variety of arrangements, including a familiar organization, an incongruous organization, unorganized arrays with non-random collections of objects, and so on. The meaning of each scene, then, could vary as function of the arrangement or particular juxtaposition of the objects, and the extent to which it is remembered could be taken to reflect its meaningfulness.

Biederman [9] showed normal subjects two types of pictures, one a familiar street scene and the other a cut and randomly rearranged version of the same scene. Subjects remembered objects and their locations in the first picture much better than in the second. Similar results were obtained by Mandler and her associates [10]. Both perception and memory of the normal street scene were likely guided by previously stored schemas of street scenes while there was no conceptual schema for the randomly rearranged scene.

What pictorial organization in scenes reveals about the hemispheres

We asked neurological stroke patients with localized damage in posterior regions of either the left or right hemispheres to remember pictorial scenes showing common organization of objects versus scenes showing unorganized arrangement of objects (that are normally encountered in the same context). The patients did not suffer from language impairments. Recognition memory was measured through pointing to the correct answer in multiple-choice arrays. Memory for organized scenes was not different between the two hemisphere-damaged groups, suggesting bilateral representation of schemas showing common object arrangements. On the other hand, memory for unorganized scenes was selectively impaired in patients with left hemisphere damage and this was particularly evident when memory for the whole scene as opposed to its individual objects was measured[11, 12].

Using the standard logic of inferring normal behavior from brain damage, we conclude that the normal left hemisphere is superior for processing unorganized scenes showing collections of objects. The normal left hemisphere is better in assigning meaning (structure?) even when it is absent. Could it be that when we "see" new meaning where the meaning is not obvious, left cognitive processes are dominant?

Violations of reality in pictures

Another tool for learning about hemispheric conceptual differences are pictures that show incongruous or surrealistic organization of familiar objects. Suppose scenes are created which violate various physical, biological, or social rules (e.g., a giraffe in an Arctic scene, a physician injecting a coffee pot with a needle, a mailbox in a living room). They appear normally organized and they represent common visual experiences except for one detail which renders the whole picture incongruous. When normal subjects were asked to remember such scenes exposed in central vision, and then tested for recognition through exposure of probe pictures in either the left or right visual half-fields, they appeared to remember them better when probes were in the right visual half-field (left hemisphere) than in the left visual half-field (right hemisphere). The left hemisphere appears to tolerate deviations from the accepted rule better than the right hemisphere.

In this century, artists such as Magritte and Dali painted common objects in uncommon relationships, that is, their paintings appear to violate known logical, physical, or social rules. In this case, art can serve as a useful tool for understanding cognitive functions in the brain. Normal subjects in my laboratory were asked to remember a series of paintings shown in central vision, half surrealistic and half realistic. Then, these paintings, intermixed with an equal number of new paintings, were presented in the left visual half-field or right visual half-field and subjects had to press a button to indicate whether or not they remembered seeing them earlier. The results showed better memory for surrealistic paintings when it was tested in the right visual half-field (left hemisphere) than in the left visual half-field (right hemisphere), with no hemispheric difference on realistic paintings[13].

Do such findings imply that there is no mechanism in the right hemisphere for detecting presence of deviations from the standard? Milner [14] found that right brain damaged patients with lesions in the anterior temporal lobe or in the parietal lobe were worse than left brain-damaged patients in detecting incongruous details in pictures. Warrington and Taylor [15] found that unusually photographed common objects could not be matched well with normally photographed objects by right as compared to left brain-damaged patients. This implies that directed detection or matching procedures as used in these latter two studies utilize the conceptual stores differently from memory as used in our studies.

Left and right meaning systems

The superiority of the left hemisphere in remembering unusual object arrangements in pictures should not be as surprising as it may appear. Consider the fact that the main speech and language centers are in the left hemisphere. People's utterances are rarely perfect grammatically, and yet listeners understand the meaning intended. This implies competent comprehension despite deviations from rules. Language, however central, is but one feature of the meaning system in the left hemisphere. What of the right hemisphere's meaning system? Among other things, it may specialize in applying conventional concepts and schemas to new knowledge, and it may operate with rigid criteria. This would seem to be a major requirement in a cognitive system that specializes in spatial orientation.

Concluding Remarks

The study of meaning representation in the brain has been examined in the field of clinical neurology for the past 100 years. The approach has been largely through the study of visual object agnosia, the acquired loss of semantic knowledge of previously familiar things, in the absence of sensory or motor deficits, or intellectual deterioration. Visual object agnosia is rare and lesion localization is often bilateral or diffuse. Assuming a unitary, modality-nonspecific central representation of semantic memory, the problem has often been attributed to access rather than to the semantic store itself. However, it is possible to examine the nature of meaning systems in the brain even in the absence of agnosia, as was described here.

The dominant view in neuropsychology fails to consider that the hemispheric "functional division of labor" in terms of language versus non-language reflects but one dimension of hemispheric differences. That is, specialization of language in the left hemisphere and of spatial orientation in the right represent only specific aspects of the general underlying hemispheric meaning systems. Indeed, we have found that there can be two full-blown meaning systems, one in the left and one in the right, which can operate separately and simultaneously in the normal brain.

Notes

1. A classic empirical demonstration of such a bias was provided by Bartlett in 1932. He asked subjects in a Western society to recall a native North America folk-tale and learned from their recall errors that biases were derived from the subjects' own Western concepts and culture. Bartlett, F.C., Remembering: A Study in Experimental and Social Psychology. (Cambridge University Press, Cambridge, 1932).
2. McCarthy, R.A. and Warrington, E. K., Cognitive Neuropsychology. (Academic Press, London, 1990).
3. Zaidel, D.W., Cognitive functions in the right hemisphere. La Recherché, 15, 332-340 (1984).
4. Zaidel, D.W., Long-term semantic memory in the two cerebral hemispheres, in Brain Circuits and Functions of the Mind, C. Trevarthen, Ed. (New York, Cambridge University Press, 1990).

5. Zaidel, D.W., Effects of violations of a face schema in the left and right hemispheres of split-brain patients and normal subjects. Society for Neuroscience Abstracts, 17, 867 (1991).

6. Rosch, E., Cognitive representation of semantic categories. Journal of Experimental Psychology: General, 104, 192-233 (1975).

7. Because of anatomical arrangement, pictures falling in the left visual half-field are normally processed initially in the right hemisphere while those falling in the right visual half-field are processed initially in the left hemisphere.

8. Zaidel, D.W., Hemispheric asymmetry in long-term semantic relationships, Cognitive Neuropsychology, 4, 321-332 (1987).

9. Biederman, I., Perceiving real-world scenes. Science, 177, 77-80 (1972).

10. Mandler, J. M., Stories, Scripts, and Scenes: Aspects of Schema Theory. 1984, Hillsdale: Erlbaum.

11. Zaidel, D.W., Memory for scenes in stroke patients: Hemispheric processing of semantic organization in pictures, Brain, 109, 547-560 (1986).

12. A subsequent study with patients suffering from unilateral brain-damage caused by penetrating missile wounds to the brain confirmed a selective deficit in left-sided patients for remembering unorganized scenes.

13. Zaidel, D.W. and Kasher, A., Hemispheric memory for surrealistic versus realistic paintings. Cortex, 25, 617-641, (1989).

14. Milner, B., Psychological defects produced by temporal lobe excision, Proceedings of the Association for Research in Nervous and Mental Disease (ARMND), 26, 244-257 (1958).

15. Warrington, E. K. and Taylor, A. M. The contribution of the right parietal lobe to object recognition. Cortex, 9, 152-164 (1973).

Figure Legends

Figure 1. Latencies in the left visual half-field (LVF) and right visual half-field (RVF) of normal subjects in a category membership decision task. The interaction of visual half-field and level of typicality is significant. Latency to high typicality members is significantly faster in left visual half-field (right hemisphere) than in right visual half-field (left hemisphere) while latency to low typicality members is significantly faster in right visual half-field.