

13 Cognitive-Neuroscience: Developments Toward a Science of Synthesis

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INTRODUCTION

Almost from the inception of the effort to develop information processing models of cognition investigators have argued that at some point there would be important links between the study of elementary mental operations crucial to the performance of complex tasks (Chase, 1978) and the brain systems that support such operations. This view is clearly outlined by Herbert Simon in his important Compton Lectures (Simon, 1981) as follows:

The main reason for this disembodiment of mind, is, of course, the thesis that I have just been discussing. The difference between the hardware of a computer and the hardware of the brain has not prevented computers from simulating a wide spectrum of kinds of human thinking It would be unfortunate if this conclusion were altered to read that neurophysiology has nothing to contribute to explanations of human behavior. This would be a ridiculous doctrine. It is to physiology that we must turn for an explanation of the limits of adaptation As our knowledge increases, the relation between physiological and information processing explanation will become just like that relation between quantum mechanical and physiological explanations in biology They constitute two linked levels of explanation . . . the limiting properties of the inner system showing up at the interface between them. (page 97).

It is the theme of this chapter that the time has arrived for the development of the detailed analysis of the physiology of human cognition. For the last 15 years, a number of separate biological fields have coalesced under

the name of "neuroscience." Neuroscience is concerned with the basic principles of organization of nervous systems. Although the field has, from its start, included studies of normal and pathological human brains, the bulk of the work has concerned animal models, and in particular, synaptic and intracellular phenomena. Except for occasional interest in language and its pathology, neuroscientists rarely choose human organisms as the object of study. In part, this arises because of the complexity of human functioning and also because of the difficulty, until recent methodological developments, in doing experimental physiology with human beings.

Within the last few years, a number of sciences related to the study of cognition in human beings have been coming into contact under the name "cognitive science." Many of the problems of concern to cognitive science arise from the great complexity of information stored in human semantic memory, and the cultural matrix in which the programming of this information develops. In the terms Simon uses in the previous quote, they are problems of software to which a science of the artificial is properly addressed. The study of semantic memory, problem solving, language and social cognition are issues of human concern that fall within the domain of cognitive science.

Although in principle any aspect of cognitive science might be illuminated by principles of neuroscience, and vice versa, it seems most fruitful to begin with the study of elementary mental operations (Chase, 1978) performed by human beings in the execution of complex behavior. These would seem to be an appropriate level of analysis for efforts to understand the relationship between mind and brain processes. Just as neuroscientists develop model systems of sufficient simplicity to work out the detailed wiring diagrams underlying animal behavior and learning, cognitive scientists interested in the interface with neuroscience need to seek model cognitive systems where appropriate experimentation may yield close contact with related neurophysiology. In many cases, the choice of such cognitive systems is dictated by the ease of time locking the occurrence of mental events to physical stimuli. What is not widely recognized by many neuroscientists is the impressive evidence that has been adduced during the last dozen years that purely mental events, such as ideas and images, can be time locked to critical environmental events (see Posner, 1978 for review). Occurrence of neuropathological syndromes and the breakdown of component mental functions provide natural sources of stimulation for the cognitive-neuroscience interface. Because of the biological bias obviously present in the study of cognitive processes from a neuroscience viewpoint, both evolutionary and developmental considerations are extremely important in the choice of cognitive systems and in their interpretation.

We will define cognitive neuroscience as the interface of neuroscience and cognitive science with the relationship between mental events and the brain

as its foremost empirical question. In our view, it is useful to divide cognitive neuroscience into subproblems based on candidate cognitive systems. The term "cognitive system"¹ is defined in terms of its relation to the idea of organ systems. Organ systems are "differentiated structures in animals and plants made up of various cells and tissues and adapted for the performance of some specific function and grouped with other substructures into a system" (Webster, *New American Dictionary*). Clearly then, cognitive systems must also depend upon differentiated brain structures even though they may be widely distributed within the brain. Thus the question of localization of function becomes one important issue within cognitive neuroscience.

Any cognitive system may be described in terms of the brain functions that support it, in terms of the subjective experiences or processing operations to which it gives rise, or in terms of the pathologies created by breakdowns of components of cognitive systems. These three approaches correspond to the disciplines of neuroscience, cognitive science, and neurology. It is these three constituent disciplines that provide historical background and a methodological base out of which cognitive neuroscience as a discipline must grow.

Our emphasis on the development of a "science" contrasts rather markedly to the usual analysis of mind-brain relationships. This is a field that has had considerable work, but much of it has been highly theoretical and philosophical. Perhaps stemming from the long tradition of philosophical speculation about the relationship between mind and brain, most of the literature involves a priori solutions to the mind-brain relationship rather than accumulation of the methods and findings that normally accompany the development of a scientific area. In this chapter, we will not stress philosophical or theoretical solutions. We do not suggest that such solutions are at hand or may ever be possible. Rather, we believe that new methods and accumulating findings have made an exciting discipline of cognitive neuroscience even should no solutions to the vexed philosophical problems of mind-brain relationships emerge.

In addition to the common influence from general philosophical questions about the relationship between brain and mind, the disciplines of neurophysiology, neurology, and psychology have had a great deal of contact over the last hundred years. In particular, all three disciplines have been concerned and influenced by general assumptions about the ability to localize particular cognitive functions within the human brain. So dominant has been the question of localization of function that it caused Miller (1978) to remark as follows:

Psychologists sometimes wonder why their neurological colleagues place so much store by the localization of functions in different parts of the brain, since it is not obvious that knowing where something happens tells us much about what is going on there. But localization is merely one aspect of the traditional neurological approach to brain science; a more comprehensive view of the neurological approach would have to include the general assumptions that (1) complex brain functions can be decomposed into simpler, more general processes; (2) these component processes can be localized anatomically and studied in relative isolation; (3) complex behavior can be decomposed into simpler, more general processes; and (4) the simpler brain processes can be correlated directly with their simpler behavioral processes. (Miller & Lenneberg, 1978, page 6)

Until recent times, the effort to make component analysis of complex mental skills (e.g., reading or chess) has not been available and, thus historically, the disciplines of neurology, neuroscience, and psychology have concentrated heavily upon localization of function. All three constituent fields of cognitive neuroscience went through periods of extreme localization prior to the turn of the century, followed by a movement toward more wholistic views strengthened by Gestalt arguments and supported by Gestalt-influenced neurologists. Through the influence primarily of modern neuroscience, all have tended to return to ideas of localization of brain processes (see Uttal, 1978 for a review). This similar waxing and waning of enthusiasm about localization of function indicates that cross-fertilization has occurred across the three disciplines, providing at least implicit recognition of the relevance of research in each of the fields for the others.

Although in a rough sense ideas of brain localization have come full circle from the nineteenth century, there are still differences between current ideas and past ones. Recognition of complex central systems have replaced undue emphasis upon strict reflexive control (Edelman & Mountcastle, 1978; Hebb, 1949). Cybernetic concepts have provided ideas about the logical principles underlying central control of input and output pathways (Wiener, 1948). These have influenced both concepts of neural organization and concepts of the complex networks that organize the flow of information in models of cognitive psychology.

The flavor of the common language of neural and cognitive scientists interested in the basis of mental processes can be seen by a comparison of the two recent quotes, one from a prominent neuroscientist (Mountcastle, 1978) and the other by a cognitive researcher (McClelland, 1978).

It is well known from classical neural anatomy that many of the large entities of the brain are interconnected by extrinsic pathways into complex systems, including massively reentrant circuits.—These modules are local neurocircuits of hundreds of thousands of cells linked together by a complex intramodular connectivity. The modules of any one entity are more or less similar throughout, but those at different

¹We thank George A. Miller for bringing to our attention the concept and term cognitive system.

entities may differ strikingly.—

(Page 39)

Distributed systems are thus composed of large numbers of modular elements linked together in eschelon, parallel and serial arrangements. Information flows through such a system may follow a number of different pathways, and the dominance of one path or another is a dynamic and changing property of the system. Such a system has many entries and exits and has access to outflow systems of the brain at many levels. A distributed system displays the redundancy of potential loci of command, and the command function may from time to time reside in different loci of the system, in particular, and in that part processing the most urgent and necessary information.

An important feature of such distributed systems, particularly those central to primary sensory and motor systems, is that the complex function controlled or executed by the system is not localized in any one of its parts. The function is a property of the dynamic activity within the system: it resides in the system as such. This may explain why local lesions of the distributed system scarcely ever destroy system function completely, but degrade it to an extent determined by lesion size and the critical role of the locus destroyed for system function. (Page 40)

The spirit of order within great complexity is also reflected in current cognitive science models and ideas. Consider, for example, a recent description of cascading processes determined from studies of the time relation of mental processing in human performance (McClelland, 1979).

1. The system is composed of several subprocesses or processing levels.
2. Each subprocess is continuously active, working to let its output reflect the best conclusions that can be reached on the basis of its inputs.
3. The output of each process is a set of continuous quantities that are always available for processing at the next level.
4. Processing at each level is based on the results of processing at the preceding level only. Outputs are passed in only one direction through the system of processes, with no skipping or bypassing of subprocesses. (Page 290)

This convergence on similar views of localization of function provides the needed conceptual basis for the organization of a cognitive neuroscience. However, the most important change that makes cognitive neuroscience a possibility is the availability of new methods for the examination of hypotheses relating brain function to psychological processes. As Mountcastle (1976) has suggested.

It has been clear for a long time—at least since the time of Lashley—that the quantitative study of behavior, traditionally the domain of the Psychologist, and of neural events in the brain, called "Neurophysiology," are conceptually different approaches to what are generically the same set of problems, an identity long emphasized by Jung (1972). What is new is that it is now possible to combine in one experiment the methods and concepts of each to yield a deeper insight into the brain mechanisms that govern behavior than is possible with either alone. In this "combined experiment," one controls and measures behavior and records simultaneously the signs of cerebral events through relevant. [p. 1].

METHODS OF STUDY

Methods play a particularly important role in every scientific endeavor. This is certainly true with respect to the hope of producing a physiological analysis of human mental activity. Although theories of localization of mental function have been present all through the history of the constituent disciplines, the methods for examination of the correlation between cognitive function and brain activity have been indirect. Much of the classical work has involved examination of brain sections following death. Those damaged areas of the brain could then be related to the behavior of the organism. *In vivo* examinations of the human brain by measurement of electrical activity have only been possible for 20 years and the use of non-invasive neurologic imaging techniques are even more recent.

Neuroscience approaches have emphasized spatial methods that give hope of a means of studying localization. Cognitive science approaches have tended to place emphasis upon temporal organization of information flow within the nervous system.

Spatial Methods

During the last few years, clinical neurology has been greatly aided by the presence of computerized tomography as a method of examination of lesions (Oldendorf, 1978; Osborn, 1979). In this technique, a series of narrowly collimated x-rays exposures is made from a number of different angles, and the data thus acquired are then used to reconstruct sectional images by computer. The spatial representation of the cortex thus achieved allows accurate location of lesions (Swets, Pickett, Whitehead, Getty, Schnur, Swets, & Freeman, 1979). In a few minutes, sufficient data can be collected to produce an accurate brain scan. Such scans provide a static picture of the health of the brain by an analysis of tissue density. Dyes may be used to enhance the differences between normal and damaged areas. The ability to obtain an accurate localization of the damaged area while the patient lives obviously provides increased opportunity for studying the relationship of human brain lesions to mental state and performance. In addition the size and location of a lesion can be traced over time as, for example, in the case of tumor growth or where radioactive treatment might produce a reduction in tumor tissue. The size and extent of lesions can be known while the subject is tested for associated cognitive deficit. This allows the possibility of quantitative analysis of the relation of brain tissue to detailed cognitive processes, such as might be involved in reading.

Radioactive tracer methods of measuring cerebral blood flow or metabolic activity may provide a more dynamic method of tracing cerebral activity during sustained cognitive tasks (Lassen, Ingvar, & Skinhøj, 1978).

One method involves the use of a radioactive xenon source, the concentration of which may be measured during sustained cognitive activity. For example, the rates of blood flow have been measured during silent reading and other cognitive tasks relative to a resting condition. The task of reading silently shows concentrated blood flow activity in the areas of the frontal cortex associated with eye movements, in visual association areas, supplementary motor area, and Broca's speech area as well. A lower level of activity is present in the posterior association area (Wernicke's area). The potential of this method for articulating the spatial localization of brain areas during cognitive activity is obvious and has already begun to be widely exploited (Risberg, 1980).

Another approach to the study of brain activity during cognition involves the use of positron emission tomography (Raichle, 1979). A glucose molecule is labeled with a radioactive tracer. The distribution of the labeled substance is monitored by annihilation radiation generated when positrons are absorbed. This radiation is sensed by an array of detectors. The limits of spatial resolution of this method may be within 1-6mm. The method has been applied as quickly as within four minutes after injection although longer times are most often employed. This method can be used to measure blood flow and may have the potential of examining dynamically the metabolism in different areas of the brain if certain assumptions are made. Ultimately one would hope to be able to compare metabolic activity in neural systems involving different transmitters as well as in spatially separate brain areas.

One disadvantage of the spatial examination methods of CT scan and cerebral blood flow is the lack of fine temporal resolution of these methods. Although methods under current development such as positron emission tomography could improve the temporal resolution to within the range of seconds (Raichle, 1979), it may always be necessary to supplement them with methods that are temporally more refined.

Temporal Dynamics

The various imaging methods described do not give the kind of dynamic picture of information flow required by the analysis of many cognitive tasks where differences of 20-100 msec are frequently found between processing codes (Posner, 1978) or successive stages (Sternberg, 1969).

The simplest chronometric method is to measure the time between two events. When the first event is a stimulus and the second the response to it, the measure is called reaction time. A very closely related technique is to provide an informative event or cue and measure the length of time it takes before the reaction to a following imperative event has reached its minimum. This technique can be used to measure the time required to en-

code the cue event in an optimal way.

Some investigators prefer to control the time subjects have available to interact with the stimulus and observe errors they make with a given exposure duration. One such technique is to follow a brief exposure of a target with a second masking event. The assumption is made that the mask serves to restrict the time that is available for dealing with the target. An alternative method to masking is to train subjects to respond at different rates of speed and then to observe the errors they make at each rate of processing. This technique makes use of the fact that the people can obtain greater accuracy by going more slowly. Measurements of the accuracy of performance following different durations of stimulus exposure are based on an implicit notion that quality of information builds up over time and that subjects can access that information at different places in its build-up. Faster access means lower information quality and thus greater errors until asymptote is reached.

In simple cognitive tasks like reading of letters and words these techniques have and are being used to trace the time course of buildup and decay of visual, phonetic, and semantic codes. For highly-familiar and over-learned items, these translations are automatic in the sense that they occur even when we attempt to prevent them from taking place. But even though they are automatic, they are not immediate. Estimates of the time course of activation of these codes suggest that the phonetic code follows activation of physical codes by 80 to 100 msec and that semantic codes require in excess of another hundred msec for their development. These time estimates arise from experiments involving various aspects of mental chronometry. Though the use of time-dependent measures is an old one in experimental psychology, in recent years there has been a proliferation and integration of methods and theory in an effort to trace the time course of activity in the nervous system.

SPATIO-TEMPORAL METHODS

Event related electrical activity recorded from the scalp of humans or other animals provides a method that involves both spatial and temporal information. Although it is often difficult to determine the exact location of the generators of such potentials, different components do give rise to different scalp distributions. Components within the first 100 msec often relate closely to sensory aspects of the signal and show scalp distribution dependent upon the modality of input. Later components tend to relate more to states of the organism and task and tend to show peaks in the association areas. There have been efforts to locate the generators of these potentials either by an analysis of their scalp distributions or by use of depth electrodes (Goff,

Allison, & Vaughan, 1978; Woods, 1980). When the event related potentials are collected from two different behavioral tasks, they can be compared chronometrically. For example, attending to a visual or auditory location produces amplification in the event related potential about 90-120 msec following input; while detecting a target defined by a semantic category tends to produce differences between targets and non-targets that do not occur for about 300 or more msec after input. These differences correspond to the distinction made in performance theories between sensory and response set and reflect the complexity of the decisions and degree of conscious processing of the unselected item. The comparison of wave form for the attended and unattended input provide a very precise and complete temporal picture of influence of the attentional instruction.

In recent years it has been possible to record from single neural cells in alert organisms. This method provides precise spatial and temporal resolution. Activity that is time-locked to a stimulus can be recorded and used to construct a picture of the firing rate of the neuron millisecond by millisecond following input. This method can provide an accurate picture of how different neural systems are affected by psychological conditions. For example Goldberg and Wurtz (1972) showed that single cells in the superior colliculus (a midbrain structure related to eye movements) whose receptive fields are targets for an eye movement show enhanced firing rates well before the eye actually begins to move. This selective enhancement effect can occur within 50 msec after the cue for the eye movement. On the other hand, cells in the primary visual areas show no such selective enhancement; while parietal cells do so but at a latency usually longer than that shown for collicular units. These results can help provide a picture of the ordering of the neural systems related to attention and eye shifts. The use of post-stimulus latency histograms is limited to organisms for which electrode penetrations are possible and this of course limits their utility for the study of higher cognitive functions in humans, but for some tasks the non-human primate makes an excellent model.

Neurological Deficits

A combination of spatial and temporal methods have given us a greatly expanded capability of learning about the physical basis of cognition. The incentive for such studies has been greatly increased by study of the disconnections of cognitive function that can be revealed by cases of brain injury. The split brain syndrome has revealed the ability to make complex discriminations by the right hemisphere without availability of information to the language system (Gazzaniga, 1970). The results obtained with this disconnection syndrome have greatly increased confidence in our ability to analyze the relationship between cognitive function and brain activity. This

faith has also been bolstered by experiments, showing that subjects with occipital lesions can orient to stimuli (with their eyes) that they are unable to bring to consciousness (Poppel, Held, & Frost, 1973; Weiskrantz, Warrington, Sanders, & Marshall, 1974). Such dissociations fit with the assumed functions of the primary visual system in conscious recognition and of the secondary (midbrain) system in localization, but they remain very striking evidence of the possibility of understanding of cognition at a neural system level. Similarly the finding in deep dyslexia (Marshall & Newcombe, 1973) that patients may demonstrate knowledge of the meaning of a word they cannot name has helped support the idea of different routes to the meaning of lexical items.

COGNITIVE SYSTEMS

These methods have already had a value in increasing the belief of psychologists in the ability to tie cognitive activity to important aspects of the brain. The view of only a few years ago that there were no convincing links between cognition and the activity of brain cells seems now to have passed in favor of the firm conviction that we will come to understand mental processes in terms of brain activity within the next generation or so.

These changes in the faith of investigators in the strength of the relationships between brain and mind face two important dangers. One danger is from a naive attempt to reduce cognition to neuroscience that may lead to an overconcentration on the physical basis of brain activity without concomitant attention to the cognitive functions performed. Reductionism of this sort tends to prevent interesting questions of cognition from guiding the development of studies of brain activity. On the other hand, cognitive scientists need not claim that their field should be completely divorced from brain activity, but there are very fundamental cognitive questions that do lend themselves to tight links to the neurosciences. The claim that cognitive science must be completely independent of the studies of brain activity is one that may be appropriately advanced against naive reductionism but should not stand in the way of the development of a genuine science at the boundary between cognition and neuroscience that will benefit from constraints in both fields.

A second danger that may prevent the development of a genuine cognitive neuroscience is the tendency of many in cognition to avoid questions like those of consciousness and of emotion that do not fit well into the computer simulations of human mentation (see Norman, 1980, for a discussion of important areas of cognitive science). No doubt the information-processing language developed in part from studies of the computer has played an important and liberating role in the development of cognitive theory.

However, many important questions that will link the unique nature of the human brain to our mental activity are not easily handled by extant computer models.

The balance of this chapter will deal with two candidate cognitive systems in an effort to illustrate how the constituent areas of cognitive neuroscience approach common problems. These areas are among the most active ones for the joint examination of cognitive, neuroscience, and neurological approaches. The first is comprehension of lexical items. On the one hand, this area is very much at the center of problems in cognition and on the other, cases of brain injury have provided opportunities to study the neural systems involved. Second, is selective attention. In this area it is possible to link central problems in cognition with studies recording from single or small groups of cells in alert animals performing cognitive tasks. The reviews of each of these areas are necessarily highly selective and designed to illustrate the various approaches and how they might be combined rather than to establish any particular theory. We do not hope to provide a complete picture of work on the relationship of brain and mind even in the two areas chosen, but rather attempt to provide a sufficiently general picture of current efforts to give the reader a feeling of new developments and some sources that can provide a more complete background.

COMPREHENDING LANGUAGE

As is obvious from this volume, there is intrinsic interest throughout cognitive science in a theory of natural language that would explain linguistic universals and the rapid development of natural language in individual human minds (Miller & Johnson-Laird, 1976). Much of this interest in language is not reflected in this chapter. The current work that best allows connections between cognitive studies and brain processes is in the area of the storage and retrieval of individual lexical items. This is a very limited aspect of language, but the relative stereotypy of lexical items in comparison to the generative character of sentences makes analysis of lexical processing more appropriate to the methods available to the constituent fields of cognitive neuroscience.

There is a long history within neurology of deficits in language ability due to brain injury. There is much active work by neuropsychologists that examines deficits in language function with the same tools and to a large extent the same theoretical ideas as used in current studies of language function in normals (Coltheart, Patterson, & Marshall, 1980; Marshall & Newcombe, 1973; Zurif, 1980). In this section we examine two of these approaches and then compare the result with studies of normal function.

Peripheral Codes

Linguistic stimuli represent an important opportunity to a neuroscience of cognition. Language is a species-specific characteristic of the human being in which input arising from different modalities has access to highly overlearned correspondences. An individual word in a skilled reader can be contacted automatically both by auditory and visual input. The neuroscience approach to nervous systems has often been bound by sensory modalities. This in part is because of the importance of the sensory modality in the organization of brain activity. The bimodal characteristics of language makes it a natural place for the examination of the integration of modality-specific pathways at higher levels of the nervous system (Coltheart, Patterson, & Marshall, 1980).

The study of reading and its deficits has been an area of intense activity relating cognitive theory to brain injury. One disorder of reading shows the parallel nature of input of information arising from the visual modality to semantic processes. Both logic and cognitive science analysis suggest that information about words may reach semantic systems both from a translation that names the word and then uses pathways already available to speech or from visually specific information that does not rely on phonological translation. Deep dyslexics, according to some analyses (e.g., Marshall & Newcombe, 1973), have interruption of pathway leading to the word name and a sparing, or relative sparing, of semantic input from vision.

The flow of information that one infers from these studies of dyslexia (e.g., Marshall & Newcombe) is similar to diagrams developed from studies of normal human cognitive function during reading (LaBerge & Samuels, 1974). An important issue is the interpretation of such a flow diagram in terms of functional systems reflected by the neurological organization of language processing. In cognitive science, the ability to dissociate functions into separate boxes is sometimes called isolability or modularity. The argument for isolability rests upon experiments that show independent manipulation of the codes present in the component boxes. One example is the effort to show independence between visual representation of a letter or word and its phonological representation. Posner (1978) has reviewed studies showing such isolability. For example, if the two words are presented in contrasting colors, subjects are slower in determining that they are physically identical but there is no increase in times to read the word names. Similarly, if the subject has to hold other names in memory, the time for physical matches is unaffected whereas the phonetic times are affected. This ability to dissociate codes by the independent manipulability of their time courses in normal subjects has been taken as favoring isolability. Good evidence of this type exists for isolability of visual and auditory codes

of words, and between each of those codes and their phonological interpretation.

The internal representation of visual and auditory words does not seem to involve isolable systems but appears to involve the same system. When subjects are performing a task requiring them to monitor auditory words for a particular phoneme its presence in a simultaneous irrelevant visual word influences their reaction times (Hanson, 1978). This suggests that the visual word produces a representation within the same system as the auditory word.

An interesting application of the common system for auditory and visual word processing has recently been proposed by Tallal (1980). She argues that difficulty in making fine phonemic discriminations in auditory tasks might predict reading deficits. This view rests upon the common code available to both visual and auditory language. Deficits in such a common code show up in reading problems. Similarly, it has been shown that long term exposure to high levels of noise that produce no discernible auditory deficit can interfere with children's learning to read (Cohen, Glass, & Singer, 1973). The main mechanism here could be a reduction in phoneme discriminability making the grapheme to phoneme correspondence loop more difficult for these children.

Syntax

These results illustrate the convergence of neurological and cognitive analysis on common questions of isolability and suggest common results that illuminate important issues. Zurif (1979) describes an extension of this approach to show the isolability of two central components both involved in an understanding of language. These are the syntactic and semantic aspects of words. Some words in the English language are used primarily for syntactic purposes (function or closed system) and others primarily for semantic purposes (content or open system). Zurif argues that there is a separate system reserved for function words.

He further argues that it is selective impairment of the syntactic system involving the function of words that typifies the Broca's aphasic rather than an expressive inability to produce grammatical speech. Zurif rests his argument on the idea that Broca's aphasics show impairment both in the production and comprehension of speech, rather than merely in its production as had been argued by others. This suggests that the distinction between Broca's and Wernicke's aphasia lies not in the receptive-expressive distinction, but rather in dissociations of central mechanisms of language.

Zurif's argument with respect to syntactic and semantic processing is a version of the isolable-system issue. It is a particularly interesting and important one since it does not involve the separation of peripheral codes

(e.g., auditory and visual from phonological) from more central language systems but a possible separation within the central language system itself. To the extent that Zurif can show isolability between semantic and syntactic processors, this will provide new tools and methods for dealing with the internal representation of the neural systems of language.

One argument (Caramazza & Zurif, 1976) is that Broca's aphasics have difficulty in the comprehension of center-embedded sentences. The idea here is that their general syntactic deficit makes it difficult for them to comprehend sentences where the syntax is crucial to an understanding of the word string. Much of this work involves showing that normals have no deficit, while Broca's are deficient in center-embedded sentences and not in other sentence forms. It is possible that normal subjects say the sentences to themselves in the process of understanding them. If such a mechanism was used, the problem found in the aphasics could be due to difficulty in generating the internal phonological string in the process of comprehending the sentence.

One effort to address this problem has examined the reaction time for normals and Broca's aphasics to decide whether a string of letters is a word or not (lexical decision) (Bradley, 1979; Zurif, 1979). The reaction times of normals show a strong dependence on word frequency for content (open class) words and not for function (closed class) words. The reaction times of Broca's aphasics are longer and show a strong dependence on word frequency both for the open class and for the closed class words. Zurif argues there may be separate stores for the two types of words. One store contains both open and closed class words to be used in the service of semantic processing. Another rapid access store contains only closed class words used for syntactic processing. Brain injury that interferes with retrieval from this second store forces use of the slower access frequency dependent store that serves for both content and function words. This account would fit with the finding that Broca's aphasics show difficulty in the production and comprehension of sentences where syntactic cues are important.

A possible alternative account for the different effects of word frequency on lexical decision time turns on the use of word frequency data. If the effect of frequency on reaction time approaches asymptote and if closed class words are really more frequent than our measures reveal, the data Zurif reports from normal on closed class and open class reaction times may come from different points on the same exponential curve. One consequence of this objection is that we are then less inclined to think of the Broca's performance as revealing a loss of processing ability for closed class words. Instead, since they use closed class items rarely, their reaction times on closed class would be slower than normal and thus the frequency effect would not be at asymptote. This interpretation does not do very well with the data showing longer reaction times on non-words that begin with words for nor-

mals but not Broca's aphasics. Although the question of isolability is still open, it is important to pursue the notion of separate semantic and syntactic processes.

Techniques are now present to examine the isolability question by studies of localization of putative separate stores. The use of simple chronometric tasks such as lexical decision allows for the time locking needed to apply such methods. For example, event related potentials might be used to localize putative components of language task (Ritter, personal communication).² If open and closed task words are handled in different brain locations, then scalp topography of critical endogenous components should differ between the two sets of words. Indeed, there are some hints in the literature now that different classes of words produce different scalp distributions in the evoked potential. One might expect a more anterior distribution for the closed class words than for the open ones.

This argument must be a step further advanced by looking at the scalp distribution of evoked potential for closed class words under two conditions. In one condition, subjects respond to the semantic aspect of the closed class words (for example, deciding whether it signifies a plural or singular condition). In the other condition they respond to the syntactic aspect of the closed class word. In the former condition, the retrieval processes should involve semantics, while in the latter, syntax. Again, assuming a difference in brain location, one would expect a different scalp distribution of the evoked potential. The use of regional blood flow might be another spatial method useful in the possible localization of neural system underlying language. Such experiments illustrate how neuroscience approaches could be used to test critical aspects of theories developed from brain damage or cognitive science.

Semantics

One of the most exciting areas of contact between studies of brain injury and normal language function is in the operation of the system that provides the meaning of words. Zurif (1979) argues that the semantic system of the deep dyslexic is identical to that of the normal but that the dyslexic does not have the peripheral codes necessary to stabilize the normally ambiguous operations of this system.

His argument for the ambiguity of the semantic system rests on the literature of spreading activation where essentially any word activates a range of semantic associations (Collins & Loftus, 1975). If a person is asked to say specifically what the word was, he must use codes available from

²These comments were made by Walter Ritter during the course of a discussion of the role of event related potentials in language studies.

visual, phonetic, or acoustic analysis rather than the semantics itself. This is more true for words that have large numbers of associations, such as concrete nouns. Abstract words may be more fully implied by their activation pattern.

Normal subjects may be primed to be aware of only one of the multiple activation patterns of an ambiguous word by context (Conrad, 1974; Swinney, 1979). The fact that the deep dyslexics show relatively little problem with auditory meaning suggests that auditory primes ought to drive their interpretation of visually presented words in predictable directions. By pursuing this line of research on deep dyslexics, we might at once determine the degree of similarity between the deep dyslexic and the normal and contribute to cognition by showing the operations of a pure semantic system unencumbered by the peripheral devices present in the normal.

The idea that a given visual word should activate a range of associations below the level of the subject's consciousness is a very important one in cognitive science (Conrad, 1974; Marcel & Patterson, 1978). It suggests that the reading and listening tasks are both sufficiently automatic that the full range of their activation patterns are not available to the subject. Nonetheless, such patterns affects the interpretation of words of which one is aware. These results open up to psychological analysis the study of those factors that produce disambiguation of the activation patterns of any given word to provide an overall meaning to a phrase or sentence.

Although many of these ties between the study of brain damage and normals remain speculative, encouraging developments within cognitive science provide additional faith in them. The early work on isolability of systems involved primarily single letters and words (see Posner, 1978, for a review). The lexical decision task has also generally been confined to words or small strings of items. Recently, it has been shown (Aaronson, 1976; Davidson, 1978) that many of the same principles occur during continuous reading tasks. Davidson (1978) showed that words fitting the overall meaning of the paragraph subjects were reading are classified as lexical items more rapidly than unrelated words. The faster speed in processing semantically related words does not extend to their homophones. Access to semantics during reading of simple material appears to be via a grapheme to semantic route, not via the grapheme to phoneme route. Nonetheless, Davidson was able to show the effects on homophones when subjects had to make a lexical decision about a word that had been presented in the string earlier. On the second occasion repeated words are classified more rapidly than non-repeated words. The effect also occurs to the homophones of repeated words. This indicates that the string of material carried in memory does include a phonological code. These results confirm many findings (Coltheart, Davelaar, Jonasson, & Besner, 1977; Kleiman, 1975) that have been made with small numbers of letters or words and show the role of the same principles in a more natural reading task.

Linguistic Awareness

While much of the processing involved in reading and listening goes on outside of awareness, it is important to develop an understanding of the role of conscious processing in the understanding of language. To do so it is important to have techniques useful in separating processing of which we are unaware from processing involving awareness. In connection with object recognition we argued that it is possible to examine mental representations independent of the activation produced by stimulus input. One effort to do so involved the lexical decision task described earlier (Neely, 1977).

This method uses a priming stimulus prior to the introduction of a stimulus to which the subject must respond. The priming stimulus may either be a neutral warning signal or a word. Sometimes the prime word is the name of a category of the stimulus. For example, the prime "animal" followed by item "dog." Subjects decide whether the item that follows the prime is a word or a non-word (lexical decision).

Let us describe how a theory (Posner & Snyder, 1975) of automatic and unattended processing predicts various aspects of this simple task. Information in automatic pathways builds up quickly and automatically. Attention, however, takes time to shift to the represented category. If automatic is taken to mean parallel activation, then one can activate many of these pathways at the same time. This implies that the activation of the pathway will have a positive effect on reaction time (benefit) but no negative effect (cost). Thus, one would expect benefit to build up quite rapidly, but cost only to be associated with the operation of a slower attentional mechanism. The results confirm this idea. Following a prime, benefit is present very rapidly, but cost builds up very much more slowly than benefit.

Neely's experiment found very systematic asymmetries in the time course of buildup of cost and benefit of the type that would be expected from the theory described above. In this condition, the priming stimulus serves both as a means of activating internal pathways and of serving as a cue for the subject's active attention.

A second condition that Neely used was to prime the subject with a category name but when it was presented the subject was supposed to think consciously of a different category. For example, if the word "animal" was presented, he was to think "furniture." Neely traced the time course of cost and benefits. According to the theory, one ought to expect symmetric buildup of costs and benefits, since there is no automatic pathway activation. This is the result. Most interesting is the case where the subject is given the word "animal" and must switch his attention to "furniture" but then is given an instance of the original category (e.g., "dog"). The theory predicts that the initial automatic benefit will switch to cost and again this is the result obtained. Some experiments have raised questions with aspects of the Neely results (Antos, 1979). Nonetheless, it remains a good demonstration

of how cognitive science thinking about a "pure" mental representation can lead to methods that separate conscious and unconscious processes involved in language comprehension.

There is evidence that violation of an expected event leads to active, highly conscious processing and to a particular component of the event related potential that is positive in sign and occurs about 300 msec after input (P-300) (Donchin, Ritter, & McCallum, 1978). Recently, such unexpected events have been studied in language tasks (Kutas & Hillyard, 1980). With a physical violation such as an unexpectedly large print, there is an enlarged P-300; an unexpected semantic stimulus however, produced an enlarged negativity at about 400 msec. Hillyard suggests that semantic violation may be processed separately from physical violations.

Recent evidence provides interesting links between the P-300 latency and aspects of awareness. Duncan-Johnson (1979) has shown that the P-300 latencies are not as labile as reaction time. A highly primed stimulus produced a P-300 that occurs before the overt response, while for an unprimed stimulus P-300 occurs after the response. This result fits with the idea that P-300 represents the entry of a stimulus to processing by a system related to the awareness of the subject rather than his response. Sometimes one is conscious of an event prior to responding, sometimes after, depending on how automatic the relationship between stimulus and response is. There are questions about some aspects of the Duncan-Johnson work because she did not dissociate the priming of the stimulus from the priming of the response. The person who expected a particular event could prepare for the motoric response of that event. Methods available in cognitive psychology could be used to insure priming of the stimulus alone.

Data arising from studies using language stimuli are of particular importance because they are at the heart of the cognitive science approach and because they allow us to get beyond sensory-specific stimuli to study aspects of bimodal processing systems. The brain injury data and the event related potential methods provide important links to the brain processes. However, language is a species-specific property of the human being and does not allow easy use of the animal models that lie at the heart of neuroscience methods. In the next section we examine some putative-cognitive systems that allow further links between human and animal results.

ORIENTING OF ATTENTION

The preceding section on linguistic awareness illustrates the importance to cognition of understanding the mechanisms of awareness. However, the use of linguistic materials prevents the kind of animal studies that are central to neuroscience methods. It is possible to forge closer links between cognition

and neuroscience work by using tasks that involve "detection" of non-linguistic stimuli. Many organisms have similar highly developed mechanisms for active scanning of the visual environment. There is a great deal known about parts of the visual system that are necessary for detection. Much of the neuroscience understanding of vision has involved study of anesthetized animals who are not using the cognitive mechanisms for detection available in alert organisms. In this section we will be concerned with efforts to understand the central mechanisms that give rise to detection when organisms are "cognitive" in the sense of using active strategies to scan their environment.

Recently there has been interest in the relationship between attention and movement both in neuroscience (Goldberg & Wurtz, 1972; Mountcastle, 1978) and in cognitive psychology (Posner, 1980). For visual events, the major concern has been in the relationship between orienting (overtly by eye movements, or covertly via shifts of attention) and the efficiency of detecting (making arbitrary responses, or being aware of) stimuli. Work in cognition has explored three general points:

1. Measurement of covert orienting of attention by changing in the efficiency of detecting stimulus events at different spatial positions.
2. The relationship between movements of covert attention and movements of the eyes.
3. The pathways controlling both covert and overt orienting.

A useful task to explore orienting involves selection of positions in visual space (Posner, Nissen, & Ogden, 1978). The subject is given a single key and asked to respond as quickly as possible whenever a visual flash occurs. A cue provides the subject with varying information about the likely spatial location of the stimulus. There is little doubt that subjects could perform this task without committing attention in advance. Subjects could simply wait until the visual event occurs and respond by pressing the key with very little likelihood that they would ever miss any of these suprathreshold stimuli. One might suspect that there would be no evidence of attention limits in this task. Indeed, many experiments using paradigms like this have failed to show selective effects (Grindley & Townsend, 1968; Mowrer, 1941). Recent results, however, have shown evidence for the role of selectivity in this task.

Evidence is of clear costs and benefits from knowledge about where in space a visual stimulus will occur even when eye movements are eliminated (Posner, Nissen, & Ogden, 1978). To a surprising extent, the mechanisms responsible for this effect are independent of the visual system. For example, this spatial selectivity is not related to the fine structure of the retina that distinguishes fovea from periphery. Although foveal stimulation is pro-

cessed faster, the costs from an unexpected peripheral event and from an unexpected foveal event are identical (Posner, 1978). This finding applies only to detection of luminance that is clearly above threshold. It is not the case that attention can compensate for the high acuity provided by the fine structure available for foveal stimulation. When acuity is required, the equipotentiality of the retina with respect to attention no longer holds. Indeed, the behavior of subjects exquisitely reflects this difference. If left free to move their eyes in a luminance detection situation, subjects quickly suppress any tendency to move them and this conforms to the optimal behavior for this task. On the other hand, in an acuity task, the tendency to move the eyes to the stimulus is very powerful and subjects attempt to do so whenever possible (Posner, 1980).

The second sense in which attentional orienting is relatively independent of the fine structure of the visual system is the relationship between movements of attention and movements of eyes. The term "movements of attention," is used because it is possible to show that attentional shifts from one place in space to another are analogue (Shulman, Remington, & McLean, 1979). That is, probes at positions between fixation and target are facilitated at times intermediate between leaving fixation and arriving at the target. This result shows that covert changes of attention can be measured quite objectively and are as time-locked as eye movements themselves. These findings fit well with similar analogue results reported earlier for imagery experiments.

Attention movements are not slaved to the saccadic eye movement system. Attention can move while the eyes are still; a program to move the eyes does not automatically cause an attention shift (Klein, 1980); and it can be shown that attention can move in a direction opposite from where the eyes are programmed to move (Posner, 1980).

This relative independence of eye movements from attention can be compared with developing work in the single cell domain (Mountcastle, 1978; Robinson, Goldberg, & Stanton, 1978). It has been shown that at the collicular level there is a close relationship between enhancement of single cell activity and eye movement. At parietal levels the relationship between selective enhancement of single cell activity and movements is in dispute. Mountcastle (1978) has stressed the close relationship of attention to movements of the hands and eyes. He finds that the earliest input to parietal lobe is to neurons that have no foveal representation and whose input is from mid-brain structures. On the other hand, Robinson, Goldberg, and Stanton (1978) argue that their data suggest that the activity of cells in area 7 is better understood as signaling the presence of a stimulus than as commanding movement.

If the simple reaction time is taken as a measure of the efficiency of detecting a stimulus and the movements of attention are thought to be related to

orienting, the behavioral results indicate that orienting and detecting are separable properties of attention. This same dissociation is born out in pathological data. Occipital scotomas produce an inability to detect consciously the occurrence of the event, but may spare the ability of the subject to orient (Weiskrantz, 1977). On the other hand, parietal lobe damage seems to reduce spontaneous orientation to the opposite side in space but preserves the ability to detect stimuli should attention be forced to that position in space.

It is possible to suppose that a single underlying mechanism is responsible for both limited capacity results discussed under language and for the luminance detection results discussed in this section. This view requires that the subject be able to orient attention either to a high level semantic analysis or to commit it at a very early stage to a location in visual space. If this single mechanism view is correct, one would expect the selection of dimensions such as orientation, size, position, and color to be handled by the same mechanism but be associated with different time courses.

One reason for favoring the idea of a single neural system responsible for both types of selection is that both the single cell results on spatial selection and the scalp distribution of P-300 implicate parietal lobe sites. Another reason for postulating a single mechanism is that one would not expect subjects to be very successful in maintaining an early selection by spatial location when occupied at the same time with an attention demanding task like mental arithmetic. If peripheral selection breaks down under conditions where the subject is occupied with an irrelevant attention demanding task, one must believe that early selection draws upon the same underlying capacity as do other aspects of attention.

The event-related potential results, however, do not seem entirely consonant with the single mechanism view. Hillyard (Hillyard, Picton, & Regan, 1978) reports a dissociation between N-100 enhancement when a spatial position is selected and P-300 when a semantic target is detected. This could suggest that early selection is programmed by some sort of filter, as originally suggested by Broadbent (1958), while late selection is achieved by a different neural system. In favor of this view is the finding that target and non-target events that arrive on the attended channel seem to produce the same evoked-potential effects prior to P-300. If the same system were responsible for early and late selection, one might expect that once selected by this mechanism, targets and non-targets would be handled differently.

There are also differences in detail between the N-100 event-related potential results and the luminance-detection reaction time results. Eason, Harter, and White (1969) and Von Voorhis and Hillyard (1977) have reported event-related potential differences (N-100) between attended and unattended positions. These studies have used blocked presentations where attention is kept fixed at one location. Under these conditions, N-100 ap-

pears to be enhanced at the attended position. The event-related potential enhancement seems also to be linked to situations in which there is rapid presentation of information from given positions in space with attention consistently directed to one position. With slow presentation and single trial cuing such as used in the luminance RT work, no N-100 effects are found. On the other hand, benefits in reaction time are smaller with blocked presentation than with trial-by-trial cuing. The reasons for these differences between event-related potential and reaction time results is not known.

A point to consider in this connection is that the paradigms that show N-100 effects also involve effective exclusion of non-targets from consciousness. In the cuing paradigm that has been described in this report for reaction time, no such exclusion occurs although the expected position has a latency advantage. Perhaps the N-100 results are indicative of filtering mechanisms used only in conditions of high overload. It would not necessarily be adaptive to prevent any information from non-attended signal sources from reaching consciousness. The difficulty of concentration that most of us have suggests that selective mechanisms are neither effortless nor completely effective. These are promising avenues for development of ideas relating different brain systems to aspects of attention.

Some work tracing the neural systems involved in spatial attention has already been carried out. It has long been believed that the superior colliculus plays a special role in programming overt movements of the eyes. Mammals tend to have stronger pathways from the retina to the contralateral superior colliculus than ipsilateral connections. It is possible to test the functional significance of this anatomical relationship by allowing subjects to view stimulus displays monocularly (Posner & Cohen, 1980). Subjects are instructed to move toward the temporal visual field in accordance with the anatomical connections cited above (Posner & Cohen, 1980). This asymmetry does not occur with eye movements to auditory commands nor does it occur strongly in conscious judgments of temporal order that do not involve movements of the eyes. There appears to be a similar bias in infants occurring even when only a single stimulus is presented (Lewis, Maurer, & Milewski, 1979).

Shulman (1979) sought to determine if a similar bias toward the temporal visual field existed in covert shifts of attention. He first determined the advantage in reaction time when attention was brought to a position in the visual field by the occurrence of a single peripheral target. He had subjects view monocularly trials in which physical targets occurred simultaneously to the left and right of fixation. A bias toward the temporal visual field should have produced a temporal field advantage of about 70 msec, but no such bias was found. This and other work leads to a rejection of the idea that covert attention is controlled via midbrain pathways alone. It should be

possible to explore this result further to determine if the pathways of the second (e.g., retinal-collicular) visual system are important in the control of covert shifts of visual attention by use of patients who suffer from collicular degeneration.

Spatial attention is currently an active area where a variety of neuroscience and cognitive techniques have been applied to common questions. The work has advanced sufficiently to suggest that alert organisms use central mechanisms in the detection of visual stimuli that are distinct from the visual system as usually studied. There is promise that an understanding of these central attentional mechanisms will aid in a general approach to the physical basis of awareness.

CONCLUSIONS

This chapter delimits a unique set of problems that concern people working at the boundary between cognition and neuroscience. We expect work on this set of problems to grow during the coming years as new techniques are used to explore the neural systems activated by cognitive tasks. A major problem of the field is to develop a level of theory that allows contact between the study of normal and pathological material and between cognitive and physiological approaches. The development of such a theory has certainly been enhanced by the use of information processing concepts. The very generality of such a language does pose difficult problems. There is a tendency to use such language in a way that avoids problems that are unique to specific cognitive systems. For example, the claim that language and visual perception are not different because they can both be described in the same propositional code does not help us to understand the dissociation that occurs in brain injury. If the goal is to develop an interface between cognition and brain processes it will not be useful to speak at a level of analysis at which brain systems do not seem to be of importance. On the other hand, too strong a concentration on the problem of localization leaves the cognitive scientist with the impression either of a new phrenology or at least a lack of commitment to the dynamic interactions among neural systems that are likely to underlie much of the interesting aspect of cognition. Fortunately, as outlined in our introduction, some of neuroscience has begun to move in the direction of understanding complex interactions among neural systems that could provide a basis for cognition.

Our main goal has been to outline two cognitive systems in which specific questions have been studied by different techniques. Although no set of principles or theory has emerged from this inquiry, we feel that promising starts for combined work have begun and that enough is known to suggest that cognitive neuroscience can be developed in the coming years.

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