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**A NEUROLOGICAL MODEL OF  
INFORMATION PROCESSING AND STUTTERING**

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A NEUROLOGICAL MODEL OF  
INFORMATION PROCESSING AND STUTTERING

by

Jason Ting Li

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ABSTRACT

A NEUROLOGICAL MODEL OF  
INFORMATION PROCESSING AND STUTTERING

By

Jason Ting Li

A neurological model of human information processing is proposed. A central focus of the model is on information processing as an active or passive phenomenon. It adopts the position that information processing varies along a continuum of active and passive information processing. Factors biasing the information processor towards more active or passive processing are discussed. The phenomenon of stuttering is examined as an example illustrating how passive processing mechanisms can become overly dominant over active processing mechanisms. A specific neurological model of the stuttering moment is developed from the information processing model proposed. The paper concludes with a discussion which attempts to reframe from a neurological perspective some fundamental concepts of the information processing paradigm such as attention, selective attention, consciousness, inner speech, active and passive information processing and voluntary and involuntary control of the information processing system.

To my parents, Ting Yi and Tsun-Hwei Li,  
for their steadfast love and faith in me.

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## CHAPTER I

### INTRODUCTION

The information-processing paradigm can be characterized by its fundamental view that human beings in certain cognitive tasks operate like an information-processing system. The fundamental capabilities attributed to such a system are the ability to represent things symbolically and to manipulate these symbolic representations (Lachman, Lachman, and Butterfield, 1979). Three basic views of man emerge--man as a passive information channel, an active processor of information, or an active/passive processor of information. At one extreme there is the view of the human as a passive information channel that can be described in strictly quantifiable terms (Hick, 1952; Hyman, 1953). At the other extreme, there is the view that, to accurately describe man as an information processor, the idea of a passive channel should be abandoned in favor of the idea that people actively process information (Welford, 1976). From these two opposing views emerges a third view of man as a variable processor of information--processing information sometimes more passively and sometimes more actively (Hasher and Zacks, 1979).

It is this third view of man as varying along a continuum of active and passive processing that is adopted in this paper. Similar to the position of Hasher and Zacks, this paper suggests that man has two modes of regulation for the information processing system--some type of automatic pilot and a more consciously controlled,

effortful operation. How much a person relies on automatic or effortful modes of regulation varies between individuals and across situations. In certain instances, an individual may process information through a very effortful, conscious mode such as when a person is first learning to drive a car. The novice driver consciously attends to relevant incoming stimuli such as stop signs, traffic lights, or the speed of the car. As the driver becomes increasingly familiar with the routine of driving, however, it is no longer necessary to rely so much on effortful processing because much of the information now can be processed automatically. This driver, as he speeds down the road, may now stop for a red light or adjust his speed in relation to the cars around him automatically, without the effortful processing which was at one time necessary. The reliance of the driver on automatic modes of processing, however, can still be said to be in the service of his capacity for higher-order, conscious direction. What is meant by this is that, though there may be an automatic mechanism temporarily in control of the information processing, this automatic mechanism is able to be controlled by more conscious, voluntary operations. Thus, if the driver suddenly detects a police car following him on the highway, he can immediately switch over to a conscious, effortful monitoring of his speed. At any given moment, the driver can voluntarily switch over to this more conscious mode of information processing. He does not do this, usually, because the automatic mode is perfectly sufficient in most circumstances. This situation can be likened to a computer programmer who selects the goals for the computer program but lets the program do the actual work. At

a given time, he can voluntarily select another automatic program to do the information processing or even discard the programs altogether and perform the processing manually, with a great deal of conscious effort. In the same way, the automatic processing mechanism, in the case of the driver, can be viewed as a "program" in the service of a higher-order "goal programmer" or "voluntary control center."

The case of special interest to this paper is when the automatic information processing mechanism not only does the "work" for the goal programmer, but actually begins to take over the control of the goal programmer. It might be said that while, in most cases, we are largely in control of our information processing apparatus, in certain situations, our information processing apparatus can become in control of us. In such instances, the voluntary control center cannot easily switch over to an active processing mode so that the automatic processing mechanism temporarily becomes the highest source of control for the information processing system. What is meant by "highest source of control" in this case is that the automatic processing mechanism assumes not only its normal regulatory function of the system but also the directing capacity of the voluntary control center. In layman terms, "the machine directs the master."

Cases such as this raise a central question to be addressed in this paper: How does the competition for "highest control" of the information processing system take place between automatic processing mechanisms and an individual's voluntary goal-programming capacity? What factors, more specifically, help determine where a person falls on the active-passive processing continuum at a given time? Phrased in another manner, under what conditions does man resemble a goal-seeking or data-driven information processor? The purpose of this paper

is to propose a theoretical formulation that addresses this central question, however it is phrased. This theoretical formulation is presented in two parts. First, an overall model of information processing is proposed which addresses the question at a general level. Then, at a more specific level, the general model is applied to the phenomenon of stuttering in an attempt to account for a postulated dominance of an involuntary, automatic processing mechanism which appears to be regulating the stuttering response.

According to the specific plan of this paper, in Chapter II cognitive psychological theories of attention and biological knowledge of the information processing system are examined in terms of their relevance to developing a model of information processing. In Chapter III a general model of the information processing system is proposed which attempts to integrate these two areas of knowledge concerning information processing into a consistent framework. The model provides an account of information processing in terms of hypothesized neural phenomena. In Chapter IV a specific model of the stuttering moment is proposed, based on the major points drawn in the preceding chapter. Finally, in Chapter V a summary of the major points of the paper is provided along with a discussion of some of the implications of the neurological model towards describing some central concepts of information processing at the level of neural phenomena.

## CHAPTER II

### CONTRIBUTIONS OF COGNITIVE AND PHYSIOLOGICAL PSYCHOLOGY TO A NEUROLOGICAL MODEL OF INFORMATION PROCESSING

In this chapter the literature of cognitive and physiological psychology is examined briefly in terms of its relevance to developing a general model of information processing. The areas of cognitive and physiological psychology are considered relevant to developing an information processing model in terms of their respective focuses on the functional and structural aspects of information processing. Reliance on both the functional and structural knowledge of the information processing apparatus is founded in the belief that the two sources of data, together, can have a positive synergistic impact on our understanding of information processing.

#### Theories of Attention

In this section some of the major cognitive theories and empirical findings concerning attention are examined with the intent of developing tentative working hypotheses about the functional information processing system. In addition, in this section I attempt to establish an explicit definition of attention.

Broadbent's studies of attention were the first to open up the area of attention to the field of experimental psychology. Prior to

this, attention was studied under the label of consciousness, largely through introspective methods (Lachman, Lachman and Butterfield, 1979). For this reason, Broadbent's filter theory is considered as the most logical place to begin in reviewing some of the modern theories of attention. The theory is built around findings from two areas of experimentation: shadowing tasks and split-span experiments. Cherry (1953) performed a series of experiments in which subjects were required to attend and to shadow a message presented to one ear while another message was simultaneously being played into the unattended ear. Cherry found that under normal conditions, subjects could not recall messages presented to the unattended ear. When features of the unattended message were changed, such as switching from German to English, no recall was observed. When these changes, however, involved gross physical features of the message, such as voice pitch, they were able to be detected in the unattended ear. Broadbent's second source of data, split-span experiments, involved presenting dichotically a series of digit pairs and then asking subjects to recall the digits. Subjects recalled the digits, not in order of presentation, but grouped according to the ear to which they were presented.

Broadbent's filter theory of attention attempts to account for these findings by postulating the presence of a selective filter which serves to block all unwanted inputs from entering into a single processing channel where conscious processing takes place. This filter is able to screen all inputs according to physical features such as voice pitch in the shadowing task or ear location in the split-span experiment. However, according to Broadbent, it cannot screen out inputs according to meaning. The more intensive, complex analysis of

information for meaning takes place only after inputs have passed through the filter into a single processing channel which may be equated with consciousness or attention. Thus, according to Broadbent, meaning in information only can have an impact on the organism and become a part of long-term memory after it has been consciously processed one input at a time in the single processing channel.

Broadbent's theory has been abandoned in the face of growing evidence suggesting that meaning does play a role in the processing of information even before it becomes conscious. Moray (1959), using a shadowing experiment similar to Broadbent's, found that people were aware of their own names even when the names were presented to their unattended ears. This experiment suggests that unattended inputs do receive some processing for meaning. Further support for this notion was supplied by Treisman (1960), using a shadowing task in which subjects were instructed to shadow a story presented to one ear while ignoring a different story being played in the other ear. In the middle of the shadowing task, the story presented to the attended ear was switched over to the unattended ear while a completely new story was introduced to the attended ear. According to Broadbent's theory, the subject should have continued shadowing the new story without noticing anything on the unattended channel, inasmuch as there was no change in the gross physical features of the message. The actual results, however, showed that the majority of subjects momentarily switched over to the unattended ear and shadowed the story they had begun with. These results suggest that the context of the original story or meaning of the input is an important factor in the preconscious selection of what

will be consciously processed. Finally, Gray and Wedderburn (1960) demonstrated, in a modified version of Broadbent's original split-span experiment, that meaning could play an important role in determining recall order. In their experiment they presented dichotically a series of signal pairs as Broadbent did in his original experiment. The modification in this experiment was that two types of signals were used, digits and words, and their presentation was mixed across ears. Broadbent's theory of selection by channel predicts that the order of recall should be determined by ear. Gray and Wedderburn found, however, that recall was by contextual meaning--words were recalled by group (i.e., Mice eat cheese) separately from the digit (i.e., 8-7-1). Findings such as these had a two-fold effect on the field of attention research. First, it led researchers away from Broadbent's notion of a rigid filter separating preconscious processing of gross physical features from the more complex, conscious processing of abstract features such as meaning. Second, it encouraged the development of new models of attention capable of explaining the role of meaning and long-term memory in the process of selective attention.

In an early attempt to provide an account for such findings, Treisman modified Broadbent's theory so that the postulated filter did not block out unwanted input completely but only served to attenuate it. According to Treisman's filter-attenuation theory, the filter sometimes passes inputs solely on the basis of gross physical features but, at other times, such as in the story shadowing task, did so on the basis of abstract properties such as meaning. The primary innovation Treisman added to Broadbent's theory was to make the filter more

flexible and open to the feedback of meanings from consciousness. Despite recognition of the potential role of meaning in determining selective attention, Treisman's theory remains essentially similar to Broadbent's in the notion that, once past the filter, conscious processing is limited to one input at a time. Thus, the emphasis in Treisman's theory is still on attention as conscious processing.

More recently, Norman (1968) has developed a theory of memory and attention which specifically addresses the issue of the roles meaning and semantic memory play in the process of selective attention. According to Norman, semantic memory is integrally tied to the automatic, unconscious processing of sensory inputs occurring prior to conscious processing. Figure 1 provides an outline of the process of selective attention he describes. Sensory features of stimuli are processed unconsciously until they activate their representations in semantic memory, what Norman refers to as nodes or addresses. In Figure 1, three sensory inputs have activated their correspondent nodes, *i*, *j*, and *k*. The input which is selectively attended to will be the one whose node has the highest level of activation. The activation of nodes depends not only on the level of activation from sensory inputs but also on the pertinence of these inputs to current cognitive activities. Pertinence is determined by the context of the inputs and may be thought of as another source of activation for the nodes. In summary, Norman's theory proposes that selective attention is based on the summation of semantic memory activation from current sensory inputs and contextual pertinence.

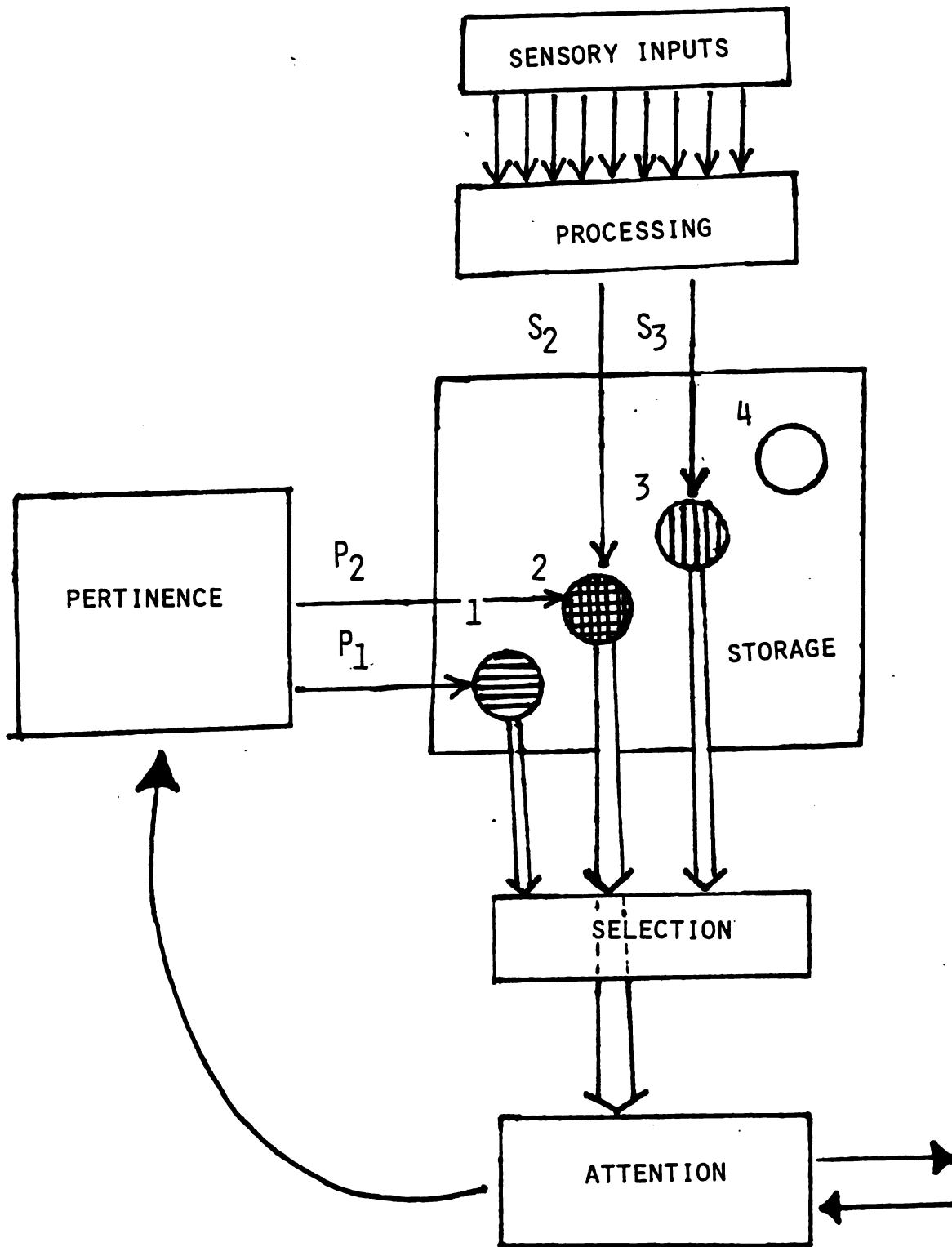


Figure 1. A view of the process of selective attention (adapted from Norman, 1968).

In Norman's theory, attention is not considered as an all-or-none phenomenon as in Broadbent's filter theory. Instead, it is considered to be a matter of degree so that inputs may vary on a continuum, from those that are unattended to and receive only partial processing to those that are attended to and receive more in-depth processing. This "levels of processing view" of attention does not limit attention to conscious processing but recognizes that a significant degree of processing, including processing for meaning, occurs during the preconscious stage. Thus Norman views attention as being synonymous with processing capacity.

Up to this point I have discussed two basic processes which have been postulated for selective attention: selective attention based on gross sensory analysis as in Broadbent's model, and selective attention based on semantic memory as in Norman's model. Both types of models of attention help to account for some of the basic observations concerning selective attention, but neither one, alone, offers a complete view.

A dual process theory of attention, proposed by Neisser (1967), attempts to account for the effects of both sensory inputs and semantic knowledge on the process of attention. In his theory, Neisser proposes that complex preconscious processes direct the focusing of conscious attention. These preconscious processes are guided by the interaction between the gross sensory features of a stimulus and stored semantic information. Thus, environmental data are not simply converted directly into percepts but, instead, are integrated with already-stored knowledge to form percepts. Neisser's view of attention and consciousness, like Norman's, is that they are a matter of degree, rather than an all-or-none

phenomenon. Unattended stimuli are not blocked out or attenuated prior to some hypothesized stage called conscious processing. Instead, unattended stimuli fall on the same continuum of processing as attended stimuli, only they have not been fully processed. Thus, degree of consciousness may be viewed as synonymous with the extent of active processing which has been performed on an input.

From the theories and findings concerning attention covered in the preceding discussion, a number of working hypotheses can be selected as a starting point in the development of a model of attention. First of all, I adopt the view of attention as processing capacity, a limited resource, which may be employed either consciously or unconsciously. This view of attention was chosen because it allows one to view attention in a much more flexible manner than if it were identified solely with consciousness. For instance, since attention is viewed as both conscious and preconscious processing capacity, one can view attention more as a matter of degree rather than an all-or-none phenomenon. The assumption that there is no great qualitative difference in preconscious and conscious processing leads one to consider the importance of all levels of processing in determining the course of attention. Second, I adopt a dual process view like Neisser's (1967) that selective attention is at least partially determined by the interaction between the gross sensory and more complex semantic analyses of incoming stimuli. Finally, the major points proposed in Norman's theory of memory and attention are chosen as a beginning framework from which to develop a model of selective attention. Specifically, these points are the

following: (a) there are internal representations of external stimuli called "nodes" stored in semantic memory; (b) the input to which selective attention is directed is the one that corresponds to whatever node had the highest level of activation; (c) activation of nodes is determined by an interaction between sensory inputs and their pertinence to current cognitive activities. These points will be elaborated in greater detail as the model is described.

The Internal Model:  
A Vehicle for Selective Attention

Norman's postulation of a node as a stored representation activated by corresponding sensory inputs and pertinence inputs suggests that it is some type of internal model of an external stimulus which is activated when it shares a number of corresponding features with either a sensory input or a pertinence input. In Norman's model of selective attention, the node is the central vehicle for the process of selection. Ultimately, it is the node of greatest activation which receives the bulk of selective attention. The notion that there are internal models needing to be activated in order for selective attention and perception to occur is not unique to Norman's theory. Hochberg's (1970) description of sets of expectations stored in memory and Kahneman's (1973) description of recognition units are two examples which seem to be pointing to the importance of internal models in selective attention.

A Biological Internal Model:  
Sokolov's Neural Model

Sokolov (1969) introduces the concept of the neural model providing a biological basis for the notion of an internal model guiding selective attention. In his neural model theory, a sensory message reaches analyzers at the level of the cortex, where its features are matched up to internal models constructed through previous experience. These internal models, which he refers to as neural models, are the reflection of external stimuli in the form of neural phenomena. They are patterns of neural excitation. Sokolov infers the presence of such neural models from experiments monitoring the orienting reflex. In these experiments, a complex stimulus is presented to subjects until their orienting reflex habituates to the stimulus. It was found that when one element of the complex stimulus was omitted, a new orienting reflex was elicited. From these findings, Sokolov postulated that the new orienting reflex was triggered when some mechanism compared the afferent stimulus with a neural model and produced signals of discrepancy.

Sokolov discusses several important properties of neural models that will be relevant to the development of the model of information processing proposed in this paper. First, neural models are manifold images of the external world. By measuring the EEG pattern for the presence of an orienting reflex after varying different properties of the stimulus, Sokolov found that various changes in stimulus properties such as color, magnitude, form, duration, or rhythm were able to elicit the orienting reflex. He used these findings to support the

notion that the neural model is capable of representing many different types of stimulus features. If the neural model did not, in some way, store a representation of certain stimulus features, changes in actual features of the afferent stimulus would not produce signals of discrepancy with the model and the ensuing orienting reflex would not occur. Second, though the neural model may represent many features of the stimulus, still, it is only a partial representation of the external agent. Only those aspects of relevance to the organism in adapting to its surroundings are incorporated into the neural model. Finally, he emphasizes the dynamic aspect of the neural model. Accordingly, the neural model of a stimulus is not a static imprint but undergoes constant revisions in order to account for the characteristics of the stimulus at a given moment. Evidence used to support this notion once again comes from observations of the orienting reflex. The orienting reflex appears only during the initial period of exposure to a novel stimulus, disappearing as the new stimulus continues to operate. Sokolov suggests that during the time the new stimulus is operating, the previous neural model is actually being replaced by a new model corresponding to the new stimulus, eliminating the signals of discrepancy and the orienting reflex.

### The Biological Information Processing System

I have now examined some of the various theories and models of attention, with a focus on gaining a functional understanding of how the information processing system works. I have also discussed the possibly central role of an internal model in the process of selective

attention and suggested that Sokolov's neural model represents a biological analogue of this hypothetical construct. Now I will turn to another valuable resource to further an understanding of the processes and mechanisms of selective attention: biological knowledge of the information processing system. By attempting to integrate the functional understanding of selective attention from cognitive psychology with structural data from physiological psychology, I hope to forge a model of information processing that is coherent with both bodies of knowledge. In this section I will examine briefly the general state of knowledge concerning the biological information processing system.

Before embarking into an explanation of how the biological information processing system functions, it may be helpful to examine the basic constraints within which the coding system must operate. First, all of the different forms of sensory data impinging on the organism are translated by special transducers into neural impulses. Second, the neurons which transmit these neural impulses throughout the system are essentially the same in terms of structural and functional characteristics. What this means is that complex information is carried not in terms of activation of unique information-carrying units such as special neural impulses or neurons, but in the *pattern* of activation of these common information units. This pattern of neural activation may vary in terms of spatial or temporal characteristics so that, in this system, information is conveyed in the form of different spatio-temporal patterns of neural activation (Boddy, 1979).

Since there is a great deal of electrical activity or "neural noise" occurring in the nervous system, when I refer to a spatio-temporal

pattern of neural activation, I mean that this pattern is distinguishable over the level of background noise. Thus, when I speak of these patterns, they are actually patterns of *relative* neural activation. At the neural level, each neuron makes a probabilistic contribution to the overall pattern of neural activation. Thus, it is not likely that exactly the same neurons are activated each time the system processes the same stimulus. More likely, the distribution of neural activation over a population of neurons approximates the typical pattern of activation to a stimulus. The basis of storage of information lies in modification of transmission properties within ensembles of neurons. At the neuronal level what may be happening is an increase or decrease in sensitivity of the cholinergic synapses, which would result in a change in transmission properties of that neuron. Thus, particular neurons may discharge neural impulses at a rate that is relatively larger than other neurons. At a macro level these activated neurons form a pattern both temporally and spatially that conveys information.

Up to this point I have been talking about the biological information processing system as a whole. When the system is viewed at the level of the individual neuron, it can be seen how different neurons function to handle different stages of information analysis. The type of features and complexity of analysis and integration varies according to the level of analysis of the different neurons. The basic function of these neurons, however, of being differentially sensitive to certain defining features of characteristics is constant at all levels.

In general, information impinging at the sensory register is

integrated into more complex forms as it ascends up the information processing system. This integration occurs when a group of neurons making up what is called a receptive field, feed into and are able to activate neurons at a higher level in the information processing system. Thus an external object may reflect light onto a certain region of the retina. If enough of the activated neurons are a part of a particular receptive field, the neuron to which they have connections will discharge. Hubel and Weisel (1962) have done work supporting the notion of simple and complex receptive fields. They found that certain cells or neurons at the cortical level were activated when slits of light were projected onto restricted regions of the retina. This type of field limited to a specific area of the retina was referred to as a simple receptive field which served to activate a simple field cell in the cortex. They found that other cells at the cortical level were activated by specific features such as specific orientations of the slits of light, or moving stimuli, irrespective of retinal location. To explain this they suggest that there are complex field cells which receive inputs from many simple cells, representing a higher order of integration of the original information. In a subsequent study, Hubel and Wiesel (1965) found evidence in the cortex of even more complex field cells and receptive fields. They refer to these cells as lower and higher order hypercomplex cells because they serve to integrate receptive fields composed of complex field cells into even higher orders of information. It may be seen how this manner of integrating basic neural information into higher and higher levels of analysis enables particular neurons such as feature analysis cells to be selectively

responsive to complex features of the environment.

I have now discussed how the biological information processing system is geared towards different levels of processing at the neural level. Considering the system as a whole it can be seen that there are four distinct stages of processing which may occur between stimulus input and response output: sensory processing, feature processing, semantic processing, and response selection. At the primary level of sensory processing, incoming stimuli from the environment are transduced into neural activation patterns which are basically isomorphic in organization. This means that the pattern of neural activation is organized similarly to the pattern of the external stimulus. For example, information about spatial location in the visual system is coded on a "mosaic" basis. At the secondary level of feature processing the neural patterns of activation are organized by features. Hubel and Weisel (1962) showed this to be the case in the visual cortex of the cat where any pattern of visual stimulation is analyzed into the different features it contains. At the gross level, mapping still corresponds to the approximate spatial pattern of the external stimulus but, at the local level, features are analyzed by separate channels. With the tertiary level of analysis, what I refer to as semantic processing, there is more speculation concerning its nature of organization and anatomical base. The phenomenological experience of being aware of the world as an integrated pattern rather than a disjoint set of features suggests that feature analyzers at the secondary level transmit their neural impulses to a higher level mechanism which somehow synthesizes these features into a coherent, integrated percept. Boddy

(1978) postulates a diffusely projecting system, radiating to widespread cortical areas, as the anatomical location of this mechanism. Finally, at the level of response selection, neural patterns of activation are postulated to activate certain motor units thereby determining selection of response.

### CHAPTER III

#### A GENERAL NEUROLOGICAL MODEL OF INFORMATION PROCESSING

In this chapter a speculative model of information processing is proposed which serves as the foundation for the development of an information processing model of the stuttering moment developed in the next chapter. The model proposed in this chapter attempts to integrate findings from cognitive and physiological psychology into a coherent conceptualization of information processing, consistent with both bodies of knowledge. Though the proposals set forth in this chapter are of a speculative nature, it is hoped that they might be useful in stimulating further discussion and research--particularly towards the goal of a closer integration of psychological and biological theories of information processing.

The chapter is presented in three parts. The first part presents an overview of the major stages of information processing which provides an overall framework from which to view the model. The second part provides a more detailed description of the basic components of the information processing system as well as an account of how these components develop to form the proposed information processing system. The third part deals with how selective information processing takes place within the information processing system. The system, proper, is first discussed in terms of how its components interact with each other to determine what information is selectively processed. Factors which

influence the interaction of these components, most notably arousal level, are then discussed in terms of their effect on selective information processing. Finally, selective information processing is discussed in terms of how all of these factors interact to bias the information processing system towards selective information processing through a voluntary or involuntary mode.

### An Overview of the Major Levels of Information Processing

In this section a brief overview of the major stages of information processing is described from the early stage of sensory analysis to the response output stage. The information processing system as a whole can be viewed as a series of connections between lower and higher order processing units. The lower order unit, described in the preceding section as a receptive field, is composed of a group of neurons feeding into a single, more complex neuron. The more complex neuron is a higher order processing unit in relation to its receptive field. It also may be one of many complex neurons which make up another receptive field feeding into still higher order processing units (see Figure 2). Thus, while the information handled by the information processing system becomes more and more complex as it ascends, the basic organization of system remains the same at each level of processing: lower order receptive fields feeding into higher order processing units. The neural activation of higher order processing units is how the system marks the passage of information up to the next higher level of processing. Any degree of neural excitation of lower order units which

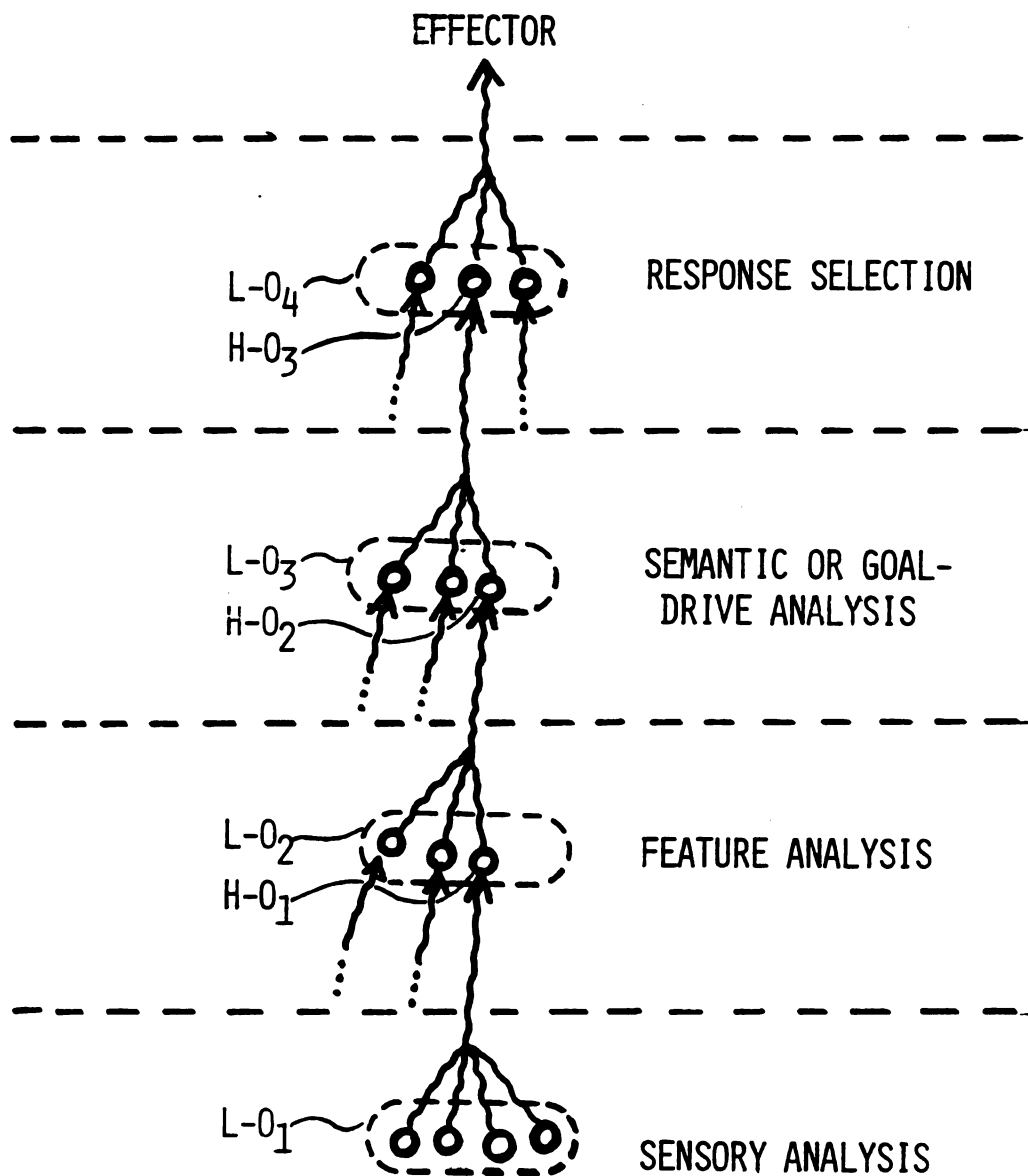


Figure 2. An information processing chain composed of a series of lower-order (L-0)-higher-order (H-0) processing unit linkages.

does not result in neural activation of the higher order unit, then, will not be further processed. The passage of information through each stage of information processing, then, is dependent not only on the degree of neural excitation coming from the lower order unit but also the threshold of activation of the higher order unit.

An outline of the major stages is provided in Figure 3. In the initial stage of sensory analysis, sensory inputs are transduced into neural activation patterns. If enough activated neurons within these neural patterns are members of a particular receptive field, then the activation threshold of the more complex neuron, having neural connections to this group of neurons, will be exceeded and the complex neuron also will be activated. Thus, receptive fields activated at this level of processing trigger new patterns of neuron activation at a higher level of processing.

At this higher level of processing, activated neurons carry more complex information pertaining to the representation of features. From Figure 3 it can be seen that this pattern of neural activation, unlike the pattern on the sensory register, is not isomorphic. This is to show that the neural activation is no longer organized to reflect a stimulus' spatio-temporal characteristics but its feature characteristics, which need not be spatially or temporally ordered. If enough of these neurons, called feature analyzing cells, fall within a particular receptive field, hypercomplex cells at even a higher level of integration will be activated. Receptive fields at this level of feature analysis are hypothesized to be neural models. Their key role in the process of selective attention will be discussed later in the

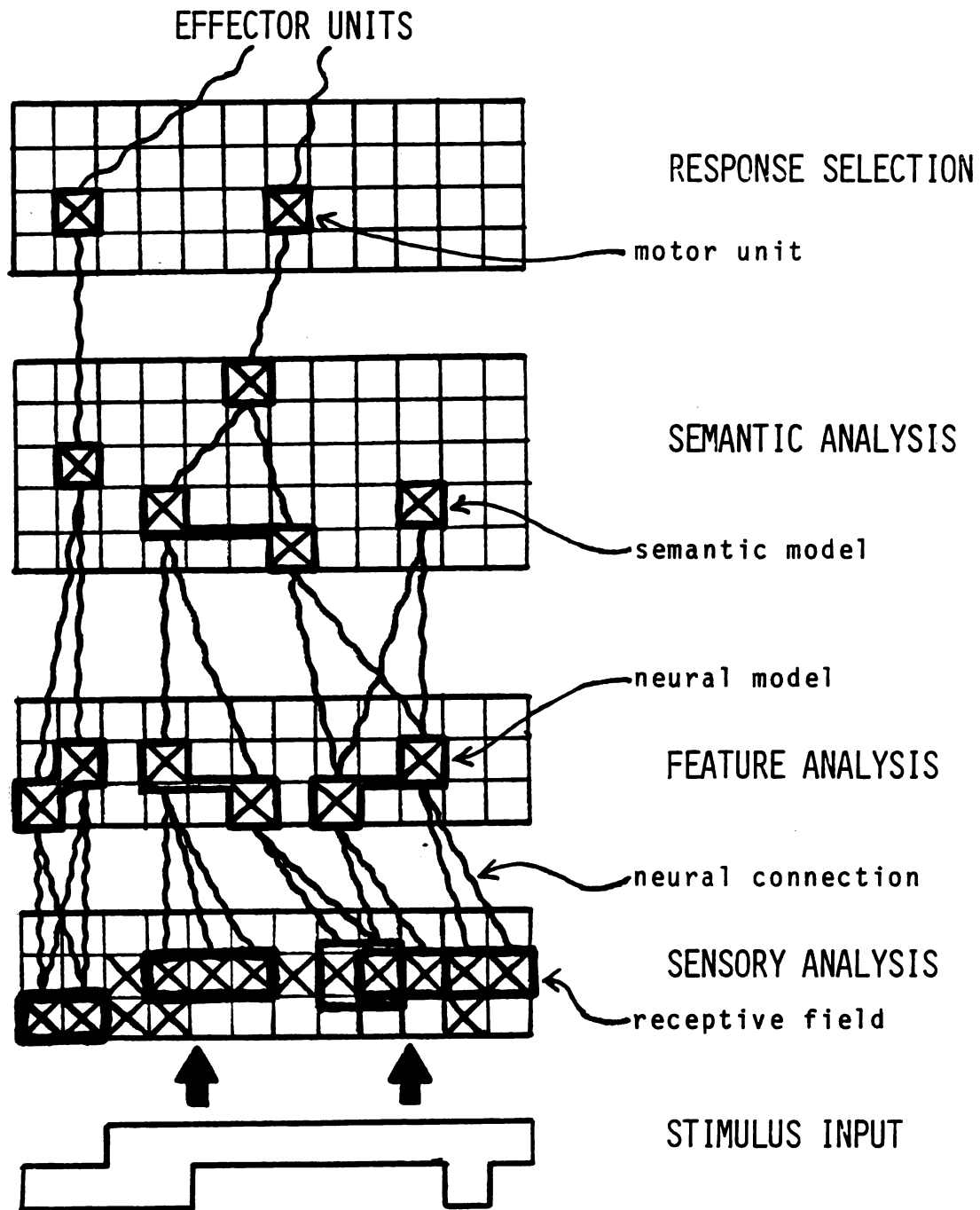


Figure 3. Major stages of information processing.  
 ☒ - activated neuron, □ - unactivated neuron,  
 ■ - neurons forming a processing unit.

chapter. The hypercomplex cells, integrating input from different feature analyzing cells, are hypothesized to function as a type of semantic representation which will be referred to as "semantic units."

Figure 3 illustrates that, at the level of semantic analysis, an activated semantic unit may either activate a motor unit on its own or be a part of a receptive field activating a higher-order semantic unit or a response output unit. The case of a semantic unit being neurally-connected to a second-order semantic unit suggests a neural basis for representation of concepts that are based on lower-order meanings. In this manner of receptive fields feeding into higher-order semantic units which, in turn, feed into still higher order semantic units, it can be seen how simple neurons might be able to provide a neural code for higher abstract concepts. The case of a receptive field consisting of semantic units feeding into a common motor unit suggests a neural mechanism for complex response regulation according to the perceived semantic context of a situation. An example may serve to clarify how these neural events might relate to response regulation. A hungry child standing in front of a cookie jar may have an immediate goal of taking some cookies from the jar. Before the response of reaching into the cookie jar is activated, the child selectively processes those stimuli which are most pertinent to this primary goal. When certain semantic units feeding into the motor units controlling the child's motor response of "reaching into the cookie jar" are activated, the child may become aware that, first, there are cookies in the jar to be taken and, second, no one is around to catch him in the act. Thus, the two requirements relevant to the motor

response output are satisfied and the child initiates the response. The semantic units representing pertinent perceptions of the task situation--"availability of cookies" and "absence of witnesses"--make up what is called a semantic model which guides the activation of motor units. It is proposed that if either semantic unit were not activated, the probability of the motor unit being activated would be greatly reduced. If, however, the child's motivation for taking cookies was high enough, such as in the case of extreme hunger, it is possible that not all of the semantic units would have to be activated for activation of the motor unit to occur. This raises the point that response activation is dependent not only upon activation of the appropriate semantic model, but factors affecting the relative ease of activation of the motor unit.

At a neural level, it is proposed that the semantic model is simply a receptive field of hypercomplex cells or "hyper-hyper-complex cells" feeding into a common motor unit. Thus, the organization of the semantic model is analogous to lower-order processing mechanisms such as the neural model and receptive fields at the level of sensory analysis. It can be seen from this discussion that, though different mechanisms are proposed to play a part in the processing of information, the basic scheme of a receptive field integrating its input into a higher-order neuron is common to them all. In summary, the information processing system can be viewed as a multi-stage system of receptive field-complex neuron linkages. A series of these linkages that form a neural pathway from sensory processing units to a motor unit will be referred to in this paper as an "information processing chain" (see Figure 2). The

most pertinent information ascends up the system for further processing when neural activation patterns sufficiently overlap with receptive fields to trigger activation of the associated neuron at the next higher level of information processing. The transmission of information up the system can be viewed as a function of the degree of activation of the receptive field and the threshold of activation of the higher-order neurons.

### Developmental Aspects of the Information Processing System

In this part of the chapter a more detailed description of the basic components of the information processing system is provided. A developmental account of how these components differentiate from an original biologically innate information processing system also is presented. For the purpose of clarity, the development of two central information processing units in the system, neural models and semantic units, is described in separate sections. In actuality, however, the development of these two types of information processing units can be thought of more accurately as occurring at the same time.

### The Nature of the Neural Model

In the preceding section an overview of the major stages of information processing was presented. In this section I elaborate on a key component of the system which plays a central role in the process of selective attention--the neural model. The model's conceptualization of selective attention revolves around the central

notion that sensory inputs are selected for further processing when they activate corresponding internal representations called neural models. Those inputs exciting their neural models to relatively higher levels of neural activation will be the ones to receive more selective attention. This is because, in terms of the model being proposed, selective attention can be thought of at the neural level as the selective activation of different processing units. An important point to clarify is that these neural models do not represent the external stimuli as exact internal replicas but more as sets of relevant features which partially approximate the actual stimulus. The neural model, then, is organized as a set of features rather than an exact one-to-one replication of external stimuli. In this way, a unique neural model does not have to be stored for each apple or orange that is seen. Instead, any stimulus having enough "apple-like" or "orange-like" features corresponding to the neural model will activate enough neurons in the appropriate receptive fields to activate the model.

It is this type of feature organization in the neural model that allows for representation not only of concrete objects such as apples and oranges, but also more abstract concepts. For example, a person may have in his past experience been exposed to abuse from a domineering parent. This individual may now be particularly sensitive to people who display a domineering attitude. He may even be so sensitive as to react with irritation to institutions that "reflect" this domineering quality. At the neural level it is hypothesized that the individual has a neural model representing this abstract domineering quality which may be applied to persons, institutions, or any other sensory

inputs which trigger off the relevant features of the model. This example serves to illustrate not only that the neural model is capable of representing abstract as well as concrete phenomena but also that the features in a neural model are organized not around sensory inputs but around conceptual meanings. The set of features, for example, comprising the neural model for a domineering attitude were not organized around any particular sensory input such as a person, institution, or situation. Instead, they were centered around a conceptual meaning, "domineeringness," which allowed the individual to selectively attend to this abstract quality in the context of a number of different sensory inputs. .

This proposed organization of the neural model is consistent with biological knowledge of the organizational structure at the level of the cortex. As was previously discussed, there are findings demonstrating that patterns of visual stimulation are analyzed at the cortex into different features by groups of neurons called feature analyzing cells (Hubel and Weisel, 1962). It is proposed that neural models are sets of feature analyzing cells situated at the level of the cortex. What enables this group of separate feature analyzing cells to function as one unified neural model is not a common spatial location in the cortex, but neural connections to a common group of hypercomplex cells at the semantic level of processing (see Figure 3). By postulating that these hypercomplex cells, integrating input from different analyzing cells, function as a semantic unit, it is readily seen how features of a neural model can be organized around a conceptual meaning as was previously proposed.

### Development of Neural Models

In this model, the neural model has been implicated as playing a key role in the allocation of selective attention. An important question to address is how do these neural models become organized? Are they present from infancy or do they have to develop? And if they do need to develop, how does this occur? How does the process of selective attention take place during infancy? This section addresses itself to these questions.

During the early stages of development, an infant is in a basic state of involuntary attention. Luria (1973) describes this stage of involuntary attention as being due to the infant's inability to voluntarily direct selective attention through the use of spoken instruction: "spoken instruction cannot yet overcome factors of involuntary attention competing with it, and victory in this struggle goes to the factors of the direct field of vision" (263). In terms of the model proposed, there is no semantic control of attention at this point because no semantic units, the internal representations of speech and meaning, have yet been developed. Without semantic units, it is hypothesized that neural models cannot yet be brought under the voluntary control of speech because there are no mechanisms with which to implement such control. Still, at this early stage of development, it is possible for neural models to be present. Their organization, however, is posulated to center not around semantic units but more primitive units of meaning referred to as "goal-drive units." These goal-drive units reflect the biologically innate goals and drives of the human infant at a neural

level. Their role as the neural substrate from which more elaborated meanings come to be represented in the form of semantic units is discussed in the next section.

Though the information processing system at this point lacks the more specific type of organization imposed by semantic units, it still possesses the basic innate organization and mechanisms necessary to carry out information processing. It is proposed that this immature information processing system has the basic components that are necessary for the formation of new processing units and new information processing chains. The components are an automatic attention-allocating mechanism, the orientation reflex (OR), and areas of the brain which neurally represent the state of different types of innate goals and drives maintained by the infant--goal-drive units. The first component, the OR, is an innate reflex that coordinates the feature analyzing cells to selectively respond to novel stimuli. It enables the direction of selective attention to occur automatically, independent of semantic control and without the benefit of neural models being connected to semantic units. The second component, the goal-drive unit, is an innately-determined neural area, which reflects the state of excitation of various innate drives such as hunger, thirst, or escape. Evidence suggests that some of these innate neural areas are located in the hypothalamus and may be either excitatory or inhibitory centers which reflect, respectively, the increase and reduction of drives (Keeton, 1972). The reduction of basic drives can be viewed as the primary set of goals for the infant. The infant's behavior, then, can be viewed as being either directed *towards* basic goals or motivated *from*

various innate drive states centering around certain conditions such as hunger or thirst. The argument can be made that in almost all behavior, directions are determined by taking into account not only the processor's present state of being but also his primary set of expectancies and goals. For this reason, an excitatory and inhibitory centers, working in close cooperation with each other, are together referred to as a "goal-drive unit." In summary, the infant during this early phase of development has two innate components of importance to the model: an OR attention-allocating mechanism, and innate, biologically-determined goal-drive units which reflect the state of the infant's drives and serve to translate feature-input information into response output information automatically.

What is being proposed is that, during early infancy, semantic units are not yet present so that attention is, at this time, a largely unmediated process dominated by the OR and innate, automatically-functioning goal-drive units. How, then do neural models develop which may be organized around and regulated by semantic units so as to bring attention more under the control of voluntary thought and speech?

(The development of neural models will be addressed in this section. Development of semantic units will be dealt with in the next section.) Razran (1961) provides some directions for thinking about this problem with his description of an experiment conducted by Biryukov on fox cubs. In the experiment, four cubs were exposed to the squeaks of mice. The fox cubs' ORs to these squeaks soon habituated. When the cubs were allowed to eat the mice, however, a single meal was sufficient to make the OR a permanent reaction to the squeak stimulus. Kahneman

(1973) cites this finding in support of the notion that the OR is elicited, not only according to the novelty of a stimulus, but according to its significance, as well. The significance of the stimulus, in the case of the fox cub experiment, appears to be defined in the context of the cub's most immediate goal of the moment--satisfying its hunger. The mouse squeaks were not categorized as significant and stored in a permanent way until they became associated with the satisfaction of hunger when the cubs ate the mice. From this example it might be hypothesized that stimuli, in general, acquire a significance or pertinence value in relation to the particular goals held important during the period of exposure. It is proposed that, when the period of attention to a stimulus overlaps with a significant change in the processor's state with respect to a valued goal, information concerning the pertinence of the stimulus to the goal is reflected in a sudden change of activation in the goal-drive unit. This sudden change in activation, which may be a boost or drop, is postulated to somehow enhance the formation of more dominant connections between those activated feature analyzing cells and the goal-drive unit. What is meant by "more dominant connections" is that impulses travelling along these neural pathways encounter less "synaptic resistance" (synapses with lower activation thresholds) than they would travelling along other competing pathways. Through the strengthening of these connections between feature analyzing cells and particular goal-drive units, the separate feature analyzing cells gradually acquire the capacity to function in relation to the goal-drive unit as a unified neural model. These hypothesized connections suggest how changes in neural

structure might be able to reflect the pertinence value of different stimulus features in relation to a particular goal. Those stimulus features most pertinent to a particular goal are the ones most likely to coincide with goal reinforcement or punishment and become neurally connected to the goal-drive unit. The features that are highly pertinent will coincide more frequently with sudden changes in goal-drive unit activation and form the most dominant connections between neural model and goal-drive unit. Such highly pertinent features are referred to as the "core features" of the neural model. Those features that are less pertinent will only occasionally coincide with goal reinforcement and, consequently, form weaker connections between neural model and goal-drive unit. These features are referred to as "accessory features" of the neural model. Thus, the system is able to code, not only for the pertinence of stimulus features through the establishment of connections to goal-drive units, but also for the strength of neural connections.

From the preceding discussion of the fox cub OR experiment and the formation of neural connections between feature analyzing cells and goal-drive units, the following conditions are hypothesized as being essential to the formation of neural models: (a) selective attention must be allocated to certain features of the environment; (b) these features must be pertinent to a valued goal as determined by the criterion of goal reinforcement or punishment. The first of these conditions, selective attention to certain features of the environment, is made possible during early infancy through the OR, which enables the infant to process novel environmental stimuli.

Later, selective attention also can be guided by newly-formed neural models to form even newer neural models. In this way, it may be seen how the development of neural models is a recursive process, relying on previous neural models to partially determine what stimulus features are available for processing. This view of how neural models develop offers a neural mechanism for guiding selective attention which is consistent with the dual process view of selective attention being determined by an interaction between gross sensory and more complex semantic analyses of incoming stimuli. Whatever mechanism is used to direct selective attention, this condition must be satisfied before any features can be incorporated into a neural model. The second of these conditions, pertinence of the stimulus features to a valued goal, is met when the activation of attended stimulus features overlaps with a sudden change in the activation of a goal-drive unit that occurs during reinforcement or punishment. The notion that the features of the environment which are selectively attended to are those that are most pertinent to the immediate and primary goals of the organism makes intuitive sense and is advanced in various forms (Norman, 1968; Sokolov, 1969). What this model proposes, in addition to the important role of pertinence in the selective attention process, is a hypothesis of how pertinence exerts this influence through the strengthening of neural connections.

Neither of the two proposed conditions for neural model formation, alone, can lead to the incorporation of features into new neural models. If selective attention is allocated to certain environmental features but there is no corresponding significant change in the

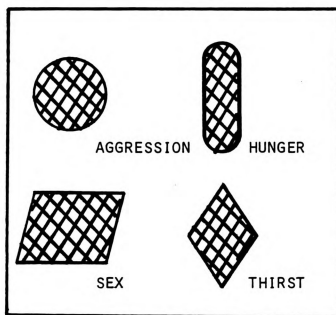
activation level of a goal-drive unit, the trace will simply fade away without becoming neurally connected to a goal-drive unit. If a goal-drive unit goes through a sudden change in activation level but there is no special activation of feature analyzing cells due to selective attention, the changing activation level will soon stabilize without having any special connections formed or strengthened between the goal-drive unit and feature analyzing cells. Thus, the essential structure of the neural model is hypothesized to lie in the formation or strengthening of neural connections. The basic working units of the system remain the same but a new organization is imposed upon them through the development of neural models.

#### Development of Semantic Units

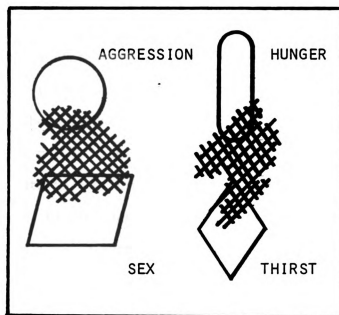
Up to this point, the "pure" case of a neural model being connected to a single goal-drive centered around goal-drive states such as hunger, sex, or thirst has been discussed. To be more accurate, though, it is necessary to consider that at any given moment, the infant is not likely to have "pure" drives. More likely, the different goals and drives dominant in an infant at any given moment are a mixture of different goals and drives. For instance, rather than having a pure hunger drive and pure sex drive, the infant may have one drive which is a mixture of the hunger and thirst drive and another drive which is a mixture of the sex and aggression drive. The point is that it is probably not accurate to think of infants, or adults, as always having drives and goals totally centered around hunger or sex or aggression. If the actual drives and goals of the infant are, more

accurately, hybrids of the pure drives and goals represented in the brain, it follows that the patterns of neural activation should not coincide exactly with the different goal-drive units of the brain but result from the activation of several goal-drive units. Thus, the neural pattern of activation stemming from a particular goal or drive can be thought of as a vector--the resultant activation pattern stemming from activation of different goal-drive units. As a vector, reflecting both direction and magnitude, the hybrid pattern of goal-drive activation varies on two dimensions: the different goal-drive areas that are a part of the hybrid and the proportion of contribution made by each of these goal-drive areas. The "pure" and hybrid states of goal-drives are depicted in Figure 4.



It is this hybrid pattern of goal-drive activation that becomes linked up to a simultaneously activated neural model. This means that each neural model becomes linked up to a group of simultaneously-activated goal-drive units. This group of simultaneously-activated goal-drive units is hypothesized to begin functioning as one unit because the separate goal-drive units begin to form neural connections between themselves and also with a common motor unit which they feed into. Thus, each neural model becomes associated with a special mixture of goal-drive units which constitute a special meaning that is associated with that neural model. This hybrid pattern of goal-drive activation which becomes linked to a particular neural model is proposed to be the semantic unit for that neural model. The process underlying the formation of semantic units can be viewed as analogous to that underlying the formation of neural models. The meaning



PURE STATE



HYBRID STATE

Figure 4. Pure and hybrid states of goal-drive activation.  - goal-drive unit,  - neural activation.

of a semantic unit is defined from a framework of the infant's pressing drives and goals. An example borrowed from Harry Stack Sullivan's (1953) interpersonal theory of psychiatry may help to make this point clearer. According to Sullivan, the infant first comes to know mother as simply a nipple. This can be explained in terms of the model by proposing that the hungry infant selectively attends to the features most pertinent to reducing his most pressing drives and goals. In the case of the hungry infant, the most pertinent feature is mother's nipple, which satisfies the infant's hunger by providing milk. Thus, a neural model is formed, not of mother in her entirety, but only of her nipple. The semantic unit associated with the neural model of the nipple, in this case, is defined in terms of its pertinence to the infant's drives for hunger and security. In this way, each neural model's associated semantic unit may be thought of as deriving its meaning from the context of the goals and drives associated with it. As semantic units form, the basic innate goal-drive units may be thought of as becoming more differentiated. In a sense, some of these semantic units may be viewed as new goal-drive units which may, in turn, contribute to the formation of even newer goal-drive units. In this manner, simple meanings may be integrated into more complex meanings which may, in turn, be integrated into still more complex meanings. What is proposed in this model is that no matter how complex the semantic unit, its meaning lies, at the most fundamental level, in the context of valued goals or drives.

### Selective Information Processing Within the Information Processing System

In this part of the chapter, factors are discussed which determine how the information processing system selectively processes information. Selective processing is described at two different stages: selective attending and selective processing. Though these stages represent different levels of processing, they may be thought of, more generally, as types of selective processing which rely on the same general processing mechanisms. The information processing system is first discussed in terms of how its components interact with each other to determine the selective processing of information. The modulating effect of arousal on the selective processing of the system is then discussed. Finally, the interaction between the information processing system and modulating variables such as arousal or fatigue are discussed in terms of how it determines whether selective information processing is conducted through a voluntary or involuntary mode.

#### Competition Between Neural Models: The Battle for Selective Attention

Up to this point, the development of the major components of the information processing system has been discussed. In the remaining portion of this chapter I will discuss how these components function together to form an information processing system that is capable of selectively processing information. In this section the system will be examined to see how selective attention might be allocated. First, however, a brief review of the major components of the system and

their functions will be presented. First, there is the neural model which analyzes sensory patterns of activation for features pertinent to the primary goals of the individual. The neural model serves as an "address" to either a semantic unit, which stores the meaning of the neural model, or an innately-determined goal-drive unit. These two types of processing units both fulfill a similar "priming" function in their respective information processing chains, by partially activating connected neural models and motor units so that they are more easily activated. For this reason both units will be classified as types of "priming units."

At this point the discussion will turn to the process of selective attention. A key stage in the allocation of selective attention occurs at the level of neural model activation. As was stated earlier in the paper, stimuli corresponding to the neural model with the highest relative level of activation will receive the most selective attention. If there is clearly one dominant neural model, selective attention will focus almost exclusively on it. If, however, there are several dominant neural models operating at the same time, selective attention will be split among the different types of input. Thus, the crucial factor hypothesized to determine the allocation of selective attention is the relative level of neural activation of the neural models.

To understand how selective attention is allocated, then, it is necessary to consider what factors determine the relative levels of activation in neural models. The first factor to consider is the level of sensory activation at the sensory register. If there is a high

level of sensory activation such as that which would result from a very loud noise, it is much easier to selectively attend to it than if the same signal were of a lower intensity, producing a low level of sensory activation. In terms of the model, the strength of neural activation at the sensory level will affect the strength of neural activation at the level of the neural model.

A second factor to consider is that neural models, themselves, may vary in their synaptic resistance to activation. Some may be strong neural models that are easily excited to high levels of activation. Others may be weaker neural models that require a greater level of excitation from various inputs because their synapses have high thresholds of activation. Those neural models that are genetically-programmed are likely to be very strong. Neural models that are frequently activated are also likely to have more dominant connections and become more easily activated. In this way, it may be seen how neural models may vary in strength along a continuum from those that are genetically-programmed to those that are frequently activated to those that are only rarely activated or newly-established. If, however, a neural model is rarely activated or newly-formed, it will probably be relatively weak in the strength of its connections.

The third factor playing a role in determining the level of activation in the neural model is the degree of activation of the priming unit to which it is connected. What is hypothesized is that there are connections running, not only from the feature analyzing cells to the priming unit, but from the priming unit back to the neural model, as well. This hypothesized connection from the priming

unit back to the neural model is proposed as a mechanism to explain how factors such as motivation, arousal, and pertinence (Norman, 1968) are able to influence the focus of selective attention. If a person is highly motivated to attain a certain goal such as reducing his hunger drive or taking notes in class (which feeds into a broader goal of getting a good grade), the appropriate priming units will reflect this heightened motivation in terms of levels of neural activation that are relatively higher than competing priming units. The activated priming unit will, in turn, raise the level of activation of the appropriate neural model through the connections discussed. These three factors interact with each other in determining which neural model will have the highest level of neural activation. Activated priming units tend to direct selective attention to features of stimuli that are most pertinent to those goals held as most urgent. This is because they raise the activation level of connected neural models so that they need less excitation from sensory stimuli to reach their activation thresholds. If the neural model's activation threshold is already lowered, due to frequent activation or genetic-programming, or if the goal-drive unit is highly activated, the neural model may be activated with the slightest degree of excitation from sensory input. The perceptual bias phenomenon in which different people exposed to the same objective stimulus generate different perceptions based on what is important to them, may be explained in terms of the priming effect of goal-drive and semantic units. What is perceived may be strongly influenced by priming units that are highly activated. Thus, if a priming unit relevant to sex is highly activated, this will activate

related neural models and the individual will most likely attend to stimulus features which have some type of sexual relevance.

#### Competition Between Motor Units: The Battle for Selective Responding

The process of selective responding is proposed to occur in a manner analogous to selective attention. First of all, the selection of response output depends on the activation of the appropriate motor units just as selective attention depends on the activation of neural models. Second, activation of motor units is proposed to be dependent on the same three general factors: excitation from activated priming units, excitation from lower-order processing units, and synaptic resistance of the motor unit. One source of neural excitation for the motor unit comes directly from the connected priming unit. When the priming unit is activated, it sends neural impulses up to its connected motor unit. This raises the level of neural excitation of the motor unit so that it requires less additional excitation to reach its activation threshold. The additional excitation needed to activate the motor unit is passed up from lower-order processing units. The activated priming unit, as discussed in the preceding section, plays an integral role in priming the neural model for activation. Once the neural model has been activated, it sends neural impulses back to the priming unit, resulting in a heightened level of activation and a larger boost of excitation sent to the motor unit. The added boost that the priming unit receives from the neural model provides the motor unit with the added excitation needed for activation. The synaptic resistance

of the motor unit, interacts with the original level of priming unit activation to determine how much of this additional excitation is required from lower-order processing units. An illustration of this process of motor unit activation is given in Figure 5.

At this point, one might ask what prevents the activated priming unit from directly activating the motor unit even before the added boost of excitation is supplied from lower-order processing units? What this model proposes is that, under normal conditions, the activation of priming units, alone, is not sufficient to raise the excitation of most motor units to the level of activation. Under some conditions, however, such as high motivation or arousal, it is possible that a priming unit may become so highly activated that it, alone, can activate its unit. In such cases, the priming unit fires nerve impulses at a high enough frequency to excite the motor unit to its threshold of activation. This may account for some instances of the "jump the gun" phenomenon, where a response is emitted prior to appropriate stimulation. The sprinter who is waiting to hear the firing of the starting gun provides us with one such example. According to Kahneman's (1973) model of attention, this runner would be in a state of perceptual and response readiness. Neurologically, this state of readiness can be traced back to the activation of one unit--the priming unit centering around the gun signal. The sprinter, in a state of high arousal, voluntarily allocates most of his available capacity to this particularly pertinent priming unit. The activated priming unit sends nerve impulses down to its neural model and up to its motor unit so that these components are primed for activation by

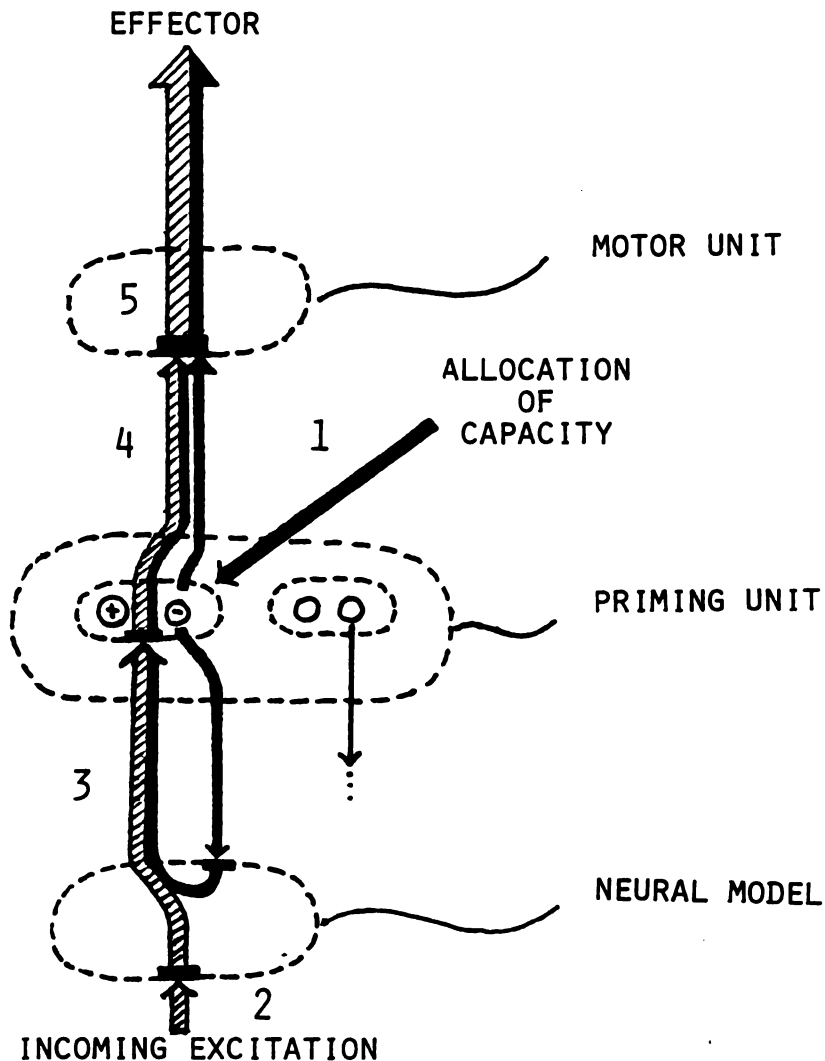





Figure 5. Normal functioning of activated priming unit in motor unit activation. Sequence of events: (1) Allocation of capacity activates priming unit. (2) Priming unit excites motor unit and neural model while incoming excitation from lower-order processing units also reach neural model. Not enough excitation to activate motor unit. (3) Neural model becomes activated and sends "boost" of excitation to priming unit. (4) Activated priming unit becomes even more highly activated. Passes additional boost of excitation to motor unit. (5) With additional excitability boost, motor unit's threshold is exceeded and unit becomes activated. Sends impulses to effector. KEY:  - excitation from original capacity,  - excitation from lower-order processing units,  - threshold of activation.

the appropriate signal. Thus, the primed neural model and motor unit reflect, respectively, the sprinter's state of perceptual and response readiness. With both of these units primed by the activated priming unit, the sprinter is able to respond very quickly to the sensory stimulation of the gun blast. If, however, the sprinter is too highly aroused, the priming unit may be so highly activated that it, alone, is capable of exciting the motor unit to its threshold of activation. Thus, conditions of overarousal can result in activation of motor units even without appropriate sensory stimulation.

#### The Relationship Between Arousal and Attention

At this point, the information processing system has been discussed in terms of how its components interact to determine what information is selectively processed. Now, I will examine how the level of arousal exerts a modulating effect on the components of the system to influence how the system selectively processes information. Before doing so, some of the general findings in the area relating arousal level to attention will be reviewed. The relationship between arousal level and attention comprises one of the most widely explored areas in attention research. The general observed relationship between arousal and attention is that, as arousal level increases, attention narrows. This hypothesis was originally proposed by Easterbrook (1959) as an attempt to explain the Yerkes-Dodson law on the relationship between arousal and performance level. The Yerkes-Dodson law consists of two parts: 1) the quality of performance on any task is an inverted U-shaped function of arousal; 2) the range over which

performance improves with increasing arousal varies with task complexity. Easterbrook's general rationale was that arousal narrowed attention by restricting the range of cue utilization. Thus, as arousal increases initially, performance improves because irrelevant cues are ignored while more attention is focused on those that are relevant. If there is overarousal, however, then performance decreases because even some relevant cues begin to get omitted. Since the time that these early hypotheses were proposed, much additional research has gone into this area. Kahneman (1973), in reviewing the literature on arousal and attention, notes that the concept of arousal as a uni-dimensional state is not entirely accurate. He distinguishes between two different subtypes of arousal: a generalized sympathetic dominance which occurs during situations of active effort and a state of arousal present during situations of rest. These two states each have their own particular pattern of physiological correlates. Still, Kahneman asserts that the concept of arousal effectively differentiates the state of a subject in a task situation from his state at rest and is a useful concept to maintain. This viewpoint of arousal is adopted in this paper, as well.

Hockey (1970) conducted an experiment which served to elaborate on the nature of the postulated narrowing of attention. His experiment was designed to test whether attention narrowed in terms of spatial location or in terms of the relevance of stimuli. In the experiment, subjects were presented with an array of six lamps and given two tasks: a primary task of responding to signals appearing in the two central lamps and a peripheral task of responding to signals

appearing in the four peripheral lamps. The signal probability in the six lamp locations was manipulated so that two conditions were produced: an unbiased condition, where signals were presented with equal probability to each source, and a biased condition where signals were biased to the two central sources. Lights were left on in the lamps until the subject responded to them, thus, ensuring that the objective probability of signal presentation was what the subject experienced. Finally, the subjects were tested in noise and quiet conditions. The results showed that under conditions of noise, postulated to narrow attention, there was no tendency for detection of signals in central locations to improve (as measured by decreased latency of responding) in the unbiased condition while in the centrally-biased conditions there was a significant improvement in detection. These findings indicate that attention narrows not by spatial location but according to signal probability. From this experiment Hockey makes the general conclusion that attention narrows, not according to physical cues such as location, but by task relevance. In other words, the narrowing of attention is not to be confused with the funneling of vision. Kahneman makes a similar point when he proposes that high arousal does not change peripheral vision but rather the rules in allocation of attention and effort, causing attention to be concentrated on the dominant aspects of a situation at the expense of other aspects.

### A Hypothesis for Narrowed Attention Under High Arousal

The effect of arousal on the model of information processing proposed in this paper provides an account of the relationship between arousal and attention at a neural level. First of all, the notion of attention narrowing according to task relevance rather than physical cues can be readily explained by the model. The nature of the neural model as a set of features organized around a priming unit has been discussed previously. They are organized with the core features being those that are most pertinent and the accessory features being those that are less relevant. At the neural level, the core features are those that have stronger neural connections to the goal unit and lower thresholds of activation than the accessory features. Recall that the features which are selectively attended to are those that, at a neural level, are readily distinguishable from the background in terms of neural activation. As a person's arousal level increases, the general level of background neural excitation or "neural noise" increases. One can picture a number of neural models of varying strengths competing for attention. As arousal level increases, capacity is diffused across the system in the form of a rising background level of neural noise. Because there is only a limited amount of capacity available for processing at any one time, the reservoir of available capacity diminishes as the background activation level continues to rise. (This means that there is less available capacity to selectively activate higher-order priming units that would normally increase the activation level of connected neural models.) Under

normal conditions, the information processing system regulates the flow of information up specific neural pathways according to two factors: the level of activation of the lower-order processing unit, and the synaptic resistance of the connection to the higher-order processing unit. Under conditions of increasing arousal where the reservoir of available capacity approaches depletion, one of these selective factors, the activation levels of lower-order units, becomes impaired. This is because higher-order priming units, normally influencing the process of selective attention by increasing the activation level of connected neural models, can no longer do this due to a lack of capacity to maintain their own state of activation. Thus, the net effect of an increasing arousal level and dwindling reservoir of available capacity is to bias selective processing towards those pathways with the least synaptic resistance--since activation level is not, at this point, a strong distinguishing factor. In terms of selective attention, then, the neural models with the least synaptic resistance will be the ones that reach the highest level of activation and capture the bulk of selective attention. As arousal level and the background noise level continue to rise, two things are happening that influence the narrowing of attention. First, there is a bias towards the most dominant neural models since they require the least additional activation to overcome their low synaptic resistance. Second, of these dominant neural models, there is a bias towards the most dominant of these. This is due to the proposition that it is not the absolute level of activation of a neural model that determines the allocation of selective attention but its relative level in relation to the background

noise level. As the background noise level continues to escalate, as in conditions of high arousal, the less dominant, less activated neural models become "washed out" or submerged in a "sea of neural noise." Whereas, under normal conditions, some selective attention could have been allocated to these less dominant, neural models-- under conditions of higher arousal level, it can be seen how they are no longer distinguishable from the level of background noise. If arousal level and background noise level were to continue to rise, eventually, the point would come when only one activated neural model was still distinguishable "above the sea" of background noise. If the noise level continued to escalate, then the less-dominant, less activated feature analyzing cells of that neural model would begin to get washed out, leaving only the most dominant feature analyzing cells representing the core features of the neural model. Eventually, even those core feature analyzing cells would be washed out if the noise level continued to rise. At this point, the information processing system would be totally incapacitated. The reservoir of available capacity would be "spent" on maintaining the high level of background noise. The neural models would all be washed out and indistinguishable from the general level of neural activation. At this point, no information can be effectively processed until the background level of noise begins to subside. This particular state of incapacity may reflect, at a neural level, what happens in such cases of overarousal when a person is literally "paralyzed with fright."

From this account of the narrowing of attention during increasing arousal, several points should be emphasized. First, the general

notion in the literature of attention of arousal narrowing along the dimension of pertinence is partly consistent but, also, partly inconsistent with the model proposed. What the model proposes is that attention is narrowed not necessarily to the most pertinent stimuli but to those stimuli with the most thoroughly-ingrained, dominant neural models. Very often, these more automatic neural models are the most pertinent models but sometimes they are not. The same argument can be made for the narrowing of attention to the core features of a neural model. Second, the narrowing of attention during arousal may be, at first, adaptive in focusing attention on, generally, more relevant aspects of the environment. But, at some point, depending on the complexity of the task, the narrowing of attention begins to exclude relevant features of the neural model and performance becomes impaired. Third, there appear to be two factors regulating the flow of information up the processing system: the level of activation of lower-order processing units and the synaptic resistance of the neural pathway to the higher order unit. These two factors interact at each stage of processing to determine whether an input will be selected for the next stage of processing. For example, a moderately activated neural model interacting with a connection of very low synaptic resistance results in activation of the connected semantic unit. Thus, the input passes on to the next stage of processing at the semantic level. This notion of the directed flow of information up neural pathways according to these two factors is illustrated in Figure 6. Finally, selective information processing and, more specifically, selective attention may be viewed as the selective

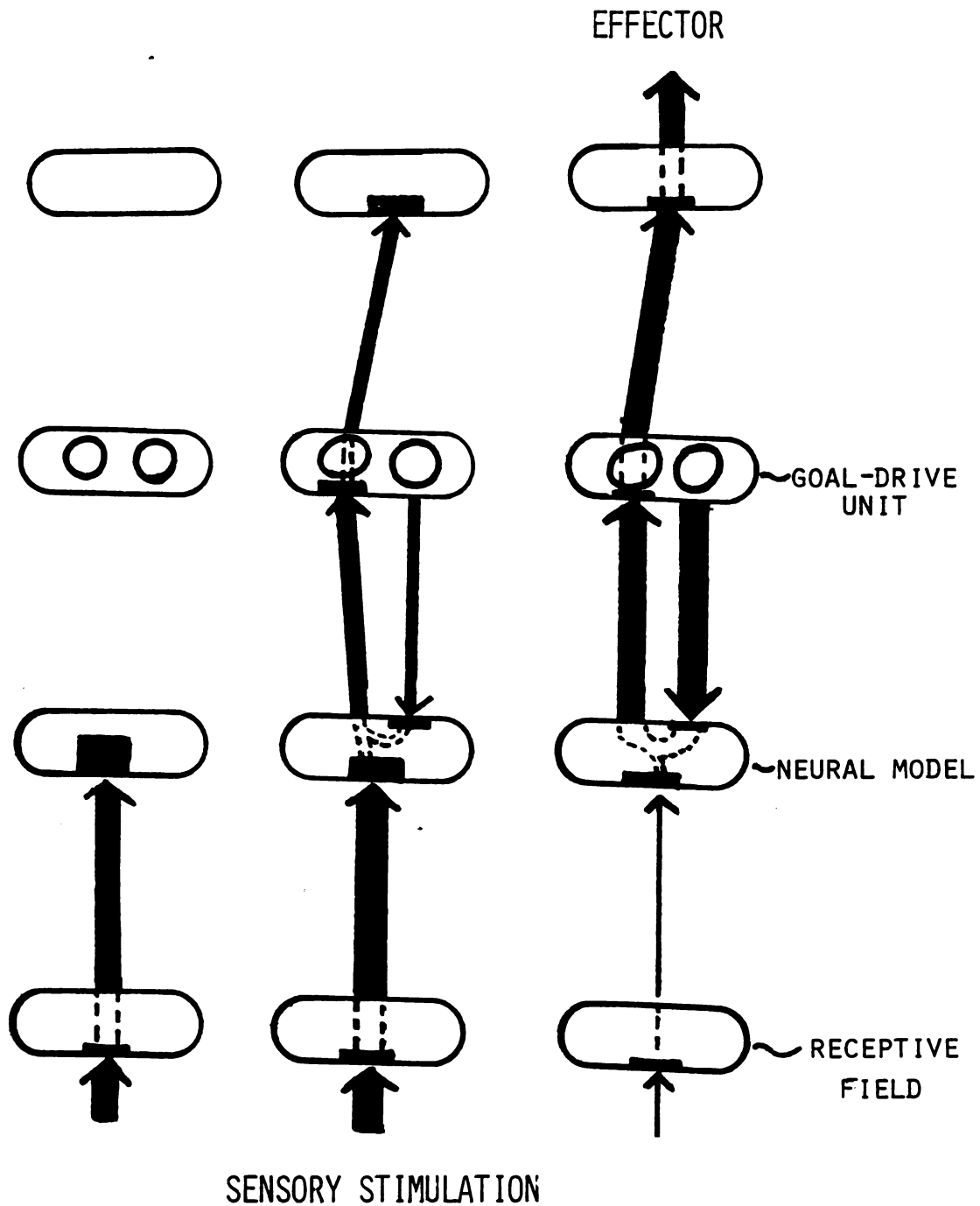


Figure 6. The directed flow of information up neural pathways according to two factors: level of activation of lower-order processing units and synaptic resistance.  
 ▲ - level of activation, ■ - synaptic resistance.

passage of neural activation "up" the information processing system.

### Competition Between Control Mechanisms: Passive vs. Active Information Processing

Throughout this paper issues have been discussed related to the involuntary and voluntary control of information processing. What has become apparent is that man seems to have two modes of processing information--a type of automatic pilot and a mechanism for exerting voluntary control. More accurately, there appears to be a continuum from passive to active information processing along which individuals fall and vary from time to time (Hasher and Zacks, 1979). In this section, proposed mechanisms for these two systems of regulation will be discussed as well as the factors influencing when one will be dominant over the other.

In the preceding section, it was proposed that activation level and synaptic resistance provide the means by which selective processing takes place. In discussing the impact of increasing arousal level on attention, it became clear that the selective investment of available capacity is important to the regulation of activation level but not the level of synaptic resistance. Activation level, then, is open to voluntary regulation through the effortful process of selective investment of capacity. Synaptic resistance level, on the other hand, is a more stable factor not open to such moment-by-moment regulation. This is because synaptic resistance level is determined by *structural* changes in the form of a neuron's lowered threshold of activation. Thus, synaptic resistance level does not allow for the flexibility of

processing offered by activation level, but it does enable processing to occur without the selective investment of capacity. With all of these points in mind, it is proposed that regulation of activation level through the selective investment of capacity forms the basis of voluntary attention and active information processing. Synaptic resistance level is proposed to allow involuntary attention and more passive information processing to take place without the allocated of capacity to maintain it. Altered synaptic resistance can also be viewed as the means by which stable components of the system are formed such as neural models, semantic or goal-drive units, motor units, and the neural connections between these units. In this way, altered synaptic thresholds allow for the formation of a stable structure to guide the processing of information: neural pathways of least synaptic resistance leading up from the sensory level of processing up to the neural models, goal-drive or semantic units, and motor units. Sensory activation and selective investment of capacity are able to influence in which of these pathways inputs "flow" up the system by affecting the activation level.

The fundamental bases of passive and active information processing have now been discussed. What, then, are the specific mechanisms by which these processes take place? Involuntary attention has been discussed as being able to occur independently of selective investment of capacity because it relies on structural synaptic change. If the neurons in a neural model have low thresholds of activation, it only takes a slight degree of sensory stimulation and no additional investment of capacity to activate the neural model. Thus,

well-ingrained, dominant neural models are able to process relevant stimuli from the environment automatically (without expenditure of capacity). As was previously mentioned, Luria describes this state of involuntary attention in the infant where the attention process is not goal-oriented but stimulus-driven. In other words, the control of selective attention at this point is not within the infant--it is controlled by whatever stimuli are most dominant in the environment.

At some point the infant begins to become more active in his processing of information. He gradually acquires the ability to control his attentional apparatus rather than let it control him. Luria postulates that, over time, the infant learns spoken instructions which evoke connections dominant enough to "eliminate the influence of all irrelevant, distracting factors" (264). In terms of the model, what appears to be happening is that neural models begin to be formed with connections to a group of goal-drive units. These goal-drive units over time begin functioning as a single semantic unit having connections leading back to the neural model. It is hypothesized that these semantic units form connecting links between the individual's voluntary control center and the information processing apparatus.

The voluntary control center is postulated to be a higher order system which is able to direct the selective allocation of capacity in the service of various goals it is able to select. Semantic units function as connecting links between the voluntary control center and the information processing center. They serve as entry points for the selectively-allocated capacity of the voluntary control center to

enter into various information processing chains. Prior to the development of semantic units, the impact of the voluntary control center on the information processing system is probably quite limited. First of all, the number of entry points available to selective investment of capacity is limited to only those priming units that have already been established--the innately-determined goal-drive units. This shortage of entry points into the information processing system means that the processor is limited in his ability, to voluntarily process information in different ways. Also, the entry points in this immature state of development being innately-determined goal-drive units, do not offer the voluntary control center options for very finely-tuned control of information processing. Only as the processor develops semantic units out of these basic goal-drive units, is the voluntary control center able to exert finer, more discriminative control over the direction of the information processing system. To clarify the points just made, the voluntary control center with or without semantic units can be compared to the analogy of a driver heading towards a remote destination. If all that is available to the driver are the major highways, he can only drive into the general proximity of the area. In a similar way, the individual processing information only according to basic goal-drive units can often only give an approximate response to the specific demands and goals of a situation. If, however, the driver has access to smaller local roads that connect with the main highway, he can then drive to the exact location of his planned destination. Similarly, the individual with an information processing system that has been

elaborated into various semantic units, is much more able to process information in finer ways and produce responses that are more finely-tuned to his specific goals. From the above discussion, the development of semantic units is proposed to enhance the ability of the voluntary control center to direct the information processing system because it allows for a greater number of specific entry points into different information processing chains. The net effect of this is to increase the amount of discriminative control the processor has over the information processing system.

An example of how a semantic unit can be used to control the direction of selective attention is provided by the tennis player who is distracted by a restless audience. In such a situation he may literally "call" his attention back to what is immediately relevant by saying to himself: "Keep your eye on the ball."

Through his use of spoken or silent speech he is able to voluntarily activate relevant internal representations or semantic units of what he wants to concentrate on. The activated semantic unit influences selective attention by priming its neural model, raising its level of excitation nearer to its activation threshold. Selective investment of capacity into a semantic unit can provide the added boost of excitation to enable information to flow up processing chains which might otherwise have too high a level of synaptic resistance. In this way, the flexible allocation of capacity to semantic units can allow the focus of selective attention to be voluntarily directed to features of the environment other than those of the most dominant neural models. (To do so, however, requires effort in the form of investing capacity into

the appropriate semantic unit.)

From this discussion it is becoming clear that there is a constant struggle going on between the voluntary and involuntary centers for information processing. This competition is complicated by the fact that voluntary and involuntary information processing actually exist on a continuum. The degree to which information processing is voluntary or involuntary can be thought of as depending on the extent to which the process is controlled by the voluntary application of capacity. The case has already been discussed where voluntary information processing is dominant. For this to be so requires a constant expenditure of capacity to maintain the activation of semantic units. With repeated activation of its connected neural model, however, less capacity is needed to be selectively invested in the semantic unit. This is because, as a neural model is repeatedly activated, its synaptic thresholds of activation become lowered. Less activation, then, needs to be contributed from the semantic unit to enable the neural model to be activated. What is happening here is that the neural model, through a structural change in its synapses, is gradually acquiring the ability to function automatically, without the added "boost" from the semantic unit. Thus, through repeated activation, neural models undergo a structural change in their synapses and become more capable of automatic information processing independent of semantic unit activation. What has just been proposed is a neural explanation of how conscious, voluntary processes can become automatic and involuntary through repetition. An example of this transition is provided by the tennis player learning to hit a backhand. At first, he may rely

heavily on verbal cues to guide his swing. Over time, however, he learns to execute the backhand automatically, without any need for spoken instruction. The information processing needed to execute a proper backhand has become automatic. This transition from voluntary to automatic information processing implies that at any given moment, attention is being regulated by voluntary and involuntary factors.

The final case to be discussed is when involuntary information processing becomes dominant over voluntary information processing. This was already discussed, to some extent, in the preceding section. In that section it was indicated that increasing arousal level drains the reservoir of available capacity so that less capacity is available to selectively invest in semantic units. To generalize from this, any factors leading to a reduction of available capacity will hinder active information processing and bias the system towards more passive processing. Some other possible factors besides high arousal which may drain the reservoir of available capacity are fatigue, boredom and depression. Broadbent (1971) conducted an experiment on the effect of high arousal on selection which provides support for the notion that high arousal level biases attention in the direction of more dominant stimuli. In one of his experiments, subjects were exposed to word pairs, with one word in heavy print and the other word in very faint print. The subjects were instructed to identify one of these words on each trial. Duration of exposure to these word pairs was gradually increased until the subject could correctly identify the stimulus. When subjects were asked to do this task under the condition of intense, continuous noise, there was a slight improvement

in identifying the heavily printed word. When the subject was asked to identify the faintly printed word, however, detection of the faint word was significantly impaired in the noise condition. From these findings, Broadbent suggests that in the noise condition, the "pull" of the heavy word became significantly harder to resist. In a similar way, when conditions reduce the available capacity needed to maintain more voluntary attention, stimuli activating the more highly-automated neural models become extremely hard to resist. Conditions such as the ones discussed, that bias the system towards using more highly automatic information processing chains are considered especially relevant to the phenomenon of stuttering which is hypothesized to be a potent example of what can happen to the information processing system under such conditions. In the next chapter, this phenomenon of stuttering will be examined in greater detail. Before the paper turns to stuttering, however, a summary of the general neural model of information processing is presented.

#### A Summary of the General Neural Model of Information Processing

In this chapter a general model of information processing has been proposed that attempts to describe how information processing occurs at a neural level. The major sources of influence on the model's development include Norman's (1968) theory of memory and attention, Kahneman's (1973) model of attention allocation, Sokolov's (1969) conceptualization of the neural model, and also the structural data on the information processing system drawn from the area of

physiological psychology (Boddy, 1978). The remainder of this chapter will highlight some of the major aspects of the model presented.

### Developmental Aspects of the Information Processing System

An a priori, biologically-innate information processing system is postulated to have two basic components from which the system is able to further develop and elaborate itself. These components are the orientation reflex and areas of the brain which neurally represent biologically-innate goals and drives called "goal-drive units." New information processing units are proposed to develop from these a priori components in the following manner: (a) The orientation reflex allocates selective attention to novel aspects of a stimulus which means, at a neural level, that a certain group of feature-analyzing cells corresponding to novel stimulus features are activated; (b) During this time the processor is also allocating attention to particular goals and drives which are represented neurally in terms of particular excited goal-drive units; (c) The group of activated feature-analyzing cells begin to function as a simple neural model when they form neural connections with excited higher-order goal-drive units. This happens when those features being attended to are "evaluated" as pertinent to the valued goals and drives of the processor by being associated with significant movement towards or away from these goals and drives. Neurologically, groups of activated feature-analyzing cells form two-way connections with those goal-drive units undergoing a sudden change in excitation; (d) As a set of feature

analyzing cells is repeatedly associated with sudden changes in goal-drive unit excitation, the connections between these two components strengthen and the separate feature analyzing cells gradually acquire the capacity to function in relation to the goal-drive unit as a unified neural model. At this point selective attention or selective activation of feature analyzing cells can be guided not only by the orientation reflex but by these newly-formed neural models. In this way, development of subsequent neural models can be viewed as recursive process, relying on previously-formed neural models to partially determine what stimulus features are available for processing; (e) At the same time that feature analyzing cells begin functioning as a unified neural model by establishing connections between themselves and common group of excited goal-drive units, this assortment of excited goal-drive units begin functioning as a unified semantic unit. This means that connections are formed between themselves and also from themselves to a common motor unit. By viewing semantic units as particular aggregates of goal-drive units it can be seen how at its most fundamental level meaning may be defined, both biologically and psychologically, in terms of the processor's most pertinent goals and drives (or most dominant goal-drive units).

#### Functional Aspects of the Information Processing System

The model poses a fundamental organizational scheme for the processing of information which is repeated at each level of processing: a lower-order receptive field composed of several units

feeds into a higher-order processing unit. Whether the particular level of processing involves selective activation of neural models (selective attention) or selective activation of motor units (selective responding), the same fundamental organizational scheme for selective information processing is postulated to exist. At each level of processing three basic factors play an important role in determining the transfer of information (neural excitation) "up" to the next level of processing: the degree of excitation of the lower-order processing unit (receptive field), the degree of synaptic resistance of the higher-order processing unit, and the degree of excitation delivered to the higher-order unit from the priming unit. This third factor, the degree of excitation received from the priming unit, can be viewed as a modulating factor upon this upward transfer of information at each level of processing. The priming unit, either an innately-determined goal-drive unit or a semantic unit, functions to transfer selectively-invested capacity from the voluntary control center to the various units connected to the priming unit. How these three factors interact determines whether the net level of excitation of the higher-order processing unit exceeds or remains below its threshold of activation. If the higher-order unit's threshold is not exceeded by its excitation level, the unit will remain unactivated and information will not advance to the next level of processing. If, however, the higher-order unit threshold is exceeded by its excitation level, then the unit will be activated, which marks the passage of information to the next-higher level of processing. As was previously stated, the general scheme for processing information

just elaborated applies to all levels of processing. Thus, the information processing system, viewed as a whole, is postulated to be made up of a number of branch-like series of these molar receptive field-higher-order unit linkages. A series of these receptive field-higher-order unit linkage capable of transmitting neural excitation from the sensory level of analysis all the way to the level of response selection is referred to as an "information processing chain" (see Figure 2).

High arousal level is postulated to have a biasing effect on the information processing system towards selectively processing information passively and involuntarily. As arousal level increases it is proposed that the reservoir of available capacity "empties" into a rising level of background neural activation. This interferes with the ability of the voluntary control center to influence the information processing system by reducing the amount of capacity available to it for selective investment into various semantic or goal-drive units. Because high arousal interferes with the functioning of the voluntary control center, it biases the information processing system towards selectively processing information through the structural features of the system. In other words, high arousal level is proposed to bias selective information processing towards passive processing by forcing the processor to rely on those neural pathways of least synaptic resistance. By changing the level of available capacity in the reservoir, different factors such as arousal, fatigue, or motivation are able to bias the system towards voluntary or involuntary processing of information.

## CHAPTER IV

### AN INFORMATION PROCESSING MODEL OF THE STUTTERING MOMENT

In this chapter a model of the stuttering moment is proposed that has its roots in the general information processing model presented in the preceding chapter. The model's particular focus is on trying to account for the basic involuntary, perseverative nature of the stuttering response. The specific plan of this chapter is to present the model in two parts. The first part of the model deals with developmental aspects of the automatic control mechanism postulated to regulate the stuttering response. The second part addresses itself to the question of what causes the automatic control mechanism underlying the stuttering response to become dominant over more voluntary control centers. This portion of the model offers a neurological account of the stuttering moment, explaining basic features of the stuttering block such as its involuntary nature, repetitions and prolongations in terms of neural phenomena.

#### Development of an Automatic Control Mechanism Behind Stuttering

In this first part of the chapter, an automatic control mechanism is proposed which is consistent with the general information processing model described in Chapter II. Developmental aspects of the automatic control mechanism are discussed.

### The Attentional Response During the Stuttering Episode

One of the key issues to address in a model which relies so heavily on the idea of an automatic control mechanism regulating stuttering is the developmental question of how such a mechanism becomes established. It is the contention of this paper that the roots for the automatic control mechanism lie somewhere within the stutterer's attentional response to threatening speech situations. In this section an attempt is made to establish what this attentional response might be immediately preceding and during the moment of stuttering.

Before postulating what this attentional response might be, it will be helpful to examine a few theories of stuttering relevant to this issue. The anticipatory struggle perspective of stuttering seems particularly relevant to the notion of stuttering being closely related to the attentional response of the stutterer. Theories sharing this perspective suggest that it is the anticipation or expectancy of speech difficulty which leads to stuttering (Bloodstein, 1975). Bloodstein provides a summary view of how such generalized expectancies of speech difficulty might arise as a learned reaction to simple repetitions of sounds occurring without effort or awareness on the child's part. These early childhood nonfluencies, he reports, tend to disappear spontaneously over time if the child does not acquire the attitude that there is something abnormal with his speech. If, however, the child's attention is somehow drawn to focus on his speech through, for example, abnormal parental reactions to

his nonfluency (Johnson, 1942), the child then begins to view these speech situations as negative and fearful. In reaction to this negative anticipation of stuttering, the child begins struggling to avoid such speech nonfluencies which only serves to exacerbate the condition. It is proposed that stuttering develops out of this anticipatory struggle reaction. What this etiological view of stuttering suggests is that a generalized expectancy or state of attention centering around the speech difficulty is the crucial aspect in the development of stuttering.

It is out of this generalized, fearful expectancy of speech difficulty that a specific attentional response is hypothesized to develop. Van Riper (1971) provides some notions of what this specific attentional response might be with his concept of preparatory set. He points out three basic components of this set which occur prior to attempting a word perceived as difficult or feared. First, the stutterer becomes abnormally focused on the tension in his speech organs. Second, the stutterer prepares himself to say the first sound of the difficult word as a fixed posture rather than as a normal blending with the rest of the word. Third, he may establish this fixed posture noticeably before he attempts overt vocalization resulting in silent "performance" of the sound. West, in a similar vein, proposed that stutterers attempt to produce speech by exerting conscious voluntary control over individual speech movements rather than the normal process of initiating automatic serial responses (West, Ansberry and Carr, 1957). What both of these views serve to point out is a possibly unique aspect of the stutterer's

attentional response to speaking problematic words: focusing of attention on *individual* speech syllables in conscious preparation for their vocalization.

It is proposed that while a generalized expectancy of speech difficulty may give rise to many different specific expectancies associated with stuttering, a specific core expectancy of difficulty with a particular speech syllable is present prior to any blocks. What this suggests, then, is that the stutterer establishes a specific focus of attention on particular problem syllables just prior to blocking on them.

This particular target of attention, the problem syllable, is hypothesized to occupy attention not only just prior to the stuttering block but, during the actual moment of stuttering itself. In fact, a focalization of attention around the problem syllable is postulated to take place as the stutterer approaches the moment of stuttering. As a stutterer approaches the point of attempting the problem syllable, arousal level is likely to increase which is accompanied by a narrowing of attention onto the most dominant aspects of the present situation--the problem syllable. During the actual moment of stuttering, with arousal level reaching its peak, the focalization of attention on the problem syllable is proposed to reach its peak, as well. This narrowing of attention onto the problem syllable will be discussed in greater detail in a later section. In summary, attention is hypothesized to proceed from a very broad focus on a generalized expectancy of speech difficulty to an increasingly narrow and intense focus on a particular problem

syllable as the moment of stuttering is approaching and initiated. Thus, the problem syllable is postulated to be the central target capturing the bulk of attention in the moments prior to and during the actual stuttering block.

#### The Hyperexcitable Syllabic Unit: Core of the Automatic Stuttering Mechanism

In the preceding section it was proposed that the stutterer learns to selectively attend to the problem syllable during threatening speech situations. One of the distinctive features of the stuttering situation is the intense type of fear which often accompanies it. This intense fear can result in a high state of arousal and an extremely narrow "hyperattentive" focus on the problem syllable. The question addressed in this section is how does hyperattention to the problem syllable contribute to the development of an automatic stuttering mechanism?

Before addressing this question, a model of normal speech production is examined. MacKay (1970) proposed a model of normal speech production at the phonetic level in which he postulates a "buffer system" which displays engrams of phonemes that are about to be vocalized. This buffer system "primes" or partially activates internal representatives of phonemes called "phonemic units" and also programs for modifying these phonemes according to the context in which they occur. These intermediate units, then, pass the primary effect of the buffer system onto a corresponding set of motor units. Final speech output is determined by a "scanner" mechanism which passes an

added boost of excitation to the appropriate motor units to activate them. The activated motor units then send a series of motor commands to the speech musculature. To summarize this model, three basic types of functional components have been proposed: a motor unit to send impulses to the speech musculature, a buffer system to prime the appropriate motor unit, and a voluntarily-controlled scanner to send the motor unit an added boost of excitation for activation of the motor unit.

With this model of normal speech production in mind, how can hyperattention to a particular speech syllable affect the normal speech process to produce stuttering? Referring back to the neural information processing model, the priming component can be viewed as analogous to the semantic unit postulated earlier in the paper. These semantic units have in common with the priming component the functions of being an internal representative of a given speech sound and a source of primary excitation for related speech motor units. Such specialized semantic units will be referred to as "syllabic units." In Chapter II it was mentioned that the relative strength of semantic units was determined by two factors: frequency of activation and level of activation. The more frequently and more highly activated the semantic unit, the more it undergoes structural change in the form of a lowered threshold, becoming subsequently more easily activated. In the stutterer's situation, then, the frequent hyperattentive focus on a particular speech syllable is postulated to considerably decrease the threshold of its corresponding syllabic unit, resulting in a hyperexcitable syllabic unit.

In the model proposed in this chapter, the hyperexcitable syllable unit is postulated to form the core of the automatic stuttering mechanism. It is proposed to be the first stage in the development of a highly automatic information processing chain underlying the stuttering response. Once the hyperexcitable syllable unit is established it can be easily activated under appropriate threatening speech situations. In such situations the activated syllabic unit passes a "larger-than-average" boost of excitation to its connected motor unit, priming it for easier activation.

When the scanner supplies its added boost of excitation, the motor unit reaches a higher level of activation than it would had the syllabic unit not been so hyperexcitable. Over time, the intense and frequent activation of the syllabic and motor units brings about a lowering of their thresholds so that the information processing chain from syllabic unit to motor unit becomes more easily excitable. As the thresholds of these units continue to lower, the syllabic unit becomes increasingly able to transmit higher boosts of excitation while the motor unit becomes increasingly easier to activate. It also becomes easier for the excitability boost supplied by the syllabic unit to, alone, activate the speech motor unit without the added boost of the voluntarily-controlled scanner. Thus, it can be seen how the hyperexcitable syllabic unit is able to regulate the speech apparatus independent of the scanner. If the excitability boost of the syllabic exceeds the threshold of the motor unit, involuntary stuttering is predicted to occur. This notion of relating stuttering to the relative level of

excitability boosts and motor unit threshold is similar to one advanced in MacKay's (1970) contextual programming model of stuttering.

In summary, what has been proposed is that the automatic mechanism behind the stuttering response is an information processing chain with units of very low threshold. This information processing chain is organized around a syllabic unit, which, in a sense, may take the place of the voluntarily-controlled scanner in controlling the speech apparatus. If the syllabic unit is able to provide excitability boosts which exceed the motor unit threshold, stuttering is hypothesized to take place. This depends not only on the strength of the excitability boost but also the motor unit threshold. These two factors are proposed to determine the duration of the stuttering block and the frequency of repetitions within the block. The most severe blocks, then, are hypothesized to occur under conditions of high arousal (which is translated into excitability boosts) and a thoroughly-ingrained stuttering response (low motor unit threshold).

#### The Automatic Control Mechanism During the Stuttering Moment

In this section the second part of the model is presented which attempts to account for basic features of the stuttering moment. The model first attempts to account for the involuntary nature of the stuttering block by addressing the following question: What is causing the automatic control mechanism to temporarily override

the higher directive control of the voluntary control center? After the question is addressed, the model proceeds to offer an explanation of repetitions and prolongation in terms of neural phenomena.

### Conditions Inhibiting the Stuttering Response

Before attempting to account for what is happening when the automatic stuttering mechanism becomes dominant over the voluntary control center, it might be helpful to examine some speaking conditions where dominance of the stuttering response seems to be inhibited. A reduction in stuttering frequency has been observed under a number of experimental conditions including speaking to an imposed rhythm, choral speaking, shadowing, singing, whispering, and exposure to auditory masking noise (Bloodstein, 1975; Cherry, Sayers and Marland, 1955). In terms of the model being proposed, what all of these conditions have in common is the tendency to distract attention away from problem syllables which might be encountered. At a neural level it is postulated that some of the capacity which ordinarily might be allocated to a hyperexcitable syllabic unit is, instead, allocated to processing novel stimuli imposed under such conditions. Thus, the hyperexcitable syllabic unit remains inactivated or, at least, at an activation level too low to trigger the motor unit controlling the speech musculature. This explanation of how the stuttering response becomes inhibited is actually a restatement of Barber's (1939) distraction hypothesis in neural terms. What the model adds to the original distraction hypothesis is a clearly specified speech interfering stimuli--the problem

syllable.

A reduction in stuttering frequency has also been observed under natural conditions, when the stutterer speaks in private (Sheehan, 1970). In this situation where there is no particular distracting stimuli present, what is operating to reduce stuttering? According to the model proposed, the private speaking situation is not too threatening a situation so that it does not elicit the general anticipatory set that is evoked in more threatening speech situations. At a neural level, this means that the hyperexcitable syllabic unit receives less capacity so that it more often remains unactivated or, at least, unable to activate its corresponding speech motor unit.

What these reduced stuttering conditions suggest is that, though the information processing chain underlying the stuttering response is highly automatic, it still requires a minimal amount of capacity to become activated. If this were not so, the stutterer would be involved in a perpetual stuttering block! These conditions also suggest that the stuttering response can be inhibited if enough capacity can be directed away from the hyperexcitable syllabic unit to keep its level of excitation below its activation threshold. To do so, however, becomes increasingly more effortful the more arousing the speech situation is and the more automatic (lower threshold of activation) the stuttering mechanism.

#### Conditions Facilitating the Automatic Stuttering Mechanism

What was pointed out in the previous section is that it is possible to maintain voluntary control over the speech apparatus, even in

threatening speech situations, so long as the level of excitation of the speech motor unit remains below its threshold. To a certain point, then, voluntary control of the speech apparatus can be maintained, but this requires a great deal of conscious effort.

Past a certain point, however, it appears that the stutterer loses control. Phenomenologically, it is as if an automatic stuttering mechanism has been turned on and will stop only after it has "run its course." What might be happening at this point to facilitate what appears to be a shift from a voluntary to involuntary control system? The neural information processing model suggests two ways by which this shift in control might be facilitated: through a reduction in the reserve of available capacity and a raising of the automatic information processing chain's level of excitation beyond its activation threshold.

It is postulated that high arousal level is what facilitates the shift in control during the stuttering block. The discussion in Chapter II concerning the biasing effect of escalating arousal towards passive, automatic processing mechanisms suggests that the rising background excitation level may be operating to both deplete the reserve of available capacity and activate the more dominant information processing chains. The stutterer's ability to actively resist more dominant, automatic information processing chains becomes impaired because there is no available capacity to redirect the flow of information through weaker processing chains. Thus, because the capacity reserve is depleted under high arousal conditions, the stutterer relies increasingly on those processing chains of least synaptic resistance. The most thoroughly ingrained processing chains relevant to the speech

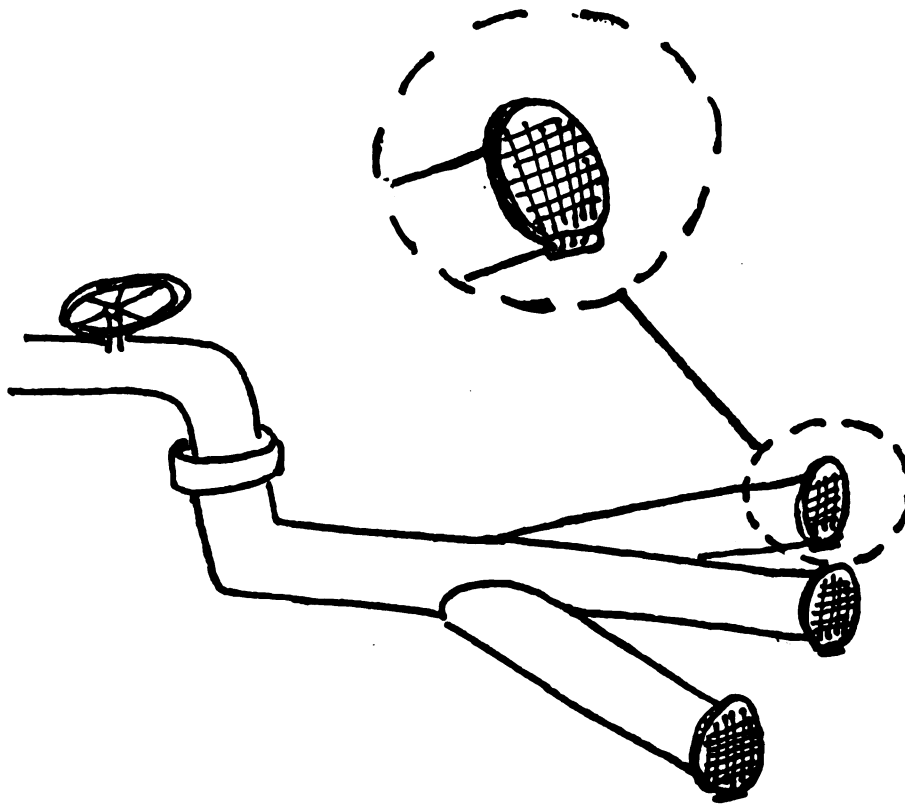
situation are those that are centered around problem syllables. These processing chains underlying the stuttering response are able to function without much or any selective investment of capacity. They are able to be maintained in a state of activation so long as the stutterer is aroused enough to keep the background level of excitation above the very low thresholds of the processing chain. At the same time, more conscious voluntary processing is impaired by the depleted reserve of capacity. Thus, the stutterer, especially during severe moments of stuttering, is in a temporary involuntary state under the domination of an automatic information processing chain.

#### The Perseverative Nature of the Block

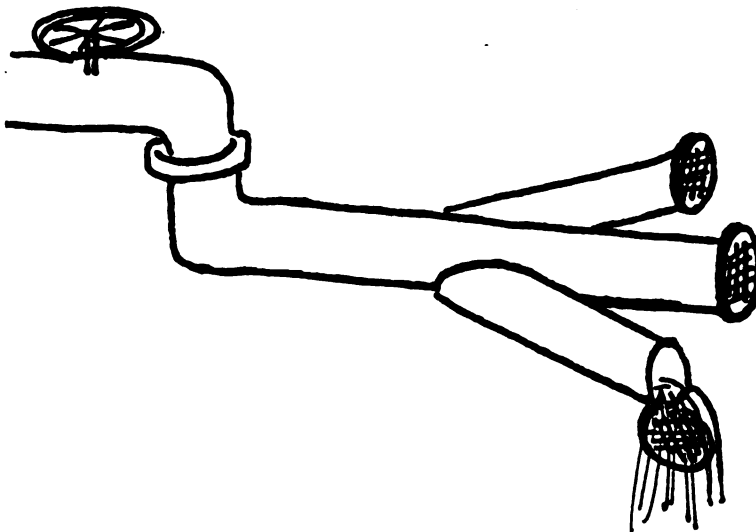
In the preceding section a neural account was given for the involuntary nature of the stuttering block. Under conditions of high arousal, it was explained how the stutterer can become directed by an automatic information processing chain. This still does not answer one of the basic riddles of stuttering: Why are there repetitions and prolongations?

To understand how the information processing system proposed might be operating to produce repetitions and prolongations, the system is described in terms of an analogy of a "hydraulic system." This hydraulic system, as depicted in Figure 7, consists of a water faucet feeding into a system of pipes with three outlets. Over each of these outlets is a flap-like valve which is held in place by a spring hinge. Outlets 1 and 2 have fairly strong hinges, while outlet 3 has a relatively weaker hinge. If water is sent into the system

80



CLOSED FLAP



OPEN FLAP

Figure 7. A hydraulic system.

through the faucet the following points are predicted:

1. Water will be forced out outlet 3 because its valve gives the least resistance to being pushed open.
2. If the water inflow is not very great, it will take a certain period of time for the water pressure to build up before it becomes greater than the valve resistance and the flap is forced open so that the water spills out.
3. As water spills out, the water pressure drops and the flap closes once again. Now, with the flap closed, the water pressure builds up again and the same cycle is repeated.
4. The higher the water pressure or the lower the resistance of the valve mechanism, the higher will be the frequency of openings and closures of the flap.
5. If the water inflow is gradually increased, the point will come where the flap never closes all the way--when the pressure of the water continually exceeds the resistance of the valve.
6. The more frequently the flap is opened and the longer it is kept open, the more stretched will become the springs on the hinge, resulting in less resistance.

When the stutterer's ability to selectively invest capacity is temporarily impaired, as under conditions of high arousal during the stuttering block, the information processing system is hypothesized to function quite similarly to the hydraulic system just described. This hydraulic analogy can be readily applied to the information processing system to gain a better understanding of how it might be working to produce repetitions and prolongations. In the remainder of this section, the predictions made concerning the hydraulic system will be applied to the information processing system in a point-by-point analysis as follows:

1. In the hydraulic system, water flows out the pipe that has the least valve resistance. Similarly, with the information processing system in such a passive state, electrical activation "flows up" the neural pathway with the least

synaptic resistance. The path of least synaptic resistance in the case of a blocking stutterer is the information processing chain built around a hyperexcitable syllabic unit.

2. Just as water does not always flow out the pipeway continuously but needs to build up water pressure before it pushes the flap open, electrical activation is postulated to "build up pressure" at the synapses of the processing chain--in particular, at the motor unit synapse. Only when the "electrical pressure" exceeds the synaptic resistance of the motor unit does the motor unit "flap open" or discharge, triggering the speech musculature to utter a repetition.
3. As the speech motor unit discharges, the level of electrical excitation or "electrical pressure" decreases once again below the threshold of the motor unit. The motor unit stops firing impulses to the speech musculature and the level of excitation begins to rise again--assuming there is still a reserve of electrical activation to flow into the information processing chain.
4. Just as the water pressure and valve resistance determine the frequency of openings and closures of the flap in the water-gating system, arousal level and synaptic resistance are hypothesized to determine the frequency of motor unit discharges. If this is so, arousal level should be directly related and synaptic resistance inversely related to the frequency of perseverative stuttering phenomena such as repetitions or stuttering tremors.
5. If arousal level continues to increase, the point will come when repetitions blend into adjacent repetitions producing prolongations. If the arousal level is so high that the level of excitation continuously exceeds the motor unit threshold, the motor unit will be in a state of continuous activation and discharge.
6. Just as the valve resistance decreases as the springs or the hinge are continually stretched during use, the threshold of activation for different units decreases with repeated and intense activation--resulting in less synaptic resistance.

Some of the major points drawn from the hydraulic analogy suggest that during the stuttering moment, the stutterer temporarily begins to function as a passive processing channel--responding to the general electrical activity present during such periods of high

arousal. The particular channel processing this electrical stimulation is hypothesized to be a highly automatic processing chain centered around a syllable unit. It is suggested that this dominant processing chain is what determines the basic features of the stuttering response such as repetitions and prolongations. These features are modulated by the level of electrical stimulation which "feeds into" the processing chain. In closing, it is suggested that phenomena such as convulsions during epilepsy or convulsions following electroconvulsive shock treatment may share some basic aspects with stuttering. Such phenomena resemble stuttering with respect to the presence of perseverative involuntary motor behavior, and high levels of electrical activity in the brain. A speculation which is offered is that, perhaps, the high background level of electrical activity in these conditions drains the available reserve of capacity and biases the processing to the most automatic, dominant processing chains possible. With conditions such as convulsive behavior during epilepsy or after electroconvulsive treatment, it seems possible that there exists low threshold processing chains which underlie these involuntary behaviors, as well.

#### Termination of the Stuttering Block

In this section the model addresses how the stuttering block eventually terminates, allowing the stutterer to regain voluntary control of the speech apparatus. The passive processing mode of the stuttering moment is proposed to continue until the arousal level begins to decline--perhaps, through fatigue of the passive processing

system to such a high level of stimulation. As the background level of excitation begins to subside the reservoir of available capacity is gradually replenished so that active processing once again can take place. Thus, it is proposed that, during the moment of stuttering, the stutterer genuinely is being controlled by the automatic stuttering mechanism. In such situations, it is very difficult for the stutterer to voluntarily free herself from the block, though she may struggle to do so. The use of interrupter devices (Van Riper, 1971)--sudden bizarre behaviors such as head body jerks, facial grimaces, or nasal snorts--to escape severe blocks appears to be an effort, on the stutterer's part, to "wrestle back" control from the automatic stuttering mechanism. By involving herself in such drastic behavior it seems that the stutterer is trying to create a distraction severe enough to free her captive attention from the syllabic unit which is maintaining the stuttering block. Such interrupter devices are successful in occasionally terminating severe blocks. The degree of struggle and effort evident in such behavior, however, indicates that the automatic stuttering mechanism must be very dominant in the midst of a severe block. In most cases, the stutterer must helplessly wait until the stuttering block has "run its course"--until the automatic stuttering mechanism becomes fatigued, arousal level declines, and control is finally relinquished back to the stutterer.

### A Summary of Major Aspects of the Information Processing Model of Stuttering

In this final section of the chapter a summary of the major aspects of the information processing model of stuttering is provided. The first part of the model is concerned with the development of an automatic stuttering mechanism which underlies the stuttering response. A highly dominant information processing chain with very low synaptic resistance is proposed to be the automatic stuttering mechanism. This dominant processing chain is postulated to have its roots in a generalized negative anticipatory set towards certain speech situations. Out of this generalized negative set, a specific attentional response develops--focusing attention on the individual problematic speech sound. Because speech difficulty is so often associated with this particular problem syllable, it becomes the most dominant target for the focus of attention during threatening speech situations. As the stutterer adopts a negative anticipatory set in response to a threatening speech situation, attention begins to focus on the problem syllable. As arousal level continues to escalate the stutterer's attentional focus on the problem syllable, it becomes increasingly narrow and intense, resulting in what is referred to as a hyperattentive focus. This hyperattentive focus on the problem syllable continues through the moment of stuttering. At a neural level repeated hyperattentive focusing on the same problem syllables over time is postulated to lead to the development of hyperexcitable semantic units representative of these individual syllables--syllabic units. These hyperexcitable syllabic units form the core of the information processing chain behind

the stuttering response. The syllabic unit is postulated to be playing a two-fold role in determining the stuttering response. First, when it is highly excited, such as during threatening speech situations, it can supply the motor unit with an excitability boost sufficiently large to trigger the motor unit and the stuttering response. Because it is capable of triggering the motor unit by itself in a hyperexcited state, the syllabic unit is able to take over the speech-regulating function of the voluntarily-controlled scanner, which normally provides the added boost needed to activate motor units. The second role of the syllabic unit in determining the stuttering response is its effect on other units in the information processing chain. By facilitating activation of the information processing chain through priming of connected units, the syllabic unit is able to facilitate a reduction in synaptic resistance in each of the units of the processing chain. In this manner, a highly-automatic, low synaptic resistance processing chain evolves which is able to direct the stuttering response without any selective investment of capacity.

The second part of the model addresses what is happening during the actual moment of stuttering. High arousal level was implicated as facilitating the shift from a voluntary to involuntary control system during the stuttering block. This shift occurs because under the conditions of high arousal, the reserve of available capacity becomes emptied into a rising level of background excitation. Without a reserve of available capacity, the system is biased towards relying on those processing chains which require little selective investment

of capacity for activation. For this reason, the low threshold processing chain centered around the hyperexcitable syllabic unit becomes the most dominant chain during the moment of stuttering.

The model provides a neurological account of repetitions and prolongations occurring during a block. From a hydraulic analogy, the information system is postulated to function as a passive channel responding to the general electrical activity under conditions of very high arousal. The passive channel in the stutterer's case is the processing chain centered around the hyperexcitable syllabic unit. Electrical excitation flows through this particular processing chain because it is the neural pathway of least synaptic resistance. The flow, however, is not always an even flow since the excitation level must increase for a period of time before it exceeds the motor unit threshold and triggers a repetition. As the motor unit discharges, the level of excitation may once again drop below threshold and begin to "accumulate" again until the threshold is, once again, exceeded. From this repeated cycle, repetitions and other perseverative phenomena of the stuttering response are proposed to be generated. If the level of excitation is great enough, however, the motor threshold is continuously exceeded, which is hypothesized to generate a continuous prolongation. The block is postulated to begin terminating when the arousal level declines due to fatigue of the information processing system. As arousal level decreases, capacity once more becomes available in the reserve enabling active processing to again take place. At this point the stutterer regains the ability to voluntarily direct the information processing system.

## CHAPTER V

### CENTRAL CONCEPTS IN INFORMATION PROCESSING: A NEUROLOGICAL PERSPECTIVE

In this final chapter I would like to make explicit some views of information processing that have been implicitly-held during the course of this paper. These views have been a major influence in shaping the neural information processing model proposed in this paper but, as could be predicted with a "sometimes" active information processor, the model itself has reshaped the original views upon which it was built. For this reason, the paper will conclude by offering some speculations generated from the general neural model on some central concepts in information processing.

In the ensuing discussion an attempt will be made to reframe in a neurological perspective some fundamental concepts of the information processing paradigm such as attention, selective attention, consciousness, inner speech, active and passive information processing, and voluntary and involuntary control of the information processing system. Attention is viewed as processing capacity or, in neural terms, neural excitation. From this stance, it follows that attention is involved at each level of processing. Since attention, from this framework, is involved in all levels of processing, selective attention is considered simply to be the selective activation of particular processing units. From this definition, selective attention does not occur until a processing unit has been activated. Also, it follows

that, in a limited-capacity system, the level of activation of different processing units reflects the intensive aspect of selective attention on different stimuli. Thus, a single, hyperexcited processing unit would indicate that the bulk of selective attention has been allocated to that particular aspect of the environment while two fairly equally excited units would indicate that selective attention has been divided between two major inputs. Proceeding on to the different levels of processing, it is postulated that consciousness and conscious thought--an awareness of the meaning behind one's experience--is derived from the activation of goal-drive or semantic units. This assumption is made because goal-drive and semantic units are proposed to provide the neural substrate of meaning, where all meaning is viewed as being ultimately derived from one's own subjective experience which is determined within the framework of one's goals, drives, and acquired meanings. It should be pointed out that this view of consciousness and conscious thought does not depend on the presence of language capacity, since it is proposed that meaning can be derived from innate goals and drives before the organization of language is imposed over them. The development of language and semantic units is, however, postulated to significantly increase the capacity for conscious thought. It is viewed as a "tool" for conscious thought, not conscious thought, itself. Related to conscious thought is the phenomenon of "inner speech." At a phenomenological level inner speech refers to the everyday experience of being able to "hear" one's own private internal monologue without any actual overt or audibly-detectable speech. Approaching inner speech from the position of the general neural model,

it can be described as an activation of semantic units at a level that is not sufficient to trigger the connected speech motor units. Active and passive information processing have already been described in neural terms.

Active processing in this paper is viewed as any information processing that is reliant on the selective investment of capacity. Because capacity is postulated to be selectively invested by the voluntary control center, active processing not only involves exercise of one's voluntary directive capacity, but also requires conscious effort in the selective allocation of capacity. Passive processing, conversely, is considered to be processing of information which is able to take place without the selective investment of capacity. From this position of passive processing as processing that takes place independent of selective allocation of capacity, automatic processing can be viewed as a synonymous term. It should be kept in mind that, though passive or automatic processing do not require the effort involved in selective investment of capacity, all information processing, according to this model, requires capacity or neural excitation to take place. Thus, passive or automatic processing is dependent on sources of neural excitation other than the voluntary control center. Neural excitation "flowing through" and activating the low synaptic resistance processing chains behind automatic processing can come from either sensory stimulation or the general background level of neural excitation in the information processing system. The latter source of neural excitation, the general background level of neural excitation, is directly related to the level of available capacity in the reservoir

for the voluntary control center (see Figure 8). Under conditions of normal arousal the background level neural excitation may be relatively low in comparison with the level in the reservoir. With increasing arousal, however, it has been previously noted that the background level of excitation begins to rise depleting the available capacity reserve. From Figure 8 it can be seen how the level of excitation in these two sources has a direct bearing on what mode of processing, active or passive, the individual relies more upon. Figure 8 clarifies also the continuum aspect of passive/active information processing. When active and passive processing were described earlier in this discussion, what was described was the *process*, itself. The notion that an individual at any given time is either actively processing or passively processing information is a misconception. The actual state of information processing under most circumstances probably involves elements of both processing modes. Individuals, then, can be viewed as varying on an active-passive processing continuum over time, influenced by factors such as arousal level, fatigue, interest level, and intensity of sensory stimulation. The employment of both modes of processing, however, does not mean to imply that one mode or processing does not ever completely dominate the other.

In the preceding discussion some fundamental constructs relevant to information processing have been examined from the perspective of the neural model of information processing. This was necessary to lay the groundwork from which the central issue of this paper can now be approached. What is meant by voluntary or involuntary information processing? To get a clearer idea of what the phenomenon of interest

"A LIMITED CAPACITY SYSTEM"

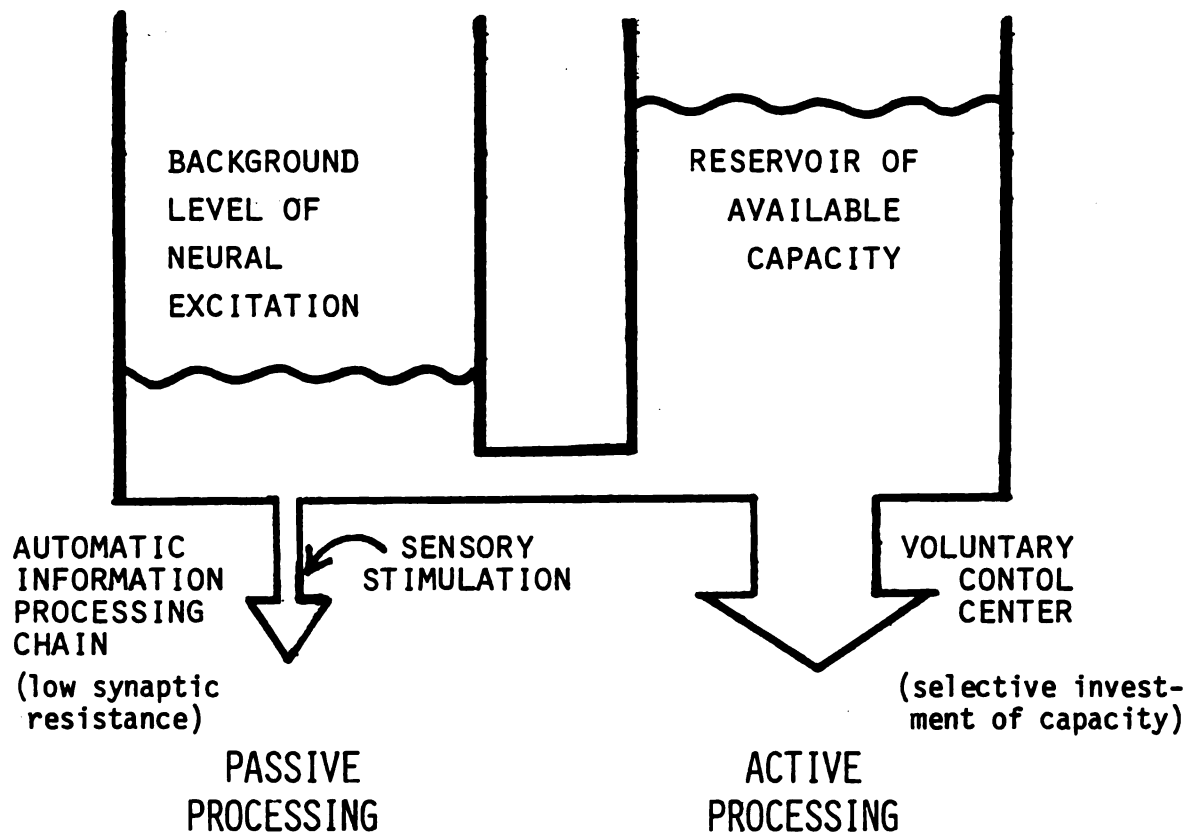


Figure 8. Factors affecting passive vs. active processing.

is, it will be useful to differentiate the notion of passive or automatic processing from involuntary processing. The two concepts may be easily confused since involuntary information processing is always associated with automatic processing. But, as was touched upon in Chapter I, there are cases where an individual is passively processing information not because her voluntary control center is incapacitated but because her voluntary control center *allows* herself to be regulated by an automatic information processing chain. In this case, the automatic information processing chain is regulating the processing of information, but in the service of the voluntary control center. Cases of genuine involuntary information processing occur when the individual is no longer able to switch from a passive processing mode over to an active processing mode. In such cases, the automatic information processing chain assumes not only the regulatory function of information processing but the directive function of the information processing system. To be accurate, the automatic information processing chain does not really "take over" or direct the information processing system in any active manner. Instead, the dominance that it assumes can be viewed more as the result of an impaired or incapacitated voluntary control center. To determine, then, what facilitates the shift to involuntary processing, one should consider how the voluntary control center can become impaired. From Figure 8 it can be seen that any factor that depletes the available capacity reservoir will be able to incapacitate the voluntary control center. It is proposed that shifts toward involuntary processing are the result of a reduction in the available capacity level of the reservoir. Thus, high arousal,

which depletes the available capacity reservoir, has been proposed as having a major effect on impairing the voluntary control center. The availability of capacity to be used by the voluntary goal center in the selective activation of different priming units is viewed as the central determinant of whether processing will be voluntary or involuntary.

The phenomenon of stuttering is of special interest to this paper because it is believed to be a well-studied example of when the voluntary control center becomes partially or totally impaired, leaving the stutterer dominated by an automatic information processing chain. Stuttering is considered important to this paper, not only as a phenomenon of interest in itself, but in terms of its implications for the general neural model of information processing. Of particular importance to the general model of information processing, the model of the stuttering proposed in Chapter IV suggests that many of the basic features of the stuttering block--its involuntary nature, repetitions and prolongations--are a function of arousal level. The model of stuttering is able to make specific predictions about various perseverative phenomena and arousal level. As arousal level increases it is predicted that: (a) the rate of repetitions and stuttering tremors should increase, (b) the occurrence of prolongations should increase. Since much of the behavior exhibited during the stuttering response is observable and quantifiable and they seem closely related to some central aspects of the general information processing model proposed, the phenomenon of stuttering seems like a logical point from which to begin investigating some of the speculations raised by the general model.

### Summary

In this paper a general model of information processing is proposed from which a more specific information processing model of the stuttering moment is developed. Both models attempt to account for information processing at the neural level. The general model views the information processing system as having a certain structure in the form of neural pathways of different synaptic resistance. Information is not processed invariably according to this structure via neural pathways of least synaptic resistance because the voluntary control center can selectively invest capacity into various priming units to boost the level of excitation in certain information processing chains. In this way, an available reservoir of capacity allows the processor to redirect the flow of information "against" the structural bias of the system. It allows the processor to develop new information processing chains or employ weak information chains over stronger, more automatic chains. By doing this, the processor is able to actively reshape the structural bias of the system since activation of information processing chains is postulated to bring about structural change in their thresholds.

Active processing which depends on the selective investment of capacity becomes impaired during conditions of high arousal. This is because, with a high level of arousal, the available capacity reservoir, becomes depleted into a rising background level of neural excitation. This means that the voluntary control center no longer has a reservoir of capacity to selectively invest into specific priming units. Thus, with no reservoir of capacity to invest, the

voluntary control center becomes incapacitated and the more automatic information processing chains become dominant and temporarily in control of the information processing system.

The information processing model of the stuttering moment postulates a special automatic information processing chain that centers around a type of semantic unit, representing speech syllables--the syllabic unit. The stutterer, learning to focus attention on the speech syllable in threatening speech situations, develops a hyperexcitable syllabic unit. In normal speech, the syllabic unit primes the speech motor unit and a scanner mechanism (MacKay, 1970) activates it. With the stutterer, who has developed a thoroughly-ingrained processing chain and a hyperexcitable syllabic unit, activation of the hyperexcitable syllabic unit, alone is sufficient to activate the processing chain. The stuttering response is hypothesized to occur whenever the hyperexcitable syllabic unit is able to activate the motor unit. With more severe blocks during periods of high arousal, the stutterer can be considered temporarily to be functioning as a passive channel. During severe blocking, the high level of background excitation feeds into the automatic processing chain. The higher the arousal level, the greater the flow of excitation through the chain. As a result of this greater flow, the stutterer's motor unit will discharge at a greater rate producing a higher frequency of perseverative behavior.

In closing, the models presented in this paper attempt to integrate a broad scope of information relevant to information processing, drawing from the areas of cognitive psychology, physiological psychology, and stuttering. The models proposed are of a speculative

nature. They are offered as preliminary models, in the hope that they might stimulate and guide future researchers in their attempts to relate more closely functional and structural knowledge of the information processing system. In particular, the model suggests the possibility of describing some rather nebulous concepts such as attention, consciousness, inner speech and voluntary or involuntary control in terms of basic neural phenomena. If such complex phenomena can indeed be described, at a fundamental level, in terms of basic neural phenomena such as electrical activity or synaptic resistance, these phenomena would become more readily open to biological investigation. For example, phenomena such as consciousness or attention might be more approachable targets of biological investigation if they could be viewed as patterns of electrical excitation of certain neurons in the brain rather than mentalistic concepts unlinked to the biology of the information processor. The speculations ventured in these models are preliminary attempts at trying to provide a biological substrate for some central constructs of human information processing. Through such an investigation, it is hoped that a closer link might be established between psychological and physiological views of human information processing.

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