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Empirical and theoretical psychophysiological considerations regarding information processing during skilled reading

Abstract

Current psychophysiological research regarding eye movements, cortical alpha rhythm, and memory mechanisms is reviewed in light of the role these phenomena may play in the process of skilled reading. A model of perceptual constriction leading to a decrease in reading performance is advanced. The psychological and physical manifestations of perceptual constriction are developed, and are discussed relative to the psychophysiological phenomena mentioned above. An attempt is made to provide a synthetic model of skilled reading and reading difficulties consistent with current theoretical and empirical knowledge. Such a model is useful to optometrists and other professionals interested in learning and reading difficulties.

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EMPIRICAL AND THEORETICAL
PSYCHOPHYSIOLOGICAL CONSIDERATIONS
REGARDING INFORMATION PROCESSING
DURING SKILLED READING

Bradley Coffey
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Forest Grove, Oregon
Spring, 1981

ABSTRACT

Current psychophysiological research regarding eye movements, cortical alpha rhythm, and memory mechanisms is reviewed in light of the role these phenomena may play in the process of skilled reading. A model of perceptual constriction leading to a decrease in reading performance is advanced. The psychological and physical manifestations of perceptual constriction are developed, and are discussed relative to the psychophysiological phenomena mentioned above.

An attempt is made to provide a synthetic model of skilled reading and reading difficulties consistent with current theoretical and empirical knowledge. Such a model is useful to optometrists and other professionals interested in learning and reading difficulties.

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Only by action on other like brains can the human potential be realized. Communicative action thus considered becomes the root rather than the fruit of language.

-- Karl Pribram, 1971

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EMPIRICAL AND THEORETICAL
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INTRODUCTION

Several advances in recent years in the fields of neuropsychology, psychophysiology, and electrophysiology have yielded much information applicable to the solution of some long-standing mysteries in optometry, behavioral optometry, vision therapy, and visual training. Members of the profession which encompasses the latter disciplines are presently attempting to generate a basis for their clinical delivery of care which is more thoroughly defined by scientific inquiry. This effort has been variably fruitful, but has been plagued by the fact that a strictly objective (scientific) investigation of a sense (vision) strongly and variably affected by subjective states yields inconsistent and often invalid conclusions. Kavner has stated that "the way we think affects our vision, and our vision affects the way we think: What we see is how we are, and how we are determines what we see" (Kavner and Dusky, 1978).

This difficulty in scientifically quantifying optometric therapies has led many clinicians to adopt a pragmatic approach to solving patients' problems. These approaches are often very effective, but their inconsistency and lack of unifying philosophy create many difficulties. Some approaches are effective for one clinician but not for another; some are differentially effective with a given patient at different points in the course of therapy; some seem applicable to nearly all cases while others are effective only in specific instances; all are difficult to communicate since no theoretical model exists

which unifies them. Work by several investigators in the various disciplines (e.g., psychophysiology, neuropsychology, behavioral optometry) which investigate the interaction of subjective and objective mental states seems immediately relevant to the generation of a unifying theoretical model.

Perhaps a key factor in the lack of development of a unifying model has been the general view that various problems of vision (such as ametropia and information processing difficulties) arise from different etiological phenomena and are thus not specifically related. Different visual problems certainly do often have very different etiologies, but in delineating these differences, the commonalities of various problems are frequently overlooked. The delineation of these differences to finer and finer degrees is, however, the essence of scientific inquiry.

One group within the vision disciplines, the functional optometrists, espouses a philosophy in which various visual problems are seen as maladaptations assumed by people experiencing levels of environmental stress which exceed their functional tolerance levels (distress). A particular maladaptation is seen to occur as the best compromise for the person to maintain required performance. The functional optometrist attempts to see the similarities in various visual problems and, moreover, sees these problems as on a continuum of visual dis-ease. The functional optometrist has also, however, been without a unifying psychophysiological model; the basis of the philosophy of functional optometry has been derived from clinical observations.

This paper will draw heavily upon recent research and theory in physiological psychology, cognitive psychology, and related fields in

an effort to develop a unifying theoretical model of visual dysfunction as it relates specifically to the reading task. The model to be elaborated later in the paper is probably applicable to most non-organic problems of vision, but will be discussed generally only with regard to reading and learning difficulties. A central theme in the model is the interactive nature of subjective and objective mental states; ie., how our past experience limits our present experience, how previous emotional experiences limit our present experience, how we project our perspectives in defining and delimiting our personal reality. The physiological concomitants of these subjective-objective state interactions will be shown to be sometimes non-conducive to efficient vision and information processing.

The theoretical model to be defined will provide a basis for understanding the various meanings which have been given to alpha rhythm, attentional states, eye movements, long- and short-term memory systems, and information processing modes associated with learning and reading difficulties. The model encompasses much available data and provides a paradigm within which future research may be conducted.

Scientists have long attempted to see vision as a linear, one-way stimulus-in/response-out type of process. Vision, as with all senses, is interactional. Our response biases (perspectives and prejudices) shape how and what we see, perhaps to a larger extent than does the actual photic input to the retina. The visual system is primarily constructive, the information contributed by the brain being very much greater than the information received from the eye (Smith, 1971).

In this light, cognitive information-processing styles may be seen to yield binocularity problems contributing to reading and learn-

ing difficulties or, conversely, binocular problems related to external environmental stressors may yield processing difficulties. A unidirectional approach is incomplete and improper. Janusian thinking is required. "Each thought or state of mind has a biological component, and each psysical action or internal biological condition has a phycho-logical effect." (Kavner and Dusky, 1978).

Succinctly stated, you can't use cause-and-effect reasoning to understand events not bound by time and space. Subjective awareness must be studied if brain [and vision] research is to get anywhere (Ferguson, 1978).

I. PERCEPTUAL CONSTRICTION

Individuals who lack the ability to see another's point of view may be referred to as narrow, set in one's ways, or as having tunnel vision. Such descriptions are most appropos to those who suffer from a constriction of perception, a functional inflexibility in mental states which interferes with one's ability to quickly shift from analytic to synthetic thought, to set one's biases aside to entertain a new perspective. Perceptual constrictions result in a narrow outlook due to changes in the individual's ability to maintain multiple thoughts simultaneously in consciousness. Such individuals may exhibit very short attention spans, difficulties in reading, aversions to intellectual challenge, emotional instability, and/or general difficulties in coping with environmental stress.

Optometrists often note inflexibility, instability, or lack of integration in the vergence and accommodative functions of the perceptually constricted individual. These difficulties are frequently treated as first-order problems. A broader perspective which holds vergence and accommodative difficulties (as well as constrictions of the useful field of view) as both causes (first-order) and effects (second-order) of the more general phenomenon of perceptual constriction is indicated by current research and theory.

Functional constrictions in the useful field of view have generally not been considered for investigation within optometry despite substantial interest early in the history of the profession (Brombach,

1936; Webb, 1940). Current texts report functional field shrinkages as being not uncommonly seen in children experiencing undue life stress (Harrington, 1976). Although optometric investigators have largely ignored the phenomenon, researchers in other disciplines have reported functional constrictions of the useful visual field as being the main adjustment made to deal with visual overload (Mackworth, 1976).

These functional constrictions in the useful field of view are differentiated from pathological constrictions in that there is no pathological etiology. Furthermore, functional field changes are dynamic and vary with changes in dynamic mental information processing styles which in turn are influenced by such factors as visual task demands, emotional preset, motivational preset, prior experience, et-cetera. See Figure I.1.

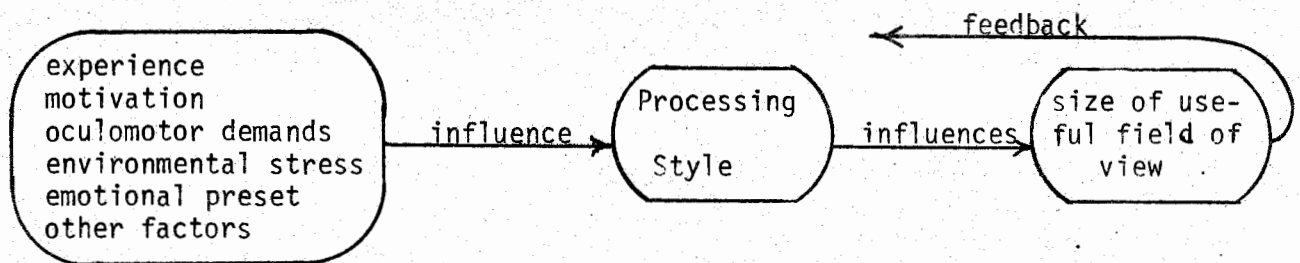


Figure I.1. Linear representation.

The useful field of view is defined as "the area around the fixation point from which information is being processed, in the sense of being stored or acted upon during a given visual task. The size of this useful field can be expected to vary between different kinds of tasks as well as between different kinds of people" (Mackworth, 1976).

A model of constriction in the useful field of view as an externalization of internal perceptual constriction may be developed from the empirical and theoretical work of Karl Pribram, a neuropsychol-

ogist at Stanford University. In addition to his experimental work in the investigation of behavior variations associated with selective brain lesions, Pribram has undertaken to synthesize a comprehensive model of brain function which encompasses the research of many disciplines including neurology, psychology, psychophysiology, and others. Many of his thoughts are especially germane to the present discussion.

With regard to the processing of visual information, Pribram (1971) has initially functionally divided the brain into two systems, frontal and posterior. The posterior association system is generally composed of occipital cortex and posterior inferior temporal cortex (together with subcortical pathways), and serves as the screen onto which selected visual information is mentally projected and decoded into significant bits of information. Frontal cortex functionally serves to provide context for incoming information to assist the human organism in interpreting context-free visual information projected to the posterior association system. These systems are highly mutually interactive. By way of introduction, the following statements by Gottlieb (1978) are helpful:

This is the function of the association [posterior] complex of organization: Making matches between outside events and long-term knowledge, seeing much, but not stopping to analyze deeply what is there. There is no episodic sense or temporal continuity. Each event is a relatively isolated, acted upon, and then dismissed experience. In reading, for example, some children are very adept at naming the letters or calling the words, but at the end of a paragraph they cannot tell you what they just read.

The frontal cortex and its lower brain connection serve a different function. The frontal system centers on specific details in the environment. It organizes sensory input in order to categorize, record, and identify surprising or unique input. It shuts down awareness of large aspects of the environment in order to concentrate on and identify smaller details. It provides a context and a meaning for the input.

A common and significant example of the posterior-frontal functional interaction is the development of an eye for detail. Two individuals of comparable visual acuities and visual skills may view the same small area of forest. The woodsperson will see much more information in the scene than will the urbanite. Based on extensive prior experience, the woodsperson will note subtle signs and symbols which are outside of the urbanite's range of perception. Bring both observers to the city and the urbanite will exhibit much more awareness of street events than the woodsperson. The woodsperson will lack "street sense" and will not be attuned to the significance of many actions of others. In both situations, both observers are exposed to the same objective visual information; i.e., the neural stimulation of the posterior visual areas will be similar. The difference in the amount of useful information each observer derives from each scene is a function of the context within which the available sensory information is processed. This context is maintained by processes of frontal cortex and is dependent upon the facility of accessing information previously stored in memory systems.

One's ability to interpret the visual world is thus dependent upon not only the delivery of uncompromised sensory visual input to the visual association areas in posterior temporal and occipital cortex, but also upon one's ability to generate a context which facilitates the association of meaning to the sensory input. Frontal processes responsible for generating context are variably involved in information processing activities relative to the complexity and familiarity of the sensory input. Simple, familiar input requires little context for interpretation while complex, unfamiliar information requires a very

specific contextual set for meaning to be derived. In the latter situation the organism's uncertainty about the input is greater. The degree of frontal involvement in any information processing task is directly proportional to the uncertainty of the organism regarding the immediate sensory input.

Pribram's experiments have shown that electrical stimulation of the two cortical areas discussed has opposite effects on the characteristics of the input channel's information-carrying attributes. These effects are measurable at the lateral geniculate nuclei and also in the optic nerve, thus implying a functional feedback loop from cortex to thalamic nuclei and also to retina (Pribram, 1971). Hare (1979) has presented additional evidence supporting such a feedback loop.

When the receptive field of a single retinal ganglion cell is measured at the lateral geniculate nucleus, the size of the responsive portion of the receptive field varies with electrical stimulation of different cortical areas. If, for example, the cell being measured is an ON center and OFF surround type, frontal stimulation will tend to increase the size of the ON portion of the cell's receptive field. Stimulation of the inferior posterior temporal cortex, on the other hand, will tend to decrease the size of the ON portion of the cell's receptive field (Spinelli and Pribram, 1967). See Figure I.2.

Other evidence is available which indicates the presence of corticofugal (cortex to sub-cortical points) processes which act to modify the information-carrying characteristics of sensory input systems. Any time a neuron in a sensory system is activated, it must undergo a short period of inactivation (a refractory period) before it can pass another signal without compromise. Refractory periods are

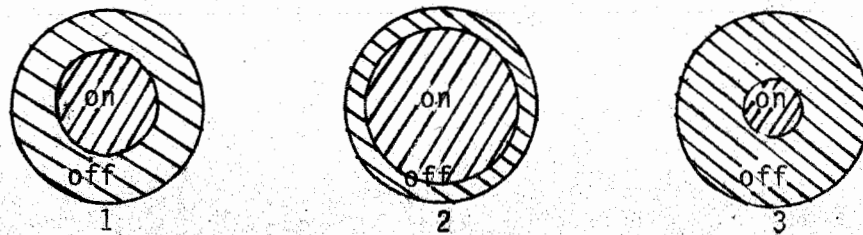


Figure I.2. Changes in receptive field of retinal ganglion cell measured at LGN associated with cortical stimulation. (1) Normal receptive field of hypothetical cell; (2) same cell's receptive field with stimulation of frontal cortex; (3) same cell's receptive field with stimulation of posterior temporal cortex. After Spinelli and Pribram, 1966 and 1967.

basic to biological systems and are involved in visual phenomena such as the critical flicker fusion frequency. Humans are capable of observing on-off cycles of a flashing lamp only up to a certain frequency; beyond this frequency, the refractory periods of the involved neurons (as well as finite neural transmission times) disallow any perceptual awareness of discrete flashes: The flicker observed at lower frequencies becomes fused into an appearance of constancy.

While measuring activity of retinal neurons in the optic nerve and lateral geniculate nuclei, Pribram has found that electrical stimulation of frontal and posterior cortex has opposite effects upon the length of the refractory period of the retinal neurons (Spinelli and Pribram, 1966). Electrical stimulation of frontal cortex tends to reduce the refractory period while stimulation of the posterior inferior temporal cortex tends to lengthen the refractory period.

Two examples of cortical control over the state of input mechanisms have thus been described. Stimulation of frontal cortex tends to increase the size of the responsive portion of retinal ganglion cell

receptive fields and to decrease the refractory period between possible successive excitations of ganglion cells. Stimulation of posterior inferior temporal cortex tends to decrease the size of the responsive portion of retinal ganglion cell receptive fields, and to increase the refractory periods between possible successive stimulations.

Pribram suggests that these reciprocal functions serve to modify the redundancy of the information contained in any sensory input. Although highly stylized, the graphic portrayal of a redundant versus differentiated flow of input information in Figure I.3 conveys the concept.

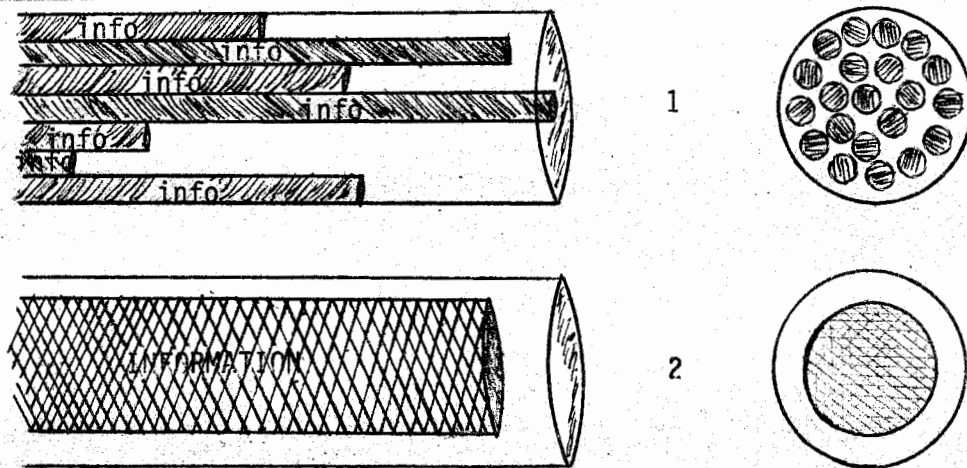


Figure I.3. Graphic representation of spatiotemporal redundancy of information in sensory input channels. (1) Differentiated information content of sensory input channel associated with posterior temporal cortex stimulation; (2) highly redundant information content of sensory input channel associated with frontal cortex stimulation. After Pribram, 1971.

Changes in spatial information organization (receptive field size) result in either one large bit of detailed information or in many smaller bits of less detailed information. Changes in temporal information organization (length of refractory period) with frontal stimulation results in very similar information transmission through all neurons in the sensory channel since the shorter refractory period

allows less variation in the timing of neuronal firing; i.e., two or more neurons are likely to fire simultaneously when there is less time available within which to vary. The longer refractory period associated with posterior inferior cortex stimulation tends to increase the variety of input information in a channel since each neuron's firing is separated by a relatively longer period of time during which variations in direction of attention may occur.

Frontal stimulation therefore yields greater redundancy in input channels: More neurons carry the same message. This tends to increase the detail of the input information but reduces the scope; the observer gains much information about a small aspect of the environment. Posterior inferior temporal stimulation yields less detailed information with a larger scope; the observer gains cursory information about many aspects of the environment.

The effects discussed above are not unlike the effects one observes when viewing a scene through a zoom lens at various settings and, indeed, such analogies have been drawn (Pribram, 1971; Mackworth, 1976). The observer may elect a broad general view of a given scene or s/he may zoom in on particular aspects of the scene. This perceptual ability exists in the human organism. When the external information is familiar to the observer, the general view is most useful since large amounts of information can be simultaneously processed without generating undue amounts of uncertainty about the input. If the external information is confusing or unfamiliar, the organism must zoom in on particular details to begin to develop an understanding of observed events. This detail accumulation process does, however, remove the details from their environmental context (due to the narrow scope) and

can lead to greater confusion unless the organism can maintain a contextual set internally. Such internal context is provided by frontal cortex mechanisms and is efficient only if adequate referents have been stored in the memory systems.

The mechanism works much like shortening a zoom lens--more comes into focused view and, in fact, direct evidence for such a zoom mechanism has been obtained in man. Thus, when I intend to focus on a large segment of a scene I shorten the zoom. Paradoxically, when I then selectively attend to one or another aspect of the scene, the meaning of the aspect becomes context consistent--i.e., free from variation in interpretation. When, on the other hand, I intend to focus on a limited segment of a scene to the exclusion of the rest, I lengthen the zoom. The segment in focus thus becomes severed from the context in which it originally occurs with the consequence that it can take on a variety of meanings depending on the bias or set of the viewer. (Pribram, 1971).

The amount of uncertainty, then, which is generated in the organism by external events of interest has a large effect on which style of information processing will be utilized. Greater uncertainty tends to elicit the high-detail, narrow-scope, frontally-mediated style while a low degree of uncertainty is more likely to evoke the low-detail, large scope, posterior-inferior-temporally-mediated style. Greater and greater degrees of uncertainty tend to narrow the scope of the individual to search for finer details which may provide some clue as to the nature of the observed event. At the same time, the individual becomes more and more dependent upon internal context for interpretation of the detailed input since the external context is increasingly limited by the narrowing of scope.

As uncertainty increases, the organism may either increase monitoring of external events (look for greater detail), or s/he may cease

to monitor externally and review the internal context being utilized to interpret sensory input. If no information is being derived from input, either the input is totally outside the realm of the organism's ability to understand or else the input is being interpreted within an inappropriate context. "The organism selects which aspects of the environment to attend--the internal plan, or the external stimulation. Thus it can selectively open itself up to the external environment or close itself down" (Gottlieb, 1978).

Our experiments showed further that stimulation of certain parts of the cortex of the temporal lobe (not the amygdala but the infero-temporal area) reduces redundancy, while stimulation of another part of the cortex (the frontal) enhances redundancy in the visual system. These opposing effects operate essentially either to "open" the organism to his environment, allowing the processing of a greater number of different signals, a greater amount of information to go on at any moment, or, conversely, to "close down" the input channels so as to restrict processing to a more limited amount of information.

The results of these experiments suggest that the organism has at least two ways in which he can internally adjust to, control his uncertainty, neither of which entail behavioral action. One way is to increase the rate with which he processes information, the other is to decrease that rate. One mechanism "opens" the organism to input, the other restricts input. Coping by way of internal control can thus be attempted in at least two ways: either through enhanced monitoring of the external environment or by minimizing the external and focusing on internal configurations (Pribram, 1971).

Pribram suggests that the decision to attempt to reduce uncertainty by external search is associated with motion or motivation. The individual must be motivated to put forth the energy required to maintain the search for information despite the inefficiency present in the sensory input channel. On the other hand, the decision to attempt to reduce uncertainty via internal search, or via reorganization of

perspectives, is associated with lack of motion and motivation, or e-motion. Such a perspective may provide insight into the style of information processing likely employed by the emotionally centered individual under pressure.

When the organism elects to search internally to reduce uncertainty, the characteristics of frontally- and posteriorly-mediated processing styles still operate. A general search of stored information in the memory systems ensues if posterior bias is chosen; a specific, highly-detailed search occurs with frontal bias.

If the sensory input cannot be effectively interpreted either through enhanced external or internal search, the organism may become overwhelmed. The nervous system may become temporarily swamped and defensive action will be taken to shut out further input. Such an action may lead to behavioral automatisms unrelated to the task (Pribram and McGuiness, 1975). These automatisms may appear as increased distractibility of the organism or seeming inability to maintain attention to the task. Increased repetitive motor activity may appear.

If the organism elects to continue its attempts at interpreting the external sensory input despite high degrees of uncertainty, effort must be expended to maintain an open sensory channel; i.e., the organism must put forth effort to oppose the defensive tendency to shut down the sensory input and retreat internally.

Effort can be defined as the measure of attention "paid" to increase or maintain the efficiency of a communication channel by reducing its equivocation [increasing its competence]. Such reduction can be accomplished by reducing noise or changing the structure of the redundancy of the communication (Pribram and McGuiness, 1975).

As the organism exerts more effort to maintain an open sensory channel, a greater focusing of attention is required. Such effortful maintenance of attention requires vigilance on the part of the organism and has hence been termed vigilant attention. The control of attention is primarily mediated through an interaction of frontal and prefrontal cortex with the subcortical amygdala, basal ganglia, and hippocampus (Pribram, 1971; Luria, 1973; Pribram and McGuiness, 1975; Hare, 1979). Since the mechanism of attentional control is frontally mediated, as the organism exerts more attentional effort the dominant processing organization, or perceptual style, becomes increasingly frontally-mediated. Thus, the attempt to maintain processing of external sensory input when faced with high levels of uncertainty results in the predominance of a processing organization (frontally-mediated) that is narrow in scope, detail-specific, and dependent upon internal contextual cues. This organization may be considered simply yet succinctly as a narrowing of available perspectives.

In analyzing input information, the brain acts as a constructive processor (Smith, 1971; Pribram and McGuiness, 1975). It attempts to interpret small bits of information in many different contexts, to look at a particular bit of input data from a number of perspectives in an attempt to reconstruct the nature of the external event. A more facile mind can reconstruct the external event from fewer pieces of input data through maintenance of a rapidly accessible, flexible pool of perspectives. Viewed in this fashion, the derivation of information from a given sensory input is seen to be equally dependent upon the perceptual set of the organism and upon the input information itself. Pribram

(1971) proposes that "the appropriate behavior at any moment depends not on the events occurring in the environment at that moment, but on the context established by the short-term memory of the behaving subject." The input acts to trigger information synthesis based upon the various perspectives which are brought to bear.

The narrowing of perspectives which accompanies effortful (vigilant) attention tends to frustrate the constructive nature of brain processing. The external input becomes constrained so that fewer contextual cues are available to assist in the assignment of meaning. Simultaneously, the availability of internal contextual cues to assist in interpretation is similarly constrained since frontally-mediated perceptual constiction affects both external and internal search processes.

The organism is left with very specific input information which is difficult to interpret since the context of the input is absent both externally and internally. The constructive processing style of the brain is thwarted when lack of context minimizes the number of available perspectives.

Specifically, we have suggested that when the frontal system becomes involved, the internal redundancy in the input channels is increased so that all of the information being simultaneously processed becomes chunked into one unit. By contrast when the posterior cortex becomes involved in the attentional process, internal redundancy in the input channels is decreased, separating the bits of information in each channel from each other. This is concomitant with enhancement of external redundancy which enhances the ability to make discriminations, that is, to categorize input.

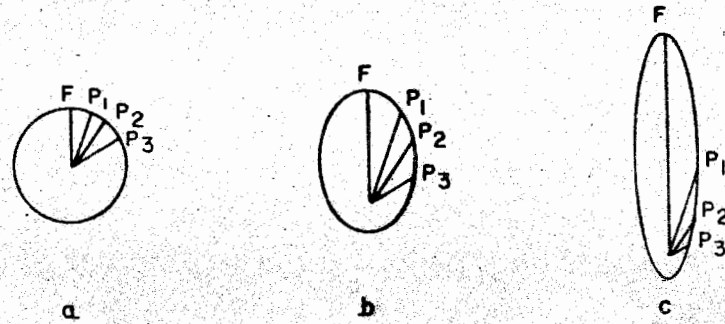
In short, we suggest that the controls on arousal and activation [preceding effortful attention] operate on the mechanisms of redundancy, on the constraints operating within and between channels rather than on the information being processed. These constraints may be conceived of as

operating on memory rather than on input information. Another way of stating this is to say that the controls operate on the context in which the informational content is processed. (Pribram and McGuiness, 1975).

The preceding discussion now allows us a general appreciation for the phenomenon of perceptual field constriction. Prior to the onset of any mental processing of information, some degree of uncertainty must be present in the organism. The uncertainty provides the stress required by all life processes to function. When the degree of uncertainty is within the organism's stress tolerance range (mentally delineated by experiences; physically delineated by state of health), a processing style may be utilized which requires little effort. Such a style is generally mediated by posterior cortical mechanisms and is associated with a broad useful field of view and broad internal perspectives.

As the degree of uncertainty increases, the organism becomes more dependent upon contextual information generated by frontal cortical structures. This dependence upon frontally generated context may, in cases of high uncertainty, bring about a constriction of perceptual fields, both internally and externally. Such constriction is manifest as the organism seeks more highly detailed input to reduce its uncertainty. Detail is gained at the expense of broadness of scope.

Senders (1976) has graphically portrayed this phenomenon in the visual system as illustrated in Figure I.4. His model of the visual input system as an antenna which may be directionally oriented to areas of high information content provides a basis for understanding the constriction of the useful field of view when large amounts of uncertainty are present.



F = FOVEAL POINT OF REGARD

P_{1,2,3} = PERIPHERAL AREAS 20°, 35°, & 60°
FROM POINT OF REGARD

Figure I.4. A "directional antenna" model--unit total capacity area is the same for all figures. (a) No focusing of attention--uniform receptive field, radius vectors all equal; (b) moderate foveal attention (or attentional demand) somewhat reduced peripheral sensitivity, with greater reduction for greater angles; (c) extreme foveal attention (or attentional demand) severely reduced peripheral sensitivity. From Senders, 1976.

If the visual input system is seen as a variable directional sensory antenna with a fixed amount of gain, the organism may utilize the antenna to tune in small areas with high resolution, or may detune slightly so as to receive much varied input with lesser resolution. When organismic uncertainty is high, the antenna is precisely aimed at a specific area in search of uncertainty-reducing information. Since the gain of the sensory antenna is fixed, a concentration of attentional energy at any one point tends to compromise the receptivity of any points peripheral to the point of centration. This occurrence in the visual system is externalized as a reduction of peripheral sensitivity in the field of view; a decrease, therefore, in the useful field of view. This effect is not unlike the zoom lens phenomenon previously discussed.

Experimental work by Mackworth and by Ikeda and Takeuchi support

Senders' model. Mackworth (1965) showed that increasing amounts of detail in tachistoscopic presentations was correlated with a reduction in the size of the useful field of view. More recent work (Mackworth, 1976) has shown that, during visual search tasks, greater concentration of detail in the search area elicits functional decreases in the useful field of view. The greater concentrations of detail increase the uncertainty of the organism in searching for a previously defined target. Greater levels of uncertainty necessitate greater involvement of frontal processes for context maintenance which concomitantly tends to "centralize" the organism and induce perceptual constriction.

The main finding of this study was that the size of the useful field of view is critically determined by the density of irrelevant items in the display. There is a marked difference between looking for a needle in a haystack and trying to find the same needle on a billiard table. In the first case the useful field of view is much smaller than in the second. In brief, we scrutinize densely crowded visual details very narrowly, but when there are only a few scattered details the gaze can process a much wider area (Mackworth, 1976).

Although Mackworth's experimental work has dealt primarily with the effects of external uncertainty upon perceptual constriction, he acknowledges the role of internal uncertainty in generating the same perceptual constriction effects. He points out the possible significance of the phenomenon in terms of organismic homeostasis:

In general, much new knowledge has been gained during the last few years about the way the brain initiates the physiological mechanisms of attention rather than wait for the environmental input to set these mechanisms in action. The interaction between the brain and the environment is two-way, and the set or motivation of the subject is as important as the physical input in determining the physiological responses. For instance, the pupil contracts reflexly when light falls on it, but it also changes accord-

ing to the cognitive state of the brain. Similarly, the useful field of view sharply constricts when there is high density of detail to be processed by the eye and brain. Both behavioral changes are attempts to prevent the processing mechanisms from being overloaded (Mackworth, 1976).

Reporting on findings closely associated with Mackworth's, Fisher (1976) suggests that "these data generally show that both comprehension [internal] and spatial factors [external] can reduce the functional field of view."

Experimental results of Ikeda and Takeuchi at the Tokyo Institute of Technology have paralleled Mackworth's findings and lend more support to the proposed phenomenon. They utilized an experimental paradigm in which foveal stimuli of varying degrees of complexity were presented simultaneously with peripheral stimuli at various points in the visual field. Subjects repeatedly showed lowered peripheral sensitivity associated with increasing complexity of the foveal stimulus.

Ikeda and Takeuchi found also that trained subjects showed a lesser shrinkage of useful field, "indicating that they learned to shift their attention toward the periphery without sacrificing detectability at the fovea." In addition, subjects showed an enhanced useful field of view around non-foveal areas toward which selective attention was directed. Both these effects have been earlier reported by Engel (1971).

On the basis of experimental findings it appears, then, that the phenomenon of perceptual constriction variably occurs relative to organismic uncertainty. If external input information is ambiguous, or if internal perceptual set is inadequate or inappropriate, high degrees of uncertainty regarding input information may be generated in the organism. To cope with this uncertainty, the organism resorts to a process-

ing mode which furnishes more highly detailed input which may be more easily interpreted. This processing mode is dependent upon frontal cortical organization which concomitantly produces a reduction in perceptual range both internally and externally. External manifestation of the reduction may be seen in a decreased size of the useful field of view. Internal manifestation of the reduction may be seen in a narrowing of perspectives available for synthesis with the external input when attempting to interpret environmental stimulation. Both effects tend to compromise one's ability during the reading task.

II. EYE MOVEMENTS IN READING

Optometrists interested in developmental aspects of vision, vision therapy, and/or vision as it relates to learning, generally suggest that the individual with poor oculomotor control is likely to experience difficulty with the reading task. Since reading is very integral to the educational process in civilized cultures, the individual experiencing reading difficulties may come to be labeled learning disabled, a general term of far-reaching implication. Such individuals may eventually be labeled dyslexic and placed in educational programs which circumvent visual learning; i.e., auditory and/or haptic learning modes are pursued.

The vision specialist attuned to these circumstances is frequently consulted in an effort to assist the individual to open the visual learning pathway and begin to utilize the evolved dominant sense (70 to 80% of the sensory afferent fibers to the brain are visual). Techniques to improve the individual's control and awareness of eye movements are utilized by virtually all therapists in an effort to accomplish this goal.

Development of a flexible oculomotor system responsible for eye movement control may enhance visual learning capabilities by smoothing and ordering the flow of visual information into the brain's processing system (Gaarder, 1970, 1975; Ludlam, 1976); by reducing the energy requirement of attention to eye movements, thus freeing more energy for attention to higher levels of information processing (Just and Carpen-

ter, 1980); by the means to be elaborated in the final section of this paper; or, and most likely, through a combination of these factors.

This section of this paper will review the relationship of oculomotor control and reading skill, and present a model for the control of eye movements that is consistent with current research. Most contemporary reading research has been done in the field of cognitive psychology without input from specialists in vision. This deficiency should be borne in mind when reviewing the reading literature. Most reading models attempting to provide insight into reading difficulties are biased toward a language basis for those difficulties; i.e., most models equate reading deficiencies with language deficiencies. These models are probably more relevant to the individual who is learning to read (approximately ages 5 to 10 years), rather than the more mature reader who is reading to learn. This paper is oriented more toward those falling into the latter group.

Oculomotor Function During Reading

Oculomotor activity during reading consists of processes occurring within the eye and processes occurring external to the eye. Though the bulk of information in this section deals with eye movement processes involved in moving the eyes across the printed page, one must bear in mind that these movement processes are directly dependent upon the quality of retinal imagery associated with accommodation and convergence processes. Some mention will be made here of the convergence-accommodation interaction in light of the discussion in the preceding section of this paper.

Interaction of Internal and External Oculomotor Functions.

In addition to eye movement guidance processes to be discussed in this section, the retinal periphery also performs another important oculomotor control function during reading. Contemporary research has implicated the retinal periphery in the control of the binocular convergence system. Skeffington (1950) and Manas (1958) have suggested various dependent interactions between convergence and accommodation. Flax (1980) and Sherman (1980) have stated that gross accommodative changes in the binocular individual are dependent upon changes in convergence. The accommodative control system per se is best suited to mediate only fine changes in focus.

The most common stimulus for vergence movement is a disparity of egocentric localization of the visual fields of the two eyes (Alpern, 1969). Such disparity results when a visual image falls on non-corresponding retinal points in the two eyes. Peripheral retina subserves the disparity-awareness mechanism and is generally responsible, therefore, for the maintenance of binocular fusion. This mechanism is exploited in binocular refraction techniques utilizing septums, vectographic systems, and convex lens "fogging" systems wherein central function of one eye is tested while fusion is maintained via peripheral fusional cues.

The retinal periphery may be seen, therefore, to be involved not only in the mediation of scanning eye movements and convergence during reading, but also in the indirect mediation of focusing changes in the binocular individual. A compromise in the integrity of the information from the peripheral retina may consequently result in undue stress upon the accommodative system. This stress results from the loss of (and

support of) gross accommodative control by the convergence system, thereby shifting total control of focusing to the accommodative system which is ill-suited to perform the task. The resulting excessive stress upon the accommodative system is especially manifest during reading.

The retinal periphery therefore has a bifunctional role in oculomotor control. It is indirectly responsible for control of focusing in the binocular individual via interactions of convergence and accommodation, and it is involved in the control of gross eye movements.

External Eye Movements During Reading.

Gross eye movements while reading across a line of English print consist of a series of short saccadic movements alternating with brief fixations. Although temporal characteristics of these movements are extremely varied relative to the individual and to the type of reading being performed, general values for saccades during reading fall between 20 and 50 msec; for fixations, between 150 and 500 msec (Bouma, 1973). The fixations and saccades may be occasionally interrupted by a regression movement consisting of a right-to-left saccadic movement performed to reread text passages. The regression may also contain vertical components if a previous line need be reread.

These eye movements are developmental in nature (Taylor, 1958; Fisher 1976) with the more skilled reader generally exhibiting slightly faster saccades, briefer fixations, and fewer regressions.

Smith (1971) believes that duration of fixations and number of regressions are more indicative of the reading task difficulty than of the reader's skill. He suggests that the most meaningful way to distinguish the eye movements of the poor reader from the skilled reader is to tabulate the number of fixations required to read a given

passage. The skilled reader should require fewer fixations since s/he is able to derive more information from each fixation. This is a key concept in the model of eye movement control to be developed in this section.

Why Saccadic-Fixation Movement?

Prior to a discussion of the control mechanisms involved in eye movements, a comment should be made regarding the significance of the saccadic fixation series of movements involved in obtaining visual information. Gaarder (1970, 1975) has developed a model of visual information processing that provides a rationale for visual input being rendered intermittent by saccadic fixations as opposed to continuous by smooth pursuit eye movements. Gaarder (1975) describes the brain as a processor of discontinuous sensory inputs. This discontinuity is related to fluctuations in the alpha brain rhythm and, in the visual system, is mediated by the discontinuous nature of input caused by saccadic movements.

Input from the visual system is suppressed (variably) during, slightly before, and slightly after saccades. This saccadic suppression results in information flow to higher processing centers occurring as an ON-OFF-ON-OFF phenomenon; information flow into the system is ON during the fixation and is OFF during the saccade.

Gaarder (1975) has shown that the processing system of the brain is more receptive to certain sensory inputs at certain times during the alpha rhythm cycle. A constant phasic relationship exists between each sensory system's point of optimally facilitated processing and the alpha cycle, regardless of variations in alpha frequency. Thus, for maximal efficiency, information from the visual system should be avail-

able for higher processing only at the point in the alpha cycle when the brain's processing apparatus is most receptive to visual information.

To ensure that visual information is present for processing at the proper moment, the onset of the voluntary saccade is also phase-locked to the alpha cycle, again independent of variations in alpha frequency. This does not imply that a voluntary saccade must occur with any periodic regularity, but that when a voluntary saccade does occur, its moment of onset will be phase-locked to the alpha cycle. The voluntary saccade therefore generates the discontinuity in input required by the brain's central processing mechanism for optimal efficiency.

The relationship between eye movement timing, alpha rhythm, and moments of facilitated cortical processing of visual input appear to be supported by the work of Wolf, Hauske, and Lupp (1978). These investigators have shown that there exists a phenomenon of momentary post-saccadic enhancement of contrast sensitivity. Such enhancement may logically serve the organism by allowing increased sensitivity in the input of visual information at the moment when greater sensitivity may be most useful to higher processing of visual input.

Gaarder also has explained that the saccade serves to "chunk" visual information from each fixation. This chunking has been referred to as digitalization (Ludlam, 1976); hence the eye movement becomes the "saccadic digitalizer". The discrete chunks of visual information are reconstructed for coding at higher processing levels. This portion of the system is thus dependent upon accurate, consistent eye movements so that no confusion occurs when information from successive fixations is

reconstructed for coding. See Figure II.1.

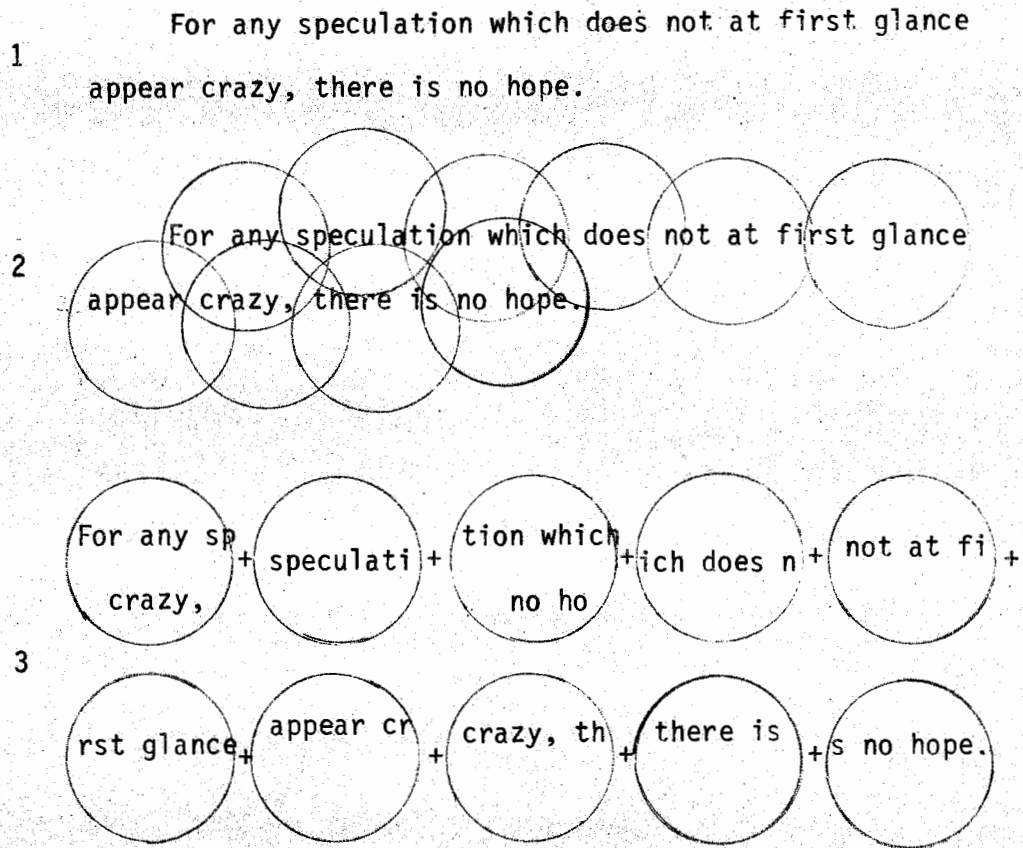


Figure II.1. Hypothetical digitalization of printed information via the saccadic digitalizer mechanism. (1) Printed passage to be read; (2) overlapping useful fields of view from ten successive fixations made while reading passage; (3) discrete "bits" of information passed to central processing mechanism for information extraction. After Gaarder, 1975.

This aspect of Gaarder's model has been supported by McConkie's (1976a) statement that "the assembling of information concerning phrases and larger linguistic structures must occur across fixations rather than directly perceiving such structures on each fixation. Rayner (1975) offers these comments:

The results of this study indicate that information is integrated over two separate fixations. Although it is

certainly true that when the eye moves and fixates a new location the new stimulus pattern overrides or masks the pattern produced by the prior fixation, it also appears that at a higher level in the processing system information from the two fixations is brought together into a single representation of the stimulus. ...at a higher level the information from the two fixations is integrated.

Further basis for the saccadic digitalizer aspect of vision may be found in a study (Kowler and Steinman, 1977) which showed that human performance at a visual categorization task improved when small saccades were made, despite the fact that the image of the target information fell totally within the foveal boundary. This finding suggests that the saccadic digitalization of visual information may be necessary for most efficient processing to occur.

Zenchenko and Vergiles (1972) have also noted the importance of eye movements in cognition. These investigators used stabilized retinal images and presented various visual search and visual problem-solving tasks to subjects. Stabilized images were kept from disappearing by varying color. Subjects performed more slowly, but correctly, on all tasks as long as eye movements were allowed. When subjects were not allowed to move their eyes while processing the stabilized display, performance dropped off significantly despite the fact that eye movement in either condition did not result in movement of the retinal image.

In a recent paper, Kowler and Sperling (1980) found that the saccade apparently does not serve the visual system through its production of abrupt onsets, a key point in Gaarder's model of discontinuous information processing. The experimental design of Kowler and Sperling, however, was such that saccadic onsets were simulated electronically by rapid shifts of the experimental display; no oculomotor activity was

required of the experimental subject. They conclude that "it is possible that there are beneficial effects of saccades, and that these effects emerge only when the oculomotor response occurs."

Control of Eye Movements During Reading

Several feasible models have been proposed to account for the control of eye movements during reading. These models have been extensively reviewed by Rayner and McConkie and by Haber, and will be summarized here.

Rayner and McConkie (1975) have divided the various models into five classes: minimal control, low-level control, high-level control, process-monitoring, and mixed models.

Minimal control models assume that saccade length and fixation duration are based upon some regular, internally-generated pattern. This model is unacceptable.

Low-level control models assume that eye guidance while reading is accomplished by monitoring upcoming text with mechanisms of peripheral vision. Fixation length and saccade length should then be predictable based upon certain text characteristics such as word length. This model appears partially accurate, but incomplete.

High-level control models assume that eye movements are related to some coding generated at higher processing levels. Such coding may be related to semantic or syntactic information derived from text which has been processed, or to hypotheses which the reader internally generates regarding upcoming textual information. Most high-level control models contain an element of low-level control; the ultimate eye movement results from a synthesis of the information provided by each system (high-level and low-level). The model to be discussed in this

paper is classed as a high-level control model.

Process-monitoring control models assume that control of eye movements is derived from monitor of some internal processing component. These models often contain a buffer memory component which theoretically acts to briefly hold information acquired during a fixation until it is needed for further processing. A process-monitoring system might monitor the inflow and outflow of information from such a buffer memory and pace eye movements accordingly. Bouma and deVoogd (1974) support such a model.

Mixed models of eye movement control entail any models which are derived from any combination of those previously mentioned. Many such models could be conceived but most models currently plausible are either high-level control models or process-monitoring models.

Haber (1976) describes random control models which are basically minimal control models; internal control model, basically high-level control models with no element of low-level control; and stimulus control models which "...include all the processes of the internal control model but go beyond it. Here the magnitude of each movement can also be determined by graphic, syntactic, or semantic features of the text being viewed in peripheral vision before they have been fully processed for meaning." (Haber, 1976). The stimulus control model therefore contains and expands upon Rayner and McConkie's high-level control model. The model to be described in this work is a stimulus control model.

To summarize, on the basis of the presented classes of models which are plausible, we must assume "that skilled readers do not simply move their eyes in a rhythmical pattern, but that where the eye is sent

and how long it remains in that location is controlled on a momentary basis, and reflects certain aspects of the processing occurring at the time." (McConkie, 1976a).

An Eye Movement Control Model

The stimulus control model of eye movement control during reading (Haber, 1976) yields a control system which is harmonious with the evolved neurophysiology of the eye. The model posits that central and peripheral information will be simultaneously sampled during reading. The human eye is equipped to attend to fine detail within approximately the central two degrees of the visual field (slightly more than eight letter spaces of the print you are reading, provided the page is 50 cm from your eye), and to discern detail of decreasing spatial frequencies as one moves peripherally from the fovea. The peripheral area is generally best suited for detecting the presence of peripheral information; it locates details and guides the fovea to those details for identification.

An eye movement control model which does not exploit both central and peripheral processing mechanisms is incomplete and probably without basis. If central processes alone are utilized during reading, one's reading rate decreases vastly and reading becomes a word-by-word process. If peripheral processes alone are used, there can be no cognitive feedback to modify reading rate relative to the reader's preset or to the difficulty of the text. A comprehensive model should then entail some process to effect eye movements based upon physical characteristics of the text, and some process to effect eye movements relative to textual information derived from cognitive processes. Such a model has

been proposed by Julian Hochberg and has received the support or verification of many investigators interested in these issues.

The model described by Hochberg (1970a, 1970b, 1976; Hochberg and Brooks, 1970) is a two-process model which utilizes text characteristics and information content of reading material to generate eye movement control. Hochberg proposes that the reader progresses through text with an hypothesis-testing orientation. The reader is considered to be continuously forming internal (subconscious) hypotheses about what will come next in the text based upon what has already been read. "I'm not talking about real or consciously reported hypotheses, but about constructs--the observer acts as though he had hypotheses." (Hochberg, 1970b). In this fashion, the reader may need sample the text only as frequently as is required to confirm or contradict the hypothesis presently held. Difficult text, therefore, may necessitate sampling every word whereas text with which the reader is very familiar may require much less frequent sampling.

The mechanisms which mediate where the text will be sampled to gain information for hypothesis testing are termed peripheral search guidance (PSG) and cognitive search guidance (CSG). These processes have been likened by Fisher (1976) to locating (PSG) and identification (CSG) processes, an interesting correlate to equivalent terminology of Skeffington (1950) and Manas (1958) for peripheral and central retinal function (control of convergence and accommodation, respectively).

The PSG process is considered to serve the CSG process by providing information regarding upcoming text such as word length, word shape, and first and last letters of upcoming words. The CSG mechanism integrates this information with higher-level text characteristics such

as syntax, semantics, idiom, and phraseology. From this integration a program is generated to move the eyes to the next likely text position where information may be found which is relevant to the constantly evolving hypotheses of what is to come (See Figure II.2). This process may occur over an approximate temporal range of 250 to 800 msec.

Peripheral search guidance was hypothesized to be a process that is activated during eye movements and tuned to pick up contours (physical cues and features) in the periphery. Information about important cues and features is sent to a higher order processing unit, cognitive search guidance, for integration and meaning extraction. As meaning increases, the peripheral search guidance process interrogates larger areas of the text (Fisher, 1976).

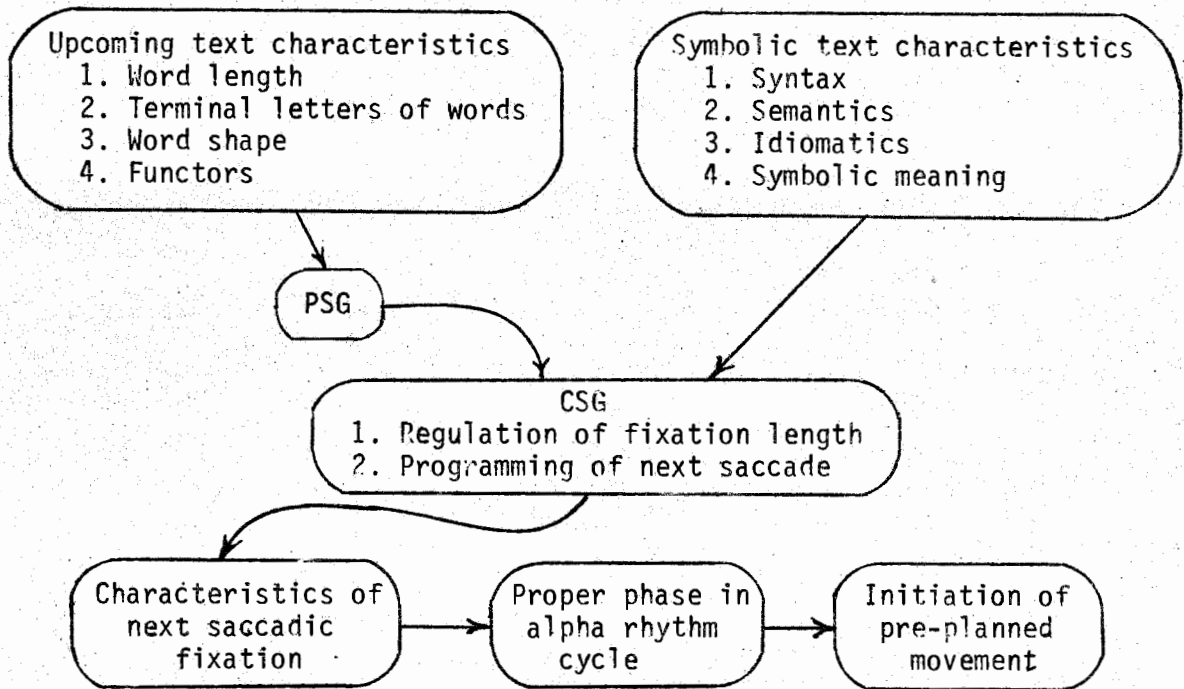


Figure II.2. Abbreviated eye movement control model: Linear representation.

Peripheral Search Guidance.

Before an eye guidance system which utilizes peripheral visual information may be postulated, it must be shown that the retinal periphery is

functionally capable of providing such eye guidance information. Much recent research exists to support and define these capabilities.

Data regarding peripheral visual acuity is somewhat useful in interpreting the functional significance of peripheral retina while reading, but is not specifically relevant to the mechanism of PSG. Since the functions of PSG are related to the determination of factors such as word length and shape, an investigation of peripheral abilities to discern these features is perhaps more useful than peripheral acuity measures based upon letter discrimination.

Investigations of the useful field of view as determined by tachistoscopic methods are equally invalid in providing information about PSG for two reasons. These methods involve letter or numeral discrimination just as peripheral visual acuity measures do. Also, and perhaps more significantly, these procedures involve static, single-flash measures with no context. The useful field of view during reading is dynamic and, in English, is greatly affected by language redundancy.

McConkie and Rayner have adopted an experimental paradigm utilizing a cathode ray tube (CRT) upon which may be projected different displays of textual material. Subjects' eye movements are monitored as they read the projected text which may be experimentally manipulated. Their work has yielded very interesting data regarding the characteristics of the useful field of view in humans during reading.

Their data have shown that specific letter discrimination and semantic information may be obtained from words that begin within 1-1/2 degrees of the fixation point; that word shape and characteristics such as first and last letters may be discriminated out to 3 to 4 degrees from fixation; and that characteristics such as word length (which

directly affects length of saccades) may be discriminated from four degrees to about 8 to 10 degrees (Rayner, 1975; McConkie and Rayner, 1975; McConkie, 1976a, 1976b). Bouma (1973) reported that initial and final letters of words could be discerned out to 5 to 6 degrees from the fixation point using tachistoscopic presentation techniques.

McConkie (1976a) suggests that visual information about a word greater than 1-1/2 degrees right of fixation may facilitate identification on the next fixation despite the fact that internal details are not perceived. This is in harmony with Hochberg's (1976) forward-hypothesizing theory and with Smith's (1971) proposal that the brain may "fill in the blanks" when incomplete information is provided. Bouma (1978) hypothesizes that the facilitation may occur due to peripheral information from the previous fixation being processed nearly simultaneously with central information from the current fixation, thus producing a reinforcement effect.

These data certainly confirm that the retinal periphery is capable of providing useful information to the PSG system. McConkie and Rayner's results may well be conservative estimates of peripheral sensitivity since their experimental design may have elicited some degree of perceptual constriction as discussed previously in this paper. The facts that the design required head immobilization by means of a bite bar, that the text was somewhat unnatural since it was a CRT display, and that subjects were paid on the basis of the number of comprehension questions answered correctly after the trials (thus creating a state of vigilance in subjects) all could contribute to some degree of perceptual constriction. Any design of this sort may also yield variable data merely due to the fact that subjects know that

their eye movements are being recorded. Any such data must be carefully interpreted (Hochberg, 1970b).

The retinal periphery has thus been shown to be functionally capable of serving a PSG role. The fact that the capability for this function is present does not necessarily demonstrate that the capability is utilized. Some evidence exists, however, to confirm this utilization.

Several investigators have shown that the useful field of view is substantially greater to the right of fixation than to the left (McConkie, 1978; McConkie and Rayner, 1976; Lefton and Fisher, 1976; Bouma, 1973), while others (Carmon and Nachshon, 1976; Fisher, 1976; Tinker, 1965) have shown what appears to be a developmental progression of this change to lateral field imbalance. McConkie and Rayner (1976) report a field imbalance of three degrees visual angle when ability to discern word shapes and terminal letters in words is the criteria. A developmental change would indicate the right field's development for some purpose, such as PSG.

Hochberg is cognizant of this asymmetrical development of the visual field and also the development of an overall larger useful field of view as reading experience increases. He notes that the inexperienced reader is much less dependent upon PSG than is the experienced reader. He has hypothesized that one's level of reading skill might be accurately measured by determining one's sensitivity to perturbations in peripheral text characteristics (Hochberg, 1970b). Fisher (1976) has likewise noted that the less experienced reader utilizes PSG much less than the more competent reader.

Researchers investigating relationships between reading characteristics and size of the perceptual span or useful field of view have consistently found that the visual field size cannot be artificially constricted beyond a critical size without causing a decrease in reading performance. This critical size varies somewhat between individuals but is invariably consistently larger than mean saccade size, thus suggesting some pre-processing of peripheral information occurs prior to fixation.

McConkie (1976a) reports changes in reading performance while artificially limiting the experimental display size to different extents. His data show that a limitation of the useful field of view to eight degrees begins to interfere with reading performance and that limiting the field to the right of fixation to three degrees essentially reduces the reader to word-by-word reading. With the latter limitation, readers demonstrated shorter saccades, more regressions, longer fixations, and slowed reading rate.

McConkie's subjects showed only a slight diminution in comprehension and he concludes that the decreased field size (perceptual span) is therefore not related to reading comprehension (McConkie, 1976b). His ascertainment of comprehension was accomplished via fill-in-the-blank type questions following the reading trials. This method of comprehension determination may yield data more representative of detail accumulation rather than information synthesis and, furthermore, may have been contaminated by the fact that subjects' remuneration for participation in the study was based upon the number of comprehension questions answered correctly.

Ikeda and Saida (1978) used an experimental paradigm similar to McConkie and Rayner's and found a substantially larger value for the minimum useful field of view required to avoid performance decrements. Their skilled readers read passages from a Japanese translation of Scientific American while artificial constraints were imposed on the available visual field. Reading performance began to drop off when the field was limited to 8 to 13 degrees visual angle. No determination of effects upon comprehension was made in the study.

A different perspective on the involvement of PSG in reading has been provided by studies which show that the functional visual field increases in individuals who participate successfully in programs to increase reading speed (Sailor and Ball, 1975). Results of this study do not indicate that peripheral vision training will increase reading speed, but do indicate that a concomitant to increases in reading speed is the development of a larger useful field of view.

On the basis of the foregoing discussion we may conclude that not only is the peripheral retina capable of providing information useful in guiding eye movements during reading, but, indeed, that this information is utilized by skilled readers extensively. Research has shown that reading may still ensue in the presence of a constricted useful field of view, but that the quality of such reading is diminished. Regarding the application of these conclusions to the hypothesis-testing model discussed, Hochberg (1976b) has stated that reading may certainly occur in the absence of peripheral cues, but that that sort of reading is not the most efficient process one may pursue; such style being likened to listening to a speaker who speaks very slowly in a phoneme-by-phoneme manner.

The visual system seems to operate in such a manner that the functional visual field, through which the information is taken into the visual system, proceeds over the text greatly overlapping. This large degree of redundancy in taking information into the visual system indicates some kind of pre-processing of information at the peripheral visual field, which eventually minimizes the pause duration at each fixation (Ikeda and Saida, 1978).

Cognitive Search Guidance.

A brief review of Hochberg's eye movement guidance model regarding cognitive control of eye movements is in order at this point. His model (Hochberg, 1970b; Hochberg and Brooks, 1970) is based upon the assumption that the reader is continually generating internal subconscious hypotheses about the upcoming textual information. These hypotheses serve as a response bias for the reader, so that s/he may sample the text only frequently enough to prove or disprove the internal hypotheses. Readers thus "guess" at what is next in store in their reading.

Determination of where to sample the text for hypothesis-testing is made on the basis of information from PSG and CSG, with PSG information forwarded to the CSG processor. Other information serving CSG is derived from contextual cues, syntactic cues, idiomatic cues, grammatical cues, and others which contribute to the information redundancy of written language. Based upon these cues, the reader subconsciously generates a hypothesis about where the next useful information lies in the text. Information regarding word length and shape (discussed previously) from PSG is integrated with the CSG cues and the next saccade is programmed. Execution of the saccade occurs, new information is assimilated, and the process repeats itself.

Until recently most experimental evidence in support of a CSG aspect of eye movement control has been generated from visual search tasks. Although these tasks (e.g., finding a given word embedded in a paragraph) have similarities to the reading task, they must properly be considered as an abstraction of reading.

Hochberg (1976a) has reported some of the visual search evidence for CSG. Fisher, in an unpublished doctoral dissertation (University of Rochester, New York, 1973) cited by Hochberg, showed that knowing the meaning of an embedded homonym in a paragraph reduced the visual search time required to find it. For example, a word such as subject was presented as the experimental word in the context of "the rights of the subject." When individuals were then instructed to find the word embedded in various paragraphs, search time was significantly less when the embedded word was in a phrase such as "a royal subject" versus when it was in a phrase such as "to subject oneself." This finding indicates that search strategies were affected by some cognitive process beyond the physical appearance of the word. Such strategies are those which also serve CSG.

Hochberg (1976a) used a similar technique with search tasks, but utilized variables of redundant (familiar) versus non-redundant (non-familiar) textual passages. Individuals were instructed to find a given experimental word in the text and report whether or not its spelling was correct. Subjects searching redundant text such as nursery rhymes found the experimental words more quickly and in fewer fixations than subjects searching nonsense text matched for word length or features. This finding implies that eye movement efficiency during reading is enhanced if the reader has a sense of where to search for useful

information. This concept is the essence of the CSG process.

Data in support of CSG derived from a task more closely approximating reading than visual search tasks has recently been reported. Malt and Seamon (1978) presented subjects with pages of text which had all interword spaces obliterated by fillers of various types. Subjects were allowed to practice reading the modified text for ten days during which temporal reading rates were measured and compared to the rate measured on the initial experimental trial. Subjects who read text with interword spaces filled with black forms showed progressive increases in reading rate over the experimental period, thus indicating an active cognitive factor that allowed a learned interpretation for the filler form. "This finding lends support to the proposal that eye guidance is partially cognitive; the reader is able to guide the eye to areas that are potentially informative on the basis of acquired knowledge and expectations." (Malt and Seamon, 1978).

These arguments lend a great deal of credence to Hochberg's eye movement control model. It must be borne in mind once again, however, that this model has evolved for the skilled reading process. The dependence upon CSG and PSG will vary with the reader's background, motivation, perceptual set, and emotional status, as well as with the complexity of the reading material. PSG is less important in the inexperienced reader, or when reading very complex material.

The skilled reader can take advantage of the predictability and redundancy of the language to sample the text selectively for only enough information to confirm or disconfirm hypotheses and decode the unpredicted, informative words. The reader does this by using CSG to predict in which words important information is likely to be found, and PSG to guide the eyes to the spot by means of the available peripheral cues. Reading efficiency is increased as eye fixations are guided to the specific regions which require more detailed analysis (Malt and Seamon, 1978).

III. MEMORY SYSTEMS

After uncompromised information from the visual input system has reached central processing levels during the reading task, the essence of meaning-gathering and comprehension derives from exchanges of energy (information) between the various memory systems of the human brain. Pribram (1971) and Hare (1979) have shown also that memory systems affect information input (at least in the visual system) at subcortical (thalamic) and possibly even retinal levels. The various memory systems which are compatible with contemporary and classical theory will be discussed in this section.

Memory theorists in the past have long debated whether information flow through memory ensues as a serial or parallel process. These arguments have led to the present-day perspective that modified serial processing occurs simultaneously in parallel circuits (Pribram, 1971; Luria, 1973; Just and Carpenter, 1980). This point will be further elaborated and is mentioned here so the reader may bear in mind that although the following discussion of memory systems is presented in step-wise serial fashion, actual functional processing within the systems adheres to no strict direction of flow.

Although different chemical storage processes are utilized in the different memory systems, there are apparently no discrete temporal distinctions between each; i.e., there is probably a continuum of temporal storage capacities ranging from less than one second to a lifetime. These temporal characteristics are probably more dependent

upon the extent of accessing cues associated with a given bit of information (idea or concept) rather than the occurrence of that bit in a discrete memory subsystem. With these stated qualifications, a brief discussion of the theoretical systems will follow.

Memory systems are generally discussed in terms of a sensory store (Smith, 1971) or icon, iconic memory, very short-term memory, sensory information store, or sensory buffer memory (Gould, 1976) lasting less than one second; a short-term working memory (STWM) with a duration ranging from a few seconds to about thirty minutes (Just and Carpenter, 1980; Alpern and Jackson, 1978); and a long-term memory (LTM) in which information assumes lifetime storage but is variably accessible depending upon retrieval strategies and accessing cues associated with each bit of information.

The STWM seems localized to the midbrain area while LTM stores are considered to lie in the cerebral cortex. Some evidence exists implicating the hippocampus as the agent which serves to transfer information from STWM to LTM (Halgren, 1978). This evidence also implies that the hippocampus is involved in active information processing in the STWM. In addition, Pribram and McGuinness (1975) have implicated the hippocampus in controlling or prolonging attention; i.e., in maintenance of vigilance to a task.

Functional Organization of Memory Systems

Information flow through human memory systems is fueled (as are all other life processes) by organismic stress. This stress should be differentiated from excessive stress or distress (Forrest, 1980), and may properly be seen as the motivational force behind the generation of any question by the individual which depends upon mental manipulations

for an answer. The stress may be generated by intellectual demands of the task (self-generated) or may be generated by social demands, emotional states, or psychological biases (e.g., pressure to perform from parents, peers, professional colleagues).

Given an appropriate stress level to bias the individual's mental processes, the brain will begin to interpret incoming information in a constructive fashion (Smith, 1971). Based upon previous experience, brain memory processes function to progressively interpret incoming data based upon minimal input. These tentative interpretations are continually revised in the STWM until a concept or idea is generated and is passed into LTM (Just and Carpenter, 1980). The brain is an economic system--it makes complex conclusions from minimal input; the accuracy and economy of this system is representative of an individual's intelligence.

External information in the realm of human sensory reception may or may not be immediately attended by the individual (Luria, 1973). Selective sensory attention has been shown by Pribram (1971) and Hare (1978) to occur via biasing of sensory receptors and/or thalamic nuclei through which all incoming sensory information must pass. Cortical and limbic processes set the bias; the individual selectively presets his sensory apparatus to be most receptive to input germane to the perspectives immediately maintained in consciousness. Kavner (1979) has referred to this function as perceptual filtering. The eye does not acquire and transmit information randomly, but instead functions according to very precise instructions received from the brain (Smith, 1971). This biasing function serves as the "first sort" of external information. We perceive what we are prepared to perceive.

Initial information coding schemes such as phonetics, syntax, word length, associated meanings, etcetera, are probably imposed upon the sensory store by the same biasing mechanisms discussed above. Just and Carpenter (1980) have shown with eye fixation data that words which stimulate or require more complex coding require more input time. McConkie (1976) concurs with this point. These coding mechanisms are utilized fully during processing occurring in STWM.

Different coding mechanisms are utilized relative to the individual's past experience and processing style. Fluent readers tend to code visual information analytically. Poorer readers prefer a holistic and context-bound coding strategy which may interfere with tasks such as reading which demand attention to internal features (Kershner, 1979).

Sperling (1970) and Hochberg (1970b) support a model of encoding reading which involves translating incoming information into its verbal equivalent. The information is coded into an articulatory plan which may then be manipulated by the processing apparatus of the brain. The plan, or program, if executed, would result in the translation of printed graphemes into spoken words. The programs generally are not executed but are coded into the speech-plan to facilitate higher processing. Ludlam (1976) has also endorsed such a system.

Sensory information in STWM is processed symbolically (in coded form) with coded information from LTM (Just and Carpenter, 1980). The information summoned from LTM is based upon prior knowledge related to the input subject matter (Hochberg, 1970a, 1970b, 1976; Hochberg and Brooks, 1970; Atkinson and Shiffrin, 1971). Actual ideas and concepts in the LTM store are probably not forwarded to STWM for processing. The ideas and concepts are more likely represented by symbols, codes, or

addresses (Sperling, 1970) which are compatible with the codes applied to incoming sensory information.

Just and Carpenter (1980) propose that information from LTM is stored in terms of structural knowledge (the idea or concept) and procedural knowledge (the program or programs which, when processed, will link the structural knowledge to other previously associated concepts). STWM has been modeled along similar lines by Estes (1980) who states that STWM in humans is oriented towards events and their attributes rather than towards the retention of items only as units of information.

Such an arrangement of information allows many concepts to be processed simultaneously in multiple parallel STWM's (Gould, 1976. The number of parallel concepts being processed is directly proportional to the number of access codes associated with any initial concept which is entered. One measure of intelligence may thus be the individual's capacity to encode many access codes for a given concept. Learning is the expansion, synthesis, and recombination of these access codes. It is not unreasonable to assume from the preceding discussion that the SWTM serves as a message center, and communication among memory systems is by means of the coded items in the STWM. This is distinct from one stage feeding its output directly to another stage (Just and Carpenter, 1980).

Daneman and Carpenter (1980) have shown recently that the capacity of the STWM (i.e., the number of parallel processes which may be simultaneously occurring) is strongly correlated with individual differences in reading comprehension performance, presumably because readers with greater capacity can integrate more elements of the text at a given time.

Just and Carpenter's model of bimodal storage (structural and procedural knowledge) is in harmony with Pribram's (1971) theory that LTM storage is accomplished through a holographic mechanism which allows simultaneous serial and parallel information accessing and processing. A complementary STWM theory has been expressed by van Heerden (1968). He proposes that fast search and synthesis functions of memory are accomplished by coding sensory input into two-dimensional holograms which, when synthesized with other 2-D holographic symbols in STWM, are transferred into three-dimensional holograms for LTM storage. The holographic model relative to brain and memory processes is much more tenable when viewed from the perspective of physicist David Bohm who asserts that all information in the universe is stored holographically and that the holographic processes of the human brain serve to translate the information into terms of human language (Bohm, 1977).

The hologram is a model for certain processes (Pribram) and the underlying nature of the universe (Bohm); not a literal, physical hologram (plate, laser beam, and optics) but rather an informational hologram, using mathematical principles.

There is a well-known observation that--in every era--the brain is compared to the most sophisticated technological system available: atelephone switchboard, then a computer now a hologram. Actually, the holographic theory suggests that some brain processes are linear like a computer, and others operate on more holographic simultaneous principles. We do not mean to imply that the brain is confined to the outer limits of contemporary technological imagination. (Ferguson, 1977).

Perhaps the most important concept to gain regarding the function of the human memory processes is their non-entropic nature when the organism is free from dis-ease. The nature of memory systems is to evolve to greater and greater degrees of organization so that less and

less sensory input information is required to generate increasingly complex conclusions.

Smith (1971) states that the skilled reader requires less input from the page against which to compare his hypotheses regarding the text content because his uncertainty is less than a less-skilled reader. According to Pribram (1971) and Gottlieb (1978), an individual's response to excessive degrees of uncertainty may result in a reduction of competence of sensory input channels. Reduced competence compromises the ease with which information may flow through sensory inputs thus placing the unskilled reader in a situation where he receives progressively less useful sensory information with which to understand an already muddled concept.

The presence of fluent and flexible memory systems is requisite to any sort of skilled reading. With adequate flexibility and stimulation, memory functions as a non-entropic, self-organizing entity; a dissipative structure (Prigogine, 1980). When the system is in a sufficiently non-equilibrium state (seeking synthesis), has many degrees of freedom (flexibility in STWM processes), and is open to the inflow of energy (information) through sensory channels, "the ensuing instabilities do not lead to random behavior... Instead they tend to drive the system to a new dynamic regime which corresponds to a new state of complexity." (Jantsch, 1976).

IV. ALPHA RHYTHM

The alpha rhythm refers to one of many ongoing, naturally-occurring brain wave rhythms which may be easily recorded by means of scalp electrodes and electroencephalographic techniques. One classical formal definition of alpha is

...the rhythm at 8-13 Hz occurring during wakefulness over the posterior regions of the head, generally with higher voltage over the occipital areas. Amplitude is variable but mostly below 50 microvolts in the adult. Best seen with eyes closed or under conditions of physical relaxation and relative mental inactivity. Blocked or attenuated by attention, especially visual and mental effort. (Chatran, Bergamini, Dondey, Klass, Lennox-Buchtal, and Peterson, 1974).

The alpha rhythm has received much attention over the past decade as researchers have attempted to ascertain the role of alpha in attention, learning, arousal, and general brain functioning. It has been popularly characterized as a desirable concomitant of various stages of relaxation.

Subjectively reported correlates of the alpha state include letting go of thoughts, floating, being relaxed yet alert, calmness, and often pleasure. Biofeedback subjects trained to suppress alpha reported states of vigilance, tension, agitation, attention to internal imagery, and anxiety. Most subjects in such studies prefer alpha enhancement procedures over alpha-suppression procedures. (Kamiya, 1969, 1970, 1974; Plotkin and Cohen, 1976). Plotkin (1980) has acknowledged the existence of an "alpha experience" usually reported as a "pleasant, relaxed and serene state characterized by a loss of body and time

awareness, an absence or diminution of thought, and a feeling of egolessness", although he does not agree that the subjective experience is associated with alpha brainwave activity. He attributes the subjective state to other variables such as sensory deprivation, sustained alertness, concentration/meditation, introspective sensitization, suggestion, and other factors which may be required by experimental alpha biofeedback methods.

The subjective correlates of the alpha-on state closely resemble those of Pribram's state of posterior organization while those of the alpha suppressed state are similar to those of Pribram's state of frontal organization. Pribram's concepts are discussed in more detail elsewhere in this paper. (Pribram, 1971; Pribram and McGuinness, 1975; Gottlieb, 1978).

Physiological Basis of the Alpha Rhythm

Most contemporary investigators agree that the rhythmic genesis of the cortical alpha rhythm occurs in the thalamus. (Hare, 1979). Many thalamic nuclei may participate in the initiation and generation of the rhythm, but the relay of the rhythm to the cortex is probably dependent upon the specific thalamic projection nuclei.

Hare suggests that the rhythmic activity is initiated by an excitatory afferent signal to one of the thalamic nuclei. By means of interneurons this signal generates an inhibitory signal to a large pool of neurons adjoining the excited axon. The inhibited pool of neurons will synchronously discharge approximately 100 msec later due to post-inhibitory facilitation. These activated neurons will then begin the spreading cycle of inhibition and facilitation at a frequency of about 10 Hz. The cycle will spread through non-inhibited thalamic nuclei and

will eventually be present at the cortical level by means of transfer through cortical afferents from specific thalamic nuclei.

Significance of Alpha

Theories regarding the significance of the alpha rhythm are plentiful. Popular perspectives include the idea that alpha may have no function and that it is merely a cycle related to the resting state of mental processing mechanisms, or the idea that the presence of alpha indicates the operation of an internal attentional scanning device in search of novel sensory input. Some evidence exists (Andersen and Andersson, 1968) in support of the theory that the alpha rhythm acts to convert afferent information from sensory receptors into the 10 Hz frequency which is most conducive in physiological activation of the cortex, hence facilitating cortical processing.

This latter concept is echoed by Gaarder:

There are also other ways in which the brain controls its own input, in other sensory modalities by using self-pacing mechanisms of intermittency. These mechanisms can be most vividly pictured by saying there are brief moments when the brain will take in a given stimulus sandwiched between other moments in which the brain's central processor is unreceptive to the stimulus, but when the stimulus may be stored to await another input moment. The cyclical alpha rhythm of the brain is closely related to these input pacing mechanisms.

The concept of the brain as a discontinuous information processor has to do with ideas that there are moments when it is less receptive and less capable of transmitting information (Gaarder, 1975).

No one theory has been shown through scientific inquiry to invalidate the others. A newer theory has been expressed by some investigators (Ferguson, 1977) who speculate that the alpha rhythm may be the timing device utilized in the generation of slow electrical waves over the cortex necessary for the maintenance of a holographic

system of information processing (Pribram, 1971).

Alpha has been considered to be inversely related to attentional states since it was first described by Berger in 1927. (Mulholland, 1969, 1974). This relationship is clarified by Mulholland (1974) who states that the diminution or absence of alpha associated with visual attention should be viewed as on a continuum; i.e., that different degrees of visual attention are associated with different degrees of alpha diminution. Visual attention appears correlated with relatively greater decreases in alpha relative to equivalent amounts of attention to other sensory systems. Attention to a visual input is therefore associated with lower alpha levels than attention to an auditory or other sensory input, all other variables held equivalent.

Mulholland (1974) further differentiates between intensive and selective attention, a dichotomization in harmony with Pribram's (1971; Pribram and McGuinness, 1975; Gottlieb, 1978) differentiation between categorization and reasoning tasks. Intensive attention and categorization tasks refer to directing attention to external stimuli while selective attention and reasoning tasks refer to guided internal awareness of ongoing processing or ongoing multi-sensory input programs. Reduction of alpha activity is more linked to direction of attention to external events. (Mulholland, 1974). Reduced alpha activity does, however, also accompany vigilant attention to internal problem solving or to internal imagery. Indeed, vigilant attention to internal imagery is one method most commonly utilized by biofeedback subjects attempting to reduce their cortical alpha activity. (Kamiya, 1969, 1970, 1974; Peper, 1971).

Gaarder (1975) supports the idea that vigilance is the key factor

to be associated with decreased alpha levels. He has found that the more intense and the more constantly vigilant one is, the less alpha one exhibits; the more relaxed and casual, the more alpha one will show. Vigilance is one correlate of a mental organization involving frontal processing discussed in Chapter I of this work.

Early research regarding the alpha rhythm attributed its generational mechanism to be associated in some manner with the oculomotor system. Present research indicates that reductions in alpha activity are associated with oculomotor activity and especially with activity requiring the accommodative triad of accommodation, convergence, and pupil constriction (Dewan, 1967; Mulholland, 1968; Peper, 1971; Plotkin, 1976). Kamiya and Hardt (1976) have argued that some investigators overestimate the importance and influence of oculomotor effects on alpha activity. They cite reports that normal alpha activity has been shown in individuals missing one or both eyes to support their position. This phenomenon may be attributable to the fact that the decrease in alpha activity is associated with the psychological intention to generate the oculomotor activity rather than the activity per se (Dewan, 1967; Ludlam, 1976).

Gaarder, in his book Eye Movements, Vision, and Behavior (1975), presents some provocative evidence that the time of onset of a saccadic eye movement may be phase-locked to the alpha rhythm. He shows that regardless of alpha frequency variation, the saccade, when it occurs, will always have its point of onset at the same phase in the alpha cycle. The eye movement need not occur at any regular interval, but when it does occur it will occur in constant phase relation to alpha. Gaarder fits this tenet into a larger model of visual information

processing based upon the discontinuous nature of cortical processing. He cites studies which show that the central processing mechanism of the brain is most receptive to sensory input when that input is presented at a specific point in the alpha cycle. He thus shows an intriguing cyclical relationship between saccadic fixations and facilitated sensory processing.

This phenomenon has been noted by McConkie (1976a) who has suggested that the durations of individual fixations and the lengths of individual saccades may be controlled by momentary mental states. He further states that these eye movement measures may be closely linked to aspects of mental processing during reading. This position is certainly harmonious with Gaarder's theory.

Gaarder's concepts are further discussed in this paper in the sections regarding eye movements and memory systems.

It has been repeatedly shown that individuals can be easily trained to control via biofeedback the amount of alpha activity which they produce (Kamiya, 1969, 1970, 1974; Kamiya and Hardt, 1976; Plotkin, 1980). Most subjects find the ability to reduce the amount of alpha present in their EEG easier than the ability to increase it, but changes in both directions may be accomplished without undue difficulty.

Some individuals have been trained to alter the frequency of their alpha activity as well as varying the amount of alpha present in the EEG. Kamiya (1970, 1974) finds that this induced change in frequency will effect a change in subjects' baseline alpha activity on post-biofeedback training trials. The change in baseline will be in the direction trained during the preceding session; e.g., if one has been working to lower one's alpha frequency during the training session,

post-session baseline alpha frequency is likely to be lower than the pre-session baseline alpha measure. A similar modification of alpha frequency has been noted in meditators when comparing baseline alpha before and after meditating (Gaarder, 1975). Other investigators have questioned the occurrence of the phenomenon in biofeedback subjects (Bridgwater, Sherry, and Marczynski, 1975).

This ability to modify the frequency of one's baseline alpha rhythm may have far-reaching implications in the realm of human consciousness. Stassen (1980) has found that an individual's EEG pattern is peculiar to the individual (something of a fingerprint of mental processes), an electrophysiological representation of the individual's style of interaction with her/his perceived reality; a correlate of one's state of consciousness. Gaarder and Kamiya have shown that baseline alpha rhythm activity, perhaps the key timing mechanism of electroencephalographic brain activity (Gaarder, 1975), can be modified through participation in biofeedback or meditation activities. This implies that the individual's state of consciousness may be affected (or effected) by these activities.

This short term alteration of consciousness may have effects upon the individual's overall state of consciousness and hence, her/his perceived style of information processing. Based upon research at Harvard, Davidson and his coworkers (1979) have suggested that a general transformation of consciousness takes place due to a cumulative effect of repeated entry into altered states such as those experienced by the biofeedback subjects and meditators mentioned above.

These researchers believe that the vehicle or technique for altering consciousness can be a critical determinant of the effects it

elicits (Schwartz, Davidson, and Goleman, 1978). Different meditation techniques and different biofeedback techniques stress different types of attentional skills which may be reflected in different types of neural patterning. Therefore, for example, repeated biofeedback sessions to diminish alpha activity may generalize to leave the subject more anxious, vigilant, tense, and agitated, while repeated sessions to enhance alpha activity may result in generalization of feelings of calmness, pleasure, and relaxation.

A peak in alpha activity and its subharmonics has been found to occur just prior to the experience of the "Aha!" phenomenon or the "felt shift" in one's perspectives (Don, 1977). Several hypotheses exist in explanation of this phenomenon, none with any scientific verification. Ferguson (1978) opines that the alpha peak may represent simultaneous harmony in the right and left hemispheres of the brain. The peak could also be indicative of the rhythmic activity underlying processing in parallel short-term working memories (discussed in this paper under Memory Systems) falling into a phase-locked cycle, thus enhancing normal alpha activity. One alternative explanation may be related to changes in cortical rhythmic activity that accompany the transition of information stored in a two-dimensional hologram (van Heerden, 1968) to storage in a three-dimensional hologram in long-term memory (see Memory Systems). Don simply states the phenomenon as being indicative of higher-order integration in the brain.

Inability to suppress the alpha rhythm has been implicated as an etiological agent in individuals with learning and reading difficulties (Ludlam, 1976, 1979; Fuller, 1978). Many dyslexics have been found to

have an excessive bias for right-brain processing (Kershner, 1979), often associated with excessive alpha activity. Ludlam (1976) has prepared an in-depth review of the literature with special emphasis on the relationship between alpha anomalies, oculomotor anomalies, and reading and learning difficulties. He has reported case studies relating ability to control oculomotor processes with ability to control alpha activity and with reading ability (Ludlam, 1979).

Ludlam (1979) has further shown that individuals unable to suppress alpha activity have gained that ability through participation in a program of optometric vision therapy stressing the development of fine oculomotor skills. These changes are accompanied by improvement in reading and learning performance. No cause-and-effect relationships are advanced.

Hyperactive and learning-disabled children have benefitted from EEG biofeedback to increase brain rhythm frequency. Lubar (1977) reports improvements of a full grade level in reading associated with three months of biofeedback therapy alone. No mention is made regarding presence or absence of oculomotor difficulties in the experimental group.

The function and characteristics of the alpha rhythm during the reading task remain somewhat mysterious. Ludlam (1979) has shown that improvements in reading performance may be associated with greater ability to suppress alpha activity. Kamiya (1980), however, has stated that the presence, frequency, and amplitude of alpha activity vary during reading, indicating that both alpha activity and absence of alpha activity may serve some function in the extraction and processing of written information. Kamiya¹ has stated furthermore that in his lab,

measurements of the amplitude of the alpha activity during reading often exceed amplitudes attained under any other circumstances by a given subject. Ludlam² disagrees with this point and believes that the alpha rhythm is continually suppressed during skilled reading requiring oculomotor activity and visual attention. Specific research in this area is lacking.

V. SYNTHESIS

Based upon the preceding discussions, let us attempt to chart the various psychophysiological correlates to the reading task, and determine the interactions of those correlates, especially when the reader begins to experience some difficulty in abstracting meaning from the written word.

As the skilled reader begins to read we must assume that a number of psychophysiological events have occurred. The reader has converged and accommodated the appropriate amounts to the reading material and frontal cortical processes have generated a tone or context within which the ensuing reading activity may be interpreted. Based upon the general nature of the reading material (derived from title, headings, reader experience, etc.), the reader develops some initial concept of what s/he is about to read. Based upon this initial concept, internal processes access potentially associated information from LTM and bring a coded representation of this information to STWM to assist in interpreting initial details from the written material to be read. This summoning of information from LTM to STWM may be associated with the presence of alpha activity if there is no conscious direction of what specific information is to be summoned into the STWM. An initial internal hypothesis regarding the nature of the text is formed and the reader begins to read across the page. As attention is directed toward the text, the alpha rhythm is suppressed and visual sensory information flows into the STWM where a TOTE process (Pribram, 1971) occurs.

The TOTE process is a mechanism by which the information content of incoming data is determined and integrated with existent information in the STWM. TOTE is Pribram's acronym for test--operate--test--exit. Sensory information is presented to the central processing mechanism where a test is performed to determine if the input is useful or potentially useful. If meaning cannot be immediately derived from input deemed useful, an operation is performed to assist in meaning derivation. The operation may consist of comparing the input to more stored data from LTM which may assist in interpretation, or the organism may search for more detailed external information to provide contextual clues for interpreting the sensory data. When a reasonable interpretation is generated, another test is performed to determine the congruity of the internal knowledge and the interpretation of the sensory input. If congruity is present, the newly synthesized information exits to the memory systems and the next bit of sensory information undergoes a TOTE process. If the internal knowledge and interpretation of the sensory input are incongruous, a new operation is performed followed by another test until a congruous interpretation is found and the information may be exited. The TOTE may thus ensue as a TOTOTOTOTE, until congruity is attained.

Alpha activity while the TOTE process is being performed may vary with alpha being suppressed during sensory input or active conscious processing. Alpha activity may increase when internal mechanisms scan LTM or while the operate phase is occurring, provided the chosen operation is an internal process rather than an external search (requiring accurate oculomotor control and visual attention) for more data. Such processing variations would account for the variations in alpha

during reading observed by Kamiya (1980).

A byproduct of the TOTE process is the generation of new hypotheses required by the CSG mechanism in programming eye movements. When the outcome of the operate process is an external search for more information, the CSG mechanism synthesizes information regarding the immediate state of the TOTE with information from PSG, and programs the next eye movement to the text area most likely to offer useful information. CSG is also utilized when a TOTE has been completed and a new bit of information is to enter the processor. The chain of events just outlined then repeats itself. This chain, consisting of the generation of the initial hypothesis, the first fixation, the TOTE, the generation of the second hypothesis, and the saccade to the next fixation point, occurs in a temporal range of approximately 200 to 500 msec.

The outlined cycle will continue until the reading is completed or until the level of uncertainty being experienced by the organism becomes too little or too great. See Figure V.1.

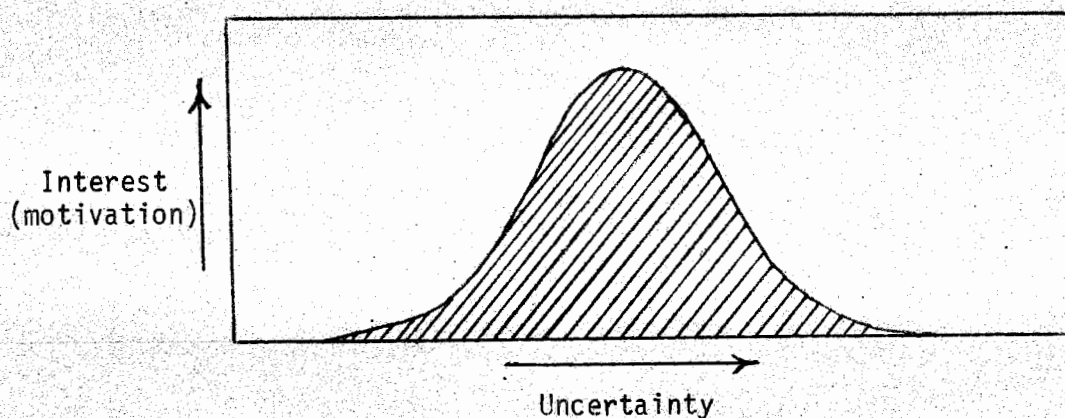


Figure V.1. Graphic portrayal of relationship between reader motivation and level of uncertainty associated with the reading task at hand.

As may be seen from Figure V.1, the motivation of the reader to continue reading varies with her/his degree of uncertainty regarding the textual information. Material which offers no challenge nor enjoyment is not likely to motivate the reader, nor is material which is beyond the reader's capabilities. The former generates no uncertainty while the latter generates levels of uncertainty which, if the reader chooses to expend effort and attempt information extraction from the material, may evoke a defensive reaction resulting in perceptual constriction. "This defensive reaction is characterized by an attempt to shut off further input and is reflected in an elevated heart rate and other changes indicative of a lack of readiness to respond meaningfully to the input" (Pribram and McGuiness, 1975).

As stated previously, Mackworth (1976) has found that the most frequent adjustment to visual overload, such as is produced when the reader can make no valid interpretation of the visual input, is the constriction of the useful field of view--the development of tunnel vision. This event is the externalization of an internal change in organization which includes a predominance of frontal cortical processes.

If the information is not familiar and is confusing, threatening, or overwhelming to the organism, a different brain process is engaged which includes arousal, frontal organization, and vigilance (i.e., the information will be processed until it is understood) (Gottlieb, 1978).

When organismic uncertainty exceeds the tolerance range of the reader and the defensive response resulting in perceptual constriction occurs, a number of systems serving the reading process become compromised. Perceptual constriction, as discussed, results in a narrowing of

the organism's perspectives and in a reduction in flexibility to move from one processing mode to another. Behaviors which are least integrated into the organism's behavioral repertoire will be the first to become inaccessible as stress-induced constriction occurs.

The reduction in useful field of view will compromise the PSG mechanism, while internal perceptual constriction tends to limit the perspectives which may be brought into STWM for utilization in interpreting sensory input. This limitation reduces the effectiveness of the CSG mechanism. Flexibility between the alpha-ON and alpha-OFF states will be compromised, further reducing the accessibility of information in LTM. These effects will result in even greater amounts of uncertainty associated with ensuing visual input. The reader will have greater difficulty determining if a new input bit is novel and requires processing since past experience in LTM, which determines novelty of a new experience, will be less accessible for comparison. The reader may then begin to process every word read to attempt to find meaning. The reader at this point is confused, has tunnel vision, is without efficient control mechanisms of her/his eye movements, and is unable to quickly shift to a new perspective. See Figure V.2.

Mackworth (1976) suggests that the efficient reader must utilize an efficient zoom lens mechanism, both internally and externally. The reader must be able to maintain flexibility between the focus of wide scope / low resolution and narrow scope / high resolution for efficient reading and information processing to occur. The reader must be able to zero in for detailed information when uncertainty is high without losing an awareness of the general theme of the reading material.

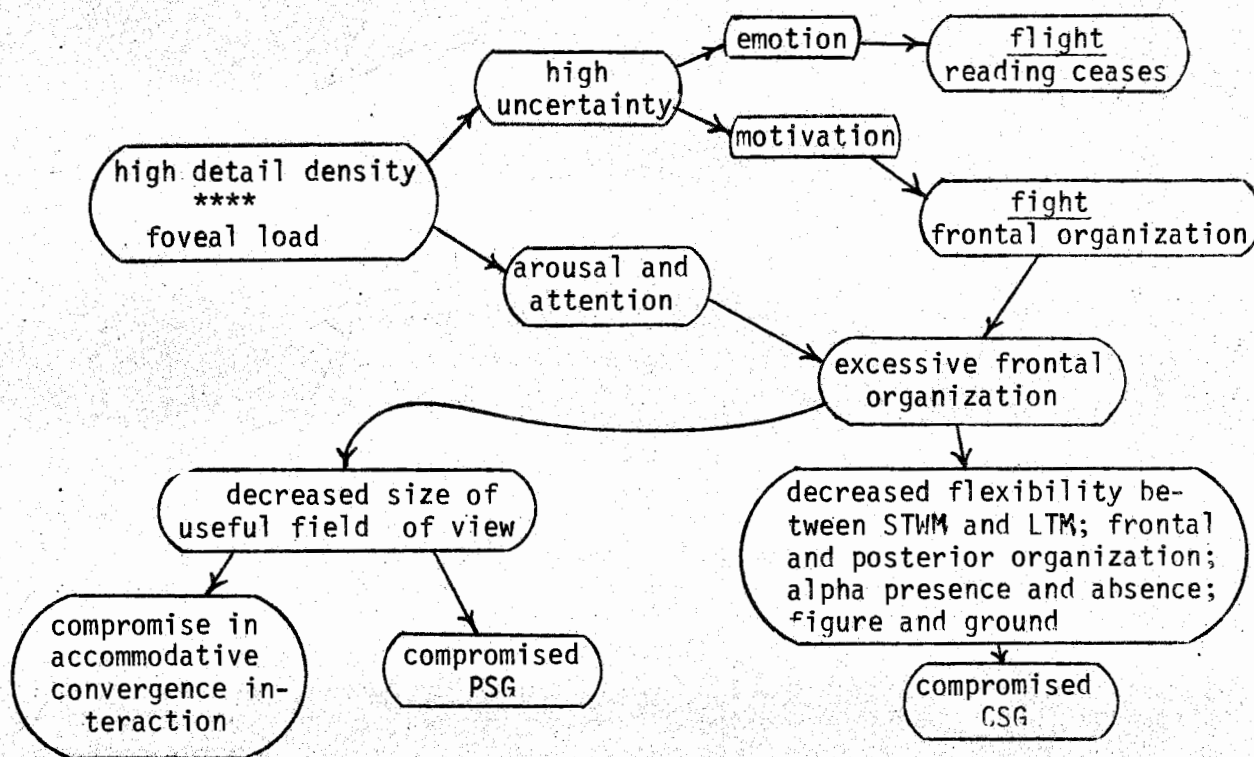


Figure V.2. A linear perspective on the loss of control of eye movements as per the described mechanism.

The inflexible reader stuck in the perceptually constricted mode requires more time to scan and is likely to gain a great deal of detailed information without a context in which to make sense of the details. The reader stuck in the wide scope / low detail mode may gain the general idea of reading, but will likely not understand specific details and how those details relate to the general theme. Efficient reading requires reader flexibility between each of these extremes. External manifestation of this flexibility may be seen in a constantly varying size of the useful field of view while reading. Internal manifestations are related to ongoing fluctuations between posterior and frontal organizational styles during reading, and possibly to

variations in presence and frequency of alpha rhythm activity during reading.

Work by Saida and Ikeda (1975) has shown a direct relationship between a constricted useful field of view and decreased reading performance. A primary factor in such decreased performance is a reduction in the rate at which reading material may be processed. Just and Carpenter (1980) have indicated that decreases in the rate of input of sensory information tends to compromise interactions between STWM and LTM. The slowing yields a decreased capacity for maintaining previous information and integrating new information.

The relationship between a constricted useful field of view and decreased reading performance was also implied in other research summarized earlier in this paper with regard to the control of eye movements. Lefton and Fisher's research also supports this conclusion.

Taken together these results suggest that a small functional visual field present in young readers probably inhibits efficient processing of successive cues and features. This shrunken visual field is probably the most limiting aspect of slow young reader performance. Any theoretical model of reading performance from the developmental aspect that precludes linguistic cues and features as being more important than basic visual cues and features seems to be inadequate (Lefton and Fisher, 1976).

We assume that the presence of a functionally constricted useful field of view is indicative of the presence of a general state of perceptual constriction; that the external manifestation is secondary to the internal condition.

These attributes of perceptual constriction may be especially devastating when viewed in light of Gaarder's (1975) model of visual information processing. The loss of accurate eye movement control

mechanisms may lead to jumbled input since successive bits of visual input may not be representative of successive bits of textual information. The coordination of the visual input data with the ongoing alpha rhythm may likely fall out of synchrony, thus allowing visual input data to be presented for cortical processing at a moment when processing of visual information is not optimal. In this situation, the reader's visual input system gathers nonsense data and presents it for processing at a non-facilitated moment. Greater amounts of attentional energy are required to gain less meaningful information.

In addition to the loss of efficiency in the PSG mechanism caused by the constriction of the useful field of view, the reader also loses control of the convergence system which is dependent upon peripheral cues for accurate posturing. The dependence of the accommodation system upon the convergence system in the mediation of gross changes in focus was previously discussed. As fine control of convergence is lost, the uncertainty in the accommodative system is increased resulting in greater stress upon the system. Greater amounts of attentional energy will be required to maintain accurate focus and the ability of the reader to attend and interpret visual input will be yet further compromised.

Each step described in the chain of events of visual information processing which requires more energy when perceptual constriction occurs draws the extra energy from the organism's "energy pool." Each withdrawal from the energy pool allows less available remaining energy to be utilized in the higher-order processes of reading. Since the processing system is relatively hierarchical in organization, higher-order processes such as comprehension and information synthesis may

become energy-starved and less than optimally operational when the discussed lower-order processes of reading are inefficiently consuming excessive amounts of energy.

Implications for Eye Movement Training in Cases of Reading Disability

The efficacy of eye-movement control training in cases of reading disability may be seen from at least three perspectives which have been broached in this work. Although most traditional eye movement training within optometry has been pursued ostensibly to enable the reader to move her/his eyes smoothly and accurately over the page, there are other possible higher-order benefits to be derived from such therapy.

The reader who has very poor control of eye movements may be disabled by a nonsense flow of information into the central processor according to the model proposed by Gaarder. According to this model, improvements in the control of eye movements allows the information contained in successive fixations to be accurately coded and reproduced in STWM, thus facilitating transfer of external printed information to its proper representative state in the brain's central processor. Although this model indicates that the benefits derived from eye movement therapy are seen externally in more accurate saccadic fixation movements, what are the internal concomitants of this therapy which may prove equally beneficial to the reader?

Luria (1973) has stated that "maintenance of the optimal cortical tone is absolutely essential for the basic condition of all form of conscious activity, namely the formation of plans and intentions that are stable enough to become dominant and to withstand any distracting or irrelevant stimulus."

As discussed, the generation of cortical tone (context) is accomplished in frontal and prefrontal cortex. Frontal cortex also contains the frontal eye fields wherein saccadic eye movements during reading originate. Command signals for eye movements generated in this brain area tend to override signals from other areas mediating eye movements (Burde, 1975).

Due to these two factors, it is not unlikely that therapeutics which tend to improve the quality of the saccadic fixation movement in reading may also result in a general improvement in the functional organization of frontal cortical processes. Eye movement therapy may yield this effect since (1) frontal eye fields are located in frontal cortex; improvement in the functional organization of the frontal eye fields may generalize to enhance organization of all frontal cortical functions; and (2) the improvement of eye movement control implies an underlying improvement in the functional tone generated by frontal cortex since eye movement control as a phenomenon is, itself, "a conscious activity" dependent upon "the formation of plans and intentions that are stable enough to become dominant and to withstand any distracting or irrelevant stimulus."

Pribram's theories concerning the holographic storage of information in the memory systems of the human brain (briefly discussed under Memory Systems) provides the basis for another potential beneficial factor in eye movement therapy. He believes that information storage in the brain is most economically accomplished by analyzing incoming information in terms of its spatial or temporal frequencies. Interactions between these various frequencies result in interference patterns which may be stored holographically (Pribram, 1971). Increases in

knowledge may be considered to be refinements of, or increases in complexity of, stored holograms.

Pribram cites evidence that any rhythmic motor movement can be represented in mathematical terms that may be characterized as a temporal hologram. This being the case, he has posited that the function of the brain's motor cortex is to act as a translator of stored holographic information into motor actions. The motor cortex analyzes memory holograms and derives and programs the motor actions representative of the stored information. Motor movements thus become an externalized representation of holographically stored frequency interactions.

If Pribram is correct, and his ideas in this realm as yet have not been seriously challenged, it may be possible to enhance the organization of stored information by enhancing the motor translation of that information. Such an effect might be obtained due to the fact that every motor action, at some level, must be planned and orchestrated by cortical processes. The planning and orchestration of the movement must itself ensue as a holographic phenomenon which could conceivably interact to increase the organization of the original holographic representation of the motor action.

In this light, the training of precise eye movement control may be seen as one means of assisting the individual to organize and elaborate her/his thinking processes. Such training may therefore advance the individual's personal insight and potentially yield an expansion of intelligence associated with increased facility of thought.

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Reference Notes

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