CHAPTER 2

THE NEUROLOGICAL BASIS OF SELF-REGULATION

1. INTRODUCTION

Chapter 1 argued that learning and development are constructive processes involving complex interactions within the maturing organism, its behaviors, and the environment. Piaget's theory of self-regulation explains much of what goes on during knowledge construction. However, as pointed out, Piaget's theory is based largely on evolutionary and developmental analogies, rather than on neural anatomy and physiology. Thus, the goal of the present chapter is to provide a more solid theoretical footing by exploring brain structure and function and their relationship to self-regulation. A considerable amount of progress has been made during the past 30 or so years in the related fields of neural physiology and neural modeling that allows us to begin to connect psychological phenomena with its neurological substrate. We begin with a discussion of how the brain processes visual input.

2. HOW DOES THE BRAIN PROCESS VISUAL INPUT?

How the brain spontaneously processes visual input is the most thoroughly researched and understood area of brain research. In general, that research aims to develop and test neural network models that have become known as parallel distributed processing or connectionist models. As reviewed by Kosslyn & Koenig (1995), the ability to visually recognize objects requires participation of the six major brain areas shown in Figure 1.

How do these six areas function to identify objects? First, sensory input from the eyes produces a pattern of electrical activity in an area referred to as the visual buffer, located in the occipital lobe at the back of the brain. This pattern of electrical activity produces a spatially organized image within the visual buffer (e.g., Daniel & Whitteridge, 1961; Tootell et al., 1982). Next, a smaller region within the occipital lobe, called the attention window, performs detailed processing (Possner, 1988; Treisman & Gelade, 1980; Treisman & Gormican, 1988). The activity pattern in the attention window is then simultaneously sent along two pathways on each side of the brain, one that runs down to the lower temporal lobe, and one that runs up to the parietal lobe. The lower temporal lobe, or ventral subsystem, analyses object properties, such as shape, color and texture, while the upper parietal lobe, or dorsal subsystem, analyses spatial properties, such as size and location (e.g., Desimone & Ungerleider, 1989; Farah, 1990; Haxby et al., 1991; Maunsell & Newsome, 1987; Ungerleider & Mishkin, 1982). Patterns of activity within the lower temporal lobe are matched to patterns stored in visual memory (e.g., Desimone et al., 1984; Desimone & Ungerleider, 1989; Miyashita & Chang, 1988). If a good match is found, the object is recognized. Otherwise, it is not. The dorsal subsystem of the parietal lobes encodes input used to guide movements such as those of the eyes or limbs. The neurons in that region fire just before movement, or register the consequences of movements (e.g., Andersen, 1987).

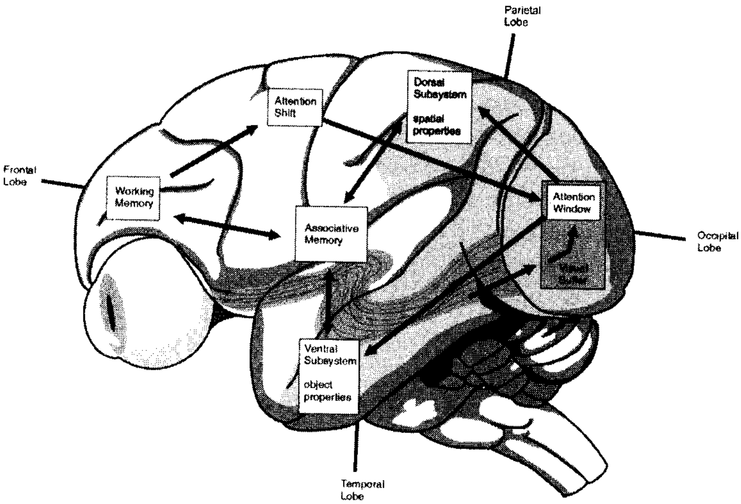

Figure 1. Brain areas involved in visual object recognition. Kosslyn & Koenig's model of the visual system consists of six major subsystems. The order in which information passes from one subsystem to the next is shown. The subsystems generate and test hypotheses about what is seen in the visual field.

Outputs from the ventral and dorsal subsystems come together in what Kosslyn and Koenig call associative memory. Associative memory is located primarily in the hippocampus, the limbic thalamus and the basal forebrain (Miskin, 1978; Miskin & Appenzeller, 1987). The ventral and dorsal subsystem outputs are matched to patterns stored in associative memory. If a good match between output from visual memory and the pattern in associative memory is obtained, then the observer knows the object's name, categories to which it belongs, sounds it makes and so on. But if a good match is not obtained, the object remains unrecognized and additional sensory input must be obtained.

Importantly, the search for additional sensory input is far from random. Rather, stored patterns are used to make a second hypothesis about what is being observed, and this hypothesis leads to new observations and to further encoding. In the words of

Kosslyn and Koenig, when additional input is sought, "One actively seeks new information that will bear on the hypothesis... The first step in this process is to look up relevant information in associative memory" (p. 57). Information search involves activity in the prefrontal lobes in an area referred to as working memory. Activating working memory causes an attention shift of the eyes to a location where an informative component *should be* located. Once attention is shifted, the new visual input is processed in turn. The new input is then matched to shape and spatial patterns stored in the ventral and dorsal subsystems and kept active in working memory. Again in Kosslyn & Koenig's words, "The matching shape and spatial properties may in fact correspond to the hypothesized part. If so, enough information may have accumulated in associative memory to identify the object. If not, this cycle is repeated until enough information has been gathered to identify the object or to reject the first hypothesis, formulate a new one, and test it" (p. 58).

For example, suppose Joe, who is extremely myopic, is rooting around the bathroom and spots one end of an object that appears to be a shampoo tube. In other words, the nature of the object and its location prompt the spontaneous generation of a shampoo-tube hypothesis. Based on this initial hypothesis, as well as knowledge of shampoo tubes stored in associative memory, when Joe looks at the other end of the object, he expects to find a cap. Thus he shifts his gaze to the other end. And upon seeing the expected cap, he concludes that the object is in fact a shampoo tube. Or suppose you observe what your brain tells you is a puddle of water in the road ahead. Thanks to connections in associative memory, you know that water is wet. Thus, when you continue driving, you expect that your tires will splash through the puddle and get wet. But upon reaching the puddle, it disappears and your tires stay dry. Therefore, your brain rejects the puddle hypothesis and generates another one, perhaps a mirage hypothesis. The pattern of information processing involved in these examples can be summarized as follows:

If... the object is a shampoo tube, (shampoo-tube hypothesis)
and... Joe looks at the other end of the object, (imagined test)
then... he should find a cap. (predicted result)
And... upon looking at the other end (actual test), he does find a cap. (observed result)
Therefore... the hypothesis is supported; the object is most likely a shampoo-tube. (conclusion)

And for the second example:

If... the object is a puddle of water, (puddle hypothesis)
and... you continue driving toward it, (imagined test)
then... your tires should splash through the puddle and they should get wet. (predicted result)
But... upon reaching the puddle (actual test), it disappears and your tires do not get wet. (observed result)

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