MEMORY and the BRAIN

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PREFACE

In this book I attempt to do two things. First, I try to identify the psychological operations we must perform to perceive something, recall or recognize it, grasp its meaning and respond to it. Second, I try to trace and identify the brain structures and pathways that make such psychological operations possible.

Memory is not an isolated process. It depends on perception, is influenced by emotion and imagination and embedded in the whole sequence from perception to action. Without memory, there can be no perception as we experience it, no learning, no motivated action. We cannot discover how memory is registered and recalled unless we know where it occurs in this sequence. To discover where memory fits in, we must analyze the total psychological sequence and identify the individual links. What I try to do in this book is to outline the brain structures and pathways that mediate each link in the chain and sketch their operations during psychological activities. That is the sum and substance of my theory of brain function. I hope to show that it is supported by a great deal of experimental and clinical evidence.

This theory was first published in my book "Emotion and Personality" (1960). It had been formulated on the basis of neuropsychological research published before 1958. During the first few years, all my attempts to trace a connected brain circuit that would mediate psychological activities from perception to action proved unsuccessful. Every new research report disproved one or the other hypothesis. But once I had worked out the present theory, everything fell into place and every new research report supported it. The functions I ascribe to various brain structures (e.g., association cor-

tex, limbic cortex, amygdala) are the only ones that will fit. Mine is a closely knit theory. If any one of the main links were changed, it would no longer fit the evidence.

The research germane to my theory spans a period of over forty years. I have included older as well as more recent findings because it is important to show that through the years, research results have supported all the links in my theory. In the late Sixties, when I was Director of the experimental laboratory at Loyola University of Chicago, we explored some of the crucial structures in my theory (anterior insula, anterior thalamic nuclei, cingulum). Reports of these investigations are mentioned throughout the book. In the last twenty years, research in the brain sciences has exploded. Obviously, I can refer only to some examples, but I have tried to include research in fields that have begun to flourish only comparatively recently (split-brain, neurotransmitters, etc.). Since this book is not intended as a historical introduction to neuropsychology, nor as a review of current research in the field, I have made no effort to be strictly up-to-date. A theory does not depend on the latest research. If it is adequate and has the support of years of research by widely scattered experimenters, it will not be replaced in a year or so.

The theory is complicated, but so is the brain. Difficult as it is, the attempt of finding definite pathways to relay neural excitation from one structure to the next, strictly correlated with the sequence of psychological functions, can provide a check and perhaps a corrective for too exuberant psychological theorizing. It is all too easy to offer any number of hypotheses for the way memory functions if we do not have to identify the pathways in the brain that might mediate these functions. Computer models of memory processing, as Tulving (1979) remarks, "may provide a sense of accomplishment to their creators" but such "correspondence models do not bring us any understanding of memory or its phenomena."

It is my conviction that the best guide to a theory of brain function is subjective experience. The only way we have been able to locate sensory and motor areas in the brain is to depend on the reports of patients after brain damage or brain stimulation. Since subjective experience must be our guide, I propose to use subjective terms. Such a description of subjective experience is not "introspection," either in the sense of Titchener or of Freud. Titchener focused on subjective feelings and sensations and would allow no other experiences; and Freud centered on personal experiences of traumatic situations. Both types of introspection could be (and were) contaminated by theoretical bias and faulty recollection.

The description of subjective experience I propose to use is often called a phenomenological analysis. We focus on a given activity and try to discover what must happen before this result is achieved (e.g., a learned discrimination, a habit, a skill). The subjective experience of one observer is used as a

clue, to be checked by the experience of every other observer using the same kind of analysis. Sensory experience is rightly considered a hallucination unless other observers confirm it; and a phenomenological analysis is unacceptable unless other observers agree.

Experiential terms help to fit each activity into the sequence from perception to action. But they have other advantages as well. Unlike objective terms, they are understood immediately because they are part of our linguistic heritage and do not have to be specially defined. A theory couched in objective terms forces the reader to learn new terms and new distinctions. Such terms not only burden the reader but very quickly go out of fashion. I try to use common English terms as far as possible to enable the reader to follow the argument. Of course, the technical terms employed in neurophysiology are necessary in any discussion of brain structures and pathways. To call the hippocampus "seahorse" or the thalamus "chamber" would not profit the reader. But I hope to avoid scientific jargon even in discussing technical matters and do my best to be intelligible to anyone who has a basic knowledge of the brain.

It is very easy to become so enamored of the terms used in one's own field that clarity suffers. As one example among many, consider Bertrand Russell's criticism of Watson's theory of language as a verbal habit, and the paraphrase couched in present-day objective terms. Says Russell:

> . . . when we recount a past incident in words we never used before . . . it is not the actual words that we repeat but only their meaning . . . thus my recollection is certainly not a definite verbal habit. (1927, p. 73–75.)

Anderson and Bower (1974) comment that

> in current terms, Russell was arguing that habits defined over surface strings of verbal units . . . will not suffice to account for paraphrastic descriptions of witnessed events. (p. 35.)

Only psychologists working in the field of memory would understand Anderson and Bower's translation at first glance. Other psychologists, let alone professionals in other fields and the lay reader, would have serious difficulties in grasping the paraphrase, but none in understanding Russell's point.

In the first, psychological, part of this book, the reader will miss many topics usually treated in a book on memory. But my aim is simply to discuss the psychological aspects of memory that can throw light on the brain structures and pathways that mediate memory registration and retrieval. I do not describe how we encode what we perceive, nor am I concerned with different strategies of encoding or remembering, or how to prevent forgetting. I try to answer the following questions:

Chapter 1. What is the role of perception in memory?
2. Is attention necessary for memory?
3. Is reinforcement or reward involved in memory?
4. Is memory unitary or modality-specific?
5. Is memory processed in definite steps or stages?
6. Are memories replayed or reconstructed?
7. What is the difference between recall and recognition?
8. Possible models of memory
9. What would be an adequate theory of memory?

In the second, neurophysiological part of this book, I want to show that each of the psychological activities discussed in the first part can be assigned to areas and pathways in the brain that mediate them (chapter 10). Many of these have been explored for their association with memory for a good many years, but have never been connected into continuous circuits activated in sequence. I attempt such connections in the later chapters, which form an extended statement of my theory of brain function.

In chapters 11–16, I review the evidence that seems to support my view of the cortical areas in which impressions are registered, and of the circuits that reactivate such registered memories. Chapter 17 deals with the diffuse thalamic system in connection with attention and the appraisal system, while chapter 18 discusses damage to the appraisal system and the affective memory circuit. Chapter 19 reviews clinical and experimental reports on split-brain patients and animals, which have given us much-needed information on the way memory functions. The extensive literature on hippocampus and amygdala tends to support my suggestion that the hippocampus is the main relay station in the action and memory circuits (chapters 20–22), and the amygdala, the relay station in the imagination circuit (chapter 23). These circuits depend on different neurotransmitter systems, which also are involved in brain self-stimulation and psychiatric illness (chapters 24, 25). Finally, chapters 26–28 describe the descending and ascending links of the action circuit that connects the sensory areas with the motor cortex, and mediates the initiation and execution of action; and of the associated motor memory circuit.

CONTENTS

PSYCHOLOGICAL ASPECTS

1 Perception

Only recently have psychologists begun again to speak of direct perception as the basis of knowledge and a "valid and reliable source of information" (Turvey & Shaw, 1979). Unless we trust our perception, we cannot come to veridical conclusions about the world. As Turvey and Shaw point out, if we do not perceive what is really out there, all knowledge, necessarily based on perception, is suspect and no amount of reasoning or inference can make it valid. If perception is not veridical, it is inconceivable that animals could have successfully coped with their environment and evolved in it. While vision alone may deceive us, neither human beings nor animals depend on the information derived from a single sense.

PERCEPTUAL INTEGRATION

It is generally agreed that sensory experience depends on selective attention. The very word "stimulus" indicates that not everything in the environment will prompt a reaction. In any psychological experiment, conditions are so arranged that the subject will respond to the stimulus selected by the experimenter. In animal experiments, the animal usually has to be "shaped" before it will attend to the selected stimulus and give the desired response. To select and attend to one thing, it must be perceptible to our sense organs. It also must be sufficiently defined to stand out from its background.

Whatever the type of energy that impinges on the organism, whether electromagnetic, mechanical, or chemical, the sensory experience depends on the specific receptor organs stimulated. A single object may be experienced via different

senses. We see a man playing the violin, hear the sound, can touch the violin and feel its vibrations. We know without any process of reasoning that the sound comes from the man playing the violin.

Individual senses cannot convey such integrated experience. All the sense of sight can do is mediate visual experience; the sense of hearing, auditory experience. Yet we see *things,* not patches of color, hear *melodies,* not single tones following one another. We touch an object and form a notion of its shape, rather than having discrete touch sensations. Sensory experience is integrated before we become aware of it. Such an integration of experience must be some kind of sensory function because it is unperceived, preattentive, as direct as all sensory experience.

A phrase coined by William James has it that the infant experiences the world as a "buzzing, blooming confusion." If James meant, as some of his successors did, that the infant's world has no articulation, that objects must be established by moving toward them and manipulating them (Schilder, 1950), it is curious that he never explained how the child would ever manage to find the objects toward which to move. A visual field without any articulation, without up or down or side-by-side would make it impossible to single out anything for attention or manipulation. More than that, there is no reason in the world why the sense of touch, in manipulating something, should convey the notion of an object separated from other objects if the sense of vision cannot do so.

Much more likely, James meant that the infant's world has as yet no meaning, that the infant sees things but does not know what they will do to him or how he can cope with them. For such knowledge, he has to touch and manipulate them and find out how they will affect him. The memory of such experiences will then gradually make the world meaningful to him.

The integration and articulation of the environment into separate objects must necessarily occur before we experience anything. It must be a sensory function, completing the experience of seeing, hearing, touching; we could call it the function of an integrative sense, mediated, like sensory experience, by the cerebral cortex. In recent years, some "preattentive" perceptual integration has been postulated by theorists. So Johansson (1979) pointed out that seeing movement when a spot of light is directed successively at neighboring positions, presupposes an integration that is an immediate sense experience without any cognitive inference. And Allport (1979) assumes a preattentive visual integration. In the nature of the case, the existence of such an integrative sensory function must be inferred; it cannot be directly demonstrated because any conscious experience already contains the result of such integration. However, such integration can be prevented, either experimentally or as the result of brain lesions.

Thus Allport (1979) points out that conscious perception of a tachistoscopic array as words rather than as rows of squiggles is limited by the rate at which this perceptual integration can operate. And Faust (1955) has reported that patients experience a disintegration of form after occipital lesions. When such a patient

looks at something for a short time, its form disappears; it may return if he looks away for a while. Usually, this disintegration of the visual field has been explained as abnormally quick fatigue of the visual apparatus after brain lesions. But if that were so, such disintegration should also be experienced without brain lesions when long periods of reading or close visual work result in fatigue. But normally, while increased visual fatigue may produce blurring or flimmering, it never results in a disintegration of the total visual field. According to Faust, this disintegration failed to occur if letters or words were shown on a tachistoscope where each item is shown separately. Only when the patient tried to read a page of print did he seem incapable of coping with the task. Faust calls this impairment "spatial blindness" and says, "Characteristic for spatial blindness is the 'loss' of things seen, together with a continual seeking with the eyes, while the transition from one thing to the other becomes extremely difficult."[1] From Faust's careful description it seems clear that this is a perceptual defect resulting in the impairment of visual integration, after damage to the primary visual cortex. In addition, the registration and recall of perceptual experience seems to be deficient as well. Faust points out that these patients are also unable to order things in imagination into a visual space. To imagine things in some side-by-side order, we need a visual memory schema. If it is missing, visual imagination cannot organize visual memory images.

VISUAL SPACE

Since Faust and other workers in this field often speak of "spatial ability," it might be profitable to ask just what is implied in space perception. How do we see space? Is space, as Kant has it, a "condition of sensibility" that necessarily precedes all sensory knowledge? Or is it a special way of seeing, as Faust seems to imply?

Our notion of visual space implies that there is a certain order among the things that surround us, that they are spread out before our eyes. There is good reason to assume that depth perception is innate: the "visual cliff" is avoided by infants of many species before any learning can have occurred. This innate perception of distance seems to give us the first awareness that some things are near and others farther away. Similarly, there is a primitive knowledge (before any concepts are formed) that something is located to one side or another, in front or behind us, a knowledge that is acquired not only by sight but by hearing, touch, even smell, and is tested by every attempt to reach or avoid the things so experi-

[1]Charakteristisch für die Ortsblindheit ist das 'Verlieren' von gesehenen Objekten zusammen mit einem ständigen Suchen der Augen, wobei der Uebergang von Objekt zu Objekt ausserordentlich erschwert ist.

enced. Not every sensory modality can give us a precise notion of the location of things around us. We know that something we touch is close at hand, but we do not know exactly how far something is that we see or hear. But various cues (relative size, relative clearness, etc.) allow us to learn how to estimate distance more accurately. We *innately* perceive things ordered side-by-side and in depth; but the *accurate* perception of distance demands experience and memory.

When a man lacks sight, it is much more difficult for him to achieve a correct notion of the direction and distance of things in relation to himself, but it is possible with the help of movement and touch. People born blind are able to find their way around the house, around the neighborhood, and even around their district, with remarkable confidence. This surely means that they have formed a notion of the way things are arranged around them. They must have a map of their environment so that they can use spatial concepts without difficulty. Of course, their space is not a picture of things spread out around them but a structure of objects in various directions and at various distances from themselves, measured by the time it takes to walk to them.

Their space perception differs from that of the sighted, as shown by reports of people born blind who later gained their sight through an operation. When such a patient first opens his eyes, he seems to think that the things he sees are touching his eyes, and often covers them with his hand, afraid his eyes will be hurt. Senden (1932), who has collected many reports of such patients, emphasizes the difference in their space perception compared to the sighted. But he draws the unjustifiable conclusion that only vision can provide us with the notion of space. It is true that a man born blind has no perception of *visual* space; but it does not follow, as Senden claims, that the notion of space is inherent only in vision and can be formed from no other sense. If it were, a person born blind would not be able to move in space with confidence while blind, but should have normal space perception as soon as his vision was restored. Actually, some patients who have regained their sight find the effort required to move with eyes open too exhausting and never learn to use their newly acquired sense of sight for their daily tasks. What seems to have happened is that while blind they formed memory images of their environment on the basis of motion and touch. Because they have no visual memory of objects and their position around them, they are unable to recognize anything by sight or to move among the things they see.

Senden reports, for instance, that such patients did not recognize simple objects on seeing them. They could distinguish a circle from a square but could not say which was a circle and which a square. But when they traced the outline of both, they immediately knew their name, and ever after could recognize these two figures, no matter what size or color they were, or of what material they were made. Apparently, when blind, the patients had learned to recognize circle and square on the basis of tactual and particularly motor memory. Since the shape traced manually and so registered and remembered as a motor memory image had no connection with any visual memory image, merely seeing the two

figures did not suggest the outlines the patients had traced and remembered. Once they had both *seen and traced* the two figures, and so connected the two experiences, they were able to recognize circle and square on seeing them.

It is curious how often we are misled by our linguistic habits. Because visual, tactual, motor, and conceptual memory normally work together, we speak of "memory" and assume that it is a single function, no matter what sense modality has produced it. When we are told that on gaining sight a man born blind cannot recognize a circle or a square although he can see that they are different, we assume that his difficulty cannot be a memory deficit because he still remembers the concept "circle" and "square" formed on the basis of motor and tactual experience.

Thus Senden assumes that the defect must be a "lack of space perception" supposedly inherent in vision. But once we entertain the notion that memory depends on various sense modalities that normally act in unison, it becomes plausible that visual memory requires the registration of visual impressions and their connection with memory traces from other modalities. We must see something and find out what it is called before we can recognize it by sight alone and repeat its name.

When sight can be used normally, together with all other senses, it will dominate our experience, not because of some mysterious "spatial" property of vision but simply because visual memory can be checked by moving about, in a way tactual memory cannot. Without sight, a person's notion of space is based on touch, hearing, and movement. The blind do not move, as Senden suggests, by calculating the distance and direction; if they did, they would never be able to move with assurance even among familiar things. They are guided by the memory of the steps they have taken in walking toward something, or the movements they have made in reaching for something or tracing its outline. Such motor and tactual memory is not as efficient as visual memory. Using sight, a man can recognize landmarks before he comes to them and so can change his direction, if necessary, without retracing his steps. A person born blind certainly acquires a concept of space: he knows in which direction to move, and approximately for how long, before he can touch a particular piece of furniture. But because this spatial map is not a visual image, such a person will be intolerably confused on gaining sight until he has tried to move among the things he sees and by manipulating them has connected his tactual and motor memory with the visual images. This takes time and effort. It is not surprising that many people on gaining their sight as adults lose patience and prefer the familiar non-visual way—just as many people who become blind never manage to acquire a scheme based on touch and movement.

In short, Senden's explanation that space is an inherent characteristic of vision comes from first mistaking the visually ordered *images* of things for the *concept* of space, and next concluding that people born blind who have no such images cannot have a concept of space. They do have such a concept, but in their sight-

less days they had to derive it from touch, hearing, and moving, without the help of the visual perception of things arranged side-by-side, in front or behind them, which is the most important basis of the concept of space for the sighted.

CONSCIOUSNESS, MEMORY AND PERCEPTION

Every perceptual experience presupposes awareness; and awareness is impossible without memory. Our awareness includes not only the present moment but a stretch of time immediately before, what William James called the "specious present." To be conscious means that we are aware of what goes on around us, that we sense, think, feel, can move and talk, that we can remember our immediate as well as our distant past, and reflect on our experiences. As Gasson says:

> what is *conscious* must indicate some psychological experience, something lived through of which we know; a *knowing* or a *wanting* or a *doing* or *happening* in us of which we have direct knowledge and which we refer to ourselves. Such psychological experience, moreover, in itself or in its content, must be fully *available* to us here and now for the needs of the present moment. (1954, p. 209. Original emphases.)

Accordingly, unconscious in its simplest sense means the absence of the activities of knowing, wanting, doing, remembering, and reflecting. A disturbance of consciousness is an interference with these activities, or their temporary loss.

Of course, some of these activities may not be observable. A person may not be able to move or to talk, yet he may be fully aware of what goes on around him. But to be conscious at all, he must be able to perceive and evaluate what he perceives. To be fully conscious, he must be aware of the external world and of his own experience, present and past, and must be able to use what he knows.

Consciousness, like memory, has been a step-child of psychological science during the last few decades. But unlike memory, it has not as yet made a comeback. Early in this century, when psychology had barely been accepted as an experimental science, Watson had insisted that consciousness is not a fit object for scientific research; that science has to restrict itself to the investigation of phenomena accessible to public observation and measurement. Whatever the methodological reasons for such an ostrich policy, psychologists have followed it for many a long year. This neglect of consciousness has impoverished experimental psychology and has deprived clinical psychology and psychiatry of help in an area crucial for understanding mental disorders as well as the effects of brain injury. Only recently, with the advent of cognitive psychology, have theorists come to realize that there is an important gap in their scientific domain. As Norman (1979) says: "the phenomenon of consciousness is so fundamental to our mental lives that it seems strange that experimental psychologists have ignored it so conclusively." (p. 142.)