BRAIN MECHANISMS AND MENTAL IMAGES

BY S. BENT RUSSELL

St. Louis, Mo.

When you think of an absent friend you may seem for an instant to see his face, *i.e.*, you have a mental image of his face. This is commonly said to be due to memory. But what then is memory? There may be readers of this article who have considered memory only from the subjective point of view. Let us for the moment now consider memory apart from the matter of images and consider it from the objective point of view. It can be shown that memory is accounted for by the operation of nerve processes. There are pathways along nerve fibers for nervous impulses. Some of these are known as association pathways. There is good reason to believe that changes of resistance at the points of junction between nerve fibers known as synapses, determine the course of nervous impulses along one path or another. The frequency and recency of previous impulses determines the synaptic resistance. Hence the nerve paths are developed by individual experience and thus memory is evolved.

The dual common path theory furnishes an explanation of associative memory. The common path is open to impulses coming from two tributary or private paths. An impulse from one lowers the synaptic resistance for an impulse from the other. We need not go further into this theory in this discussion. Let us take it as an explanation of associative memory for the purposes of this demonstration.

Before you can have a memory image of an object you must at one time be conscious of the object itself. Let us consider briefly how perception can be explained in terms of nerve processes. A man is never conscious of an object unless there be communication from the object to his brain. We may say further that there must also be a molecular change at some brain center or centers that bears a correspondence to the

object. In other words, the object causes a nerve impulse from a sense organ to a brain center and the impulse causes a response (molecular) at the brain center. To mention a special case, when a point on the retina is stimulated by a ray of light from some object, there is an impulse sent by way of a certain nerve fiber to a certain nerve center in the cerebral cortex, where it provokes a molecular response that corresponds to the retinal stimulation. We see that each visible point of the object has a line of communication by way of the retina and a particular nerve fiber to a brain center. All the points together produce a pattern molecular response in the brain. This joint response simulates the object in view.

Let us for convenience use the term 'mimetic response' to express the molecular response that simulates the object as represented at a sense organ.¹

To put it another way, there is a registering mechanism in the brain center that transforms the afferent impulse into light equivalent, heat equivalent or other sensation equivalent as the case may be. That is, it in effect reverses the transformation that occurred in the sense organ. When a ray of red light for example falls on the retina, there is a change in the brain center the same as if a red light had penetrated it. Let us term this hypothesis 'the mimetic theory of perception.'

This explanation of perception is not complete unless we make allowance for the effect of association mechanisms. You will see this if you think of a trained musician listening to a well-known melody on one hand, and a man without any musical training listening to the same melody for the first time on the other hand. The brain correspondence will be far greater in the former case. Every individual has to be trained to see and hear things as they are. Brain correspondence increases with knowledge, *i.e.*, with the development of associa-

¹ The writer has presented an explanation of mechanisms of associative memory and of their functions in intelligent and purposive behavior and in consciousness in the following articles in the *PSYCHOLOGICAL REVIEW*. 'The Effect of High Resistance in Common Nerve Paths,' 1916, 23, 231-236. 'Compound Substitution in Behavior,' 1917, 24, 62-73. 'Advance Adaptation in Behavior,' 1917, 24, 413-425. 'Communication, Correspondence and Consciousness,' 1918, 25, 341-358.

tion mechanisms. In other words, a man's habits determine the definiteness of his perception.¹

We must also make allowance for the effect of language and other forms of expression upon perception. Naming and numbering are great helps in perception. In learning to describe his environment, a man develops association nerve paths that serve to increase his brain correspondence with the world he lives in.

Keeping these matters in mind, we can say we have in the mimetic theory, a satisfactory explanation of consciousness as it reflects a man's present environment. The purpose of this discussion is to bring out an explanation of the memory image in terms of nerve processes. Before attacking the problem, let us note the difficulties we have to meet. It is not so hard to conceive how a ray of red light can cause a disturbance in a brain center that is characteristic of redness as it is to conceive of a nerve impulse aroused in the ear by the sound of the word red, for example, producing a disturbance in a brain center that is so characteristic of redness that the subject will for an instant see a red color in his mind. That is, he is conscious of red when there is in reality no red to be seen. There is, you will allow, an apparent paradox. Why should an impulse coming from the ear, arouse an image of light? We can think of a ray of red light penetrating a brain center and causing a characteristic molecular disturbance like a light ray acting on a photographic plate. We can go another step and think of a ray of red light stimulating a sensory nerve ending and so causing a nerve impulse which goes to the brain center and by aid of a special mechanism reproduces there the disturbance at the sensory ending caused by the red ray and characteristic of redness. But why should some other kind of stimulus produce a molecular disturbance that has a quality belonging to red?

In other words, if we seek explanations in terms of nerve processes, the one for consciousness of the past is far more difficult than that for consciousness of the present.

On account of the obvious resemblance, the memory image

¹ W. B. Pillsbury, 'The Essentials of Psychology,' 1911, p. 157.

is often considered as composed of sensations that are centrally aroused instead of coming from the effect of the environment acting directly as in perception. In these terms we would note that an explanation of a centrally aroused sensation by nerve processes is by no means as simple as in the case of a true sensation. If the reader can see the point of difficulty it will help him grasp the demonstration given herein.

As the next step let us take for illustration the case of a young man of normal mind sitting in a boat and drifting down a river. As he drifts along he observes different objects along the bank and of course is conscious of each in turn. Let us say it is the second time he has made this voyage. He will have from time to time mental images of objects that have passed out of view and sometimes he will have an image of an object ahead of him that will soon come into view. Suppose at one time he passes a gravel bar on which he sees a flock of white cranes. Later on he passes another gravel bar and has a memory image of the white cranes. At one time he passes under a railroad bridge and is startled by the roar of a train. Later on he passes another bridge and has a memory image of the roar. Let us see if we can find an explanation of these memory images in terms of nervous mechanisms.

In a book published some years ago, Professor Kirkpatrick describes images as the result of the functioning of brain centers that are made active in perception by impulses coming from sensory centers, while in imaging they are made active by impulses coming from some other direction.¹ The theory that will now be advanced does not conflict with Dr. Kirkpatrick's view.

Returning to our illustration, when the man observes an object in the first instance, there is, as we have already stated, a molecular change in the cerebral cortex that simulates the object and which we term the mimetic response. That is not the whole story, however, as there is another process too. In the case of vision for example, the mimetic response only lasts while the retina is stimulated by the object or for a moment more. There is a second process that is a recording

¹ E. A. Kirkpatrick, 'Genetic Psychology,' 1909.

process. Let us call this record making process the 'tuning process.' It is a specific molecular change that is more permanent than the mimetic response. There is one tuning process for light, one for sound, one for heat, etc. After the tuning process has occurred in a certain center, any nerve impulse that reaches the center will cause a molecular disturbance that simulates the original stimulus disturbance in the sense organ. In this way we have correspondence of a brain center with a past environment. This simulating process in the nerve center is, we will say, a conditioned molecular response. Let us term it the 'sounder response.'

In our illustration when the man is conscious of his present environment, there is a series or procession of impulses through certain brain centers. In other words the mimetic response is a series of molecular changes in the brain centers that bears a correspondence to the environment. The tuning process is also a series of molecular changes that bears a correspondence to the environment. At the same time it leaves an impression on the molecular structure that also bears a correspondence to the environment. We may liken the mimetic response to a gust of wind passing over a sheet of water and causing a ripple that is soon gone and we may liken the tuning process to a gust of wind passing over a smooth sand bed and leaving the familiar ripple marks that remain for a time.

The sounder response is conditioned by the tuning process. It is a series of molecular changes that bears a correspondence to the environment that caused the tuning process. There must of course be a specific sounder response that corresponds to light and another that corresponds to heat and another for sound and another for taste, etc. When a man has a memory image of a noise he heard a minute ago, there is in one of his brain centers a sounder response that is provoked by a nerve impulse coming, we will say from some association nerve path. The effect is the same as if there were communication from the noise-making object to the brain center that took a minute to reach the brain center. It is something like the thunder peal that reaches the ear some seconds after the lightning stroke that made it.

In the same way when a man has a memory image of an object that has recently passed out of view, there is in one of his brain centers a sounder response that is provoked by an impulse from some association nerve path. The effect is the same as if the object were still in communication with his brain. In his mind's eye he sees perhaps a red triangle although there is no red triangle now present to stimulate his organs of vision.

Let us now consider the tuning process again. A harp string can be tuned by turning the peg that holds it and thus changing the tension. With a given string a certain tension will produce a certain note, say C. Now a certain tension means a certain relation of the molecules to each other. The tuning operation produces a certain molecular arrangement that corresponds to the note C. As long as this molecular arrangement is preserved the string when struck will give the sound of C. The note C is of course a vibration at a certain rate and thus we see the molecules are so arranged by the tuning operation as to give when struck, a certain response. We may use the harp string as an illustration of a brain center. We may suppose that a nerve mechanism exists by which a certain brain center can be brought into a certain molecular arrangement so that thereafter any nerve impulse will produce a particular response or movement.

The tuning process is, we have stated, a change in the molecular structure. We may compare it to the alteration in litmus paper that is changed in color from red to blue when it is wet with an alkaline liquid. We note that after the change the paper gives off blue rays when exposed to light. We may also compare the tuning process to the case of paper that is tinted with some color that is not fast. If a ray of sunlight falls on it, a faded spot remains that will be seen whenever there is any light on the paper and so is a sort of memory image of the sunlight ray. Hence we may think of a bright object in view of a man as causing a little faded spot in his brain that is brought out by any passing nerve impulse that comes later on.

Let us remember that the man is never conscious of the mimetic response or the sounder response. He is conscious

of the object itself that furnished the stimulus, whether it be in the present or past environment. In the case of an image, the effect on consciousness is the same in kind as if the object were still in communication with the brain center.

It may make these explanations more clear to you if they are illustrated by a diagram or table like the one below. Let the features of the object seen in the first instance be represented by the letters A, B, C, D, E, and the impression on the retina be represented by the letters A₁, B₁, C₁, D₁, E₁, and the mimetic response by A₂, B₂, C₂, etc., and the tuning process by A₃, B₃, C₃, etc., and the sounder response by A₄, B₄, C₄, etc. The table follows:

Object	A	B	C	D	E	Object
Retinal image	A ₁	B ₁	C ₁	D ₁	E ₁	
Mimetic response	A ₂	B ₂	C ₂	D ₂	E ₂	Perception
Tuning process	A ₃	B ₃	C ₃	D ₃	E ₃	
Sounder response	A ₄	B ₄	C ₄	D ₄	E ₄	Mental image

Let us now go back to our case of the man drifting down the river. We will take the experience of the bridges. There is a certain center in the man's brain that is reached by a certain nerve path coming from the ear. It is also reached by a certain association path that has one connection with the ear and one with the eye. When the man sees the first bridge, there is an impulse from the eye via the association path and when he hears the roar of the train there is an impulse from the ear via the association path and one via the other path from the ear. The sound impulses cause a tuning process in the brain center. Later on the man observes the second bridge and there is an impulse from the eye that follows the association path more easily as it is now more open because the two impulses in succession, caused by the experience at the first bridge, have made it so. When the impulse reaches the brain center, there is a conditioned molecular response and the man has a sound image of the train roar at the first bridge. Please note that the response simulates a sound although the provoking impulse originates in the eye. This is the apparent paradox that we remarked in the beginning.

You may comprehend the case better when you see it presented in a diagram as in Fig. 1. The circle *V* represents the visual organ, the circle *A*, the auditory organ and the circle *R*, the brain center. At the sight of the first bridge an impulse travels from the eye at *V* by the dotted line path *C* to the center at *R*. The roar of the train sends a second impulse from the ear at *A* by the common path *C* to *R*, and a third impulse by the dotted line path *B* to *R*. The last two impulses provoke a tuning process in *R*. After the first and second impulses have passed over path *C* it is more open to later impulses. The sight of the second bridge later on sends an impulse from the eye at *V* by the path *C* as shown by a heavy line, to the brain center *R*. There is now a sounder response at *R* that simulates the roar of the train at the first bridge. A path line on the diagram of course represents a plural number of nerve fibers.

FIG. 1.

On consideration you will find that the explanation just given for a particular case will answer for all memory images. There are many cases of course, where a large number of association nerve paths are required to produce a definite memory image. The larger the number, the higher will be the degree of correspondence with the environment at the time of observation.

The association nerve paths must be developed by individual experience. A baby cannot have mental images like an older person. A baby must learn to talk before he can hear words in his mind. He must learn to sing before he can hear a song in his mind. He can only coördinate impressions that have become familiar. He learns to form images step by step. He must learn to walk before he can image distance relations and space relations. We have previously observed that perception is determined by a man's habits to an important extent and the same thing is true of mental images. The study of language and expression, also, must have an important effect in developing the mechanisms for making mental images.

A man who has learned how to write a good description of a landscape has no doubt increased the definiteness of his mental images. You are perhaps able to look at a new model of an aeroplane and memorize it so as to have a good memory image of it a week afterwards and have never remarked that your ability to do this is the result of long and repeated practice on similar objects. On consideration you will see that these statements fit in with our theory that the image is due to a conditioned molecular response that simulates a past environment at one time in communication with the brain centers responding.

We find then that a typical memory image accompanies a compound sounder response and is due to the operation of tuning process mechanisms and association mechanisms, the latter serving to coördinate the former.

We have found an explanation of how the brain can simulate a past environment. Let us pass on to the case where the image corresponds with a coming environment. Let us return to our illustration of the man on the river. Suppose he sees in the distance ahead of him a column of smoke and then has a mental image of a landing pier at a village around the next bend. At first thought this appears to be an image of a future environment but on second thought we find that the man's mental image is the result of his previous voyage over the same route. The same rule will apply to all cases where the image appears to anticipate the object. The mental picture of things to come is made up of elements derived from past experience.¹ A man can imagine an aggregate that he has never seen but it will be made up of familiar units. The power of combining mental images is acquired by degrees. It must be largely due to social environment and to language associations. What one man has observed another man can image by the medium of language. The younger are taught analysis and synthesis by their elders.

It is evident then that an image of a coming environment is due to the same nerve mechanisms that serve for the image of a past environment. All mental images are really memory images in kind.

¹ Pillsbury, *op. cit.*, p. 131.

In considering these brain processes, one should keep it in mind that the power to form an image diminishes with time. You perhaps have a clear mental image of a particularly fine cigar that was given you yesterday, but had it been a week ago you probably would have no image to speak of. The longer the time, the less is the conductivity of the association nerve paths and sooner or later the mechanisms will fail to coördinate so as to simulate the past environment.

The kinæsthetic impulses from actual and incipient muscular movements have much to do with provoking sounder responses. Acting, talking and thinking are all linked together by association mechanisms. Behavior habits and language habits serve to prevent the untimely occurrence of sounder responses as a rule. It is not always true, however, as a man can sometimes be reading aloud and at the same time, have mental images having no connection with the words which he is subconsciously repeating.

When a man is awake but resting quietly in an unchanging environment, he is usually unconscious of his environment or, as we say, he is lost in thought. From our point of view there are no mimetic responses in his brain centers and his nerve-muscle system is occupied with a series of incipient muscular movements accompanied frequently by a series of sounder responses in the brain centers. There is a constant flow back and forth of efferent and afferent (kinæsthetic) impulses which penetrate one cortical center after another. Those centers that have been tuned by past experience give a characteristic conditioned molecular response. It is thus that mental images transpire more commonly. The man may be thinking of future events but it is always in terms of what he has seen and heard before.

Having reached these conclusions regarding the mental operations of a man, it will not be amiss to consider briefly the mental processes of animals lower than man. Do monkeys, dogs and other intelligent animals have mental images? We know that the nervous system in these animals is much the same as in man and in behavior also there is much resemblance. The brute learns by experience as does the man. In man we

find great superiority in expression as he has an articulate language which the brute has not. There is, however, communication with the brutes. The baying of a beagle on the trail of a rabbit, no doubt has in its changes more meaning to the other beagles than even to the experienced hunter. The available evidence indicates that the nervous mechanisms in the animal are of the same kind as those in man. Therefore it is probable that a squirrel has a mental image of a nut that he has hidden away for future use, the same as a man would have, and that a fox has a mental image of the bone that he buried and will one day dig up. A bird probably has a mental image of her nest that she built herself with the aid of her mate just as a man has of a hut he has constructed. In the man's brain the association mechanisms are far more complex. The number of association nerve paths is much greater.

In conclusion let us say that a mental image can only occur when there is a coördinated molecular response in a brain center that is conditioned by a former environment. The response is conditioned by means of registering mechanisms in the center and of association mechanisms. The response is the same in kind as if the environment in question were still acting upon the sense organs and so upon the center. The man is not conscious of an image as such but of the environment as it was. He sees it around the corner, one might say. Usually, of course, the response is very much fainter than in the case of direct stimulus from the sense organ in perception.

The registering mechanism at the brain center when in communication with the environment, acts by retransforming the nervous impulses into specific molecular changes that simulate the environmental action upon the sense organ. The result is a permanent set of the molecules that is a factor in subsequent responses to excitation by any nervous impulses that reach the center. The responses in the registering centers are further conditioned and also coördinated by mechanisms of association. These mechanisms function in the same way as they do in the case of conditioned reflexes which cause muscular movements. The same sort of association mechanisms govern the responses in the registering centers as govern the responses in the muscles and other effectors.

The knowledge that a highly intelligent man has of the world about him is due to the brain mechanisms that have gradually become organized and developed from his birth up. This applies also, of course, to a man's knowledge of himself.

Finally we cannot escape the conclusion that in a man's consciousness of past and future, brain mechanisms are an essential factor. Without brain mechanisms a man would have no more mental power and no more consciousness than an apple tree.