BRAIN RHYTHMS*

By PROF. E. D. ADRIAN, O.M., F.R.S.

University of Cambridge

IN 1929 Prof. Hans Berger, of the Psychiatric Institute at Jena, published the results of some work on which he had been engaged for many years. He had set out to record the electric currents developed in the human brain, and had shown that if metal electrodes were fixed to the scalp, it was possible to detect a regular oscillation of electrical potential which was not due to muscles or skin glands or any other source outside the skull, and could only have come from the nerve cells of the cerebral cortex. The oscillation had a frequency of 9–10 a second. It only appeared when the subject was at rest with attention relaxed and eyes closed; but it obviously represented some kind of continuous activity in the brain covering a fairly large area. What he discovered was then quite unexpected. It has made us revise many of our ideas about the brain and has brought us a little nearer to understanding what goes on in it.

The oscillation, Berger's α rhythm, represents a very small change of potential, about 50 microvolts, and a very small ebb and flow of current in the cerebral cortex. There is nothing unexpected in the fact that brain cells develop small currents when they are active, for all active cells do so. The unexpected thing is the regularity of the rhythm. It is true that if it were not so regular, it might never have been detected, but the regularity means that large numbers of brain cells must be working in unison at the same rate. We should have expected something much more complex and variable—activity varying from moment to moment and from place to place—and not the uniform pulsation shown in a typical record of the electroencephalogram.

We should have expected this because the brain is a great sheet of nerve cells and interlacing nerve fibres, and its working must depend on the spatial distribution of activity in it. This is determined by the particular pathways which must be taken by the incoming and outgoing messages, for the messages are all in the same form wherever they come from, and it is because they arrive in different regions that we interpret one as sight and another as sound. We know, for example, that if one looks at a bright cross, the initial event in the brain will be the activation of a more or less cross-shaped area at the back of the occipital lobe, and that if one hears a sound a pattern will be reproduced in the temporal lobe corresponding to the areas of vibration in the cochlea. All the external events of which we are aware are recorded as spatial and temporal patterns of excitation in the sense organs. These patterns are reproduced in the brain with a good deal of editing, omission of details and heightening of contrasts, and it is from them that we reconstruct our external world.

Now the α rhythm of the electroencephalogram comes from large areas in the occipital region and to some extent from the frontal area as well. At first sight this seems to leave little room for all these diverse patterns of electrical activity. But actually the regions where the potential change is at a maximum are not those where the messages from the sense organs are received in the brain, but are the

neighbouring 'silent' or 'association' areas. Also, to make the rhythm appear, the eyes must be closed and the attention relaxed, so that the brain is relatively inactive, at least so far as vision is concerned. Thus the regular wave sequence is derived from certain parts of the cerebral cortex when these have little to do. The cells there are not concerned with the incoming signals and so will be free to beat in unison, and if fairly large areas are so beating our records from the head will show the α waves and will not show the small local irregularities which are probably going on all the time so long as we are conscious.

Fig. 1. NORMAL ELECTROENCEPHALOGRAM SHOWING THE α RHYTHM. THE MAXIMUM POTENTIAL CHANGE IS 45 MICROVOLTS.

The cells of the cortex might beat like this when they are left alone because this is how they are made; because like heart muscle or ciliated cells they cannot remain alive and inactive; or the beat might be imposed on them by rhythmically active cells in some other part of the brain which can act as pacemaker to the association areas. Wherever the pacemaking region may be, the important fact is that the rhythm is much the same from one person to another. For clinical purposes, therefore, an electroencephalographic recording can be used as an index to show whether the brain is working normally or not, and for this reason it has become an important technique of clinical neurology. Apart, however, from the value of these records as a means of diagnosis, there is the problem of their significance in relation to the normal mechanism of the brain and of the mind. Do they tell us anything about the neural accompaniment of perception and thought?

The statement that one can record the electrical activity of the brain through the skull raises the hope that one should be able to detect all sorts of brain events connected with consciousness. The hope begins to fade when it is realized that the main feature of our records is a rhythm from nerve cells which are relatively inactive. But there is something of interest to be learnt from them. It is true that we cannot yet record the detailed activities of different parts, but only the gross changes when a whole area goes into action; yet these do give us some novel information about the physical accompaniments of thought and in particular about the process of attention.

To begin with, it seemed that the α rhythm was much less interesting. It might have been merely a spontaneous beat of the nerve cells in parts of the cortex, particularly those concerned with vision—a beat developing whenever the cells were not stimulated by messages from the eyes. Opening the eyes would break up such a rhythm in the receiving area, because the visual pattern there would mean that different groups of nerve cells would be discharging at different frequencies. Something of this kind can certainly happen in the regions where a message enters the cerebral cortex, for in records from the exposed brain (in anaesthetized animals) the arrival of a message in the receiving area produces small, rapid waves in place of the slower and larger α

* Friday Evening Discourse at the Royal Institution delivered on February 4.

rhythm. But the α waves are not confined to the receiving areas of the brain, and it can be shown that in fact the presence or absence of messages from the eyes is not the essential condition for the disappearance or return of the α rhythm.

As far as vision is concerned, what really determines the presence or absence of these waves is not whether visual messages are or are not coming into the brain, but whether we are or are not attending to them—whether we are looking at anything. Man is a visually controlled animal, and if our eyes are open there is usually something in the visual field which catches our attention or some part of it. This is not true for all mammals; the rat and the cat seem to rely more on other senses and can be quite inattentive to sights. But with us the only sure method of shutting out sights from the mind is to close the eyes. Normally, therefore, opening the eyes means that we start looking, or that we become attentive to the visual field. The α waves then disappear, and they return when we close our eyes and cease looking. But shutting the eyes does not cut out all light from the retina, and the α rhythm appears in the brain however much or little light may be falling on the closed lids. Even in a pitch-black room, if we open our eyes and start trying to see something, the rhythm goes, although opening the eyes cannot have altered the illumination of the retina. Sooner or later, when we have given up the attempt to see, the waves will return although the eyes are still open.

What matters, therefore, is not the excitation of the retina but the turning of attention to the visual field or away from it. This can be shown even more clearly in another way. In daylight and with the eyes open, the attention can rarely be abstracted completely from vision except for short periods; something keeps on 'catching the eye' and coming into the mind, even though we have most of our attention fixed on other things, a sound or a smell, for example. The reason why the visual field cannot be completely ignored is that the picture of it in our brain has patterns and sequences which arouse interest by recalling memories or starting some new train of activity. But if we can make the visual field convey less meaning, it will cease to be so attractive and our attention can leave it more easily. A simple way of securing this is to wear spectacles which will throw everything out of focus. When this is done, although the eyes remain open, the α rhythm will appear much more readily than when the visual field is in its proper focus. With the field blurred, we have only to listen intently to a sound and the α waves will begin, to cease again if we transfer our attention back to vision. Here, too, there has been no change in the illumination of the retina but only the shift of attention. It may be noted that it is not only the intellectual interest of the field which holds our attention. Any movement in it or any sudden change of illumination will do so; and there is a great variation in the ability of different persons to detach the attention from vision, and in the same person at different times.

All this shows that the α rhythm is an activity which appears in the cerebral cortex when the attention is not directed to vision, and disappears when it is. The mental act of looking somehow prevents the α waves from developing in certain parts of the brain,

Fig. 2. THE α RHYTHM APPEARS WHEN THE ATTENTION IS TRANSFERRED FROM VISION TO HEARING. THE VISUAL FIELD HAS BEEN MADE UNATTRACTIVE BY + 10 D SPECTACLES. DURING THE MIDDLE SECTION OF THE RECORD THE ATTENTION IS CONCENTRATED ON THE TICK OF A WATCH.

parts which are likely to be concerned in analysing the visual pattern. The α rhythm is therefore a rhythm of inattention, a positive activity which fills those parts of the cortex which are for the moment unemployed. It is not the basic rhythm of unstimulated nerve cells, and there must be some kind of competition between the message from the eyes and from the source of the α rhythm to decide which shall control the cortical areas.

To, examine this competition in more detail, we must have some way of recording the sensory activity of the brain as well as the α activity. All the messages which reach the cortex will produce their own electrical accompaniment, and this can be recorded well enough if electrodes can be placed on the surface of the brain. But if we can get no nearer than the scalp, the potential changes generated in any group of nerve cells will usually be obscured by those of other groups near by, and the record will then show us nothing. Fortunately this difficulty can be overcome, in part at least, by making all the cells work in unison. This can be done, as far as vision is concerned, by making the field more or less uniform and lighting it with a flickering light. The nerve cells are then forced to work in unison at the frequency of the flicker, and we can record their electrical activity through the skull up to frequencies of about 30 a second. This gives us a method of tracing the visual messages in the brain, for by means of the flicker rhythm they can be made easy to recognize.

Provided that the flickering area is in the centre of the visual field, it need not subtend more than a few degrees at the eye to give a potential oscillation at the same frequency in the occipital region. The waves are more or less where one would expect them to be, in the right occipital region if the left half of the field flickers, and vice versa. But the flicker waves are not confined to the visual receiving area: they are found also in the neighbouring areas, those from which the α waves come when the eyes are closed. The flicker area is not so large as the α area, but on occasion as much as a quarter of the brain surface seems to pulsate with the flicker rhythm. The retinal messages must then have spread widely and impressed their rhythm on some of the association areas of the cortex.

Now if the eyes are open, the flicker will keep the visual attention engaged and the α rhythm at bay. But if the eyes are closed and the flickering light is thrown on the closed lids, the subject will be conscious of the flicker but the conditions will favour the α rhythm, since closure of the eyes is usually coupled with the withdrawal of attention from vision. In these conditions the two rhythms can be seen to compete for the cortex, and sometimes to co-operate if their frequencies allow of it. The flicker-rate will sometimes appear in patches with the α -rate in between, and if a rapid flicker is turned on suddenly

Fig. 3. ELECTROENCEPHALOGRAM FROM THE OCCIPITAL REGION, SHOWING THE CHANGE FROM THE α RHYTHM TO THE FLICKER RHYTHM WHEN THE EYES ARE OPENED AND THE SUBJECT LOOKS AT A SCREEN LIT BY A FLICKERING LIGHT. THE RATE OF FLICKER (17 A SECOND) IS SHOWN BY THE PHOTO-ELECTRIC CELL RECORD BELOW.

the area of the brain giving the flicker rhythm may be large at first and may then shrink rapidly, giving place to the α waves but persisting longer in regions nearer the visual area. If the flicker is made equal to or twice the α -rate, we may find the two summing up to give very large regular waves. Such a combined rhythm usually takes some time to build up as the two sets of waves have to be synchronized, but there is evidently an interaction between them and a tendency to remain synchronized as long as their frequencies are not too far apart. These wave effects vary from one subject to another and there are variations according to mood, time of day, etc.; in general, the sleepier the subject the more the α rhythm will predominate, and the brighter the flicker the more persistent will be the flicker rhythm.

The interaction and interference of these rhythms shows how the cortex, or certain parts of it, may be put at the disposal of our attention. If we decide to look, or if it is decided for us by something 'catching our eye', a change occurs which prevents the α rhythm from occupying the regions surrounding the visual receiving area. If we can turn our whole attention to a watch ticking, the α rhythm comes back. What brings this change about?

The evidence is still rather scanty. It is likely that the whole of the cerebral cortex is concerned, in that it is the balance of activity in every part which determines where the attention will turn and how long it will be held in one field; but the executive act, the direction of the attention to the particular field, is probably carried out by a relatively small central region in the neighbourhood of the thalamus and near the main incoming pathways. It is from there that the α rhythm seems to be controlled, and it is at least probable that it is the sudden disturbance of this region which causes the loss of consciousness after a blow on the head. This central directing region must act on information received from the cortex, for it will be all the memories and associations stirred up by a stimulus which will determine its interest, and these are presumably not aroused until the message has reached the cortex. But the central region must balance up the conflicting claims of different stimuli and must then decide which should have the main share of the attention, its function resembling that of a central university committee which has to decide which branch of learning should be supported by the next benefaction.

The visual stimuli always get the lion's share. If they are at all interesting, the central region will suppress the α rhythm over the occipital area, so that the visual pattern has a considerable part of the cortex set free for its analysis. When the visual

pattern ceases to be interesting and the attention is directed to sounds or other sensory messages, the occipital lobe is not turned over to those but is filled again with the α rhythm. This is shown very clearly in records in which the visual waves are made recognizable by the use of a flickering light, and if the flicker happens to be at twice the α rate a partial diversion of attention will be enough to give the large compound waves at the α frequency.

Apparently the occipital part of the brain is used to analyse sights, and sights only. What parts deal with the patterns aroused by sound and touch we cannot yet say. The areas seem too small to be easily detected, and must certainly be much smaller than the areas which deal with vision. On the other hand, a concentrated mental effort may sometimes abolish the α rhythm although the eyes remain shut. Presumably in this case the whole of the α area may be turned over to non-visual activities.

There are still many gaps in the evidence, but there is much to support the view here put forward, namely, that there is a deep-seated part of the brain which contains the mechanism by which attention is directed one way or the other, and that the α rhythm is under the control of this region, if it is not directly produced by it. If this is so, it is not difficult to understand that abnormalities in the α rhythm are often associated with abnormal kinds of behaviour. The most valuable application of the electroencephalogram in medicine is in the localizing of diseased regions and tumours of the brain by the change in the character of the waves. Another is its use in detecting the sudden explosive discharges of the nerve cells which occur in the brains of epileptics. But quite apart from such obvious disorder of the brain cells, the electroencephalogram may show an α rhythm which is definitely abnormal, irregular, faster or slower than usual or with odd-shaped waves, and in a significant proportion of the subjects who give such records there are abnormalities in the mental or emotional sphere which may be a serious handicap. There are, of course, many factors besides the constitution of the brain which determine whether we react like our fellows or not, but the brain is a not unimportant factor and the electroencephalogram seems to offer a means of assessing some of its deviations from the normal. It remains to be seen whether its use for this purpose will have much practical value: at present the most that can be said is that if we had to appoint someone to a responsible post and had an unlimited field of candidates, it would be safer to exclude the five per cent whose electroencephalogram showed the most unusual features.

That is a very long way from saying that the electroencephalogram can tell us how the subject will think and act. In fact the information which it gives relates to a very limited field. But the limitation arises mainly from the fact that we can only record the gross effects and not the detailed patterns in the brain. With present methods the skull and the scalp are too much in the way, and we need some new physical method to read through them. We need the "patent double million magnifying gas microscopes of hextra power" with which Sam Weller thought he might be able to see through "a flight o' stairs and a deal door". In these days we may look with some confidence to the physicists to produce such an instrument, for it is just the sort of thing they can do; but until it is available we have to confess, with Sam Weller, that "our wision's limited".