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Zur Deutung des normalen Elektrencephalogramms und seiner Veränderungen.

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Electrocorticograms in man: Effect of voluntary movement upon the electrical activity of the precentral gyrus*.

By

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With 6 figures.

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It will be recalled that BERGER originally described the alpha and beta waves of the human EEG as characteristic rhythms for all cortical regions. Opening the eyes with attention depressed the alpha waves without affecting the beta rhythm. Shortly thereafter KORNMÜLLER and TÖNNIES (1932) and KORNMÜLLER (1932a and b, 1933) described specific patterns of electrical activity, the „Feldeigenströme", which were considered specific for each cytoarchitectonic area (VOGT). In general KORNMÜLLER believed that the slower frequencies were derived from granular cortex, while the more rapid frequencies characterized agranular cortex.

BERGER (1931) by direct registration from a trepanation hole and TÖNNIES (1934) by leading from the scalp found fast activity of the ß-type (16—22 per sec) in the precentral region and ADRIAN and his colleagues (1934, 1935) then proposed that most, if not all, the human alpha rhythm was derived from the occipital lobes. Recording with closely spaced electrodes in different human subjects JASPER and ANDREWS (1936, 1938) showed that there were rhythmic potential waves at frequencies between 8 to 12 per second which could be derived from parietal, temporal and frontal regions independent of the occipital alpha rhythm which is predominant in most subjects. They pointed out further that the beta rhythm (25 per sec) is characteristic of the

* Reprint No. 307. We are pleased to have the honour of taking part in this tribute to Prof. HANS BERGER, the founder of electroencephalography. His sustained vision which carried him through an exemplary series of rigorously controlled systematic experiments on human subjects finally convinced skeptical scientists throughout the world of the validity and value of records of the electrical activity of the human brain.

electrical activity from the central region, where it can be obtained in pure form in certain subjects. This beta rhythm recorded from the vicinity of the central fissure was not affected by weak visual stimuli which blocked the occipital alpha rhythm. It was blocked, however, by tactile stimulation to the contralateral side of the body, or by intense stimuli producing a generalized „startle“ response. Their records were obtained from the scalp surface through the unopened skull.

Further attempts to confirm the presumed relationship between electro-cortical activity and specific cortical areas were made by RHEINBERGER and JASPER (1937) recording with implanted electrodes on the dura in the unanesthetized cat. Although certain consistent differences in pattern did exist between occipital, temporal, and post-central areas, the variability of pattern from time to time was so great in unanesthetized animals that constant differentiation was not always possible. CLARK and WARD (1945), in studies of the electrical activity from different cortical areas in anesthetized and unanesthetized cats concluded that „specific patterns were observable, especially in stages of sleep, from the frontal and occipital regions and vertex. Tracings from the temporal region . . . displayed less characteristic differences (p. 110)“. It seems clear from these studies that the electrical pattern from certain grossly different areas does possess certain differential features which may be considered characteristic for a given area, even though these differences are frequently changing, and maybe obliterated entirely by local or generalized excitatory conditions of the cortex.

There have been few reports of extensive studies of normal electrical activity from the exposed human cortex. FÖRSTER and ALTENBURGER (1935), and SCHWARTZ and KERR (1940) describe early techniques and preliminary results. SCARF and RAHM (1941) described electrocorticograms obtained from various areas of the exposed cortex in 17 patients who came to operation for a variety of intracranial lesions. These authors found that the alpha rhythm was not confined to the occipital lobes, but was recorded as well from parietal and temporal areas. In only one case did they record rhythmic waves of alpha frequency from the frontal lobes. Beta activity, with an average frequency of 18 cycles per second, was found most prominent over the frontal lobes, and was found somewhat in the anterior portion of the parietal lobes. The central sulcus was found to limit the alpha activity more definitely than it did the beta activity. They concluded that the alpha rhythm might be allied in some general way with sensory function.

During the past ten years, in the course of operative exploration of the cerebral cortex in the conscious human subject (in patients with focal epilepsy) there have been numerous occasions to record electrical activity from normal cortical areas at a distance from a small focal epileptogenic lesion. For the present report we have selected typical records from different cortical areas to establish the most common normal patterns in the electrocorticogram. In addition we have made special studies of the beta rhythm found most characteristic of the precentral gyrus to determine particulary the effects of voluntary movement.

Technique.

These observations to be discussed here were made in the course of operations carried out for the treatment of focal epilepsy. The whole procedure was conducted under local anaesthesia and an observer placed to make adequate report of the patients movements. The surgeon (W. P.) and the electroencephalographer (H. J.) were able to converse during the procedure through a glass partition by means of a loud speaker.

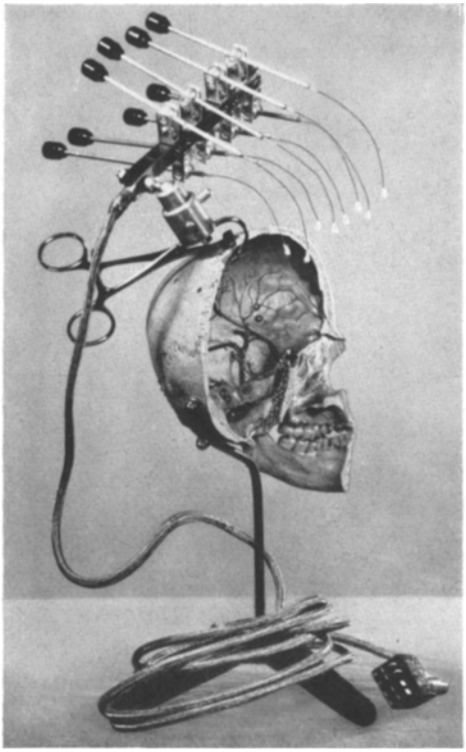

Fig. 1. Electrodes in adjustable holder attached to bone clamp as used for electrocorticograms in man. The entire electrode assembly with its cable may be sterilized by the autoclave.

Many modifications of electrode design for convenience of application and electrocorticograms free of artefacts has resulted in the set of eight electrodes shown in fig. 1 and 2. An electrode holder is mounted upon a specially designed instrument that may be clamped firmly to the skull at the margin of the cranial opening. Movement of the electrode holder is secured by means of a ball and socket joint of the type used in tripod camera mounts. The grounded metal shield around the cable of wires leading to the electrodes is attached to the bone hemostat which provides the ground or „earth“ contact to the body of the patient.

The 8 electrodes are mounted in two banks of 4 each above and below an insulating fibre tube containing the end of the cable of wires. Each electrode consists of a silver rod 15 cm in length at the end of which is attached a piece of flexible silver wire with a fused ball at its tip. A small coil at the point of attachment adds greater flexibility. This flexible end piece is insulated with a „plastic“ varnish except for the ball tip, so that it can be inserted along the base of the skull or deep within fissures while still recording only from its tip. A bit of cotton wool is attached around the tip before the electrode is chlorided. The silver rod is mounted into an individual ball and socket joint screwed solidly to the fibre tube. Each electrode is independently adjustable in all directions, the rod slipping in and out of its ball when greater or less length is required.

Records were taken with a six channel ink-writing oscillograph which responds well up to 100 cycles per second. The amplifiers were built permanently into the gallery of the operating theatre. They were of the usual balanced push-pull design with degeneration for in-phase signals to make possible a rejection ratio of well over 1000 to 1.

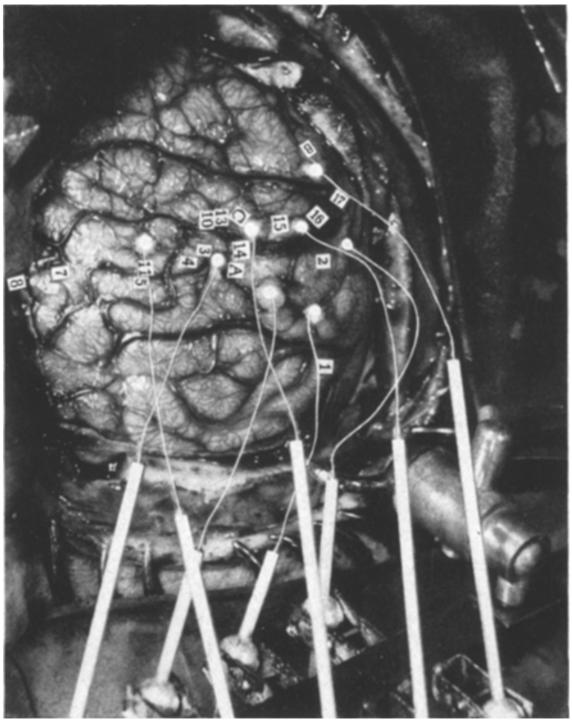

Fig. 2. Photograph of the human cortex exposed at operation with recording electrodes in place. Paper tickets are placed on the cortex with letters indicating ECG findings and numbers indicating responses to electrical stimulation. Stimmlation at 13 caused movements about right eye, stimulation at point 15 caused closing of the hand, 2 sensation in the arm, 3 sensation in the hand. Beta waves were obtained from both precentral and postcentral gyri and forward as far as point marked B in the premotor area. High voltage alpha waves were obtained at point marked A and over all of exposed parietal lobe posteriorly.

It was found impracticle, as a routine, to employ unipolar recording since a stable reference electrode is difficult to maintain during the operative procedures. Consequently electrodes are usually connected in serial pairs, the upper bank of four electrodes being lead to the first three amplifiers, and the lower bank of four electrodes connected to amplifiers 4, 5, and 6. When studies of the electrical activity from a given homogenous cortical area were being made we made sure there were a pair of electrodes within the area, so that the pattern of activity for that area was not intermingled with activity from reference electrodes.

Either before or after the initial electrocorticogram and sometimes during electrocorticography the surgeon identified the precentral and postcentral gyrus by means of electrical stimulation of threshold intensity. Small paper tickets

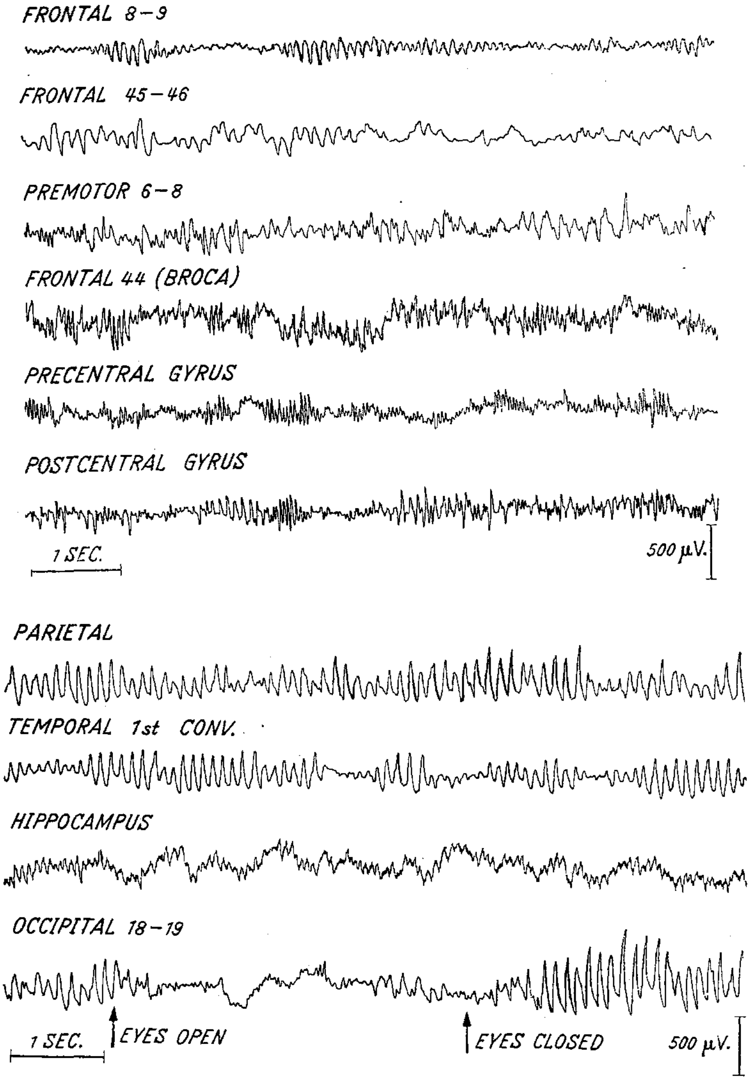

Fig. 3. Sample electrocorticograms showing characteristic spontaneous electrical activity from specific normal cortical areas in the unanaesthetized human subject.

were placed upon the cortex (Fig. 2) at points where stimulation produced a positive response and the nature of the response was immediately dictated to a secretary. Other areas frequently gave interesting results during stimulation and these were identified in a similar manner.

By means of stimulation the precentral gyrus was, therefore, identified with certainly and the movements which found representation there. Thus the recording electrodes could be placed upon the appropriate area for any voluntary movement that was to be studied.

Results.

Pattern of spontaneous activity from different cortical areas.

Our results are in general agreement with those of SCARF and RAHM with respect to the central fissure as a most important line of division

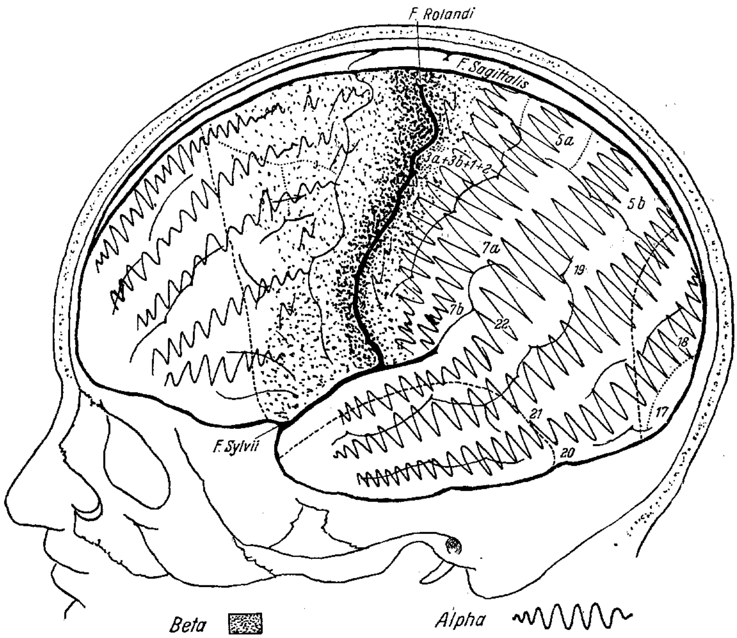

Fig. 4. Diagramatic representation of cortical areas giving rise to alpha rhythm as opposed to those showing beta rhythm (stippled).

between patterns showing a predominance of alpha rhythm, and those showing more beta (18 to 30 per second) activity (Fig. 3, 4). We found, however, that the area of high voltage regular alpha rhythm, relatively free of other frequencies, did not include the post-central gyrus. It began abruptly in the parietal lobe when the electrodes were placed on the gyrus just posterior to post-central gyrus. Alpha waves of a continuous regular form and of high voltage (about 500 microvolts) were recorded throughout the parietal cortex, from the peristriate portion of the occipital cortex, and from the mid and posterior portions of the lateral surface of the temporal lobe. In the relaxed patient, free of sensory stimulation, these areas gave rise to almost identical patterns of electrical activity with regular waves at 8 to 11 per second, and without a significant amount of beta or other frequencies. The voltage of alpha waves was frequently somewhat higher when approaching the occipital lobe. We cannot be certain, from our records,

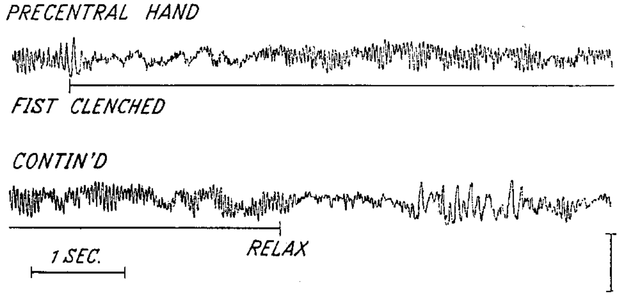

Fig. 5. Electrocorticogram from the precentral hand area of the left hemisphere during clenching of the right fist. Note the arrest of beta rhythm at the beginning and at the end of the sustained contraction, but not during the maintainance of a continuous contraction.

whether a good alpha rhythm can be obtained from the striate area alone, since the records we have obtained from this area have been considered abnormal.

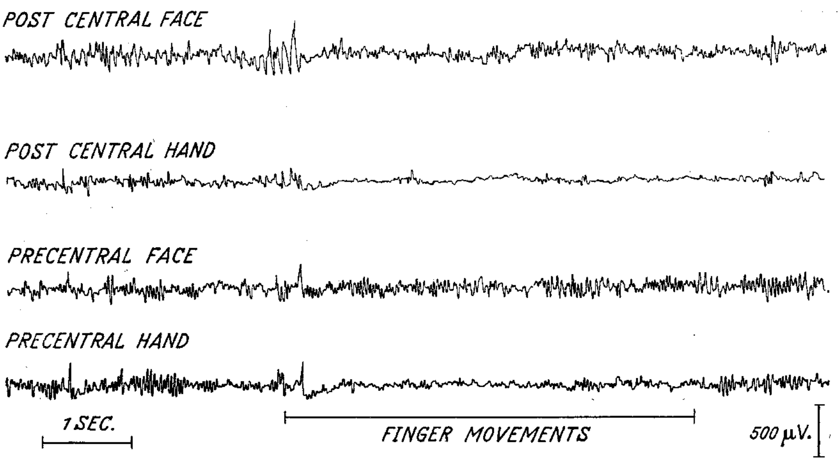

Fig. 6. Electrocorticograms taken simultaneously from the post central face and hand areas and from the precentral face and hand areas during continuing movements of the fingers (successive touching of fingers to the thumb).

The precentral gyrus, as determined by electrical stimulation, gave rise to the most distinctive and characteristic electrocorticogram (Fig.3, 5 and 6). Practically „pure" beta rhythm, regular waves at about 25 per second at 100 to 250 microvolts in amplitude, made it possible to identify the precentral gyrus on numerous occasions, even before its exact localization had been determined by electrical stimulation. In two patients the correct site of the precentral gyrus was located from the record taken through the unopened dura, later found to be correct when the cortex was stimulated beneath this point marked on the dura. At times distinction between the activity from the precentral and post-central gyri is difficult since their patterns of spontaneous activity may be extremely similar. However, if one can compare them simultaneously one finds a greater admixture of lower frequencies (10—12 per second) in records from the post-central gyrus, even though the beta rhythm may be, at times, almost as prominent.

Rapid frequencies were also characteristic of the electrically excitable cortex anterior to the precentral gyrus, probably what would correspond to area 6 of BRODMANN, and including the frontal opercular area of speech arrest with electrical stimulation (BROCA), or area 44 of BRODMANN. The activity from these „premotor" areas, however, was not as regular and contained frequencies more commonly between 17 and 22 per second with an admixture of slower waves. An admixture of 6 per second waves was particularly frequent from the gyrus just anterior to the precentral gyrus (area 6).

We have never observed an alpha rhythm from the tip of the temporal lobe or from its ventral surface. From the hippocampal gyrus and uncus, and extending laterally onto the anterior portion of the insula and mesial tip of the temporal lobe we have observed a characteristic pattern composed of a regular low voltage rapid rhythm at about 14 to 16 per second on a background of irregular slow waves (see Fig. 3). This was obtained with the patients fully awake.

From the more anterior frontal regions the electrical activity was often rather amorphous and of low voltage, with occasional bursts of regular alpha waves at 8—10 per second, but with very little more rapid activity. Occasional slower waves between 3 and 6 per second of low voltage were seen. From the precentral gyrus rostral there was a gradual diminution in the amount and regularity of the rapid rhythms. They were practically absent from regions corresponding approximately to 9, 10, 45, and 46 of BRODMANN. A lower voltage (100 to 250 microvolt) alpha rhythm was observed at times from these areas although it was never as high voltage, continuous, and regular, as the alpha rhythm of parieto-occipital regions.

Effect of voluntary movement upon the precentral beta rhythm.

All electrodes were placed on the precentral and postcentral gyri in certain cases after these areas had been carefully outlined by electrical stimulation. Care was taken to place a pair of electrodes within the hand area, and a pair within the face area in the example shown in Fig. 6. Then the patient was asked to move his hand, or fingers.

When the patient was asked to ,,clench your fist" there was a prompt but transient blocking of the beta rhythm from the motor hand area, as shown in Fig. 5. The blocking lasted only about one second, even though the fist remained clenched. It was blocked again following the command ,,relax" with relaxation of grip. The beta rhythm was maintained at normal amplitude and regularity except for about one second during the initiation and relaxation of the contraction.

Successive continuous movements of the fingers, such as touching the thumb to each finger in rapid succession produced a more continuous blocking of the precental beta rhythm. The activity from the postcentral hand area showed a similar change.

In certain patients a few waves at about one half the beta frequency (about 12 per second) appeared shortly following relaxation of movement. Only regular beta waves were present during a sustained contraction such as during clenching of the fist. The initial blocking of the beta rhythm, however, was the same for the initiation of movement as it was for the relaxation of movement.

In certain patients the beta rhythms from the face area of the precentral gyrus was blocked with the hand area during initiation of a strong contraction such as clenching the fist suggesting some spread of the blocking effect throughout the motor system, possibly related to synergistic contractions. A lesser effect was also seen at times from movements of the ipsilateral side of the body, but the maximum effect was seen from movements of the contralateral part at the site of its representation as determined by electrical stimulation.

We have never observed an increase in voltage of activity from the precentral gyrus during voluntary movements. It would seem that the beta rhythm is characteristic of the activity of the ,,resting" motor cortex in a manner analogous to the alpha rhythm for the occipital cortex. Activation by voluntary movement seems, therefore, to block the beta rhythm in a manner similar to the well known effect of visual stimuli upon the occipital alpha rhythm.

Discussion.

We have been able to confirm in the conscious human subject the specificity of pattern of spontaneous electrical activity for certain given cortical areas but not in a manner which would make possible a differentiation into finely divided areas corresponding to a particular cytoarchitectonic schema such as that of BRODMANN or VOGT. As described originally by BERGER cortical areas giving rise to a dominant pattern of regular ten per second waves, the alpha rhythm, are very extensive indeed, certainly not confined to the occipital lobes. Rhythmic waves within the alpha range of frequencies were most rarely observed from the precentral gyrus and never from the anterior temporal region, or from the fusiform and hippocampal gyrus or uncus, beneath the temporal lobe. A regular alpha rhythm was occasionally recorded from the anterior frontal region but of low voltage and poorly sustained as compared to the posterior temporal, parietal and occipital regions where it was most prominent. The post-central gyrus is definitely not included in the „good" alpha areas, since the predominant activity here was also a beta rhythm, although more alpha waves were intermingled than in records from the pre-central gyrus. It would seem that the more rapid frequencies, with little or no alpha rhythm, arise from those areas from which motor responses can be elicited upon electrical stimulation. It is the sensory elaboration areas which give rise to the best alpha rhythm, and to a lesser extent the anterior frontal elaborative areas.

The blocking of the beta rhythm from a local area of the precentral gyrus during voluntary movement must be considered a form of activation which desynchronizes unit discharges to disperse the organization of activity making possible the regular rhythmic potential waves of the cortex at rest. The fact this effect occurs only upon the initiation of movement is of particular interest. This suggests that the motor cortex may be involved chiefly in phasic „voluntary" movement under normal conditions. It remains possible, however, that the rhythmic pattern of synchronous electrical activity which may return during a sustained contraction, after becoming desynchronized initially during the initiation of movement, does not truly represent a return to the resting state insofar as centrifugal discharge is concerned, but simply a state of equilibrium of activity permitting again a synchronization of unit discharge.

Of further interest is the observation in one patient that blocking of the precentral beta rhythm occurred before the actual initiation of the movement, in response to the command „get ready to move your fingers". The cortex showed evidence of the alerting signal before movement was initiated. No definite change in the record could be detected in this patient when he was asked only to imagine the movement. The blocking reaction of the precentral beta rhythm seems closely related to the mechanisms of attention or readiness to respond. This draws closer the analogy with the well known importance of attention upon the blocking of alpha rhythm from the parieto-occipital areas.

Conclusions.

Characteristic normal patterns of electrical activity obtained directly from the exposed normal human cerebral cortex are presented. The area of maximum alpha activity begins in the gyrus just posterior to the post-central gyrus and extends throughout the parietal, posterior temporal, and at least a portion of the occipital lobe. A lower voltage alpha rhythm may also appear in some subjects from the anterior frontal region. The more rapid frequencies characterize the sensory-motor regions. The precentral gyrus gives rise to a pure 25 per second beta rhythm which has enabled its location before identification by electrical stimulation.

Voluntary movement serves to block the precentral beta rhythm in a manner similar to the blocking of the occipital alpha rhythm with visual stimulation and attention. The blocking of the precentral beta rhythm occurs, however, only upon the initiation of movement and upon voluntary termination of a posture which the patient has assumed. It is not sustained during a maintained contraction such as clenching the fist, but blocking occurs at the beginning and cessation of the act. Sustained blocking occurs only with continuous consecutive movements requiring sustained attention. Blocking also occurs with preparation for movement or „readiness to move" before the movement actually begins.

These findings would be consistent with the suggestion that impulses reach the precentral gyrus at the beginning and at the termination of a posture that is assumed voluntarily.

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Zusammenfassung.

Charakteristische normale Formen der elektrischen Hirntätigkeit bei direkter Ableitung von der freigelegten menschlichen Hirnrinde werden beschrieben. Das Gebiet maximaler α-Aktivität beginnt in der unmittelbar hinter der Postzentralwindung gelegenen Hirnrinde und dehnt sich über den ganzen Parietallappen, den hinteren Temporallappen und zum mindesten einen Teil des Occipitallappens aus. Ein α-Rhythmus niederer Amplitude erscheint bei manchen Personen auch

in der vorderen Frontalregion. *Die sensomotorischen Regionen sind durch rasche Frequenzen charakterisiert.* Die Präzentralwindung zeigt einen reinen 25/sec-β-Rhythmus, der die Lokalisation dieser Windung schon vor der Bestätigung durch elektrische Reize erlaubt.

Willkürbewegungen blockieren den präzentralen β-Rhythmus in ganz ähnlicher Weise, wie der occipitale α-Rhythmus durch optische Reize und Aufmerksamkeit blockiert wird. Eine solche Blockierung der präzentralen β-Wellen entsteht jedoch nur bei Beginn einer Bewegung oder bei willkürlicher Beendigung einer bestimmten Haltung des Patienten. Die Blockierung hält nicht während einer dauernden Kontraktion, etwa beim Faustschluß weiter an, sondern entsteht *lediglich bei Beginn und Beendigung des motorischen Aktes.* Langdauernde Blockierung tritt nur bei fortgesetzten Bewegungen auf, die dauernde Aufmerksamkeit verlangen. *Die Blockierung findet sich auch bei Vorbereitung der Bewegung und „Bewegungsbereitschaft" schon bevor die wirkliche Bewegung beginnt.*

Diese Beobachtungen passen zu der Annahme, daß die Präzentralwindung von Erregungsimpulsen zu Beginn und Ende willkürlicher Haltungen erreicht wird.

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