HANS BERGER ON ELECTROENCEPHALOGRAPHY

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To anyone in the field of electroencephalography, there is no name more familiar than that of Hans Berger. Yet few have actually read his papers and thus have any accurate knowledge of his contributions to electroencephalography and of the motives that impelled him in his search for the human electroencephalogram. All of Berger's papers are written in a difficult and involved German and it is therefore understandable, at least in this part of the world that they are seldom read. There are, however, other more subtle reasons for this neglect. Berger's contemporaries looked upon him as an amateur, a hobbyist, and physiologists especially (perhaps because he had not come from their ranks) often affected toward him and his work an incredulous, we-know-it-all-better attitude. Although the scientific community had to acknowledge Berger's merit in discovering the human electroencephalogram, he is often credited with little else beyond the mere fact of having somehow stumbled upon his discovery. What a different story unfolds, though, when one takes the trouble to read Berger's original papers! No doubt, he laboured under some handicap, because he was primarily a clinician and not a physiologist. In some ways, however unconsciously, he turned his handicap into his prime asset, and this for two reasons. Firstly, he was less prone than a pure physiologist to be overwhelmed by the magnitude of the problems of recording bioelectrical potentials from the human brain. The pure physiologist, in all likelihood, saw no merit in such an attempt. How much easier it was to record action potentials from peripheral nerves! Why bother with the human brain, the complexity of which would defy any intelligible analysis? Berger had no such inhibitions. Secondly, Berger was acutely aware that the professionals would try to dismiss his findings as artifacts on the basis of their technical know-how. He therefore obsessively and painstakingly investigated and eliminated with Teutonic thoroughness all causes of artifacts. He thus succeeded in proving the cerebral origin of the waves he recorded and of disproving all possible extra-cerebral or artifactual sources.

To understand Berger's work and his very personal and original approach to electroencephalography, it is necessary to know about his origins.

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1 Editor's Note: This paper embodies the main remarks of the author's address at the annual banquet of the American Society of EEG Technologists at Atlantic City, New Jersey, on June 9, 1967. The American Society of EEG Technologists and The American Journal of EEG Technology are privileged to have this significant contribution to the historical literature submitted for publication. — (D.M.B.)

2 The author acknowledges his indebtedness to Dr. R. Jung, Freiburg i. B. and Dr. R. Werner, Jena, for the biographical data and the quotations from Berger's diary appearing in this article. Most of these were obtained from the two following sources: 1) R. Jung: "Hans Berger und die Entdeckung des EEG nach seinen Tagebuechern und Protokollen", in R. Werner (ed.) "Jenenser EEG Symposium. 30 Jahre Elektroencephalographie", VEB Verlag Volk und Gesundheit, Berlin 1963. 21-53; and (2) R. Werner: "Hans Berger zum Gedaechnis", ibidem 13-19.
and the time he lived in. Hans Berger, son of a physician and grandson, on his mother's side, of the well-known German poet, Friedrich Rückert, was a typical product of the Germany of the late nineteenth century, into which he was born in 1873. His physician-father and his maternal poet-grandfather can almost be taken as symbolizing the main cultural currents of this age of German history. They shaped Berger's personality and outlook. There was in Germany at that time a vigorous blossoming of natural sciences, of which medicine formed an integral part, but there was also a romantic striving for the realm of poetic myths, where free reign was given to the heart and mind to explore spiritual realms, believed to be hidden behind the cold realities of the objective world. More than elsewhere in the Western world, these two currents of human thought co-existed in Germany. Berger throughout his life exemplified this characteristic German dichotomy. As a youth he was intensely interested in natural sciences and mathematics. He was also extremely fond of poetry and loved to read philosophical books. While serving on the Western front with the German Army in World War I, he avidly read Spinoza, Kant and Renan's *Life of Jesus*. For him, as for many of his German contemporaries, there was no gulf separating two cultures, the scientific and the poetic-philosophical. To him this was all one world. As a teenager he devoured a book dealing with the body-mind problem, which he had found in his mother's library. This question was to absorb his interest throughout his life. It prompted him in his student days to abandon astronomy for medicine and later to become a psychiatrist. The theme of the psycho-physical relationships runs as a "Leitmotiv" through all his writings, including those on electroencephalography. Physiology interested him only insofar as it held out some hope to clarify the connection between the material and spiritual. To him, the soul was no independent entity but a reality somehow mysteriously connected to the material physiological processes of the brain, especially its cortex. The search for this mysterious connection was the motive for all his studies on the human EEG; everything else was subordinate to it. This single-mindedness explains why Berger, although he obviously saw in the electroencephalogram most of the features with which we are now familiar, looked upon them with quite different questions in mind than those we ask ourselves today. He was not interested in localizing lesions; the EEG interested him as the expression of the integrated activity of the whole brain. This is why, even in his later years, he persisted in recording only with one or two channels, usually between a frontal and an occipital electrode, and why he made no attempts to localize with precision the site of origin of any abnormality, except in one case, that of a woman suffering from focal motor seizures, which he describes in great detail in one of his papers. But even there, the focal discharge was studied insofar as it could elucidate more general problems of brain function.

On the other hand, Berger was intensely absorbed by the changes in the EEG accompanying alterations in the psychological state, both normal and abnormal; hence, his studies on attention and its effect upon the EEG, as well as his investigations on the EEG changes in general anesthesia, insulin coma, asphyxia, epilepsy, postictal coma and stupor and various forms of dementia and psychosis.

Berger joined the Psychiatric Clinic of the University of Jena as a junior staff member in 1897 at the age of 24. Right from the start, he was some-
"Reproduction of a page from Hans Berger's protocol book describing one of his first recordings of the EEG with clay electrodes. The circle outlines a post-operative skull defect. The two brush-like electrodes are placed within the confines of this defect. The entry is dated June 28, 1924. (Courtesy of Prof. Richard Jung, Freiburg im Breisgau, from R. Jung, "Jenenser Symposion" VEB Verlag Volk and Gesundheit, Berlin, 1963)."
what isolated in his interests, which were oriented towards psychophysiolog-ical investigations and not, as was fashionable at the time, towards the morphological study of the central nervous system or the phenomenological analysis of psychiatric syndromes. There was then little interest in the questions which Berger intended to investigate. He first hoped that by studying cerebral circulation and changes in brain temperature, he might be able to approach some basic questions of psychophysiology. His quest was for what he conceived as “psychical energy”—a concept he had borrowed from the Danish psychophysiologist, Lehmann. This term is frequently mentioned in his diary, of which excerpts have recently been published by Jung, but one does not find it in his papers on the electroencephalogram, except once in the altered form of “psychophysical energy”. The concept was based on the notion that metabolic energy in the brain is converted partly into heat, partly into electricity and partly into “physical energy”. Berger hoped that by measuring the heat and electrical output of the brain, the third variable, psychical energy, might ultimately become indirectly measurable by extrapolation. Berger soon realized that his studies on brain circulation and brain temperature were too crude for such an ambitious purpose and thus in 1902 he attempted for the first time to record electrical potentials from the brain of experimental animals. This work was performed in the basement of the Hufeldhaus, an annex to the Clinic. The records were taken with a string galvanometer, but many of them were not very satisfactory to Berger and he became discouraged because of his frequent lack of success in obtaining useful records. Eight years later in 1910, he decided to abandon his attempts at recording the electrical activity from the brain of experimental animals. An entry in his diary, dated November 30, 1910, reads as follows: “Of nine experiments, one success and even this one rather doubtful, because in this case skin currents could not be excluded in the experiment. One can therefore not say that I gave this thing up lightly. Eight years! Trying always again and again.” A few days later he noted in his diary: “I definitely plan to finish up the experiments on the cerebral cortex of dogs” and then he adds: “Observations on man”.

Only fourteen years later, in 1924, was Berger able to carry out this intention. The First World War interrupted his scientific studies. Immediately after the war, in 1919, he succeeded Binswanger as Chairman of the Department of Psychiatry at the University of Jena. It was Berger’s good fortune that in the years following the war, many patients with skull defects were available for study. Also Guleke, the Professor of Surgery at Jena, was interested in neurosurgery and provided him with a number of patients with operative skull defects. In 1924, Berger started to investigate these patients, first by stimulating the cortex extradurally in the area of the trephine opening and recording the electromyogram. His interest soon shifted towards the problem of recording the electrical activity of the brain itself. This most important decision of his life is recorded in his diary only in a very brief, partially stenographic entry, dated June 2, 1924. It reads: “The idea to search for cortical currents in humans with palliative trepanations.” From then on, this search was to be an uninterrupted endeavor for 14 years. Berger was then 51 years old when he started in earnest to look for the human electroencephalogram. His early studies on man were again done in the base-
ment of the Hufeldhaus but soon he set up a laboratory next door to the Director’s Office in the main building of the Clinic. Recordings were always done late in the afternoon and all electrical machinery and equipment in the main and adjacent buildings had to be turned off to avoid contamination of the record with artifact. Fortunately for Berger, the main supply line delivered DC power. The first records were taken with a string galvanometer and without polarizable clay electrodes put on the skin over the skull defect. Later, subcutaneous needle electrodes or extracutaneous lead or silver foil electrodes were used. The string galvanometer was subsequently replaced by a more sensitive coil galvanometer and in still later years by an oscillograph, with amplifier, especially constructed for Berger by Siemens. All records were taken on photographic paper, upon which a light beam was projected by a moving mirror. The movements of the latter reflected the fluctuations of the cerebral potentials. Berger never abandoned this photographic recording method, even in later years, when the ink writing apparatus had been developed by Tönnes. Since Berger was able to acquire only one oscillograph, many of the two channel recordings are written with different amplification, side by side, with a low gain one taken with the coil galvanometer. On July 6, 1924, when attempting to take a record with clay electrodes from the skin covering a postoperative skull defect in a 17 year old patient, Berger observed for the first time small tremulous movements of the galvanometer string, indicating the probable presence of brain waves. The search continued with better success and after many periods of near-despair, when Berger was ready to give it all up again, he had finally convinced himself that potential fluctuations of genuinely cerebral origin could be recorded, not only from the area of the skull defects but also extracranially in people with intact skulls. After five years of work and innumerable checks and counterchecks on all possible sources of artifacts, Berger finally, in 1929, published his first report on the human electroencephalogram, in the “Archiv für Psychiatrie und Nervenkrankheiten”. In it he described the alpha rhythm and beta rhythm—terms which he introduced, however, only in his next publication one year later. This first paper, like all of his subsequent ones, is an intensely personal document. There is no hiding of all the agonies of doubt and vacillations that went through his mind before he had satisfied himself that his conclusions were well-founded. In the light of today’s scientific papers, the style is rather unusual and undoubtedly the Editor of the EEG Journal, if he were to receive Berger’s papers for publication today, would straightaway send them back to the author with a request for “extensive revision.” Berger wrote, essentially, straight from the heart. His very personal, human and passionate involvement is never hidden behind an artificial facade of scientific coldness. In his later papers he often covered familiar ground again, to counter some criticism or misconception that had meanwhile been voiced and which he felt he could not leave unanswered. For Berger, who out of extreme shyness hardly ever attended any scientific meetings, pen and paper and the printed page were the media through which he felt capable of getting into the fray of a scientific debate. Being thus physically shielded from his potential opponents, he could engage in an argument without feeling inhibited. This explains the unique style of his writings.

Of Berger’s main contributions to electroencephalography space allows mention of but a few.
In many ways, his first paper is the most fascinating one. In meticulous, carefully designed experiments, Berger proved that the waves he later was to describe under the names of alpha and beta waves cannot be attributed to any vascular, circulatory, cardiac, respiratory, muscular or cutaneous currents nor to vibratory movements of the head. He proved that, therefore, they can only originate from the brain and that they constitute in the true sense of the word, the electroencephalogram of man. In doing these experiments, Berger clearly identified the most common artifacts that may contaminate an EEG record.

Berger's second major contribution was the EEG study of the phenomena of attention. This was based on the simple observation that any stimulus that engages the subject's attention arrests the alpha rhythm. Berger recognized that this phenomenon had nothing to do with sensory, even visual stimulation as such, but represents a diffuse cortical response, signaling an increase in the level of attention. He showed that any increase in attention, e.g., the performance of mental arithmetic, elicits this reaction. He explained this response as a consequence of a diffuse inhibition of the alpha generating mechanism of the cortex. His theory was that any focusing of attention requires a narrow concentration of ganglionic activity upon the small cortical area, subserving the recording of and the response to a particular event and that the remainder, i.e., the majority of cortical elements, had to be simultaneously inhibited. Only by creating such a contrast, a "potential difference" or "gradient", as he called it, between a focus of increased activity emerging from an inhibited surrounding, was a sensory or psychological event sufficiently distinct to be consciously perceived with clarity and attended to. Berger spoke of "a narrowness of consciousness" at the time of attentive behavior, during "which all other psychic processes are simultaneously shut off", this shutting off becoming visible in the arrest of the alpha rhythm, exemplifying the widespread cortical inhibition that takes place under such circumstances, the small focus of increased activity being usually missed in the human EEG.

In his ninth paper, Berger goes even one step further in discussing this problem and says:

One would have to assume then as a second condition for the occurrence of conscious phenomena that resistance exists against the tendency to equalize this potential difference. This equalization probably occurs in an oscillatory manner and takes, as one may conclude, for the duration of the principal oscillations of the EEG a minimal time of about 25-50 sigma. To this event corresponds the mental process. We can go one step further and assume that in this leveling of potential difference, which meets a resistance, a transformation perhaps of the electrical potentials takes place into that which Kurd Lasswitz designated in a preliminary manner, with the general expression of psychophysical energy, assuming that the conscious processes are immediately connected to this. This psychophysical energy is immediately reconverted and leaves physiological traces behind in the form of structural changes of the cortex and of the central nervous system in general. In time there occurs a continuously progressing alteration of structure and thus, psychophysical processes are laid down in material form in the brain. Only the way through this psychophysical energy leads to such structural changes, which in the case of repetition of the mental processes can influence new processes to a marked degree. As Lieder has discussed it in such an excellent way, the central nervous system, especially the cortex, thus undergoes in the course of the individual life, an historical evolution, which cannot be reversed.
Some of these ideas are living or hotly debated concepts in modern neurophysiology. That the arousal response of the cortex is dominated by inhibitory events in cortical cells has recently been beautifully shown by Klee. That contrast, we would perhaps prefer to call it the signal-to-noise ratio, is important for the analysis of incoming messages at the cortical level and probably, hence, for perception, is now amply documented. The principle of the inhibitory surround, as a fundamental mechanism for discrimination is equally well-known, although the scale upon which we now apply these concepts is much more microphysiological than Berger envisaged it.

It is fascinating that as early as 30 years ago Berger already speculated about the possibility of permanent structural changes being induced by ongoing cortical activity, a concept which is looked upon as very avant-garde today.

A corollary to Berger’s concept of diffuse cortical inhibition in attention states was that of disinhibition occurring in some normal conditions, such as sleep and in some pathological states, such as barbiturate anesthesia, hypoxia, insulin coma and generalized seizures due to “genuine” epilepsy. To understand this concept, it is necessary to sketch the role in the regulation of cortical activity which Berger attributed to the thalamus, or nearby upper brainstem centers. Berger thought of the cortical alpha rhythm as a diffuse and homogeneous cortical process driven by a subcortical pacemaker in the thalamus or nearby upper brainstem. According to Berger, this thalamic pacemaker under ordinary circumstances exerts some restraining or inhibitory effects upon the cortex and at one point he indicates that the more powerful inhibition during attention probably also originates from the upper brainstem—prophetic words again! Berger thought that under certain conditions this regulating or restraining influence exerted by the thalamus is switched off, resulting in diffuse cortical disinhibition. This state is signalled in the EEG by the onset of what today we would call diffuse slow wave activity. Berger described it, however, as a disturbance in the normal regulation of alpha waves, resulting from the removal of the normal thalamic regulatory control. Under these conditions, alpha waves were thought to occur precipitously, thus fusing into groups, appearing as slow waves, with superimposed ripples. Sleep is an example of such activity. Diffuse cortical disinhibition, according to Berger, leads to unconsciousness, because of lack of a proper “potential gradient” in the cortex. There are no longer circumscribed areas of activity clearly delineated by an inhibitory surround. Perception, discrimination and thus consciousness are lost. This situation can also result from pathological conditions, such as anoxia and hypoglycemia or can be brought about artificially by barbiturate narcosis. In all these conditions, the thalamic pacemaker is switched off and the cortex disinhibited. A similar situation is responsible for the sequence of events characterizing the generalized tonic-clonic seizure of “genuine” or idiopathic epilepsy. Here again, the primary event is an active switching off of the thalamic pacemaker which leads to diffuse cortical disinhibition and seizure activity. Diffuse cortical disinhibition manifests itself not only in the EEG, but also in the periphery by myoclonic movements, which can be seen in sleep, anoxia, insulin coma and during the induction stage of anesthesia. The myoclonic
features of minor seizures in idiopathic epilepsy have a similar origin and in the major tonic-clonic convulsion these manifestations reach an extreme form.

During the last few years of Berger’s active life, recognition came at last. A trip to Paris in 1937 to the International Psychology Congress was the high point of his career. He was rather bewildered by the realization that he had become an international celebrity. “In Germany I am not so famous”, he is reported to have remarked on this occasion. Shy as he was, even there he shunned the limelight and people who wanted to talk to him had to hunt him up in his hotel room. Soon after the Paris triumph, tragedy struck; on September 30, 1938, while making rounds in his Clinic, he was called to the telephone. He was informed abruptly that on the next day, October 1st, he was to resign from his post as Chairman of the Department and to turn over the affairs of his Clinic to his successor, since he had reached retirement age. The blow was stunning not only because it was unexpected but also because it was administered in such a rude and brutal manner. He never recovered from it. The brutality was probably intentional; it is likely that the move was directed by Nazis, who had by then infiltrated the University administration. These people had no particular liking for Berger, who, as they knew, had no use for their barbaric brand of political philosophy. Berger left the Clinic as he was ordered. His laboratory was dismantled by his successor and Berger was thus deprived of all means to continue his research on the human electroencephalogram. He retired to a small Thuringian town. In 1941 he fell victim to a depression, which he mistook for a cardiac condition. On May 20, 1941 he wrote the following entry (which was to be his last) into his diary: “Tuesday, on my desk at 10:00 o’clock. I try again and again to get out of bed, after having been laid up for more than 8 weeks. I have behind me days of despair, in which I yearningly wished for my early end. I have sleepless nights during which I keep brooding and struggling with self-accusations. I am unable to read or work in any organized way, but I want to force myself, for like this it is unbearable . . .”

“All the loved ones write to me so kindly and send me good wishes and flowers. B.B. v.E. and also Mrs. v.L., Ursula and Ruth look after me so touchingly. I am often so full of despair and impatient. I have read all papers on EEG and made abstracts. Kornmüller is reprimanded often and from many sides. I have read Napoleon’s memoirs (10 volumes), which interested me very much. I have wonderful flowers near my bed, which make my heart heavy, but patience, little brother”. Here ends Berger’s diary. Ten day’s later, in a fit of depression, he took his own life. He was buried in the cemetery behind the Friedenskirche in Jena, near the place where he had worked for so many years.

It is hoped that this tribute to the father of electroencephalography has succeeded in letting the reader share some of the fascination and excitement that exude from his writings. Those who are of the second generation can only recapture the atmosphere of those days through this medium. Berger’s papers, because they are so personal, are uniquely suited to bring alive those early years of electroencephalography.