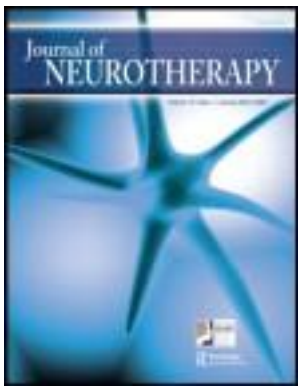

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The History of EEG Hans Berger

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The History of EEG
Hans Berger: Psychophysiologist.
A Historical Vignette

T. J. La Vaque, Ph.D.

Historically, Hans Berger deserves undisputed credit for the discovery of the human electroencephalograph. It is rarely reported that his discovery was the result of a 40-year search for the physical basis of mind. The search began as a result of a near-death "telepathic" experience in his youth. The history of Hans Berger reveals him to be a dedicated scientist fascinated with psychophysiology and, in the end, a tragic figure.

It is impossible to examine the history of electroencephalography without recognizing the German physician, Hans Berger (1873-1941) as the individual singularly responsible for the discovery and development of human brain wave recording. This is the history of an individual who was regarded by his peers as a rather indifferent psychiatrist, something of a pedant, an individual for whom routine was so invariant that one of his colleagues stated that "His days resembled one another like two drops of water." (Ginzberg, 1949) It is the story of a man who pursued his goal with an obsessive single-minded persistence for more than 40 years, who finally achieved success, only to have circumstance and world events remove him from the position of influence and recognition that he so richly deserved. It is a story that ends tragically with his suicide at the age of 68.

Berger's extraordinary contribution to the study of brain function came about, not because of an interest in neurology or psychiatry, but as the result of his nearly obsessive search for the physical basis of mind. His early academic interests certainly had nothing to do with psychophysiology. Biographers differ about Berger's early scientific interests. According to Pierre Gloor, Berger entered the Berlin University in 1892 to study astronomy. (Gloor, 1969) According to a contemporary of Berger's, Raphael Ginzberg, Berger's initial interests had been mathematics and physics. (Ginzberg, 1949) Whatever his original intent had been, Berger's life was changed dramatically by a traumatic experience that catalyzed his lifelong search for the physical basis of mind.

In the spring of 1893, just before his 20th birthday, Berger was serving his duty as a volunteer in the German army. One morning he was participating in training maneuvers when his horse stumbled and lost balance. Both he and his horse were thrown down an incline to fall beneath the rumbling wheels of a large artillery piece, drawn by six dray horses. Berger later acknowledged that he knew that was to be the moment of his death. By whatever fateful circumstance, young Berger barely escaped being crushed beneath the huge wheels. On that evening, he received a telegram from his father inquiring about his well-being. The inquiry was the result of an agitated concern expressed by his older sister, who told their parents that "she knew with a certainty" that Hans had suffered an accident. She was so insistent that she caused Berger's father to send the telegram. Over 40 years later, Berger still had no doubt this event represented a true telepathic experience. "This was a case of spontaneous telepathy in which at a time of mortal danger as I contemplated certain death, I

transmitted my thoughts, while my sister, who was particularly close to me, acted as the receiver." (Berger, 1940, quoted in Gloor, 1969, p. 2)

That event apparently had a profound impact upon him. Upon his return to his studies later that year, Berger switched to the study of medicine, with a specialty in what then was known as neuropsychiatry, studying first in Würzburg, then Munich, Kiel, and Jena. He received his doctorate in medicine four years later, in 1897, and took a position as a junior staff member at the Psychiatric Clinic of the University of Jena. There he remained for 41 years until his retirement in 1938, at the age of 65, having served as Dean of the Medical School, Rector of the University, and finally, director of the hospital. Despite his tenure, his colleagues did not regard him in high favor for his scientific or psychiatric skills. In fact, Ginzberg described Professor Berger as "shy, reticent, and inhibited" and "obviously fond of his instruments and physical apparatus and somewhat afraid of his patients". According to Ginzberg, the medical faculty also looked upon him with some disfavor when they felt he used political means to obtain an appointment as *professor ordinarius* to succeed his well-regarded predecessor, Otto Binswanger, who was described as "brilliant" and having an "overwhelming personality". A greater contrast in personalities than that between Binswanger and Berger would be difficult to imagine.

For the most part, Berger was a non-controversial figure in his own community. Ginzberg describes him as a "good" German who appeared more like a Prussian officer than physician, except for his short and stocky build. He had three daughters and a son, and it was his habit to take daily walks with his family, "the children walking in front and the tall mother and stocky father bringing up the rear". His biographers again seem to differ with regard to Berger's political attitudes... Ginzberg described him as "a reliable member of the Nazi community", while Gloor stated that Berger disliked the Nazi's, and "they retaliated by disparaging his work". In any event, the rise of the Third Reich and the further isolation imposed upon Berger with the advent of World War II would ultimately have catastrophic consequences for him.

Although Berger published several papers that were primarily neuroanatomical in nature, he never swerved from the original purpose for which he entered the study of neuropsychiatry, i.e. his fascination with psychophysiology and the "mind-body problem". Berger's tenacity was extraordinary. His clinic and administrative duties frequently interfered with his investigations, but he persistently returned to his search for the material representation of mind. His attempt to study consciousness and brain function was of course limited by the technology available to him. He used such primitive techniques as cerebral plethesmography, the measurement of cerebral circulation, and the recording of brain temperature during mental effort.

By any measure, Berger should never have succeeded. It is difficult to appreciate the technical limitations under which he worked. The technology available for bioelectric recording was extremely primitive and relatively insensitive. In addition, he operated outside of the scientific mainstream, apparently uninfluenced by the scientific *"zeitgeist"* that shapes the politics of science. He worked in such isolation that even his colleagues didn't have a hint of his activities. Again, according to Ginzberg: "His closest hospital and university associates were permitted no glimpse of the work Professor Berger carried out in strict privacy. To his own staff the man now universally recognized as one of the great scientists of his time remained primarily a personification of rigid discipline and devotion to routine. He was credited with little scientific or psychiatric insight." (Ginzberg, 1949) His methods bore little resemblance to work being done by others and so, when he finally did begin to publish, no one took particular note. His work was so far out of the mainstream that it required *five years* and eight scientific reports "On the Electroencephalogram of Man" before an established British neurophysiologist (Edgar D. Adrian, or Lord

Adrian, Baron of Cambridge) set out to debunk his work, and instead replicated the phenomenon of "The Berger Rhythm." (Adrian & Matthews, 1934a)

Berger was most certainly aware of earlier reports regarding electrical activity of the brain. In 1870 two German researchers (Gustov Fritsch and Eduard Hitzig) demonstrated that the brain was responsive to electrical current when they stimulated the sensory-motor cortex of a dog and produced movement. Caton, an English physician, had reported the results of his work demonstrating the presence of electrical activity in exposed rabbit brain in 1875. The Russian physiologist Napolean Cybulski provided evidence of the electrophysiological nature of seizure using a dog, and Pravdich-Neminsky published recordings of electrical brain activity from exposed dog brain preparations in 1912. Pravich-Neminsky coined the term "electrocerebrogram", a term which the meticulous Berger later rejected as a "linguistic barbarism." (Berger, 1929; Niedermeyer, 1993)

The available technology was hardly conducive to electrophysiological research. Electrophysiologists were restricted to the use of "string galvanometers", most frequently used in clinical settings to record electrocardiograms. The device used a magnetic coil principle which, when current passed, set up a vibration in a quartz fiber. In order to obtain a permanent record with time markers available, a mirror was attached to the "string", and the minute vibrations were reflected to a strip of photographic paper moving at a constant speed inside of a light-tight chamber. Berger began using a string galvanometer in 1910. Prior to that (1902-1910) he employed a device known as a capillary electrometer while unsuccessfully attempting to record electrical activity from the brain of a dog. In 1926 Berger obtained a double coil galvanometer, which was more sensitive and aided his observations. Finally, in 1932 he received an oscilloscope for use in his laboratory. From that time on, he was forever limited to two-channel EEG records, one channel recorded with a relatively primitive galvanometer, the other with a "modern" oscilloscope. Since he could never quite align the two channels, the records look rather odd, with hand-drawn lines interposed to show the temporal correspondence between channels.

Thus, for almost 30 years, Berger searched for a means of measuring the "energy of mind". In 1924 the idea occurred to him to attempt electrical recordings from patients who had undergone "palliative trepanations" (trephinations), a surgical procedure which opened the skull to relieve intracranial pressure associated with inoperable tumor growth. He identified other patients with traumatic "skull defects" as well. Such individuals appeared to be relatively available due to injuries sustained in World War I and common equestrian accidents. He reasoned that since there was a relatively thin sheath of tissue covering the trepanation site or the site of other skull defects, the problem of measuring weak electrical activity might be simplified. Finally, on July 6, 1924, while recording from the skin overlying a trepanation site in a 17 year old patient, Berger recorded minute, almost microscopic vibrations of the galvanometer mirror. Those vibrations heralded, for the first time in history, the presence of electrical activity recorded from the human brain. One can only imagine Berger's reaction when he sensed that he was, after decades of failure, successfully recording human electrical brain activity and tapping, perhaps, the energy of mind.

Still, very few people had even a hint of his activities. Berger's attention to detail was matched by his secrecy. As noted previously, Berger was a shy, retiring, and somewhat insecure man. He could not tolerate the idea that others might show his findings to be the result of artifact. He thus spent an additional and, in current terms, rather unbelievable five years assuring himself that the phenomenon he was measuring was not due to some non-cerebral artifact, such as brain pulsation, electrical activity associated with blood movement within the blood vessels of the brain, or even electrodermal or electromyographic sources. He developed different recording techniques that did

not rely upon the presence of bone defects. One method, which he used frequently, relied upon the insertion of needle electrodes beneath the scalp to the periostium, the thin sheath that covers bone. In one experiment, he inserted recording needles to the surface of his own tibia, "as far as the bone", to demonstrate that the phenomenon he was recording was not due to electrical activity at the interface of soft tissue and bone. The recording technique improved over the years, until he was using saline electrodes placed at the frontal and occipital regions, using a bipolar recording technique. As he became more confident with his technique, he incorporated the help of a few colleagues and his own son, Klaus, as subjects in his laboratory.

Finally, in 1929, at the age of 56, Berger published his first report. (Uber das elektrenkephalogramm des Menschen... "On the Electroencephalogram of Man") Between 1929 and 1938, Berger published 14 more papers, each with exactly the same title, distinguished from one another only numerically. (Second Report, Third Report, etc) In 1969, Pierre Gloor published english translations of Berger's 14 primary papers (Gloor, 1969) to celebrate the 40th anniversary of Berger's first publication. We are indebted to Gloor's scholarly work, for without it so many would be barred from the opportunity of reading Berger's work. Berger wrote in an era before the demand of journals for standardized report styles structured as "Introduction, Method, Results, and Discussion" sections. As a result, his papers are almost conversational in character, and provide a wonderful insight into both the work and the man, from the evident pride in his announcement of the human electroencephalogram in the first paper to his equally evident irritation with critics in his last paper of 1938. In order to preserve the sense of the man and his work, the rest of this paper will include many direct, sometimes lengthy, quotes from Berger's papers, as translated by Gloor.

Berger's work went far beyond the simple description of the EEG, and extended all of the way to the first attempts to quantify the EEG using Fourier analysis in an attempt to identify meaning in the mathematically defined "subgroups" of the waves he had discovered. Thus, Berger would clearly understand the current development of quantitative EEG. His work includes many neurological observations, but these occurred simply as a by-product of his interest in psychophysiology.

"Because, for linguistic reasons I hold the word 'electrocerebrogram' to be a barabarism, compounded as it is of Greek and Latin components, I would like to propose, in analogy to the name 'electrocardiogram', the name electroencephalogram for the curve which here for the first time was demonstrated by me in man. I therefore, indeed, believe that I have discovered the electroencephalogram of man and that I have published it here for the first time." (Berger, 1929)

By any account, one would have expected this announcement by the 56 year-old Berger to have taken the research world of neurophysiology by storm. Instead, his work was either ignored or was met with disbelief. He provided a fairly detailed account of the history of his discovery, and provided substantial technical information for those who would replicate his work. In his first report he described two characteristic wave types, the larger with a slower time course and the shorter with a more rapid one.

"From the beginning, this was my hope: That it would become possible to record from the human scalp with an intact skull the oscillations of the electrical current which can be obtained from animals from the surface of the brain and in humans with bone defects from the epidural space, and thus to fulfill what ***Fleischl von Marxow*** *had said: 'It may even become possible by taking records from the scalp to perceive the currents generated in our own brain by various mental acts'...."*

Berger described in detail the many procedures he used to eliminate any artifact as the source of the curious waves he was recording. He again described the "larger and slower" waves and

differentiated them from the "smaller and faster" waves, initially referring to them as "waves of the first and second order". The beginnings of his decision to name the frequencies is found in this passage of his first paper:

"Of many investigations I select only those of P. Hoffman and H. Strughold. They studied in man by means of action currents the voluntary innervation in movements at the elbow joint and found that a double rhythm of the action currents can be demonstrated. They distinguish between a rhythm A and a rhythm B."

At the very end of his first paper, Berger again focused on the psychophysiological implications of his findings:

"I am inclined to believe that with strenuous mental work the larger waves of the first order with an average duration of 90 σ are reduced and the smaller 35 σ waves of second order become more numerous. Especially in experiments on my son Klaus I gained the impression that with exacting intellectual work, even with just a high level of attention, the smaller and shorter waves predominate." (Berger, 1929)

We see, in his second report, the historic introduction of symbols and abbreviations that continue to be used by everyone working with brain wave recording.

"For the sake of brevity I shall subsequently designate the waves of first order as alpha waves = α-w, the waves of second order as beta waves = β-w, just as I shall use 'E.E.G.' as the abbreviation for the electroencephalogram and 'E.C.G' for the electrocardiogram."

Berger's work was so voluminous, so detailed, that it is impossible to summarize his work in this paper. Despite the lack of any response or recognition of his work from the larger scientific community, Berger continued to publish and expand his investigations of human brain function using the electroencephalograph. The breadth and scope of his work is astonishing. He examined the obvious and technical aspects of the E.E.G., such as different types of electrodes, different recording sites, and bipolar vs. unipolar (referential) recordings. His laboratory was the first to quantify the E.E.G. using Fourier analysis (Berger, 1932b; Berger, 1934b; Berger, 1938) and the first to examine the effects of maturation on the E.E.G.. (Berger, 1932a) He reported what now would likely be called the "interhemispheric asymmetry" associated with neuropathology ("...there is a disturbance in the coordination of the activities of the right and left cortical areas...") and he described the cortical areas as normally "marching in step." (Berger, 1933a; Berger, 1933b; Berger, 1936) He investigated the effects of drugs and general anesthetics (Berger, 1931; Berger, 1934a; Berger, 1937a), "slowing" of the E.E.G. in brain pathology (Berger, 1931; Berger, 1932b; Berger, 1937b), epilepsy (Berger, 1931; Berger, 1932b; Berger, 1933b; Berger, 1934b; Berger, 1936; Berger, 1937b; Berger, 1938), sleep (Berger, 1931), and psychopathology (Berger, 1931; Berger, 1937b).

Berger consistently returned to the issue of identifying what those various states of altered consciousness or pathological states indicated about human beings as psychophysical beings. He continued to be particularly interested in the influence of attention and problem solving on the E.E.G.. (Berger, 1929; Berger, 1930; Berger, 1931; Berger, 1932b; Berger, 1934b; Berger, 1937b; Berger, 1938) He was as aware of the research of the experimental psychologists such as Wundt and Helmholz as he was of the research in neurophysiology and neurology. He saw the "waxing and waning" of attention described by Wundt as consistent with the continual shifts between α-w and β-w he identified. (Berger, 1932b) It is fascinating to observe that the same aspect of the E.E.G. continues to be investigated to this day. (Makeig & Inlow, 1993)

Finally, in 1934, his work received recognition as the result of a replication of his findings by neurophysiologists of international repute. It is fairly clear that Adrian and Matthews

had set out to "debunk" Berger's work, only to discover that his observations were correct. It is probably the attitude initially expressed by Adrian and Matthews that represented one of Berger's greatest fears, and why he spent so many years convincing himself of the validity of his work. Adrian and Matthews' publication represented both a vindication of his decades of work and a challenge to his place as the singular expert in the study of E.E.G. Adrian and Matthews wrote:

".... a number of workers have recorded the potential changes which take place in the exposed cortex of animals. Their findings have been difficult to reconcile with Berger's as the potential changes have been much less regular and have rarely shown any sign of a persistent rhythm at 10 a second. Our own work (Adrian & Matthews, 1934b) led in the same direction. We found it difficult to accept the view that such uniform activity could occur throughout the brain in a conscious subject, and as this seems to be Berger's conclusion we decided to repeat his experiments. The result has been to satisfy us, after an initial period of hesitation, that potential waves which he describes do arise in the cortex." (Adrian & Matthews, 1934a)

Adrian and Matthews replicated Berger's work, and also immediately engaged him in a controversy that irritated Berger. Berger had insisted that the alpha rhythm arose equally from the entire cortex. Adrian and Matthews disagreed, and immediately even attempted to change Berger's terminology. "Since the effect is so characteristic we shall refer to it in the future as the Berger rhythm. Berger calls it the electroencephalogram, but the shorter title avoids the suggestion that the rhythm is produced by the entire cortex." (Adrian & Matthews, 1934a)

Berger would have none of it:

"I disagree with the statement of the English investigators that the E.E.G. originates exclusively in the occipital lobe. The E.E.G. originates ***everywhere*** *in the cerebral cortex.... In the E.E.G. a* ***fundamental function*** *of the human cerebrum intimately connected with the psychophysicial processes becomes visibly manifest. This is clearly demonstrated by the above discussed close relationship of the E.E.G. with the processes of attention, which represents the most important psychophysical function. I therefor also consider it more correct to retain the term E.E.G., which I coined as the discoverer of these potential oscillations in man, rather than to exchange it for the term* ***Adrian and Matthews*** *have chosen and by which I feel greatly honored."(Berger, 1935)*

Once Adrian and Matthews replicated Berger's work, there was an immediate international response. E.E.G. "centers" began to appear in the United States and Europe, most particularly England. Many of the first reports from those centers were merely replications of data already reported by Berger, but that was a necessary process in order for the rest of the neurophysiological communities to "catch up" to Berger's decades of work. Berger was now 62 years old, and had devoted his entire professional life to his interest in psychophysiology. He was also a meticulous scientist, and never strayed from what he considered the "right path" of the natural sciences. He had almost single-handedly discovered and researched and developed the surface E.E.G., working for years in relative isolation. Thus, when others produced reports that were, in his view, erroneous, his impatience became increasingly evident in his writing:

"Extreme caution is in order when one interprets the curves, as I have learned from eleven years of experience, and in particular much consideration has to be given also to the ***psychophysical*** *conditions under which the E.E.G. is recorded. I shall presently show that even excellent physiologists have made the most serious errors when they failed to take into account precisely those psychophysiological factors." (Berger, 1935)*

And finally:

"From the beginning of my investigations

in 1924 I always endeavored to show that even when recorded from the skull or from the scalp, the E.E.G. reveals the potential oscillations of the brain and more specifically those of the ***cerebral cortex.*** *Since 1929 in my numerous publications I have time and again demonstrated this by means of records. In 1931 (Third Report, Vol. 94, p. 130, Figure 30) in a recording taken from the cortex and from the hemispheral white matter of the human cerebrum, I demonstrated again that the E.E.G. as I describe it originates from the cerebral cortex itself.." .."In spite of this it is repeatedly being stated, and this always by the same people, that the proof has not been supplied that the E.E.G. described by me reveals the potential oscillations of the cerebral cortex. For this reason in my Eleventh Report (Vol.104, 1936) in figures 2 and 3, I again published E.E.G.'s which had been recorded directly from the human cerebral cortex with needle electrodes. Yet the same objection is always being repeated in the same manner. In Figure 9 I therefore demonstrate once more...." "Thus if only the unfounded criticism would stop that no proof has been established that the E.E.G. as I describe it is identical to the potential oscillations of the cerebral cortex!" (Berger, 1938, p. 310-311)*

Berger' s success was also his nightmare. He was inevitably drawn into the mix of scientific controversy, some of it perhaps disingenuous. His work became widely recognized everywhere except Germany where, because of the tide of world events, he again was relatively isolated at the very time his influence could have been most widely felt. Other laboratories began investigating the E.E.G. with technology that Berger could not hope to match. After more than four decades of work and dedication, "ownership" of the E.E.G. was taken from him. In his final paper, his attention again turned to the experience that had set him on his course so many years before. Note his possessive reference to the E.E.G.:

"Previously I had already indicated that my α-w and β-w bear no relationship to the electromagnetic oscillations which according to ***Cazzamaii*** *emanate from the human brain. It is out of the question that the α-w and β-w of my E.E.G. exert any influence at a distance; they cannot be transmitted through space." (Berger, 1938)*

Ultimately, his "ownership" of the E.E.G. was taken from him in fact as well as symbolically. At the age of 65, after 41 years of service at the University of Jena, Hans Berger was forced into retirement. Again, his biographers differ about this event. Ginzberg stated "There is no reason to assume that Berger's early retirement was in any way linked to political circumstances. He had been a devoted subject of Wilhelm, an obedient citizen of the short-lived Weimar Republic, and a reliable member of the Nazi community." (Ginzberg, 1949)

Gloor takes a somewhat different view of the event. "Berger' s early publications on the EEG appeared when Hitler rose to power and when the Nazi party gradually took over control of all aspects of German life. The University of Jena was badly affected by the blight of Nazism, both in its faculty and student body. Berger disliked the Nazis and they retaliated by disparaging his work. Those who acted in this manner were not only party functionaries, but also scientists who had espoused the new political credo. Berger was distrusted by those in power and was even forced to submit to censorship the few papers which he presented abroad, as for instance the one he gave at the International Congress of Psychology in Paris in 1937. A year after the meeting in Paris he was subjected to the most humiliating experience of his life. While making rounds in his clinic, on the 30th of September 1938, he was called to the telephone. He was informed abruptly that on the next day, the 1st of October, he was to retire from his post as chairman of the department and turn the clinic over to his successor." Shortly thereafter, his laboratory was dismantled.

He "retired" to Bad Blankenburg, near Jena, where, according to Ginzberg, he took a position as head of a private sanatorium. Over the next three years he became increasingly

despondent, ultimately becoming almost bedridden. He left notes in his diary which clearly described his major depression:

"I have behind me days of despair in which I yearningly wished for my early end. I have sleepless nights in 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..." (Gloor, 1969, p.12)

Ten days later, on May 30, 1941, Hans Berger took his own life. On his study wall hung a quatrain written by poet Friedrich Rueckert, Berger' s grandfather:

"Each man faces an image
Of what he is meant to become
As long as he does not achieve it
He cannot attain his full measure of peace."

It is clear from Berger's writing that he was acutely aware of the influence of attention and mental effort upon the EEG, and in fact regarded mental effort and attention as being the primary "psychophysiological" event reflected in the shift from alpha to beta in his recordings. The work of Adrian and Matthews focused upon visual activity as being of great significance in producing changes in the EEG frequency. Adrian and Matthews (1934) went so far as to record the EEG after lengthy habituation to a dark room with the eyes opened, and reported that the alpha rhythm then persisted. They became very interested in the influence of the visual system upon changes in "the Berger rhythm", but also found that a problem that "claims the whole attention will abolish the rhythm though the eyes are shut."

At the same time, they created what was actually the very first EEG feedback experiment recorded in the literature, but were focused upon an entirely different problem.

"Again some of the evidence on the effect of opening the eyes in the dark was made by one of us listening to the rhythm from his head in a loudspeaker. This made it possible to correlate the impression of not looking or looking with the presence or absence of the rhythm. In this case, as when the eyes are open in daylight, the subject can hear that the rhythm ceases, for opening the eyes does not prevent one from listening; but the non-visual activities which abolish the rhythm demand so much attention that a subject engaged in them cannot listen at the same time and can never hear whether the rhythm has been affected or not." (Adrian and Matthews, 1934, p.371)

Since this paper is intended to be a tribute to the extraordinary work of Hans Berger, it seems to be appropriate to understand that, although he contributed hugely to the neurological applications of E.E.G., and to early attempts to quantify the E.E.G., his primary focus was psychophysiological. It thus seems appropriate to end this paper with a quotation from the final published words of his final paper. Here, after over 40 years of work, his final sentences did not address the neurological implications of his work, or the numerous technical details of his work. He returned to the question that had drawn him to his studies in the first place:

"....I would like to draw attention to a certain point I have made in the past. When mental work is performed or when the type of activity designated as ***active conscious activity*** *becomes manifest in any way as, e.g., upon the transition from the passive to the active E.E.G., a considerable* ***decrease*** *in the amplitude of the potential oscillations of the human brain occurs in association with this shift in cortical activity." (Berger, 1938)*

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