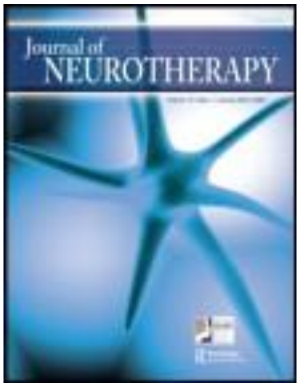

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The First Communications About Operant Conditioning of the EEG

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HISTORICAL ARCHIVES

THE FIRST COMMUNICATIONS ABOUT OPERANT CONDITIONING OF THE EEG

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Neurofeedback clearly makes key contributions as a clinical tool for the treatment of neurological and behavioral disorders. It also has a critical role to play as a tool for the investigations of basic scientific questions of how human subjective experience is related to its biology. Indeed, it got its start as a tool for investigating the relation between EEG activity and its subjective concomitants. Recounted here is an account of how the author's interests in this area led first to the study of dreaming sleep using the EEG, followed by an analysis of the conceptual status of subjective experiences like dreams, introspective reports and physiological indicators. At the same time, in the laboratory the development of operant discrimination of brain events became a primary focus, and its results led to the development of EEG biofeedback, now known as neurofeedback, involving both training in the control of the fluctuations in EEG alpha activity, as well as in the control of the central frequency of alpha. The practical applications of neurofeedback in the clinic are not reviewed. Personal contacts with others who learned of my work are described.

HISTORY

While I was a graduate student in the Department of Psychology at the University of California at Berkeley in the 1950s, I was interested in the general area of self-perception, that is, the perception by persons of their own features, behavior, and body processes, including their feelings, emotions, thoughts, and memories. The subjective experience aspect of perception and all other cognitive processes was always of interest to me as a major challenge for the science of experimental psychology. The kind of behaviorism at the time, which minimized or even denied the scientific utility of references to subjective experiences, was often a dominant attitude then. For me, such elements of private experience as feelings, images, thoughts, and hopes were a fundamental feature of human life and not mere verbal reports of same. The apparent denial of their relevance for understanding behavior for the sake of scientific rigor seemed self-defeating. It was encouraging to me as a student in classes taught by Professor Edward Chace Tolman that even though he experimented only with animal behavior and shared much of the behaviorist tradition, he insisted on the role of cognitive processes to account for the behavior of his rats as they learned their way through elevated mazes. Among his many publications were *Purposive Behavior in Animals and Men* (1932), now cited in *Encyclopædia Britannica 2010*, followed by *Cognitive Maps in Rats and Men* (1948). These clearly anticipated recent developments in cognitive psychology.

I continued my interest in the subjective components or aspects of human behavior after joining the faculty of the Department of Psychology at the University of Chicago in 1953. Two research activities then ongoing at Chicago were important in shaping my subsequent thinking about the science of this often murky field. First, across the street from my

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office was the Department of Physiology, where Nathaniel Kleitman and his student William Dement were following up some of the early work initiated on sleep and dreams in Kleitman's laboratory. They were using the EEG for detecting the electrical activity of the brain and the electro-oculogram (EOG) for detecting eye movements of the sleeping subject. This laboratory was the place of discovery that persons would much more often report they had been dreaming if awakened during periods of sleep with rapid eye movements and a mixed frequency low voltage EEG activity than if they were awakened during periods of the absence of such activity (Aserinsky & Kleitman, 1953).

Like perhaps most others, I was excited by the potential contributions this research could make to a wide variety of disciplines but particularly to the physiology of private experience. I was fortunate to be permitted by Kleitman to use his laboratory to pursue a few research questions raised by their work. Dement, in his last year of medical school at the time, kindly taught me the technology of EEG and EOG recording of sleeping subjects. The work confirmed my confidence that subjective experience was indeed a part of the biology of human life and therefore a part of all natural phenomena. Some of the results of the research are published in this author's 1961 chapter entitled, ''Behavioral, Subjective and Physiological Aspects of Drowsiness and Sleep'' in D. W. Fiske and S. R. Maddi's *Functions of Varied Experience*.

Most pertinent for the present discussion is a theoretical issue that arose concerning the status of introspective reports. The issue is generally applicable to all studies of subjective experience, but in the case of dreams the issue was the correct interpretation of the less-than-perfect indication of dreams by their physiological indicators, the EEG and EOG. Was it the failure of the indicators or the failure of the verbal report when a subject would verbally deny having been dreaming when awakened from sleep in which the indicators nearly always predicted dream reports? And what about the other imperfection: What should we think of a report of dreaming upon awakening when such indicators were absent?

This imperfect relationship between dream reports and their physiological indicators led to confusion and some minor controversies among researchers in the field as well as among the bystanders fascinated by the results of the studies. The issues led me to examine the assumptions, the rationale, and the logic underlying all scientific studies of private phenomena. With the help of a Venn diagram (see Figure 1), a former student and new colleague, Johann Stoyva, and I described what appeared to us to be that logic, in the article titled ''Electrophysiological Studies as the Prototype of a New Strategy in the Study of Consciousness'' (Stoyva & Kamiya, 1968).

Briefly, the concept is that both verbal reports of dreams and physiological indicators are imperfect indicators of the postulated private event, the first because of the facts of forgetting, confusion, and the limitations of language, and the second because they are essentially only remote individual correlates of parts of a complex pattern of neuronal and bodily activity. However, the two independent indicators are correlated across time with each

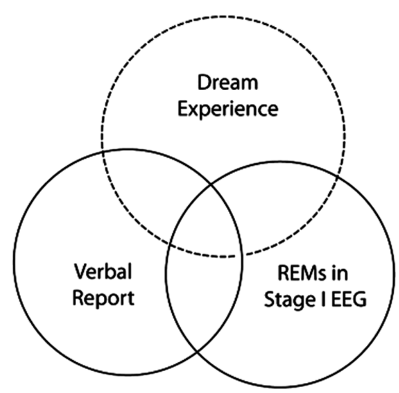

FIGURE 1. The domain of dreams as an object of study is represented as a dotted circle to represent their status as hypothetical constructs inferred from verbal reports (solid circle), historically the only objective indicator of dreaming. The predictive value of specific physiological indicators (solid circle) immediately prior to awakening of the sleeper for reports of dreaming is represented as the overlap with the domain of dreaming. The overlap of the two indicators of dreaming represents the convergence of the objective indicators on the hypothetical construct of dreaming, thereby increasing confidence in the promise of further inquiry into their place in nature.

other and thus converge toward validating the inferred private event as a hypothetical construct, increasing confidence that the inferred process had actually occurred as a real event. An analogy in physics that seems appropriate is that although no one had directly observed an electron, a huge number of very independent observations converged toward confirming its existence.

To return to the laboratory and the EEG: While learning the technology of EEG recording, my curiosity was piqued by a feature of the EEG alpha rhythm recorded from the occipital regions of the scalp of fully awake young adults, resting with their eyes closed. In the graphic record the trains of these roughly 10 Hz rhythmic waves would appear and disappear in an intermittent and irregular sequence. They would appear roughly from five to 30 times per minute, with the duration of the trains and their absences ranging from only a few tenths of a second to perhaps as long as 15 s or more. There were wide individual differences in both number and duration of the alpha wave trains per minute.

I wondered whether these transient fluctuations in an individual were associated with any changes in subjective experience of any sort. Since the earliest days of EEG research in the 1930s it was known that whether the eyes were open or closed clearly affected the dominance of alpha activity. Also, through personal communication from another early researcher in the field, Geoffrey Blundell, now deceased, I learned that W. Grey Walter and colleagues, experimenting informally in the 1930s and through the 40s, had observed what had happened in the paper recordings when they entered into specific states of mind. Among the things they found was that whether they had kept their eyes open or closed, if they had engaged in certain mental activities such as imagining close-up visual scenes and then reviewed how that affected the paper recordings of the EEG, they found reductions in the amplitude of the occipital EEG alpha compared to moments when they were not engaged in such imagery. Experts are not required for these observations; they are shared by nearly all who have tried the same personal experiments. It is also well established by now that alpha activity is diminished with drowsiness and completely absent from the graphic record with the onset of sleep or with some psychoactive drugs.

So, the mapping of relationships between subjective experience, internal behavior, mental activity (or whatever we should call it), and EEG activity was started in the early part of the history of EEG research. However, my concern was whether the more transient durations of the trains of alpha of about 2 to 6s might be associated with changes in subjective quality. With no idea of how to explore the possibility, I set it aside. A few months later a method of training persons to detect the fluctuations occurred to me, and if it was successful, inquiry into their subjective quality might be useful. I can attribute the idea of the method to my second fortuitous contact with the research activity at Chicago, this time in the Psychology Department itself. Operant conditioning studies with animals were being conducted by Howard F. Hunt, from whom I learned much about operant methods. A common method of operant conditioning uses a specific discriminative stimulus to control behavior during reward training. This kind of discrimination training is widely used in operant conditioning of the externally observable behavior of humans, including their verbal behavior. It typically involves the learning of stimuli that are located in the immediate environment of the trainee, outside his or her body. I became intrigued by the possibility that the same contingencies of training could be used to train persons to discriminate some stimuli inside their bodies, like the ongoing normal fluctuations of some measure of their own physiological activity. If they could, private stimulus concomitants of the physiological activity could be inferred, and introspective reports of the quality of experience of such concomitants might be useful in gaining knowledge of the subjective qualities of the physiological activity.

Such casting of introspection as the discrimination of private correlates of physiological activity seemed promising as a way of starting to bridge the gap between the earlier goals and methods of psychology (e.g., Wundt, Titchener, James, et al.) with that of more historically recent goals and methods, à la Watson, Tolman, Skinner, and others.

It is obvious there are many physiological activities with clear private stimulus correlates, such as inhaling versus exhaling in the course of respiration, or the heart pulse as felt by the person with a finger over an artery. And certainly the exposure of receptors to above-threshold stimulation is associated with specific subjective sensations and perceptions.

However, aside from the long-term correlates of EEG alpha and subjective states noted earlier, are there subjective qualities related to the brief changes in alpha occurring within seconds of each other? No one had ever reported such a relationship in fully awake persons who are asked to sit quietly with eyes closed for a few minutes and report all that is going on in their minds. There is a good reason for this, of course: The act of providing a running verbal account of every moment of consciousness would interfere with the recording itself, because of the artifacts of movement, and the electrical activity of muscle from the scalp during speech would bury the EEG signal in noise. Also the act of talking would itself activate parts of the brain with its attendant electrical activity. This is not to say that behaviors other than speech, prekeyed to signify specific elements of mental activity, may not be fruitful.

To address the question about alpha and subjective experience experimentally, I chose in 1958 to use discrimination training in which the discriminative stimulus was the presence of an alpha train as opposed to its absence. To help the trainer detect the presence or absence of alpha activity I had my research technician, who was skilled in electronics, build a filter with a pass band of 8 to 12 Hz to filter out the rest of the EEG. This eliminated the confusion for the trainer, who without the filter would have had to overcome visually the intrusion of the full range of nonalpha EEG frequencies (roughly 1–45 Hz) output from the EEG amplifier to make a visual judgment of the amplitude of the alpha activity in the graphic record. For some subjects the trainer would not have been able with sufficient reliability to judge the presence or absence of alpha activity without the filter.

(Further improvements were later made by adding electronic detection of the amplitude of the filtered alpha activity for later experiments. This completely eliminated the need for the trainer to judge the presence vs. absence of the alpha activity. However, the amplitude detector had not been available for use at the time of the work reported here.)

The abstract printed here (Figure 2) summarizes the work on discrimination training done at Chicago, and continued in the first year or two following my acceptance of a position on the faculty of medical psychology in the Department of Psychiatry at the University of California at San Francisco.

It was clear from the beginning that subjects could indeed learn to discriminate the presence versus absence of EEG alpha activity, thereby confirming that the fluctuations have some private stimulus correlates.[1]

However, due to the frequent shifts from one state to the other, the time allowed for the periods of the two states before the trainer gave the signal for the subject to choose his response was relatively brief. Each state, once selected by the trainer, was seldom allowed to exceed more than about 6 or 7s to avoid its ending before signaling the subject to make a judgment; the detection of a difference was perhaps much easier than to judge what the difference was. Whatever the reason, the method used seemed much less suited to gain verbal descriptions of the states than when we later turned to training the control of the states as opposed to their discrimination, owing to the much longer periods of each state involved in the control experiments. The detection of such transient states by the subjects is much easier than the verbal description of their

[1]The use of the word *stimulus* here is not to imply sense receptors in the brain upon which stimuli impinge. I am referring only to whatever mechanism or process that makes two different brain states of a person differentiable by him.

CONDITIONED DISCRIMINATION OF THE EEG ALPHA
RHYTHM IN HUMANS

Joe Kamiya, Ph.D.

Abstract of a paper presented at the Western Psychological Association, 1962, San Francisco

Combining methods of behavioral analysis and physiological recording in a study of "introspection", a conditioned discrimination training procedure was used to determine whether there were private stimulus concomitants of the EEG alpha burst. With monopolar recording of the EEG (ear to left occuput, scalp electrodes), and with the subject lying relaxed with eyes closed, E sounded a single ding of a bell aperiodically about 5 times a minute, randomly scheduling the dings to coincide half the time with the occurrence of an EEG alpha burst, and half the time with the absence of alpha. The subject was instructed that with each ding in the training trials he was to try to guess either "yes" or "no", depending on "how he felt" at the time of the bell. The "yes" responses to dings with alpha and the "no" responses to dings without the alpha were reinforced by being called "correct" by the experimenter. Results:

In about 50 to 500 trials, six subjects learned to make nearly 100 per cent correct responses. As a control over the possibility that the bell ding sounded differently on the two types of trials, in a second procedure the subjects were asked to make guesses out loud as to when their "yes" or "no" states occurred, without the aid of the bell. The subjects could do that also. One subject could not offer any verbal description of why he performed so accurately. Five felt that it was related to what they were thinking about or to their efforts to imagine visual scenes. In some of the subjects the discrimination appears possible only if they try deliberately to alternate their states of mind between visual imagination and relaxed inattention in a regular pace so that they can more easily discern their state as required by the experimenter. In a third type of procedure, it is found that the alpha burst can be produced by the subject, upon command from the experimenter, who asks S to produce the states accompanying their verbal responses in the discrimination procedure.

Preliminary analyses of cardiac and respiratory activity, eye movement and muscle tension indicate that these are not stimulus sources accompanying changes in the EEG.

FIGURE 2. Conditioned discrimination of the EEG alpha rhythm in humans (Kamiya, 1962), original abstract. Reprinted and discussed in Kamiya (1968, 1969, 1970).

subjective quality. Despite this, I was encouraged to note that the discrimination training method did establish there are private stimulus correlates that permit the discrimination of the two EEG states, even for quite brief transient states of the EEG as seen in the fluctuations of alpha activity.

Now we turn to the feedback-trained control of the alpha rhythm. From the very first participant in the EEG alpha discrimination study, it had become clear that training persons to discriminate high versus low amplitude EEG alpha rhythms led to their ability to control the rhythms voluntarily upon command by the trainer. Later in the year I undertook work to determine if subjects could be trained to control the rhythm without first conducting the discrimination training method used in the previous study. The output of the filter used before was then used by a device to provide a smoothed moving average of the alpha amplitude, which then controlled the auditory signal in the subject's room. The signal was a steady tone of fixed amplitude in our early studies. The tone remained on as long as there was alpha activity above an arbitrarily set amplitude threshold, appropriate for each subject's normal range of amplitudes.

The trainees were asked while they sat alone in a dark room with eyes closed if they could learn to increase the percentage of time the tone was on, and their progress was accumulated quantitatively every minute to result in the percentage of on time of the tone was reported to the subject over the intercom. The majority of trainees were able after about four training sessions to increase their average alpha percentage times above their starting baselines. With the specific variable of alpha percentage time, it was found that for nearly all trainees the very challenge of the task of increasing the alpha percent time causes them to reduce it below their initial baselines taken with each training session, with recovery toward it and going beyond requiring repeated training sessions. One subject wryly remarked after his first session that I had succeeded in inventing a most diabolical device; it presented a task that seemed easy to perform, but instead it was designed to cause the person to fail if he tried to succeed, and to succeed only if he did not try to succeed.

As far as I know, this experiment, conducted in 1958, was the first to demonstrate that an automated external feedback signal for monitoring persons' EEG activity was used to train persons in the control of specific features of the EEG. However, I felt that an improvement in the design of the experiment was needed; an unknown portion of the increase in percentage time of alpha might have occurred over the sessions simply because of the passage of time, perhaps because subjects became more accustomed to being in the laboratory over the several sessions of their participation. Learned EEG alpha control could be more convincingly demonstrated if they could learn to both increase and decrease their alpha activity percentages. So I decided to train a new sample of subjects. The tone feedback system of the previous experiment was used again, and they were told the percentage time of alpha once per minute for 5 min as they tried to increase their alpha activity scores. Then for the next 5 min they were asked, with the aid of the same feedback signal and 1-min performance reports, to decrease their percentage time of alpha. The reversing of the task every 5 min was continued to the end of the session.

Eight of the 10 subjects were able to affect the tone, increasing or decreasing the percentage of time that the tone was on, as was requested of them. After 40 trials, 20 up and 20 down, the average alpha percentage time for increase trials had risen to 53% and for the decrease trials had fallen to 17% (see Kamiya, 1968 for more detail). It appears that alternating the blocks of trials as we did helps the subjects to contrast the two tasks more sharply and improves the rate of learning the control of alpha.

The verbal descriptions were more detailed and confident than with the previous method of only increasing the alpha durations. Visual imagery was again reported as effective in decreasing alpha, and sometimes a slight tension in the eye region was mentioned, suggestive to me of ocular motor involvement, which is known to suppress alpha. Because no hints were given to the subjects on how best to decrease the tone, it is clear that by trial and error they discovered by themselves what any coached subject could immediately use without any training to produce decreases in alpha. For increasing the percentage time of alpha, several subjects reported as effective entering into a state of alert calmness, a singleness of attention, and a passive following of the tone. Alpha waves seem to result from an alert, nondrowsy state, with a minimum of concrete visual imagery.

It is important to point out that these qualities are not reported by some subjects, and there were sufficient differences in the reports of the different subjects that I got the impression that a significant contributor to the differences was differences in the history of language usage and past experience in attending to internal body sensations. I believe that this represents a major challenge for any science of the relationship of subjective experience to physiological processes and that new methods are needed to improve the specification of the subjective properties of the two states.

TRAINED CONTROL OF EEG ALPHA FREQUENCY IN HUMANS

So far the concern with the alpha rhythm has been its amplitude and how well it can be brought under control. I wondered whether the frequency of the rhythm can also be

TRAINED CONTROL OF EEG ALPHA FREQUENCY IN HUMANS

Joe Kamiya

(Abstract of invited address given at Stanford University, September, 1966)

The frequency of the EEG alpha rhythm has been regarded as highly stable for a given individual, typically varying less than one half cycle per second. This has led to a common belief that alpha frequency is not subject to modification by learning. A study just completed in our laboratory, however, suggests some plasticity of this parameter.

Occipital-ear EEGs taken with eyes closed were filtered with a band pass of 8-12 c.p.s. By means of digital control circuitry every second alpha cycle was compared in duration (with 1 ms. resolution) with an arbitrary standard duration of time. The standard was chosen for each subject such taht approximately one half of the measured cycles were longer in duration than the standard, the other half shorter. A 300 c.p.s. click was sounded in the subject's room for each short alpha cycle and a 1000 c.p.s. click was sounded for each long alpha cycle. The subject thus could hear for each alpha train an irregular alternation of low and high clicks, with runs of one click type seldom exceeding 10 or 12 clicks in the pre-training session.

Subjects were informed that the clicks were dependent on their brain waves, and that their task was to see if they could learn to control the relative predominance of one click over the other. In each block of five trials, each consisting of 200 total clicks, the subjects tried increasing the predominance of high clicks. This was followed by an equal length block of trials for low clicks. A monetary bonus was offered for increased difference scores between these two conditions.

Eight of ten subjects learned to control their alpha cycle durations after three to seven one-hour training sessions. The average difference for all subjects, in per cent of long alpha cycles, between the two alternating experimental conditions grew from 0 to 9% in seven sessions. Three of the more successful subjects, trained for a total of nine sessions, showed an average difference score of 15%.

FIGURE 3. Trained control of EEG alpha frequency in humans (Kamiya, 1966), original abstract. Reprinted and discussed in Kamiya (1968, 1969, 1970).

controlled with feedback, and if so, what subjective correlates it may have. To test the idea a method for training changes with some form of feedback was needed. A method described in Figure 3 was tested, and proved successful. Data on subjective correlates were not gathered.

CONTACTS WITH STERMAN, SKINNER AND BROWN

I did not publish much of my work. I have given many presentations at various universities and informal scientific and civic groups. I have enjoyed talking to many individuals who came to visit my laboratory or to talk about their related work. I was always pleased to hear that others had been influenced by my work. One of these was Barry Sterman of the University of California at Los Angeles, who in the early 1960s told me that he had heard my presentation at a scientific meeting and tried the method adapted for the cats that he was studying in a seizure control research project (reference *Journal of Neurotherapy,* Volume 14, Issue 4, for that historical exploration – *Ed.*). He said the method worked quite well for training his cats. He has for years used neurofeedback for increasing sensory motor rhythm activity in humans with reliable success in treating epilepsy.

Another pleasant personal meeting took place in the early 1960s with B.F. Skinner, Harvard University, who had heard of my work and came to meet me and visit my laboratory for about an hour when he was at the University of California campus in San Francisco for the day. He observed me administering discrimination training to a subject in a sound-deadened and darkened room while I watched a moving strip chart displaying the subject's EEG.

It was clear to me that he was intrigued by the possibilities of this kind of training. Later, from reading one of his books (Skinner, 1957), I realized that the internal discrimination I was training clearly fit his general conception of what he labeled as ''tacting''—from contacting, as in objects in the environment by naming them.

It must have been rewarding for him to see the actualization of a method of discrimination training that he had developed for external stimuli, an example of training which he had named ''self-tacting'' in his book now being used for internal stimuli and the concept of self-tacting, which he wrote about, being displayed before his eyes in live action. But he was a perfectionist. After watching me for a few minutes he had some constructive comments about how the timing of the trials could be improved with the use of automatic identification of the EEG states. He commented in a friendly manner that it might be useful to have a more programmed system for classification of the EEG. He was right, and I was glad to inform him that such a device was being built as we spoke.

Another noteworthy person I met at a scientific meeting in the mid-1960s at Stanford University was Barbara Brown, who had not known about biofeedback training of the EEG. She was very much impressed with the possibilities she saw in the method of training, and soon thereafter she created her own laboratory at the Sepulveda Veterans Hospital in Southern California. She authored the book *New Mind, New Body: Biofeedback* (Brown, 1974).

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ADDENDUM: RETYPED ABSTRACTS

Conditioned Discrimination of the EEG Alpha Rhythm in Humans

Joe Kamiya, PhD

Abstract of paper presented at the Western Psychological Association, 1962, San Francisco

Combining methods of behavioral analysis and physiological recording in the subject of ''introspection,'' a conditioned discrimination training procedure, was used to determine whether there were private stimulus concomitants of the alpha burst. With monopolar recording of the EEG (ear to left occiput, scalp electrodes) and with the subject lying relaxed with eyes closed, E sounded a single ding aperiodically about 5 times a minute, randomly scheduled for the dings to coincide half the time with the recurrence of an EEG alpha burst, and half the time with the

absence of alpha. The subject was instructed that with each ding in the training trials he was to try to guess either "yes" or "no," depending on how he felt at the time of the bell. The "yes" responses to dings with alpha and the "no" responses to dings without alpha were reinforced by being called "correct" by the experimenter.

Results: In about 50 to 500 trials, six subjects learned to make nearly 100 percent correct responses. As a control over the possibility that the ding bell sounded differently on the two types of trials, in a second procedure the subjects were asked to make guesses out loud as to when their "yes" or "no" states occurred, without the aid of the bell. The subjects could do that also. One subject could not offer any verbal description of why he performed so accurately. Five felt that it was related to what they were thinking about or to their efforts to imagine visual scenes. In some of the subjects the discrimination appears possible only if they try deliberately to alternate their states of mind between visual imagination and relaxed inattention in a regular pace so that they can more easily discern their state as required by the experimenter. In a third type of procedure, it is found that the alpha burst can be produced by the subject, upon command from the experimenter, who asks S to produce the states accompanying their verbal responses in the discrimination procedure.

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Trained Control of EEG Alpha Frequency in Humans

Joe Kamiya, PhD

Abstract of invited address given at Stanford University, September 1966

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Eight of the ten subjects learned to control their alpha cycle durations after three to seven one-hour training sessions. The average difference for all subjects, in percent of long alpha cycles, between the two alternating experimental conditions grew from 0 to 9% in seven sessions. Three of the more successful subjects, trained for a total of nine sessions, showed an average difference score of 15% (see Kamiya, 1968, 1969 for more detail).