A Search for Alpha Power Changes Associated with Anomalous Cognition

By

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Abstract

Serious research into extrasensory perception (ESP) has been conducted since the 1930's, and a number of different protocols have been established to elicit the phenomenon. The large database to date has been analyzed by critics and statisticians alike, and the consensus is that the result meets generally accepted criteria for evidence of a statistically based, information transfer anomaly. These include homogeneity of effect size and conceptual replications. We provide a brief overview of three of the most common procedures and their results as the basis for the justification to engage in a search for a central nervous system (CNS) correlate to ESP. As part of that search, we conducted an experiment to detect event-related desynchronizations (ERD's) resulting from an ESP stimulus. Three subjects contributed a total of 70 trials during which both ESP and EEG data were collected. The ESP data, which have been blind judged by an established rank-order method, yielded independently significant results for two of the three receivers, and the overall ESP result was significant at $p=0.006$ (ES = 0.303). Using a cross correlation technique, which was twice as sensitive as standard signal averaging, we did not observe any evidence for an ERD in response to an ESP stimulus. Our analysis technique was sensitive enough to detect a 20% decrease from prestimulus alpha power. We discuss a number of possible explanations for this null result.

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Introduction

Our laboratory has been conducting Extra Sensory Perception (ESP)[2] research under US Government contracts since 1972. Despite the continuing skepticism in the scientific community, the evidence for ESP has met all the existing criteria set by the standards of science (Bem and Honorton, 1994; Utts, 1991; Utts, 1995). Professor Utts, a statistician from the University of California at Davis, was part of an evaluation team commissioned by the US Central Intelligence Agency to review US Government-sponsored ESP research (Mumford, Rose, and Goslin, 1995). In the abstract of her contribution to this review, Utts wrote:

> Using the standards applied to any other area of science, it is concluded that psychic functioning has been well established. The statistical results of the studies examined are far beyond what is expected by chance. Arguments that these results could be due to methodological flaws in the experiments are soundly refuted. Effects of similar magnitude to those found in government-sponsored research at SRI [SRI International] and SAIC [Science Applications International Corporation] have been replicated at a number of laboratories across the world. Such consistency cannot be readily explained by claims of flaws or fraud.

It is this consistency that provides compelling evidence for the validity of the phenomenon called extrasensory perception or ESP.

It is beyond the scope of this paper to provide an overview of the current status of research parapsychology; however, detailed descriptions and meta-analyses can be found in Radin (1997). In the Background Section below, we will give brief outlines of three different methodologies to set the context for the main topic of this paper.

Background

Serious laboratory investigation of ESP has been conducted since the 1930's when J. B. Rhine studied the apparent enhanced hitting rate on cards that contained the symbols, star, cross, circle, wavy lines, and square (Rhine, 1964). The basic theme of the experiments involved an individual who focused his/her attention on a card and attempted

[2] ESP is defined as an ability to obtain information by mental means alone while being completely isolated from that information.

to "send" the image to a second individual who was not in direct sensory contact with the sender and who attempted to guess the symbol. A typical run consisted of a deck of 25 randomly ordered cards with five of each of the five symbols.

Between 1934 and 1939, 791,700 trials were conducted that produced a hit rate of 21.55% where 20% is expected by chance (effect size = 0.011 ± 0.001, z = 9.76, $p = 8.6 \times 10^{-23}$ (Honorton, 1975)[3]. This body of literature has not been without its critics. G. R. Price (1955) wrote in *Science*:

> Believers in psychic phenomena … appear to have won a decisive victory and virtually silenced opposition. … This victory is the result of an impressive amount of careful experimentation and intelligent argumentation. Against all this evidence, almost the only defense remaining to the skeptical scientist is ignorance, ignorance concerning the work itself and concerning its implications. The typical scientist contents himself with retaining … some criticism that at most applies to a small fraction of the published studies. But these finding (which challenge our very concepts of space and time) are–if valid–of enormous importance … so they ought not to be ignored.

Price went on to conclude that the results are "'incompatible' with current scientific theory." He further concluded, "My opinion concerning the findings of the parapsychologists is that many of them are dependent on clerical and statistical errors and unintentional use of sensory clues, and that all extra chance results not so explicable are dependent on deliberate fraud or mildly abnormal mental conditions." This critique spawned an exchange in the pages of *Science* (Price, 1955; Bridgman, 1956; Rhine, 1956a; Rhine, 1956b; and Soal, 1956). But Meehl and Scriven (1956) point out that Price's argument rests on two highly questionable assumptions, namely that contemporary scientific knowledge is complete, and that ESP necessarily conflicts with it. Seventeen years later, Price retracted his accusations of investigator fraud (Price, 1975).

[3] All error estimates in this paper are one standard error.

Using the tools of modern meta-analysis, Honorton (1989) later reviewed the precognition[4] card-guessing literature published between 1935 and 1987. This database comprised 309 studies reported by 62 investigators. Nearly two million individual trials were contributed by more than 50,000 subjects. The overall-hitting rate was 0.228 for an effect size of 0.02000 ± 0.00175 ($z = 11.4$, $p = 1.5 \times 10^{-30}$). Honorton examined and rejected a large number of possible "normal" hypotheses that might have provided an explanation for this result.

Modern approaches have focused on more cognitively rich target material. These types of experiments are called "free response" since a subject is not constrained in reporting his/her mental impressions. The first of these attempted to mimic the often-reported ESP experiences in dreams (Ullman, Krippner, and Vaughan 1973). In these experiments, a sender was alerted when an isolated and monitored individual began a REM period. During that time, the sender attempted to transfer a randomly selected rich scene into the dream of the subject. When the REM period ceased, the dreamer was awakened and asked to report the dream. This continued throughout the night, the sender using the same target material for each REM period. An analyst, who remained blind to the target choice, compared the dream transcripts to a number of different targets that included the actual target used in the trial. The blind rank-order number of the actual target was the dependent variable. A total of 450 sessions that were conducted between 1966 and 1973 have been reported in the literature. Radin (1997, page 71) analyzes the results and converted the outcome to an effective binary hitting rate of 0.61 ± 0.13 ($p = 1.5 \times 10^{-6}$). Child (1985) examined this literature and was unable to find any artifactual explanation for the anomalous transfer of information into dreams.

Because dream investigations are time consuming and labor intensive, Honorton and Harper (1968) developed a mild sensory isolation approach to elicit ESP using a more efficient methodology. Independently Braud and Braud (1973) and Parker (1975) developed similar ideas. The technique now known as the Ganzfeld provides unpatterned sensory input to the visual and auditory systems. After relaxing in such a state for approximately 30 minutes an isolated subject is asked to describe aloud any internal

[4] Card guessing studies using precognition require that the subject guess a symbol *before* the trial target card is randomly selected.

imagery that may occur. At the same time, a second isolated individual attempts to "send" mentally a randomly selected target image to the subject. Often the "sender" is allowed to hear the subject's mentation, but the subject is completely isolated from the "sender." At the end of the session and differing from the dream studies, the subject is asked to rank four images in order of correspondence with their internal experience. The number of first-place direct hits is often used as the outcome measure.

Approximately 2,500 trials have been conducted using this technique with an overall hitting rate of 0.332 ± 0.034 ($p = 6 \times 10^{-22}$)where 0.25 is expected by chance (Radin, 1997, page 88). Bem and Honorton (1994) provided a critical analysis of a substantial portion of this database. Potential flaws such as data selection in the studies, sensory leakage paths and inadequate randomization were examined and rejected and the authors were unable to identify any artifacts that could account for this result.

Thus, we conclude from this extensive body of work, that a weak but statistically robust "information transfer anomaly" meets the usual requirements of scientific rigor and replication.

The approach that we use in our laboratory is conceptually similar to the ganzfeld technique but differs substantially in the methodology. We have coined a new term– *anomalous cognition* (AC) that we believe is more descriptive of the observable results than is the term ESP.[5]

A Typical Anomalous Cognition Protocol

The following is representative of a data collection protocol for a single anomalous cognition trial. In an actual experiment, the timing and target type might be different. Typically, a single trial requires at least four people:

1. A *Receiver* who will register his/her impressions of a randomly chosen target.
2. A *Monitor* who, while blind to the target, will assist the Receiver in responding to it.
3. An *Analyst* who will conduct the assessment of the trial data while remaining blind to the target selection and to the experimental details.

[5] We adopted this terminology because it is more descriptive of the phenomenology and, therefore, is free of implications of possible mechanisms. That is, some individuals apparently become aware (cognition) of information in ways we currently do not understand (anomalous).

4. An *Assistant* who will randomly select the target.

Suppose a trial begins at 10:00 AM. Then at:

- 10:00–A monitor and a receiver are sequestered in a laboratory.
- 10:05–An assistant randomly selects a target from a pre-defined set.
- 10:10–Session begins.

At this point, both the monitor and receiver are completely blind to the target choice; thus the monitor is free to encourage the receiver to draw and write his/her impressions of the selected target.

- 10:25–Data collection ends.

The data are secured, and the assistant is asked to provide the selected target as feedback. Thus, the receiver and monitor can see what correspondence may exist between the receiver's response and the intended target. It is important to note that the feedback and its associated correspondence with the response do *not* constitute an analysis.

- 10:30–The session ends.

Subsequently an analyst who is blind to all experimental details assesses the data.

Rank-Order Analysis

In this protocol, the pre-defined set, from which the target photograph was selected, contains 100 photographs arranged into 20 packets of five photographs each. The photographs within a packet are designed to be as different from one another as possible. The random selection of a target is accomplished in two steps. First, a packet number between one and 20 is chosen randomly. Second, a target number between one and five is chosen randomly to designate the actual target from within the selected target pack.

For each trial, an analyst is given the receiver's response and a target packet number and nothing else. The analyst's task is to select the photograph from within the pack that best corresponds to the response. Then in turn, the analyst must select the photograph that second best corresponds, the third best correspondence, and so on. The analyst is obliged to perform the rank-order of the targets with regard to their correspondence with the response regardless of the quality of the match with the response.

Under the null hypothesis of no information transfer, the rank distribution is uniform and the average rank number over many trials should be 3.0. In fact, since the distribution over *N* trials should be uniform across rank numbers, an effect size can be computed as:

$$ES = \frac{\left(R_{\exp} - R_{ave}\right)}{\sqrt{\frac{n^2 - 1}{12}}},$$

where R_{ave} is the average rank over the *N* trials, R_{exp} is the expected average rank, and the denominator is the standard deviation of a uniform, discrete distribution with *n* possibilities. In most of the research conducted within our laboratory, n = 5 so $R_{exp} = 3.0$, and the denominator above reduces to the square root of two. A z-score may be computed from:

$$z = ES \times \sqrt{N}.$$

Two Examples of Anomalous Cognition

We have chosen two examples of AC to illustrate the type of data that are seen from experiments using the above protocol. The first of these is a single trial that was taken from a recent experiment. The second is from a two-trial "field" experiment to determine the degree to which AC can be used to identify high-technology targets. The examples are representative of the quality from the classes of experiments that we have been conducting since 1972.

A Single-Trial Laboratory Example

Figure 1 shows the complete response from a single trial from a laboratory experiment.

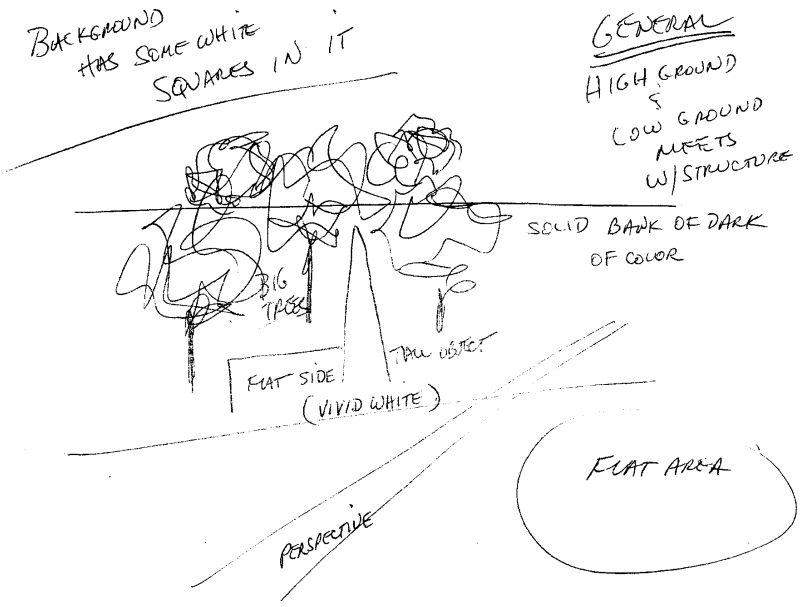

Figure 1. Complete AC Response from a Recent Experiment

The target pack, from which the target photograph was randomly selected, is shown in Figure 2.

Figure 2. Analysis Pack for the Laboratory Example

In this trial, a blind analyst chose the photograph of the road (i.e., the bottom left picture) as the best match, and it turned out to be correct.

High-quality "Field" Example

As part of our work under a US Government contract, we were asked to determine the degree to which anomalous cognition could provide information about high-technology targets. Differing from a typical laboratory protocol, the sponsors provided the social

security number of an individual whom we had not met (i.e., a target person). We were told that on a certain date, that individual would be located somewhere in the continental USA. The experiment team was blind to all other aspects of the trial.

We were instructed to ask one receiver to describe the environment in which the target person found himself at 00:00, 08:00, 16:00, and 24:00 hours on the specified date. It is beyond the scope of this paper to describe the extensive data from this multi-session trial. Figure 3, however, shows most of the response from just one of the sessions.

The target person had to drive through the Altamont Pass toward the site for an electron accelerator experiment. Figure 4 shows a portion of the extensive windmill farm in that section of California.

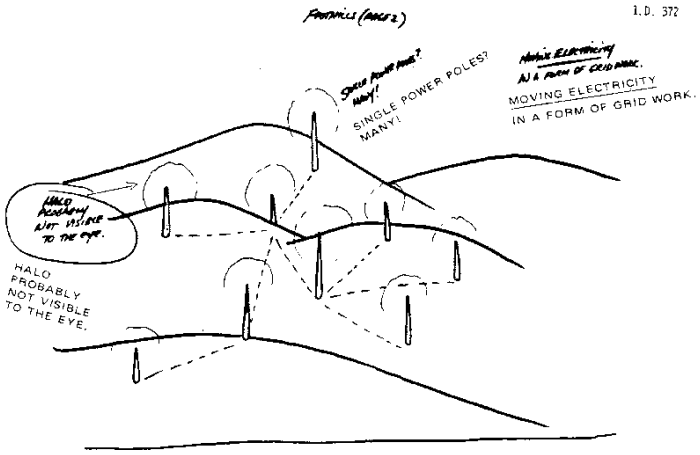

Figure 3. Response at 16:00 h

Figure 4. Windmill Farm at Altamont Pass

Quantitatively speaking, approximately 15% of our data are of the quality shown for this trial. Because this was not a formal laboratory trial, a rank-order analysis was not used. Instead, we defined the target as a fuzzy set of elements that could be weighted according to the sponsor's criteria. Our fuzzy set analysis (May et al., 1990) provides a quantitative way of determining the percent of the target that was correctly described (i.e., called the accuracy) and the percent of the response (i.e., called the reliability) that was correct. In this isolated example, the sponsor and we computed a reliability of 100% and a 95% accuracy. For the entire trial, which included a 50 MeV electron accelerator, the accuracy and reliability were 77% and 78%, respectively. A similar trial, which was conducted a year later against a high-power microwave generator, produced an accuracy and reliability of essentially the same values.

It is beyond the scope of this introduction to provide a complete historical review of the research that has spanned more than 25 years in our laboratory alone and 75 years worldwide. However, we have presented the meta-analytic results and the preceding examples as motivations for the search for neurophysiological correlates to anomalous cognition.

Search for a Neurophysiological Correlate to AC

Our search for a central nervous system (CNS) response to an anomalous cognition stimulus began in 1973 when we found that alpha band (8 to 12 Hz) power changed significantly concomitant with a remote and isolated flashing-light stimulus (Rebert and Turner, 1974; May, Targ, and Puthoff, 1977). Even though there was statistically significant evidence of a change in alpha power, the single participant in the study was unable to demonstrate cognitively in which epochs the remote light was flashing. In addition, there was considerable ambiguity as to the EEG lead and direction of the alpha power change for the observed significant effects. That is, significant increases or decreases of in-band alpha power were observed on different electrodes at different times. Thus we abandoned this line of investigation until 1986. At that time, we used magnetoencephalographic techniques to search for evoked-response-fields occurring concomitant with a remote flashing sinusoidal stimulus (May, Luke, Trask, and Frivold, 1990). Although the initial results were encouraging in that we apparently detected

significant spontaneous primary alpha phase shifts, we were unable to replicate our findings (May, Luke, and James, 1994).

In 1994, we reported to our sponsor the interim results of a detailed search for an AC-induced event-related desynchronization (ERD) that was conducted at Stanford University (May, Luke, and James, 1994). That experiment was based on the knowledge that spontaneous EEG reveals short-lasting, task- or event-related amplitude changes in rhythmic activity within the alpha band. This amplitude change, or desynchronization, is one of the elementary phenomena in EEG. It was first described by Berger (Gloor, 1969) in EEG as alpha blocking, and was later termed event-related desynchronization (ERD) by Pfurtscheller and Aranibar (1977). ERD's can be quantified as a function of time and can then be used to study cortical activity patterns during the planning of motor behavior (Pfutscheller and Aranibar, 1979) and sensory stimulation and cognitive processes (Pfurtscheller, Lindinger, and Klimesch, 1986; Klimesch, Pfurtscheller and Lindinger, 1987; and Sergent, Geuze, and Van Winsum 1987). Kaufman, *et al.* (1990) provide a more recent example of cognitive process-related ERD's, which they call alpha suppression. They found significantly shorter ERD's when subjects simply responded to a target stimulus compared with the ERD's that occurred when a subject had to search visual memory to determine whether the target matched one previously presented.

It is clear that ERD's occur as part of the cortical response to a wide range of external stimuli, cognitive tasks, and motor functions. ERD's are, therefore, a likely variable to use to study how the central nervous system might respond to AC stimuli. If the CNS is involved with AC in a similar way, then it would be surprising if AC did not produce an ERD.

It is difficult, however, to predict the character of putative AC alpha responses especially if the stimulation occurs in an area that is located in a brain region not accessible to typical EEG recording, such as in the hippocampus or subcortical structures. AC-stimuli may evoke a classical ERD or an event-related synchronization, that is an increase of alpha power (Ota et al., 1996; Shaw, 1996; Ba□ar, 1997; and Ba□ar, et al., 1997), or no significant change in alpha but rather changes in theta (4 to 8 Hz) because of possible hippocampus involvement. To complicate matters further, it is also not clear whether a decrease or an increase in theta should be expected (Klimesch, 1996). Since the

experiments described here gave solid evidence for AC, the outcome of an ERD analysis should lead us to a greater understanding of how AC may be involved in the central nervous system whether an ERD is observed or not.

Experiment Protocol

In this section we provide details of the anomalous cognition and EEG protocols for the study to determine whether an AC-mediated ERD can be identified.

General

The experiment was conducted in a standard psychophysiology laboratory at Stanford University. This laboratory consisted of two adjacent rooms, one of which contained a shielded and sound attenuated enclosure that was designed for EEG and sleep studies. In the enclosure was a comfortable chair that was positioned approximately 0.5 m in front of a small window behind which was a computer monitor. This monitor was designated the feedback monitor. The second room was the control room, which contained a computer-based EEG collection system, a monitor for displaying targets, and other associated hardware.

Anomalous Cognition Design

In contrast with the majority of our earlier CNS studies, we designed a protocol in which the receiver's AC performance could be measured at the same time as the CNS data were being collected. To accomplish this we asked each receiver to acquire information about a randomly selected target and to provide sketches and words with regard to her/his impressions according to a modification of our standard protocol.

Targets and Target Selection

We used our standard target pool, a collection of 100 photographs, which had been carefully sorted into 20 packets of five dissimilar pictures each (May, Utts, Humphrey, Luke, Frivold, and Trask, 1990). These targets were all digitized and stored for later recall. A target for a trial was selected randomly by first choosing a target pack and then a target from within the selected pack. A standard pseudo random number generator, which was seeded for each trial by the computer system clock, was used to provide the random numbers for the selection process (Lewis and Payne, 1973).

Receivers

Three experienced receivers were asked to participate in this experiment. They were chosen on the basis of their availability, their willingness to participate in an EEG study, and especially upon their previous and sustained good performance.

Experimenters

There were two experimenters in this study. The first was a neuroscientist, whose primary responsibilities included designing the neuroscience portion of the experiment, interacting with the receivers and maintaining and securing the AC data. The second was a psychologist, whose primary responsibilities included preparing the receivers for EEG data collection, running the computer-based data collection system, and storing the EEG data for later analysis.

Number of Trials

The total number of trials for this study was 70 and was determined, in advance, by receivers' availability.

AC Data Analysis

A single analyst, who was otherwise not associated with the experiment, was presented with the words and drawings along with the target pack associated with the trial. The task was to rank-order the targets from the best to the worst match to the response. After all *N* trials were analyzed for a single receiver, an effect size was computed as described above.

EEG Parameters and Stimulus Design

To reduce the preparation time and subject stress before a trial, only five leads were used. EEG signals were recorded from electrodes, which were held in place by a standard cap, at positions O1, O2, P3, P4, and Cz. EEG signals were measured and recorded with 16-bit resolution, and were sampled at a rate of 125 measurements per second. These electrodes were referenced to linked mastoids.

The stimulus sequence consisted of a 1-second on period followed by a 2-second off period. On a random, but counter-balanced basis, either the selected AC target or a control target was displayed during the on period on the isolated control room monitor. The control target, which we labeled the pseudo stimulus, was a digital image the same

size as the selected image, but whose pixel color values were identical to the display monitor's background color (i.e., black). The net effect of the pseudo stimulus was to provide a control that was nearly electrically identical to the stimulus but was "invisible" to any observer. Figure 1 illustrates this sequence. The white line, which is shown as part of the pseudo stimulus, was not visible on the remote monitor and is shown here to illustrate how the pseudo stimulus was displayed.

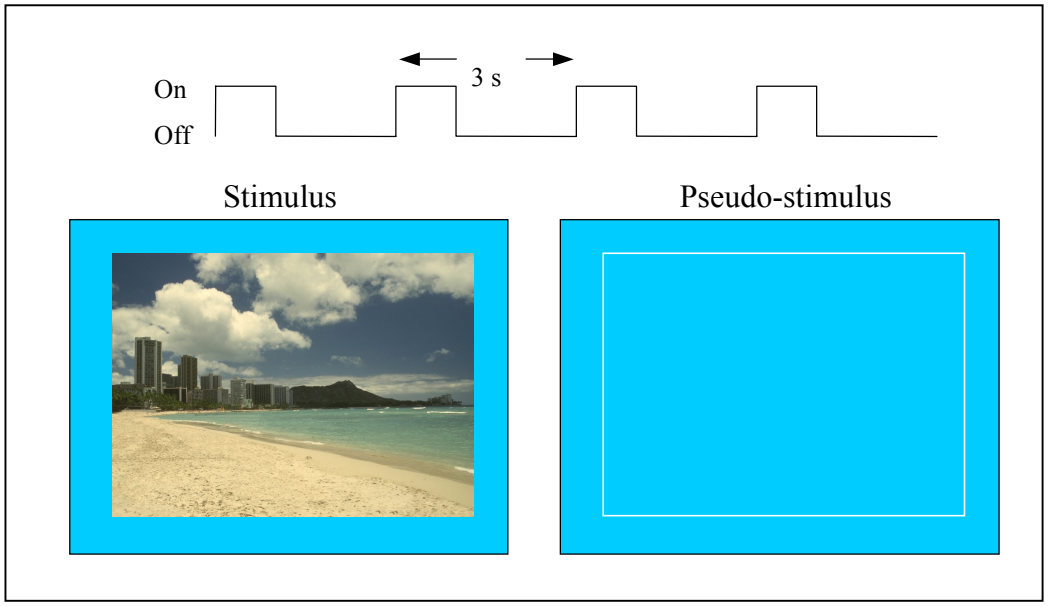

Figure 1. Stimuli Sequence

Fifty stimuli of each type were randomly interleaved with the constraint that no more than three of any type could be adjacent. To an observer, the control room monitor appeared blank most of the time but with an occasional 1-second display of a photograph. The selected target image was used throughout the trial. The trials, however, were conducted without a sender, that is someone who tries to "project" the target image to the isolated receiver.

Trial Protocol

After a preparation time for EEG lead placement of approximately one half an hour, a receiver was seated in the shielded enclosure, and a clipboard and pen were placed adjacent to the seated receiver. The neuroscientist experimenter gave verbal instructions about how the trial was to proceed, closed the chamber door, and returned to the control room.

The 15-minute trial duration was divided into three 5-minute segments. During the first five minutes, designated the AC Condition:

- A random target stimulus sequence was displayed on the remote computer monitor, and the feedback monitor was turned off.
- The receiver attempted to acquire target information silently and to remember as much as possible while remaining as relaxed and as motionless as possible.
- EEG data were collected throughout this 5-minute period.

During the second 5-minute period:

- The EEG data were ignored because of a significant potential for movement artifact.
- The receiver debriefed the experience from the previous 5-minutes by writing and drawing as much as could be recalled. The receiver was encouraged not to attempt to use AC during this time.
- This response, which we call the behavioral data, was collected and stored for later analysis.

During the last five minutes, designated the Feedback Condition:

- The feedback monitor was turned on, and the same stimulus sequence that was used during the first five minutes was displayed directly to the receiver as feedback.
- EEG data were again collected.

Thus, the information gathered in each trial was comprised of three sets of data: EEG under AC conditions, the behavioral data, and EEG under feedback conditions.

AC Behavioral Results

Table 1. shows the results of the blind rank-order judging of the behavioral data for the three receivers:

Table 1. AC Results

Receiver	Trials	Mean Rank	ES	p (1-tailed)
009	18	2.389	0.432	0.033
372	24	2.500	0.354	0.042
389	28	2.750	0.177	0.175
Total	70	2.571	0.303	0.006

The expected rank was 3.0 and *ES* is the effect size.

Two of three receivers in the study showed individually significant evidence for AC, and the combined effect size for the 70 trials was 0.303±0.120, p = 0.006. Thus, our EEG data during the first five minutes of each trial was collected during periods when there was significant evidence that high-quality AC had occurred.

EEG Data Analysis

Not all the EEG data from the trials could be used in the analysis. Some were rejected because of muscle artifact or file corruption. These decisions were made prior to any analysis. We were able to use 18, 11, and 20 runs from receivers 009, 372, and 389, respectively, for a total of 49 trials containing a total of 2,450 stimuli for each condition.

To begin the analysis for a trial, the total 5-minute feedback record was bandpass-filtered between 8 and 12 Hz using an finite impulse response (FIR) design with a Hanning window. We computed the envelope of the alpha power as a function of time by taking the absolute value of the FFT of the filtered data and used it in all further analyses.

In the next step, we used standard ensemble signal averaging on a stimulus-by-stimulus basis to observe ERD's in the feedback data. These ERD's, suitably normalized, were defined as templates in further analysis. A unique template was constructed for each run of 50 feedback stimuli for all runs and for all subjects.

We assumed that if an AC-mediated ERD existed, it is likely to be quite small and would therefore not be found by the usual signal averaging method. Therefore we used a cross correlation filter technique. Consider the alpha power envelope following an AC stimulus. Suppose the ERD template as a function of time is given by g_i, the ith sample

of the template. Suppose further that the alpha power-envelope data is given by x_i, the ith sample of the data. We construct the cross correlation function in the usual way as:

$$C(l) = \frac{\sum_{i=1}^{n} x_{i+l} \times g_i}{\sqrt{\sum_{i=1}^{n} x_i^2 \sum_{i=1}^{n} g_i^2}},$$

where l is the correlation lag and n is the number of sample points in the template. That is, imagine comparing the template not with the data at i, but rather offset by l samples to the right. Normalized by the zero-lag autocorrelations, C is in the range of $-1 \le C \le 1$ (Ifeachor and Jervis, 1993). It can be shown that such a filter is the most sensitive method of extracting a *known* signal from a Gaussian noise background. This correlation for a single stimulus can be converted to a Fischer's Z by:

$$Z_f = 0.5 \ln\left(\frac{1+C}{1-C}\right).$$

The mean-Z over 50 stimuli is give by:

$$Z = \overline{Z_f} \times \sqrt{n-3},$$

where the Z_f*'s* are averaged over the 50 stimuli and Z is distributed as N(0,1).

Summary of the Analysis

For each trial, we constructed an ERD template from the feedback EEG record as described above. Figure 5 shows one example of ensemble averages of the alpha power envelope for 50 stimuli and 50 pseudo stimuli.

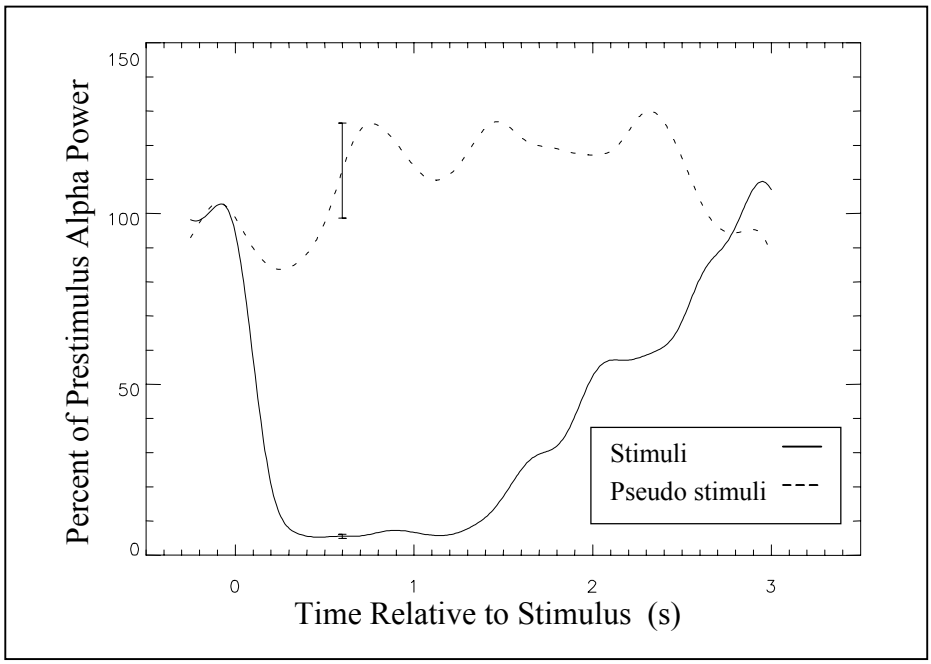

Figure 5. Feedback ERD

The error bars shown at 0.6 s post stimulus are one standard error. We see that the alpha power dropped to a few percent of its prestimulus value and remained suppressed for approximately one second during the feedback period.

We noticed that the trailing edge of the ensemble-averaged derived ERD, where the alpha power returned to prestimulus levels, was highly variable from run to run. This is consistent with Kaufman *et al.'s* (1990) finding that high-level cognitive processing suppresses alpha power. For example when a target photograph is displayed during feedback, one second is sufficient time for the receiver to become cognitively engaged in the photographic content. We might expect this to vary considerably across runs.

Given the lack of cognitive response of AC, it is reasonable to assume that an AC-mediated ERD would not persist as long as an ERD from a direct stimulus. In order to increase the sensitivity of our analysis to AC-mediated ERD's, we used a template that excluded the variable trailing edge of the ERD, and only included the leading edge of the feedback ERD from zero to one half a second poststimulus. Thus the number of samples in the template corresponding to half a second was 63.

Analysis Testing

First we needed to assure ourselves that ERD's could, in fact, be seen during the feedback period using the correlation technique. Figure 6 shows another feedback ERD, the template, which is located between the dashed lines, and the associated a-score for the correlation with the feedback stimuli over one run of 50 stimuli, which is shown as a solid line. The z-score for the correlation of the same template with the feedback pseudo stimuli is shown as a dashed line.

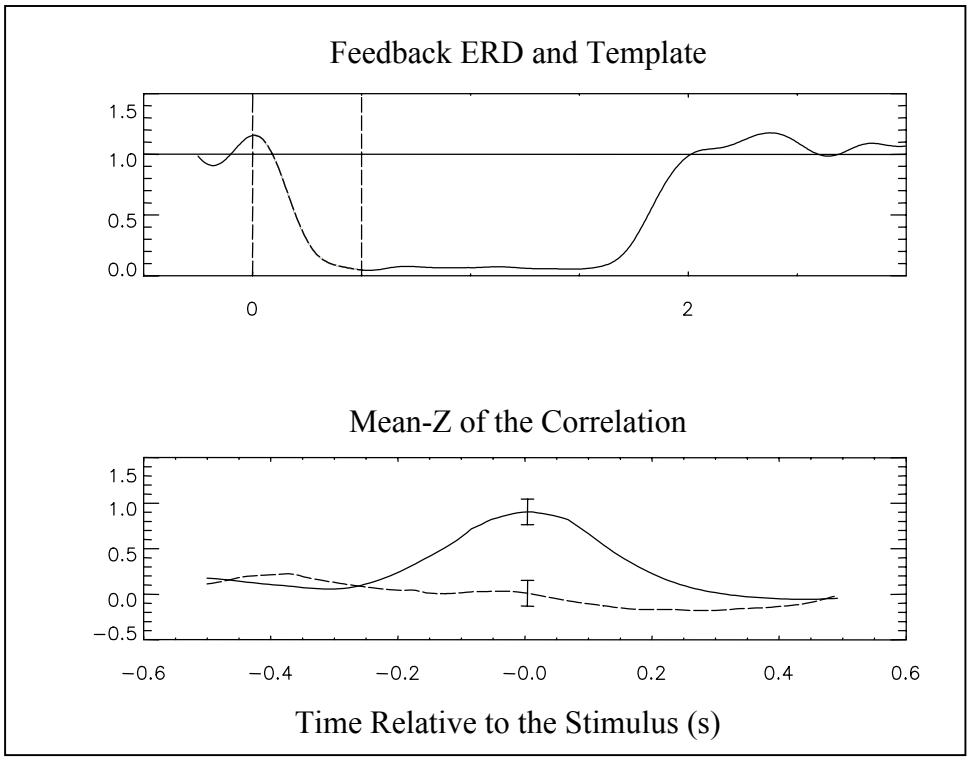

Figure 6. Z-Score for the Correlation with Direct ERD

As we would expect, the difference between the correlation of the template with the feedback is significantly larger than with the feedback pseudo stimulus ($t(98) = 4.47$, $p=1.05 \times 10^{-5}$). The sensitivity of the correlation technique will be discussed below.

ERD Analysis Results

We analyzed all data for O1, O2, P3, and P4 relative to reference linked mastoids and again relative to Cz. The analysis proceeded in two stages. We computed the mean-Z for the correlation with the direct feedback stimuli and their associated pseudo stimuli. The correlation range was from –0.5 to 0.5 seconds relative to the stimulus. Secondly, we

performed the same calculation of the AC-stimuli and their associated pseudo stimuli. Single mean t-scores were computed for the mean-Z's across all runs for a given receiver.

Feedback Stimuli

For the feedback stimuli, we expected and observed a strong correlation with the templates for all runs for all receivers. Figure 7 shows one example of the averaged z-score for the correlation for O2 across 18 runs (i.e., 700 stimuli of each type) from 009 (Single-Mean $t(13) = 4.90$, $p = 1.4 \times 10^{-4}$). The dashed curve is the z-score for the correlation for the feedback pseudo stimuli. The error bars correspond to one standard error. The peak occurs near zero because the template for the correlation began at zero.

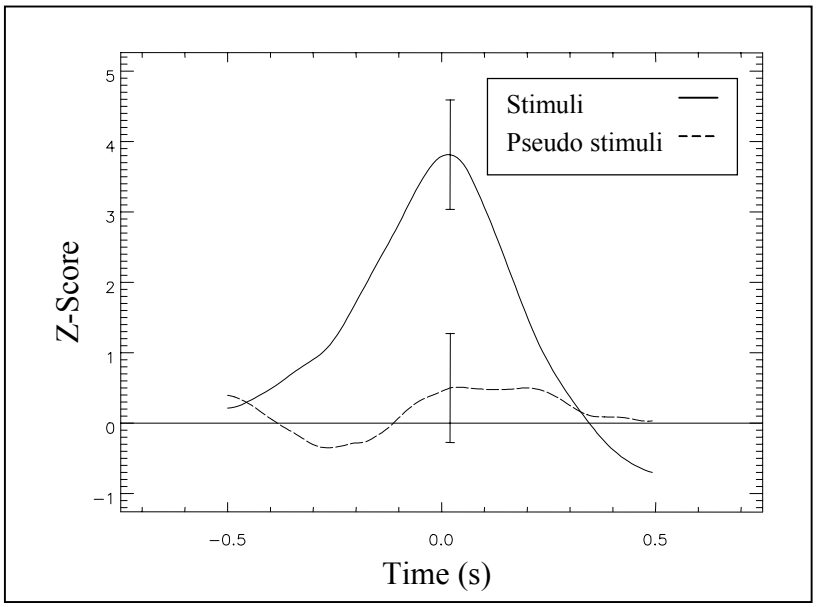

Figure 7. Z-Score of the Correlation for Feedback Stimuli on O2: 009

AC-Stimuli

We did not observe a significant correlation of alpha power with AC-stimuli for ±0.5 seconds relative to the stimulus. Tables 2, 3, and 4 show a summary of the results for each receiver. The single-mean *t*-score was computed for the largest peak in the correlation range. EEG leads that contain *(r)* mean the analysis was relative to Cz. The time relative to the stimulus of the largest correlation is shown as Δt.

We computed the time relative to the stimulus for the maximum correlation of the template with the feedback EEG data, and it is displayed as a table footnote for each

receiver. Note that this is a precise measure compared to the variation observed for the peak of the correlation of the template with the AC EEG data.

Table 2. Receiver 009 Results

EEG Lead	*Single Mean t-Score (13)*	*1-t P-value*	*Δt(s)*
O1	0.778	0.225	-0.371
O1(r)	0.902	0.192	-0.363
O2	0.592	0.303	0.024
O2(r)	0.840	0.208	-0.008
P3	0.646	0.265	0.379
P3(r)	1.040	0.158	-0.371
P4	0.501	0.311	0.403
P4(r)	0.688	0.251	-0.282

Δt for the feedback stimulus was 20 ± 4 ms.

Table 3. Receiver 372 Results

EEG Lead	*Single Mean t-Score(10)*	*1-t P-value*	*Δt(s)*
O1	0.489	0.318	0.185
O1(r)	0.543	0.300	0.105
O2	0.271	0.396	0.089
O2(r)	0.737	0.239	-0.395
P3	0.467	0.325	-0.500
P3(r)	0.466	0.325	-0.500
P4	0.408	0.346	0.427
P4(r)	0.572	0.290	-0.355

Δt for the feedback stimulus was -3. ± 16 ms.

Table 4. Receiver 389 Results

EEG Lead	*Single Mean t-Score(17)*	*1-t P-value*	*Δt (s)*
O1	0.418	0.341	-0.153
O1(r)	0.447	0.330	-0.105
O2	0.442	0.332	-0.145
O2(r)	0.526	0.303	-0.113
P3	0.666	0.257	0.427
P3(r)	0.374	0.356	0.242
P4	0.566	0.289	0.016
P4(r)	0.523	0.304	-0.226

Δt for the feedback stimulus was 6 ± 12 ms.

To illustrate the correlation for the AC stimuli we show in Figure 8, the z-score for the correlation for O2(r) for 009.

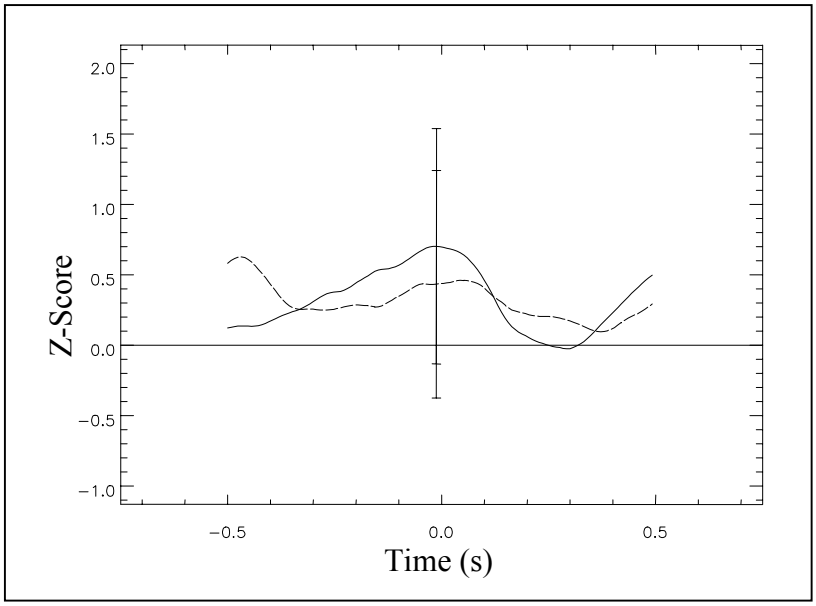

Figure 8. Z-Score for the Correlation for AC Stimuli on O2(r): 009

The ensemble averages for the AC stimuli showed no interesting visually or statistically assessed effects.

Discussion

As discussed above, the cross correlation method is known to be the most sensitive way of extracting a known signal from stationary gaussian noise. EEG data, however, are not statistically stationary and in the case of a putative AC-mediated ERD, the signal is unknown. Therefore we must determine the sensitivity of the method in this application.

We determined a realistic estimate of the sensitivity by adopting a template, which used only the "leading" edge of an idealized ERD shape. This template was inserted into the EEG record at the each of the stimuli locations, with a specified fractional transition depth (e.g., 0.2) at the known stimulus points, and the analysis was performed over all runs for each receiver.

The idealized template, shown in Figure 9, was derived from the Wood-Saxon potential, which is commonly used in nuclear physics to approximate a square-well potential with rounded transitions. The Wood-Saxon potential is given by:

$$y(x) = 1 - \frac{d}{1 + e^{\frac{(x - x_{1/2})}{\lambda}}},$$

where d is the fraction transition depth, $x_{1/2}$ is the point at which the template is ½ of its original value, and □ is a free parameter to adjust the slope of the leading edge.

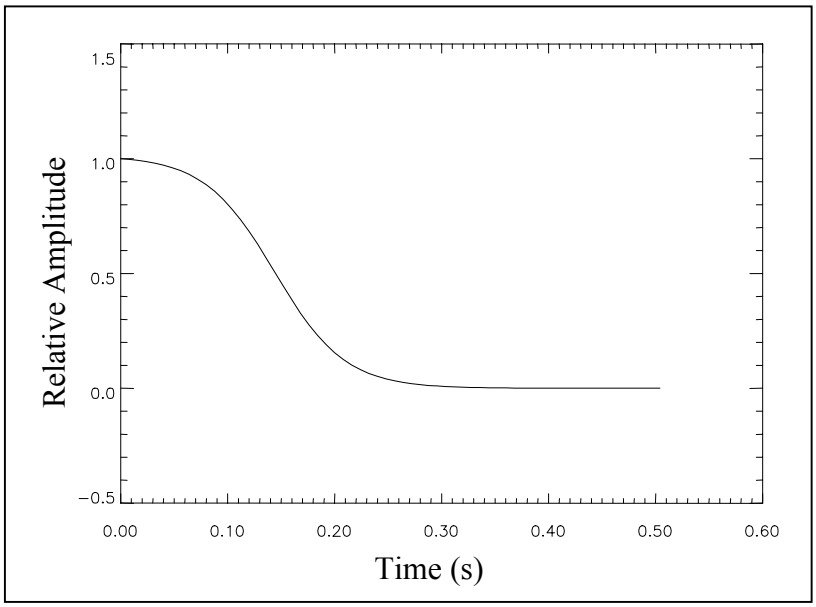

Figure 9. Idealized ERD Template

The observed sensitivity for the three receivers is shown in Figure 10.

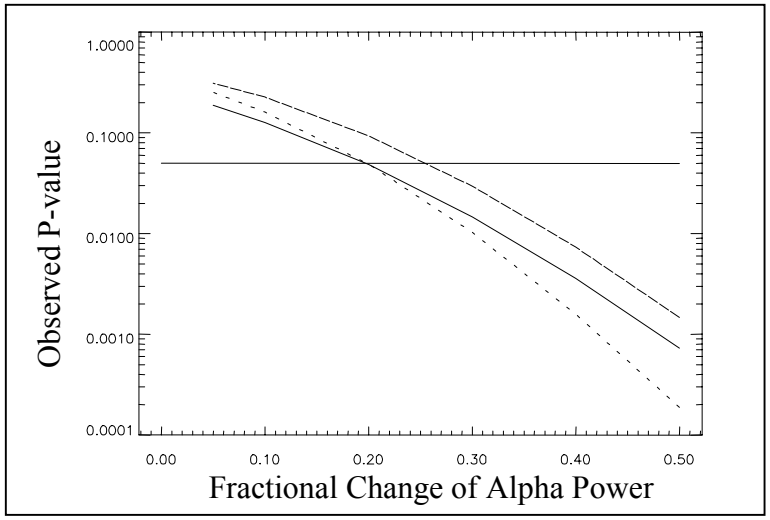

Figure 10. Sensitivity of Correlation Method

The sensitivity for 009, 372, and 389 are shown as solid, short dashed, and long dashed, respectively. The solid horizontal line is at $p = 0.05$. This simulation shows that an ERD

with a fraction change of 0.20 from prestimulus alpha power would have produced a significant correlation for 009 and 389. A 0.26 fractional change would have been required for 372 because of the fewer number of runs.

We now can compare the correlation method to the ensemble averaging technique. Under an optimistic assumption of stationary gaussian noise, define the signal as:

$$y = A \times erd + N(0,1),$$

where A is an ERD amplitude in the range [0,1], *erd* is a 0-to-1 idealized ERD, and N(0,1) is normally distributed gaussian noise with a mean of zero and a variance of one. After *n* trials, the average signal is given by:

$$\bar{y} = A \times \overline{erd} + N(0,1/n).$$

Thus the single-mean *t*-score with *n-1* degrees of freedom is given by:

$$t(n-1) = A \times \overline{erd} \times \sqrt{n}.$$

Table 5 shows the minimum amplitude change that is required for detection of an ERD for both the correlation method and for standard signal averaging.

Table 5. Comparison of Sensitivities at p=0.05

Receiver	*Runs*	*Fraction of Prestimulus* □	
		Correlation Method	*Averaging Method*
009	14	0.20	0.47
372	11	0.26	0.55
389	18	0.20	0.41

We note that even with the incorrect, but optimistic assumption of stationary gaussian noise, the correlation method is twice as sensitive as the more traditional signal averaging technique.

Conclusions

We did not observe an AC-mediated ERD over the posterior region of the central nervous system even though there was strong cognitive evidence for AC in the study. We can speculate as to why this is the case.

- Evidence for AC. Perhaps no ERD's were observed because of a lack of evidence for AC in the experiment. The effect sizes shown in Table 1, however, appear to rule out this possibility. The effect size for the two independently significant receivers was about one half of the values for these same individuals in their last experiment (Lantz et al., 1994). The estimated hit rate, however, corresponding to an overall effect size of 0.303 is 0.321. We convert this to an effective binary hit rate as 0.654 so that the results can be compared to the published rates. The most current picture of all AC experiments published to date can be found in Radin (1997, page 106). Our effective binary hit rate is higher than the mean value of other experiments of approximately 0.60.
- Timing of AC Reception. Since we do not have an independent measure of *when* the data are acquired by AC, we cannot be sure that it occurred during the five minutes of the AC-portion of the EEG data collection period. It is even possible that the receiver acquired the information during the behavioral debrief five minutes when the EEG was ignored.
- EEG Lead Placement. It is possible that the null result arises because the EEG leads were placed only on posterior regions. Perhaps temporal or frontal lobe activity might have revealed an ERD; however, alpha power measurements are relatively insensitive to lead placements.
- Timing Assumption. By their nature, ERD measurements contain an implicit assumption. Namely that CNS responses are time-locked to the stimuli. There is substantial evidence that AC is not so time stable (Honorton and Ferrari, 1989; Jahn 1982). While the evidence for precognition[6] is statistically robust, it is not a necessary condition for AC. Thus, time-locking is not forbidden.

Perhaps a likely answer is that the AC is involved with the central nervous system in the deep, and/or ancient structures–areas difficult to asses with scalp EEG.

A qualitative evolutionary argument suggests that humans do not need AC for survival, and thus AC ability might be vestigial. By implication, then, neurons that are specialized or optimized for the detection of AC might reside in the "older" structures of the brain. If

this is the case, then it is likely that alpha power would not be affected by AC stimulation although theta power might be (Klimesch, 1996).

A further difficulty might be that EEG is the wrong technology to use for the search for the CNS's involvement with AC. Burgess and Gruzelier (1997) recently addressed the issue of the validity of using EEG to localize cognitive functions. Gevins and coworkers have argued that many lateralizable differences between cognitive tasks can be accounted for by non-cognitive factors such as differences in stimulus parameters, in motor responses, or in task difficulty (Gevins et al., 1979a, 1979b, 1979c). CNS changes can only be localized to areas on the scalp with most EEG systems. This view is considered to be outdated because of recent advances in EEG technology (Gevins, 1996; Gevins, et al., 1994; Nunez, et al., 1994). Since at least tens of thousands, perhaps hundreds of thousands of neurons have to be simultaneously active to produce the rhythms which are recorded with scalp EEG, "in order to proceed from phenomenology to physiology, we really need to go to sources. We have to make an effort to specify what are the sites in the brain which generate these signals we are measuring" (Ba□ar and Schurmann, 1997, p. 456)

In the case of EEG, the sources are believed to be predominantly cortical (Burgess and Gruzelier, 1997). Ehrenwald (1977) noted that "…the presumed cerebral localization of psi phenomena is predicated on the concerted action of both cortical and subcortical brain regions." As we stated above, it is likely that deep and/or ancient brain structures, such as the basal forebrain, hypothalamus, thalamus, basal ganglia, and brainstem, are involved in AC.

[6] Statistically significant results from stimuli that were randomly determined and presented in the near future of the subject's response.

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