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<p>This report describes a number of experiments related to the effects of mental imagery and other high-level cognitive tasks on the spontaneous activity of the brain. The basic procedure involves narrowly bandpassing the magnetoencephalogram (MEG), computing the average response to a stimulus or event within that bandpass, and computing the variance around the average. The variance at any point in time subsequent to the stimulus is a measure of mean square field (power). Power in the alpha band (8-12 Hz) was found to show a prominent change in level subsequent to presentation of a form. Simply watching the form results in a dip in alpha power, but when subjects attempt to determine if the form had been seen previously, the duration of the reduction in alpha</p>													
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power increases significantly, and is correlated with reaction time (RT). The distribution of alpha across the occipital and parietal areas shows remarkable individual differences in both symmetry and magnitude. This is not caused by variations in skull thickness. The changes in this distribution during the course of performing a search of visual memory suggests that the effects are localized to visual cortex. Performing the same type of analysis of activity in the beta band failed to confirm the hypothesis that beta activity replaces alpha activity. Instead beta activity shows the same kind of reduction in power during a search of visual memory. However, the data suggest that beta activity arises from an at least partly different neuronal population than that which gives rise to alpha.

In another experiment subjects either tried to form an image of an object represented by a visually presented word, or to find a rhyming word. The latter task did not produce a change in activity of visual cortex, while the same words produced a profound change in activity of visual cortex during imaging.

Acoustically presented words were also found to produce changes in MEG activity arising in the visual areas when they were used as cues to forming a mental image. (AW) \*

Tonal stimuli were used in a Sternberg-like paradigm in which subjects had to search memory to determine if a recent tone was or was not a member of a set of previously heard tones. This was found to modulate activity arising in temporal lobe, and not to modulate occipital alpha activity.



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**INTERIM SCIENTIFIC REPORT****ATTENTION, IMAGERY, AND MEMORY: A NEUROMAGNETIC INVESTIGATION**

AFOSR Contract No. F49620-88-K-0004

by Lloyd Kaufman, New York University

**INTRODUCTION**

This interim report describes ongoing research, sponsored by AFOSR under Contract No. F49620-88-K-0004. The research is being conducted at the Neuromagnetism Laboratory (NML) of New York University and at the Center for Neuromagnetism (CNM) of the School of Medicine of New York University. The CNM is located at Bellevue Hospital and it includes two 7 channel neuromagnetometers, which makes it possible to measure the neuromagnetic field at 14 positions at one time. This capability foreshadows even more advanced systems, and it was fully utilized in two of the major areas of research described in this report.

This report outlines the progress made during approximately the first year of the contract, and it forecasts the work that will be completed in the second year.

**Evaluation of 14-channel Neuromagnetometry System**

The purpose of this work was to assess the precision and reliability with which dipolar sources are located using a 14-channel system composed of two 7-channel neuromagnetometers and the probe position indicator (PPI) used to locate the head with respect to each of the sensors. The attached paper provides all of the details of this work, which involved using a spherical "phantom", a plastic model of a skull and actual human subjects. The precision with which a dipolar source could be located within a spherical phantom and within a model skull was found to be less than 3 mm in three dimensions. Also, the determination of location was highly reliable since 20-30 independent determinations were in full agreement with each other. The human work demonstrated that the equivalent current dipole sources of the magnetic N100 component of the auditory response was located on the floor of the sylvian fissure of each subject, with variations in source location related to anatomical differences among subjects, as revealed by MRI scans. Furthermore, this work confirmed earlier reports of the tonotopic sequence along the floor of the fissure. The reader is referred to the attached paper (Yamamoto, et al., 1988) for details. The essence of these results have already been confirmed by Papinicolaou, et al. (1989).

**COGNITION AND BRAIN ACTIVITY***Background*

In our original proposal, which was submitted to AFOSR on 30 July 1987, we outlined a novel approach to the study of cortical activity associated with mental imagery. In the previous report we described some of the experiments that were then in progress. Since that time the experiments were completed and the results of some are to be presented at the forthcoming International Conference on Biomagnetism in August, 1989. The abstracts of these papers are attached. Also, one paper was completed and

submitted to *Science* for review. A copy of that paper is also attached to this report (Kaufman, et al., 1989).

In all the experiments described in the attached abstracts and paper we found that the magnetic fields associated with the spontaneous magnetoencephalogram (MEG) varied profoundly with different types of cognitive tasks. In a recent article on computational neuroscience, Sejnowski, Koch and Churchland (1988) make the point that "it is difficult to imagine a major advance in our understanding of brain function without a concomitant development in direct, efficient techniques for probing the mechanisms of distributed processing. (p. 1300)" In this connection they mention (MEG) as one of several new methods that may contribute to our knowledge of the computational networks of the brain that make complex cognitive processes possible. In this report we describe results that can lead to the realization of that goal.

The cognitive tasks involve the manipulation of mental images based upon stimulation by physical images, visually presented text, tone bursts, and acoustically presented words. We have also conducted pilot studies on mental rotation, and plan work on effects of different levels of processing on brain activity.

#### *Modulation of Brain Activity During Mental Imagery*

To summarize our findings, as described in the attached preprint by Kaufman et al. (1989) we measured the average power of both alpha and beta activity over the occipital and parietal areas and discovered spatially selective suppression of activity in both bands when abstract figures were briefly presented visually. Subjects first saw 3 of the forms in sequence. Then, several seconds later, one form was presented for 100 msec, and subjects responded in one of two ways. First, they simply pressed a button whenever they saw this final "probe" form, regardless if they had seen it before. Alternatively, they pressed one button if the form had been one of the previously seen set of forms, and another button if it was new, i.e., not a member of the memory set. The first condition is the simple RT task, while the latter is the choice RT task. The RT in the latter condition was much longer than that of the simple, and the duration of suppression in both MEG bands was commensurately longer. The visual evoked field did not show the same effect on its duration. Thus, searching visual memory results in long periods of suppression of both alpha and beta activity. Furthermore the distribution of the magnetic field associated with this suppression effect on the scalp is consistent with the notion that activity of visual cortex is modulated during the comparison of mental images.

There were some ancillary findings that could not be described in the previous Interim Scientific Report. First, the distributions of alpha band and beta band activity across the scalp is often asymmetrical in a given individual, and differs from individual to individual. Furthermore, the variance in the distribution of beta band activity across the scalp cannot be accounted for by the variance in the distribution of alpha band activity. This despite the fact that both bands exhibit a correlated suppression in amplitude. Several inferences may be drawn from these ancillary findings. First, the asymmetry cannot be due to variations in skull thickness, as is stated in the EEG literature. Secondly, beta does not replace alpha during blockage but is correlated with it. Thirdly, the sources of beta are in large measure different from the neural sources of alpha. A final conclusion is that the suppression effect, if it is related to classic alpha blockage, is not caused by elevated arousal or visual attention per se, but is in large part related to

stages of processing of vision-related mental events.

It should be noted that the literature describing the background to the foregoing project was surveyed in the preceding Interim Scientific Report, and much of it is covered in the attached preprints and abstracts. Hence, there is no need to repeat it here. However, it may be of some use to provide a brief summary of the methodology employed, as it is also used in our other experiments described below.

#### *Comments on Methodology*

Kaufman, et al. (1967; 1970) employed a comb filter to remove all harmonics of the fundamental frequency of a periodic stimulus from the EEG before rectifying and averaging the EEG. This method involved using a delay line and subtraction procedure as well as a complicated procedure for producing a stimulus (Kaufman and Price, 1967). The analog procedures used to accomplish this involved subtracting the activity that is time locked to the stimulus from the ongoing activity, then squaring the remaining activity before averaging (an analog square-law detector was employed). This gives the power (mean square voltage) of the background activity and shows how it varies as a function of time between stimulus events. A non-varying measure of power in this interval implies the presence of "noise" that is independent of the evoked response. However, systematic and repeatable fluctuations in power as a function of time between stimuli implies a modulation of the background activity by the stimulus. The powerful digital computers that are now available make this process much easier to implement.

The variance about the mean response to some stimulus is proportional to the power of the background activity. In the EEG this measure (variance) represents mean square voltage, while in neuromagnetometry it represents mean square field. Consider the definition of variance. It is the normalized sum of the squares of the differences between the mean response and the field (or voltage in the case of EEG) at any instant of time within the epoch. In effect, this means that the average response is subtracted out, and the difference between the average and the instantaneous value of the field is squared. This value is added to that of all of the other values occurring at the same time after each stimulus event. For example, if the brain activity subsequent to a stimulus is sampled 256 times, there will be 256 variances associated with each average response. If the noise is uniform and independent of time after a stimulus, then these variances will statistically equal to each other. However, if the output of the brain should vary, depending upon its state at different times within the averaging epoch, the variance should change reliably as a function of time.

With this information in mind, it is easy to understand our basic procedure. A subject is presented with some stimulus or some set of stimuli and required to perform a well defined task with respect to these stimuli. The total MEG activity between 0.1 and 50 Hz is recorded throughout the experiment. To obtain an average response, a particular stimulus event is chosen as a reference signal and averaging of the activity time-locked to the stimulus (both before and after its presentation) is done in the usual manner. Since we store all of the ongoing activity, it is possible to compute the average response in a narrow bandwidth, e.g., 8-12 Hz, of the digitally filtered MEG. Because of the narrow bandwidth the average response does not resemble the usual evoked response but we have found it to contribute as much as 25% of the mean square field when it is not subtracted out. This is the main reason for not following the procedures devised by

Pfurtscheller (1977). In an event, after filtering the entire record, the average response and its variance are computed. This variance is the critical measure because, as we have stated, it shows how the mean square field associated with a cortical source varies as a function of time before and after stimulation. We are particularly concerned with how the fluctuations in variance (field power) are related to the nature of the mental task. Now let us turn to some other results obtained using these methods.

### *Visualizing and Rhyming*

In these experiments, conducted by Kaufman, Glanzer, Cycowitz, Williams and Schwartz (1989) words were presented near central fixation and subjects were asked either to form an image of the object represented by the word, or to find and silently recite a word that rhymes with the word that had been seen. The motivation was provided by the inference of Shepard and Metzler (1971) that visual cortex is involved in manipulating mental images. Again, we used modulation of alpha as an index of whether or not visual cortex was involved in the two kinds of mental operations - one involving images and the other a language related task. The details are given in the attached abstract.

We have already gone beyond the findings described in the abstract. We now have data supporting the hypothesis that alpha is suppressed by presenting easily imaged words even though the subject is performing the rhyming task. The depth and duration of the suppression is intermediate between that which occurs when the subject is actively visualizing such words (the maximum effect), and when the subject is merely looking at a nonsense word (shortest duration effect). We interpret this to mean that there is an immediate perceptual processing that is modality-bound, but once the processing involves a mental image the visual cortex continues to "work". However, this "work" is terminated rapidly when the task is translated to the linguistic domain, so that the effect in the rhyming task resembles that associated with nonsense words. This suggests that effects should be found in temporal lobe when subjects are performing the rhyming task. We intend to follow-up on this conjecture.

### *Modulation of Activity of Auditory Cortex*

The preceding experiment caused us to consider the possibility that activity of other brain areas may be similarly modulated by the performance of a cognitive task. Toward this end we designed an experiment in which three different musical notes were played in sequence, and another "probe" note was played 2 seconds later. As in the first experiment described in this report, subjects had to determine if the probe note had or had not been a member of the original memory set. There was one major difference in procedure, however. Subjects were shown a number, 1, 2, or 3 about 2 sec before each memory set. The number '1' meant that they had to store only the last of the three notes for subsequent comparison, '2' that they had to remember the last two notes, and '3' that they had to remember all three. Thus, we were able to manipulate the size of the memory set while making no change at all in the physical stimuli. The different size memory sets were mixed at random, and responses depooled later so that we could examine the effect of memory set size.

To be brief, we found that activity in the 8-12 Hz band originating in temporal areas, probably auditory cortex, was indeed modulated during the search of acoustic memory. Control measures failed to reveal any corresponding change in alpha

originating in visual or parietal areas. We also have preliminary evidence that the duration of the suppression is larger for longer set sizes. This work is continuing.

### *Visual Memory Set Size*

We are concurrently conducting an experiment similar to that above, but using the visual polygons of the first experiment. Instead of musical notes, we present three of the polygons in series shortly after either a high, medium or low pitch tone. The low pitch tone means the subject has to remember only the last of the polygons, and so on. This too permits control over memory set size without affecting the physical stimuli. In most subjects there is a monotonic increase in duration of suppression with memory set size. We have not yet correlated this with RT, nor have we yet separated correct from incorrect responses. This will be done shortly. However, we do know that "new" stimuli (those not in the memory set) give the same duration of suppression as do "old" stimuli, thus confirming Sternberg's result that the search of visual memory is exhaustive.

### *Auditory Word Experiment*

In the last report we described an effort to produce words using a speech synthesizer. We were finally successful and have just begun to collect data using auditory words that are either imageable or abstract, which allows us to do an experiment that complements the one described in the abstract. Preliminary trials show that imaging the object represented by an imageable acoustically presented words results in specific suppression of visual activity in the alpha band.

### **Forecast**

The major forecast is that we shall complete all of the experiments described above that are as yet incomplete and prepare papers for publication. In addition we plan a new experiment.

In this new experiment we shall present letter stimuli as in the classic Sternberg paradigm. We shall use 1 to 6 different letters and a target letter that could be either new or old. There will be one difference, however. Sometimes the target letters will also be presented in a different case, i.e., lower case if the memory set letters were capitals, and *vice versa*. This will allow us to test the hypothesis that when a visual match is not possible, there will be concomitant activity in the auditory or speech areas, and such activity will be less likely when a visual match is possible.