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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Electroencephalographic (EEG) and performance measures were obtained from eight adult male subjects during a sequence of 18 trials over a six-hour period consisting of alternating performance and non-performance epochs in a flight simulation task. EEG data were subjected to a limited bandpass frequency analysis. Task engagement (performance) was associated with greater density in central cortical rhythmic patterns, while a reciprocal decrease was observed in parietal-occipital activity. The opposite relationship was observed during non-

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) performance segments, with density greater in parietal-occipital data. This reciprocity was most consistent in the central 8-11 Hz and parietal-occipital 4-7 Hz bands.

EEG activity from these two areas was also found to be modulated over time, with linear trends related to performance epochs and periodic trends associated with non-performance epochs. Central rhythmic activity tended to increase progressively over trials in performance epochs while parietal-occipital patterns showed the opposite trend. Parietal-occipital activity was greatest during non-performance epochs and both areas showed an in-phase periodic pattern, with a cycle duration approximating 90 minutes. → ORIGINATOR-SUPPLIED KEYWORDS:

Performance was measured by a composite score of visual-motor speed and digit recall accuracy. This measure indicated a linear trend across trials which appeared to parallel the increased central 8-11 Hz EEG activity and the reciprocity between central and parietal-occipital EEG patterns observed during performance epochs. No relationship was apparent between this performance measure and the cyclic EEG pattern during periods of non-performance.

The consistent reciprocity observed between central 8-11 Hz and parietal-occipital 4-7 Hz EEG activity, both during task non-task alternations and across trials paralleling performance increments, suggests that these two EEG measures can define relevant state characteristics. Accordingly, they could be used to track both vigilance and competency in flight operations. This conclusion will direct future studies aimed at confirming these relationships and applying operant conditioning procedures in an attempt to achieve voluntary control of functional state in this context.

INSTRUCTIONS FOR PREPARATION OF REPORT DOCUMENTATION PAGE

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MEASUREMENT AND MODIFICATION OF SENSORY SYSTEM EEG CHARACTERISTICS DURING VISUAL-MOTOR PERFORMANCE

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Measurement and Modification of Sensory System EEG Characteristics During Visual-Motor Performance

INTRODUCTION

The primary objective of this study was to evaluate specific electroencephalographic (EEG) measures during scheduled performa ce in a visual-motor task approximating skills required in military flight operations. It was hoped that specific parameters of these measures could be used to estimate the functional state of the central nervous system in relation to performance characteristics. Ultimately, this information would be employed in an effort to modify state characteristics using methods of EEG operant conditioning so as to assure adequate, and in some applications optimal, performance in such tasks.

The EEG measures selected and the approach to their analysis was based on previous research in the areas of CNS state organization and EEG pattern interpretation. Specifically, studies of performance modulation in cats trained in various operant response paradigms together with a corresponding analysis of sleep state periodicity (Sterman et al., 1972) had found evidence supporting the concept of a basic-rest-activity cycle, proposed initially by Kleitman (1963). The perspective which this concept provides, namely that both sleep and waking states are modulated by a functional pacemaker organized at a brain stem level, suggests that all physiological activities and their ultimate integration during performance should have periodic characteristics. This perspective, together with the known influences of circadian modulation, learning trends and fatigue, underscored the need for an expanded approach to the search for reliable physiological predictors of performance.

Other work conducted in our laboratory had focused on the mediation and functional significance of differing frequency patterns in the EEG of primary sensory cortex (Sterman and Bowersox, 1981; Sterman & Shouse, 1982). In particular, we had examined thalamocortical interactions in relation to rhythmic patterns in the sensorimotor EEG and derived a strategy for their functional interpretation. The resulting orientation suggested that frequency analysis of EEG activity from specific cortical areas might provide an effective measure for the task of tracking and eventually modifying the functional states of the brain.

METHODS

Eight adult male subjects, ranging in age from 29-48 years, were employed in this study. Each subject was monitored polygraphically during 6 hours of an alternating performance and non-performance schedule. Monitoring was carried out in a mock-up of an F-16 fighter cockpit while performance consisted of achieving a series of assigned flight paths through manipulation of orientation (joy stick) and velocity (throttle) controls in a video simulated flight scenario. Subjects were instructed to complete each assigned course change as quickly as possible and to cease "flying" activity until the next adjustment was ordered. Instructions, pre-recorded on cassette tapes, were delivered through a radio headset at 15 min. intervals and both the timing of performance and compliance with instructions were monitored systematically. The resulting sequence consisted of 18 periods of task execution, one every 15 minutes, followed by comparable periods of verified non-task activity. During non-performance periods, activities varied from quiescence with eyes open or closed to reading of magazine or textbook materials. A 15 min. "break" at 45 min. intervals provided for stretching, eating or toilet activities. During these periods a special monitoring cable was disconnected from a master input plug to allow egress from the recording situation without removal of electrodes.

Monitoring parameters included selected EEG leads, a chin (digastric muscle) EMG, and end-expired CO_2 percentage in respiratory gas. Respiratory gas was collected from the mouthpiece of a regulation Air Force oxygen mask worn by the subject, and drawn through a short length of polyethylene tubing to the recording head of a Beckman LB-2 gas analyzer. The present discussion will be limited to a review of EEG findings only.

The two standard bipolar EEG placements included central and parietal-occipital sites (C_1-C_5 and P_3-O_1 according to the International 10-20 System). Gold-plated cup electrodes were fixed to the prepared scalp with collodion adhesive and attached to Oxford Medilog miniature preamplifiers on the back of the head. These leads, together with that from an ear clip ground electrode, were fed to a Grass polygraph and magnetic tape recorder. Leads from the amplifiers of the polygraph were fed also to a bandpass frequency analyzer which automatically registered activity in two selected frequency bands (4-7 Hz and 8-11 Hz) from each cortical recording site every 15 sec. From these data, mean EEG bandpass values were determined for each confirmed performance and non-performance epoch of the entire 18-trial sequence. In order to combine data from subjects with differing baseline EEG voltages, bandpass values from each subject were converted to standard Z scores, with reference to the grand mean of all performance and non-performance epochs.

Prior to each course adjustment instruction the subject was presented with a seven digit code number which he was asked to repeat. Following completion of each trial the subject was instructed to repeat the code number once again and was then given a new code number in advance of the next course adjustment instruction. This sequence of immediate and delayed digit recall testing was continued across all trials. The assessment of performance consisted, therefore, of a measure of the time required to complete the requested course adjustment and a measure of the accuracy of digit recall. Course adjustments were calculated in advance to equate for the machine time required for changes in speed, altitude, and compass heading. A formula was derived to combine measures of course adjustment speed and recall accuracy in order to provide a single quantitative estimate of performance for each trial. These data were also converted to standard Z scores in order to examine group trends.

RESULTS

Analysis of EEG data showed clearly that the sequence of performance and non-performance epochs across the 18 trials of this design imposed an ultradian periodicity on all of the EEG frequency bands studied (Fig. 1). For parietal-occipital recordings this periodicity was most marked in the 4-7 Hz band with performance suppressing and non-performance enhancing activity at this frequency. Conversely, in central cortical recordings periodicity was clearest in the 8-11 Hz band and this activity was generally enhanced during performance and suppressed in non-performance epochs The consistency of this cycling was particularly surprising in view of the variability of activity during non-performance periods, and suggests a clear dichotomy between scheduled and non-scheduled activities. Additionally, the reciprocity observed between parietal-occipital and central cortical EEG characteristics in this regard (Fig. 2) indicates that quite different functional activities are occurring in these two cortical areas in relation to this dichotomy.

- Place Fig. 1 about here -

If one examines this periodicity closely it is apparent that the reciprocity of frequency modulation between performance and non-performance epochs at both cortical sites was not constant. That is, the degree of modulation appears to vary over time. In order to examine this variability systematically difference scores were calculated for the central 8-11 Hz and parietal-occipital 4-7 Hz bands by subtracting each non-performance epoch bandpass value from the preceding performance epoch value for the two most modulated frequency bands across trials (Fig. 3). This analysis disclosed a marked ultradian periodicity in both bands, with an estimated cycle length ranging from 75-90 min. The quantitative sign of this periodicity was to some extent opposite in the two bands, suggesting the same reciprocity as was seen in the periodicity imposed by the performance schedule. Moreover, data from central cortex showed a graded increment in difference score peaks over trials while that from parietal-occipital cortex showed a reciprocal decline in troughs over trials.

- Place Fig. 2 about here -

In an effort to evaluate the origins of this periodicity and its trends, a different analysis was explored. In this case sequential bandpass values from performance and non-performance epochs were plotted separately across trials (Figs. 4 & 5). Considering performance epochs only (Fig. 4-A), a general trend was observed in all data such that the activity in central cortical EEG frequency bands showed a gradual increment in density across trials, which leveled off by the middle of the six-hour session, while the parietal-occipital frequency bands showed a more modest and reciprocal decline. That is, as trials progressed the incidence of central 8-11 Hz band activity increased while that in the posterior 4-7 Hz band decreased.

- Place Fig. 3 about here -

Composite performance Z scores are also shown in Fig. 4 (B). These data, with one exception (trial 5), show a delayed increment in scores across trials indicating a significant and sustained improvement in performance by the ninth trial. We attribute this trend to a practice or learning effect since, while all subjects had been given the opportunity to practice this task, none achieved stable proficiency until the prolonged training provided by this test.

-Place Fig. 4 about here -

Data from non-performance epochs were very different (Fig. 5). In contrast to the sustained trends of performance epochs, the pattern observed during non-performance epochs was periodic, with both frequency bands in phase and the greatest density registered by the parietal-occipital 4-7 Hz band. This periodicity also showed an estimated cycle range of 75-90 min.

- Place Fig. 5 about here -

DISCUSSION

These findings indicate that the linear trends noted across trials in the difference score analysis were due to changes associated with performance epochs while the periodicity in difference scores resulted from modulation within non-performance epochs. It is reasonable to assume therefore that the demand character of the task dominated neural functioning during performance periods. The resulting cerebral engagement would be expected to mask or perhaps override the underlying functional periodicity. During non-performance epochs, however, attentional demand was greatly reduced. Under this circumstance, intrinsic periodicity was revealed.

A number of additional conclusions can be drawn from these findings. First, as might be expected, state changes during wakefulness also influence physiology systematically. In this case, the state changes were dictated by an experimental task schedule. While this is not a surprising finding, it is indicative of the many influences which can confound the study of biological activities outside of the laboratory. Additionally, when more complex physiological variables are of interest, such as the EEG in this case, experimentally imposed periodicity can define the limits of response within a given context, aid in selecting appropriate quantitative measures, and provide important clues concerning the functional substrates of the response observed.

With regard to the latter, it is apparent from these data that rhythmic EEG activity in central cortex, resembling the mu (Gastaut, 1952) and sensorimotor (Sterman et al., 1974) patterns related to movement suppression, was specifically enhanced during a finely controlled visual-motor task. Conversely, rhythmic activity over visual cortical areas was decreased in a reciprocal manner. A broader evaluation of changes in both EEG and performance characteristics over trials suggested that the same reciprocity between rhythmic activity from these two cortical areas was associated with a sustained improvement in performance. These observations, together with the non-reciprocal periodicity observed during non-performance epochs, suggests that the reciprocity of these measures may define specific brain states related to both vigilance and the quality of associated performance in this type of task. Therefore, tracking such measures may indeed provide a basis for anticipating performance decrement and/or sustaining optimal response characteristics.

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FIGURE LEGENDS

Fig. 1. Mean bandpass density response (Z score transform) in two frequency bands from EEG data recorded over two different cortical sites across 18 trials of alternating performance and non-performance epochs in a video flight simulation task. Data from parietal-occipital cortex (P_3-O_1) at A show decreased density in 4-7 (□) and 8-11 (+) Hz activity during performance epochs (indicated by trial numbers) and increased density during non-performance epochs (indicated as points between trial numbers). Data from central cortex (C_1- C_5) at B show the opposite pattern but primarily in the 8-11 Hz band (+). At this cortical site density was increased during performance relative to non-performance. Periodicity here was related to the experimental work schedule.

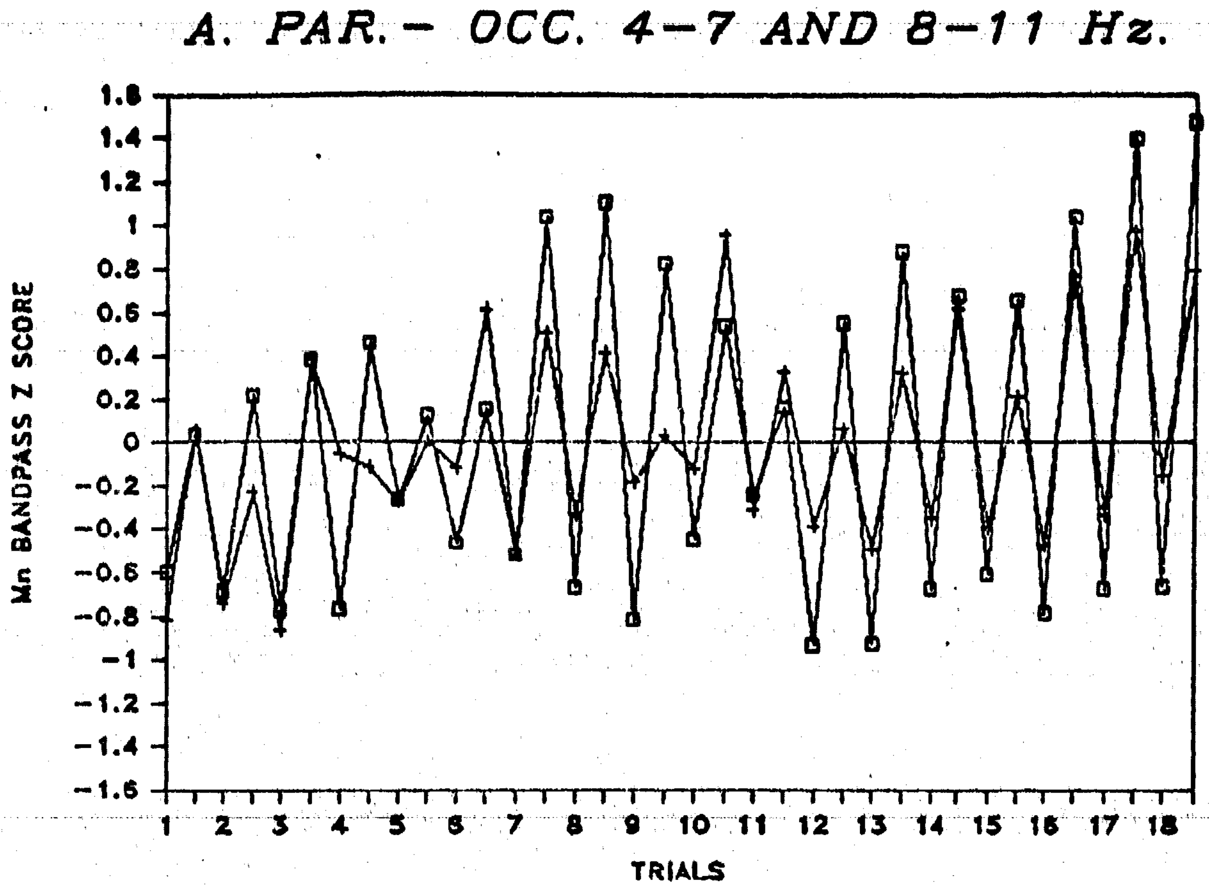
Fig. 2. Mean integrated bandpass data as in Figure 1 but showing parietal-occipital 4-7 Hz response (□) combined with central 8-11 Hz response (+). Note relatively consistent reciprocity in these two EEG measures in relation to the sequence of performance and non-performance epochs across trials.

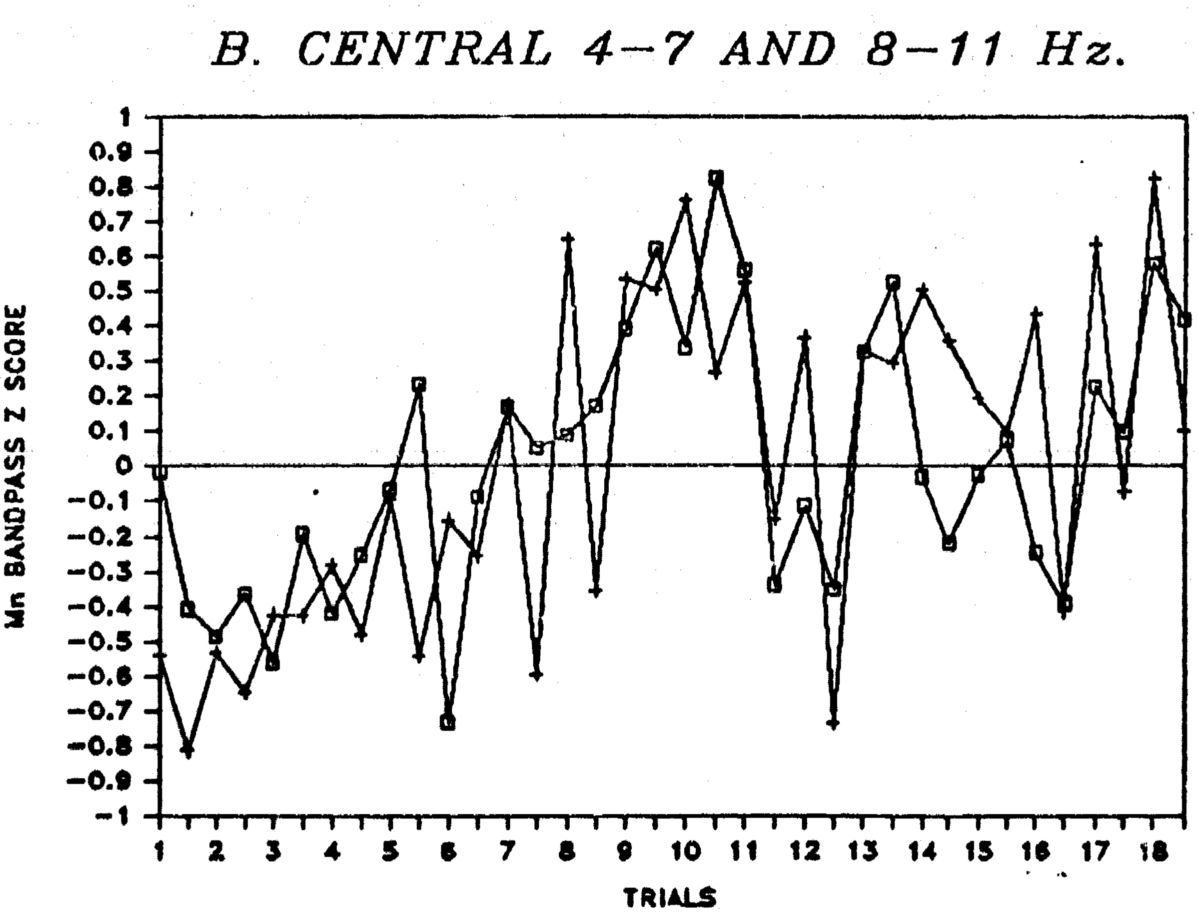
Fig. 3. Plot of successive "difference scores" derived by subtracting bandpass density values obtained during non-performance epochs from those registered during subsequent performance epochs. Scores from central 8-11 Hz data (A) show a marked periodicity ranging from 75-90 min, with peak values trending upwards across trials, while those obtained from parietal-occipital 4-7 Hz data (B) suggest a somewhat slower and reciprocal periodicity, with troughs trending downwards across trials.

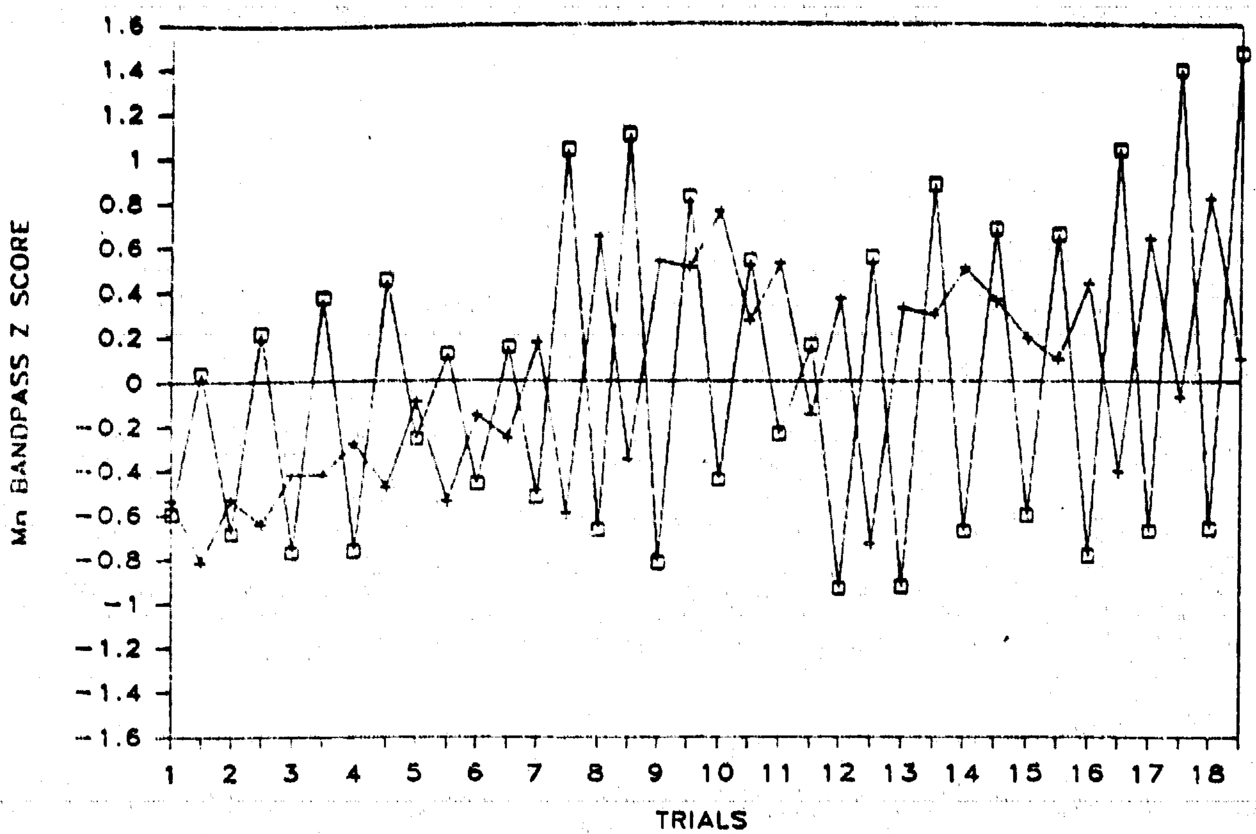
Fig. 4. Mean bandpass Z scores for central 8-11 Hz (□) and parietal-occipital 4-7 Hz (+) EEG activity during the performance epoch of each trial are shown at

A. Note tendency towards reciprocal trends and increment in central 8-11 Hz activity across trials. Corresponding composite performance Z scores are shown at B. This function tends to follow the curve for central activity but with a lag, and suggests a direct relationship between central vs. parietal-occipital EEG reciprocity and performance.

Fig. 5. Mean bandpass Z scores for central and parietal-occipital frequencies as in Fig. 4 but derived from non-performance epochs across trials. Note reversal in density from data obtained during performance, with parietal-occipital 4-7 Hz activity (+) consistently greater. Both EEG measures show an in-phase periodicity across trials approximating 90 min.

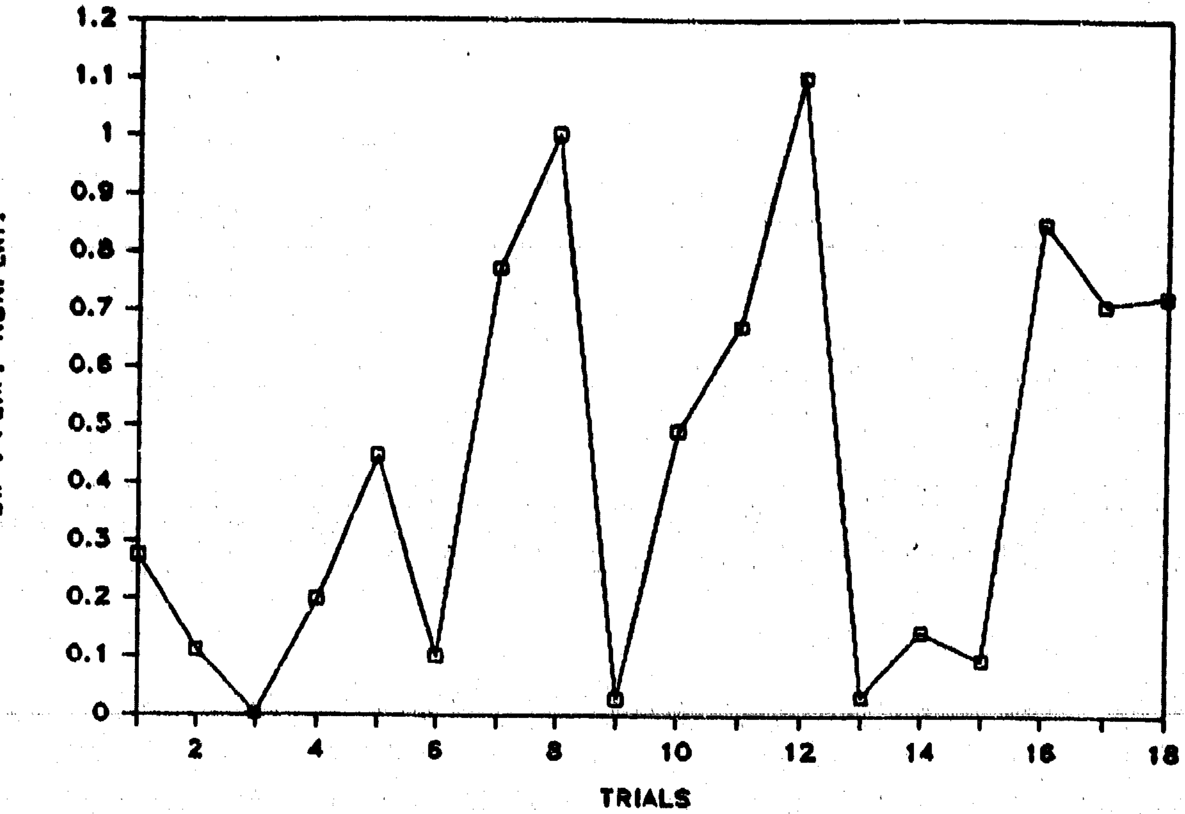

A. PAR. - OCC. 4-7 AND 8-11 Hz.
Mn BANDPASS Z SCORE
TRIALS


B. CENTRAL 4-7 AND 8-11 Hz.
Mn BANDPASS Z SCORE
TRIALS

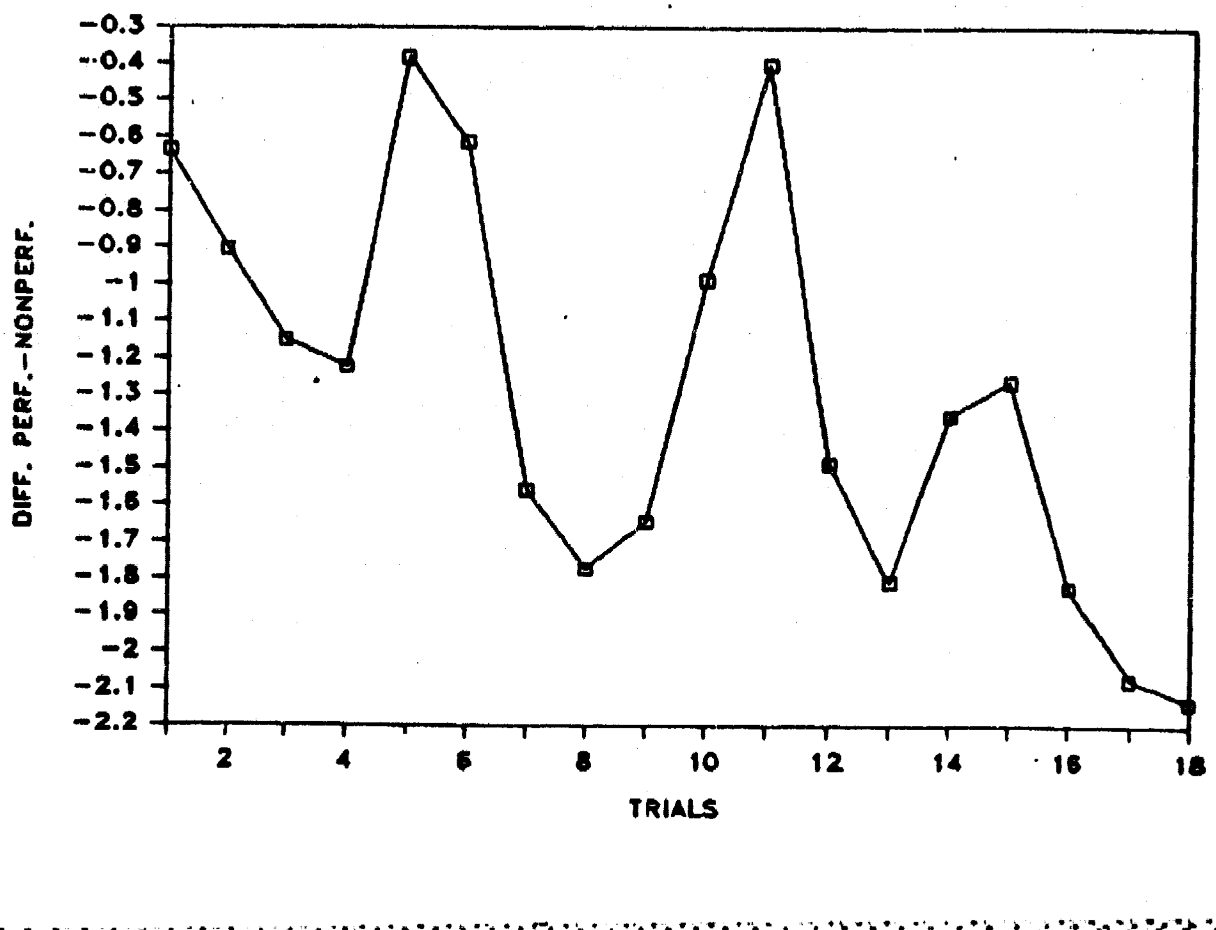


Mn BANDPASS Z SCORE
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
TRIALS

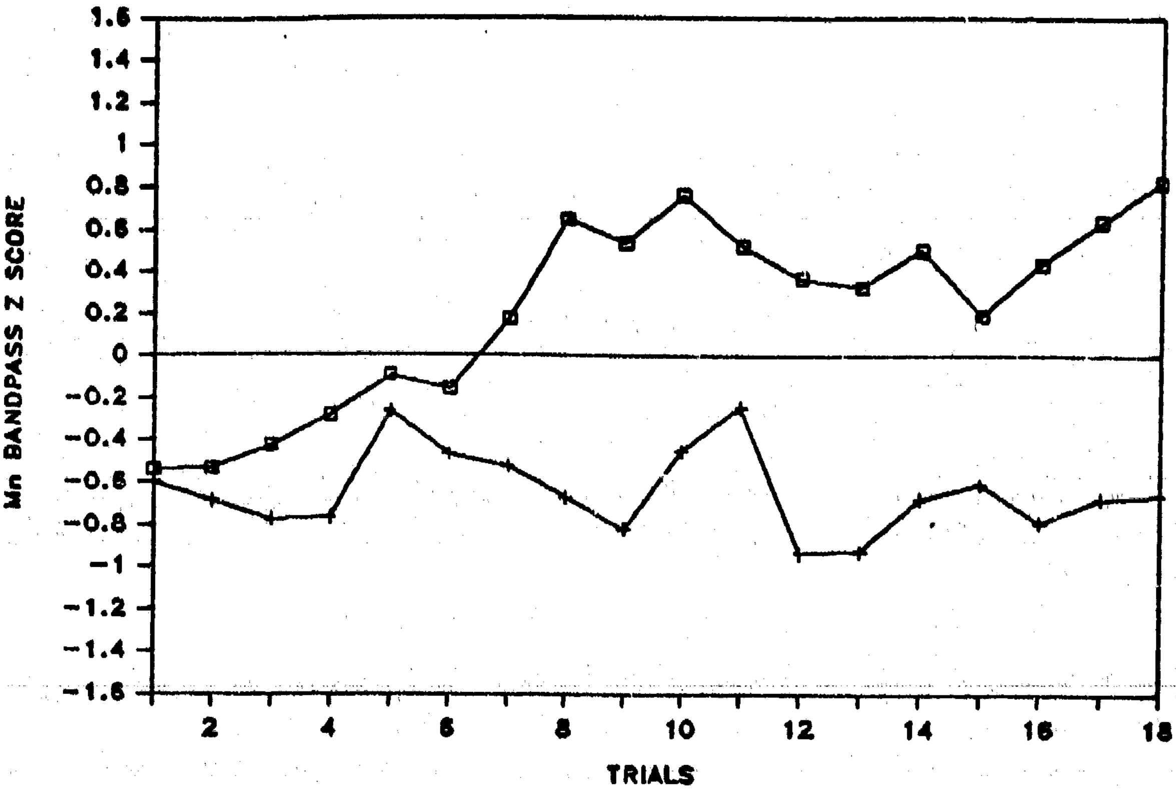
A. CENTRAL 8–11 Hz.



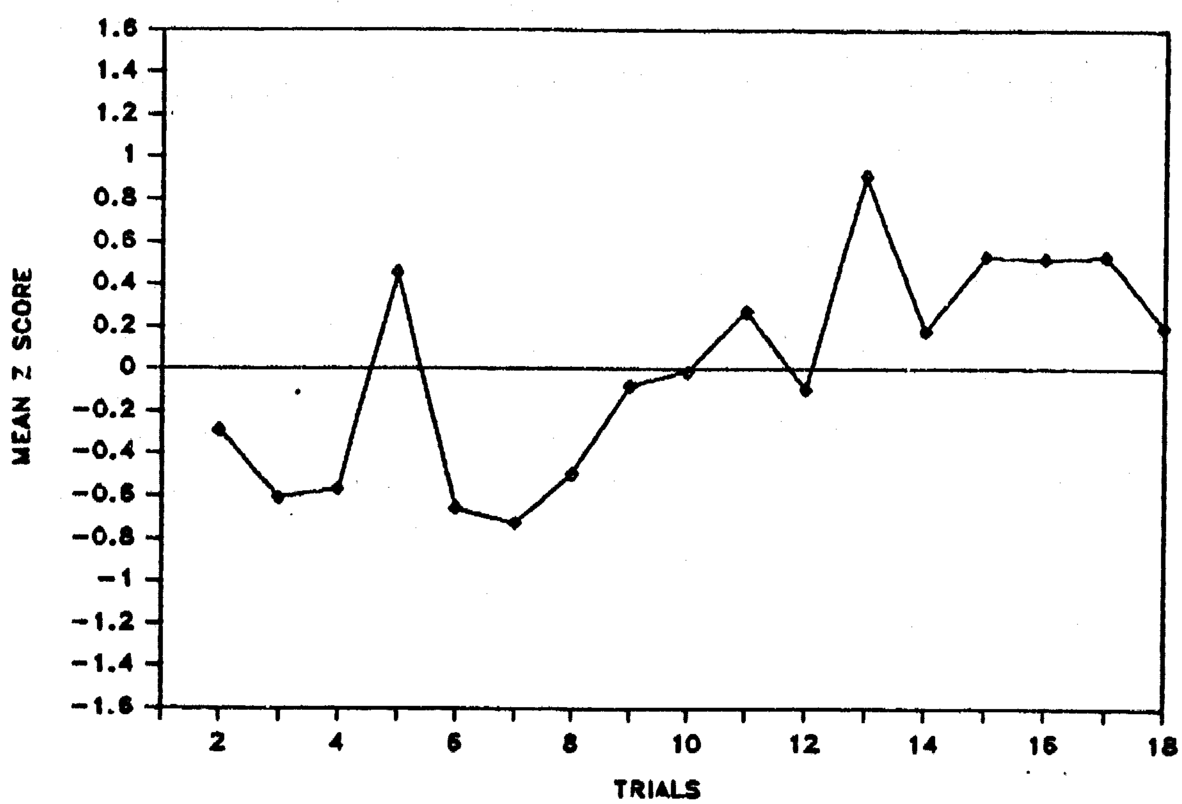
B. PAR.–OCC. 4–7 Hz.



A) EEG CHANGE OVER TRIALS (PERF.)



B) PERFORMANCE CHANGE OVER TRIALS



EEG CHANGE OVER TRIALS (NON-PERF.)