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MEASUREMENT AND MODIFICATION OF SENSORIMOTOR SYSTEM FUNCTION DURING VISUAL-MOTOR PERFORMANCE

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Both laboratory and in-flight studies were carried out in order to evaluate the utility and feasibility of EEG monitoring as a means of identifying central nervous system correlates of performance and G-force effects during military flight operations. Four studies were conducted, two with controlled laboratory simulation, and two in actual flight during military training missions. Data analysis focused on EEG power-spectral density characteristics and their temporal modulation, specifically in sensorimotor and visual cortical areas. Several consistent findings emerged. During competent performance, a highly unique discrepancy appeared between left and right hemispheres in central 8-15 Hz activity. This pattern disappeared as performance degraded. The temporal modulation of this activity also reflected these changes. During high G-force situations, power at frequencies below 8 Hz was progressively and non-specifically enhanced. Continued competent performance, however, was still reflected by the pattern described above. These findings are discussed in terms of their neurophysiological implications.

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Measurement and Modification of Sensorimotor System Function During Visual-Motor Performance

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Preface

The studies reported here represent the Final Report for Air Force grant #AFOSR-82-0335 initiated 30 September 1982 under the supervision of Alfred Fregly, Ph.D. As elaborated below, this program, while seeking to discover and evaluate basic functional correlations between brain substrates and visual-motor performance, did so within the context of meaningful flight-related experimental circumstances. This orientation was deliberately chosen due to the firm conviction that the vast differences between limited laboratory perspectives and the actual demands of high-performance military flight restricted the useful extension of findings to field-related problems. The laboratory scientist and the field investigator often come from significantly different training and experiential perspectives. In many instances this is appropriate, since the theoretical emphasis of the basic scientist only rarely articulates effectively with the practical orientation of the field scientist. However, in the realm of the boundaries of higher nervous functions, this dichotomy has yet to be productive. It is hoped that the preliminary findings reported here, from a combination of laboratory and actual military flight studies, will help to reinforce a more effective integration of basic and applied efforts. The significant challenge facing manned flight in this era of rapidly advancing technology will clearly require some new strategies.

I. Introduction

The challenge of central nervous system assessment in relation to the physiological and cognitive demands of modern military flight has several distinct components. First, the data collected must accurately identify a relevant index of brain physiology. Second, the methods used to obtain requisite biological signs must not interfere with pilot comfort or performance. Finally, the information derived must ultimately provide the pilot with extended capability and/or response alternatives. From the beginning of our work in this area we have addressed this challenge from the perspective dictated by these considerations.

In order to properly encompass all of these requirements, we initiated parallel programs of laboratory and field studies. The laboratory experiments focused on a search for relevant measures which could be applied to an on-line assessment of CNS function. The field studies, on the other hand, addressed the problems of eventual applications in light of real operational demands. Additionally, the field studies provided for an assessment of G-force influences which could not be simulated in the laboratory.

The functional orientation for all of these studies was directed by past experience in studies of sleep physiology. The perspective which this background provides is somewhat unique in the area represented by this conference. Our emphasis is on the concept of "physiological state" which differs significantly from a consideration of moment-to-moment fluctuations in neural activity or performance capability. The concept of recurring physiological states is best understood through reference to the states of sleep and wakefulness. Clearly, brain physiology and associated behavioral manifestations are different in these two states. However, it is today well documented that sub-states exist within both sleep and wakefulness (1,2) and that these can be both intrinsically or situationally determined (3,4). That is, both physiological organization and behavioral response characteristics are continuously modulated by an interaction of internal biological periodicities and external environmental circumstances. This modulation determines the background "set" or functional framework within which a given response occurs.

In seeking to track this modulation within the context of CNS assessment, we have focused upon the spontaneous electrical activity of the cerebral cortex, the electroencephalogram or EEG. This measure provides a continuous, real-time, dynamically modulated and totally non-invasive index of the "background state" of CNS organization. Because functional topography and frequency modulation are important attributes of this measure, our emphasis was on the activity recorded from task-appropriate cortical regions from which frequency patterns were at least partially clarified in the neurophysiology literature. Thus, electrodes were placed over visual and sensorimotor cortical areas to evaluate the putative command functions involved in the visual-motor tasks associated with aircraft control. Additionally, our analysis focused on the frequency components of these signals as they related to the theoretical basis of thalamocortical substrates for EEG rhythmic activity in the visual and somatosensory pathways.

Years of neurophysiological investigation have established the fact that naturally occurring rhythmic patterns in the waking EEG from sensorimotor and visual cortical areas arise from thalamic neuronal generator mechanisms and their gated discharges to localized cortical projection areas (5,6). These generators are intrinsic to thalamus (7,8), reflect the status of specific sensory pathways (7,9,10,11), and result in cortical rhythmic patterns the characteristics of which are determined by the independent, functional modulation of cortical excitability (12,13,14). For example, the occurrence of rhythmic 8-15 Hz patterns recorded from central cortex (the so-called sensorimotor rhythms) are facilitated by immobility and can be altered or blocked by arousal or gross movements, respectively (15,16,17). Moreover, at least in relation to sensorimotor rhythms, hemispheric laterality differences are seen in the waking state (18).

Our strategy was to examine the interplay between visual and sensorimotor cortical EEG frequency patterns in relation to the type and quality of flight-related control performance required and demonstrated. Our initial studies involved laboratory simulation of relatively simple flight scenarios in order to document functional predictions in an optimal situation for recording and experimental control. Subsequent studies involved in-flight recordings from Air Force pilots undergoing target acquisition training in a multi-engine aircraft, and typical training maneuvers in high-performance fighter aircraft, in which high G-force stress was a factor.

II. Methods: General Overview

All of the studies to be described here utilized similar EEG recording and analysis procedures. Signals were recorded from gold-plated, cup-type electrodes (Grass Instruments) placed in bipolar arrays on the scalp according to the standardized International 10-20 System (19). Placements included bilateral central cortex (C1-C5 and C2-C6) and unilateral or bilateral parietal-occipital cortex (P3-O1 and P4-O2). A ground lead was placed also over the mastoid bone behind the left ear. The skin was cleansed and abraded prior to electrode attachment with a high viscosity electroconductive paste (Grass EC-2). Electrodes were further secured by various methods (see below). In all cases, electrode resistance measurement readings below 2000 ohms were required prior to and after recording sessions in order for the data to be considered valid. Except for a few cases of failed connections or damaged preamplifiers, no data were lost as a result of this convention.

Since the ultimate evaluation of recorded EEG data would involve power-spectral analysis, the issue of artifact reduction and anti-aliasing measures was significant. Scalp electrodes were attached to miniature preamplifier units (Oxford Medilog) at close proximity to the high impedance recording source. These amplifiers increased signal-to-noise ratio by approximately 10:1, thus greatly reducing potential cable noise. In laboratory studies the signal was fed directly to post-amplifiers in a Grass model 78 polygraph and from these to a pre-filtering and scaling unit on the front end of our VAX model 11/750 computer (Digital Equipment Corporation). Pre-filtering by this unit provided a rolloff of 6db (50% attentuation) below 0.5 Hz and above 40 Hz. In-flight studies utilized a specially designed flight vest which contained a pre-filtering unit providing a 6db rolloff below 2 and above 30 Hz. The signal was then fed to a post-amplifier unit in the vest which also provided a second-stage rolloff of 6 db below 1 and above 60 Hz. Finally, the filtered and amplified signal was led to a miniature 4-channel FM tape recorder (TEAC, Model HR-10G). These extra filtering measures were introduced in recognition of the fact that in-flight recordings would be subject to greater movement and muscle artifacts than those obtained in the stationary laboratory setting. Data recorded on the FM tape unit were subsequently played-back in parallel to the laboratory polygraph and pre-processing equipment described above, thus providing a third stage of artifact reduction for this context.

In all studies, a 3 min. calibration signal, consisting of a 9.5 Hz sine wave of 50 uv peak-to-peak, was played into the recording system prior to each data collection session. This signal provided a calibration reference for a standardized 50 uv scaling of one volt peak-to-peak at the time of computer analysis. The analog data were then digitized and subjected to Fast Fourier Transform using the algorithm of Jennrich (20) as modified by Pacheco et al. (21) and Mason (22). Successive 16-second epochs (2048 data points) were analyzed with 128 coefficients summed to provide a resolution of 0.5 sec from 0-40 Hz. Calculated spectral estimates were sorted into seven consecutive 4 Hz frequency bands between 0-27 Hz, thus dividing power into bands corresponding to functionally meaningful frequencies within the human EEG (ie; 0-3 Hz=delta, 4-7 Hz=theta, 8-11 Hz=alpha, etc.). The spectral densities of these frequency bands were computed by calculating the area under the spectral distribution generated for each 16 sec. epoch. Values were log transformed and simultaneously stored on the VAX hard disc and down-loaded to a hard disc on a laboratory PC computer. Adjusted data files were then subjected to graphic and statistical analysis through use of Lotus and Matlab software programs.

III. Findings

The program to be reviewed here was initiated several years ago and includes both laboratory and actual in-flight studies. Except for the initial laboratory study, which represented our inauguration to this field, all of our other investigations are still ongoing. In most instances, the data have all been collected within the context of more or less strict research protocols, depending upon the circumstances of the study. However, we were to discover that the analysis of consecutive 16 sec. epochs of EEG activity from multiple cortical recording sites in many subjects across extended protocols was to generate both exciting opportunities and frustrating problems. The opportunities stemmed from the fact that extensive, high quality EEG data were successfully obtained from a variety of flight-related contexts. The problems were created by the vast amounts of data so obtained and the many analytic options one might choose in seeking common and relevant trends. Accordingly, data analysis is still underway and it appears that this effort will continue for some time. What we present here are the initial, consistent findings which hold promise for providing insight and guidance in our search for meaningful indicies of function.

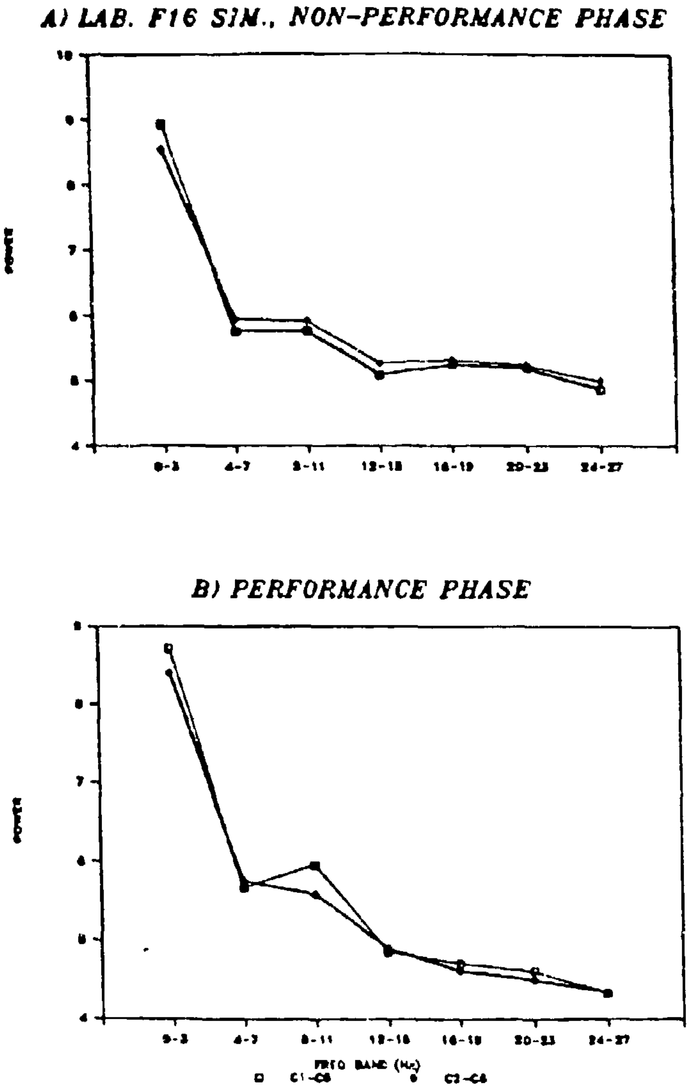


Figure 1. Mean power-spectral density distributions derived from three subjects and comparing EEG data from non-performance epochs (A) with correspponding data from performance epochs (B). Note that only during performance of the F-16 flight simulation task was left central 8-11 Hz activity enhanced.

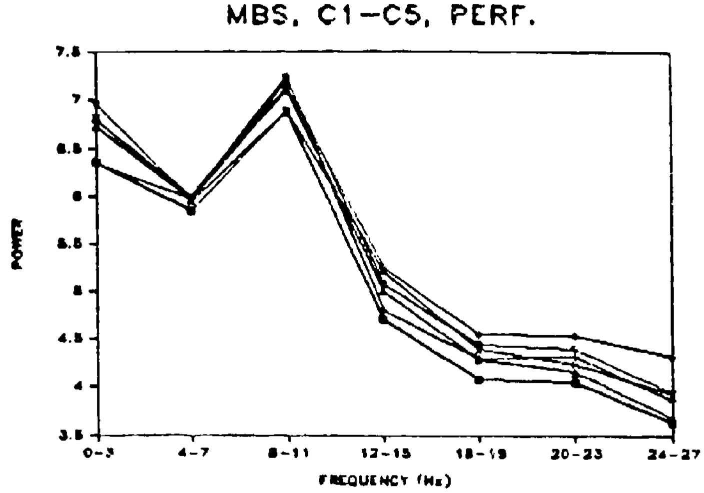
A. Laboratory Studies

1. F-16 Simulation: Performance versus Non-Performance

This study employed six male volunteers between the ages of 25 and 45 years. Three of these subjects were pilots, one a senior flight officer with the California Air National Guard, and two with civilian licenses. The other three had no formal flight training. Each was provided with several brief practice sessions on a video game involving a rudimentary flight simulation of an F-16 fighter aircraft. An authentic aircraft seat was used in front of a video display and was fitted with left and right hand controls for velocity and attitude, respectively.

After familiarity with the task was achieved, each subject participated in a six-hour protocol involving successive 10 min. flight legs during which specific instructions regarding aircraft positioning and speed were to be followed. After each leg, the subject was allowed 5 min. to read, make notes or simply consider the requirements of the task. Breaks or rest periods were provided for 15 min. each hour. Bilateral central and parietal-occipital EEG activity was recorded continuously during these sessions, as described above, except for the break periods. In this case, electrodes were secured in place by collodion-soaked pads. EEG data were subjected to power-spectral analysis as detailed above.

The performance tasks in this study were well within the capabilities of the subjects but the primitive nature of the program made control of the aircraft rather difficult. Thus, subjects worked hard to perform the instructed flight profiles. Unfortunately, however, we were unable to obtain quantitative performance data in this context. Accordingly, our analysis was limited to an evaluation of EEG changes with the alternation of flight-performance versus non-flight-performance epochs. Since our interest in this communication is focused on a search for discriminating variables in sensorimotor and visual cortical EEG patterns, we shall consider this dimension here. Other findings from this study have been reported elsewhere (23).



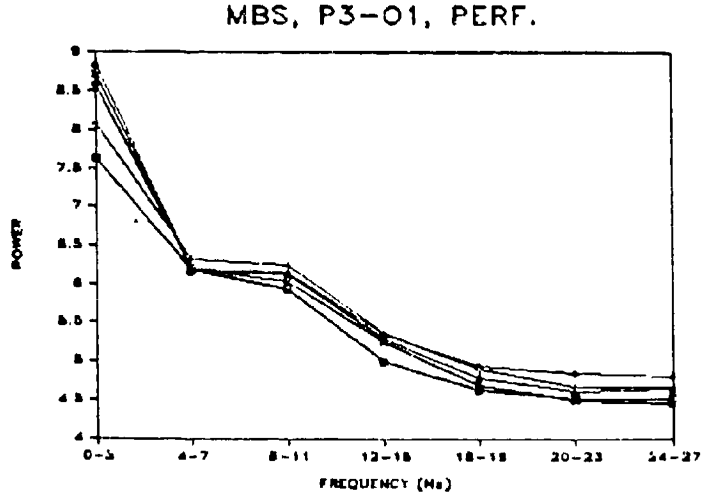


Figure 2. Power-spectral density distributions averaged over three 10 min. flight performance epochs in each of six consecutive hours of our F-16 flight simulation task. Data are from one subject, and compare spectral profiles from left sensorimotor cortex EEG recordings (top) and left visual cortex recordings (bottom). One data block was lost from the P3-O1 recordings due to electrode failure. Note the extremely consistent elevation of activity at 8-11 Hz from left sensorimotor cortex during this performance and its absence in visual cortex. This subject showed unusually low 0-3 Hz activity in central recordings.

The most consistent finding in this regard was a significant increase in 8-11 Hz activity in sensorimotor cortex exclusively during flight-related performance (Fig. 1). Moreover, this incease occurred differentially in left central recordings (C1-C5) in four of the six subjects and across the entire protocol. This enhancement of left central 8-11 Hz activity was extremely consistent, and was not reflected in simultaneously recorded data from parieto-occipital cortex (Fig. 2). Of the four subjects showing this effect, two were right-handed and the other two were left-handed. While performance comparisons were difficult in this study, the data obtained suggested that these four subjects, three of whom were the trained pilots in this group, performed better than the remaining two subjects.

2. Cessna Simulation: Good versus Poor Performance

Ten subjects were recruited from the U.C.L.A. Air Force R.O.T.C. program for this study. Each had at least 50 hours of solo flying experience and all were healthy males ranging in age from 19 to 25 years. Subjects were called at random from a master list provided by the local R.O.T.C. coordinator. They were told that participation would require 10 to 15 hours and that the time commitment would vary depending on how quickly each acquired the skills necessary to fly the simulator. Training and testing took place over a period of six months.

The video P.C. program "Flight Simulator II" (Microsoft Corporation) was chosen because it offered realistic performance features with which most Air Force R.O.T.C. cadets would be familiar. This program simulates the instruments and flight characteristics of a Cessna 182 class, single engine, 148 MPH, retractable gear aircraft. Subjects were provided with up to four one-hour practice trials on the simulator in order to assure standard familiarity and mastery of its various features.

Subjects were monitored electroencephalographically during approximately five hours in the final test session. EEG placements included bipolar and bilateral central and parieto-occipital leads, as described above. Electrodes were fixed to the prepared scalp with collodion adhesive and attached to the Oxford Medilog miniature preamplifiers. These leads, together with that from the mastoid ground, were fed to a Grass model 8-16 electroencephalograph, and an eight-channel Crown Vetter model A magnetic tape recorder. Leads from the EEG machine post-amplifiers fed EEG data directly into the VAX computer system for on-line data analysis.

A Mitsubishi Video Printer (model P50-U) printed hard copy of the video screen every thirty seconds during the flight legs. This printout yielded information concerning the plane's present position, heading, altitude, air speed, rate of ascent/descent, position of the throttle, yoke, and flaps, as well as the same view the subject saw through the "window" of the plane at that moment. Information tablulated from this printout was later utilized in the evaluation of subject performance.

Before testing, each subject was assessed for transient physiological factors which might affect their performance. The Stanford Sleepiness Scale was utilized along with questions designed to give a general overview of the subject's current activity level in order to discern if anything unusual had occurred on the day of testing. This assessment included: quantity and quality of sleep the previous night, naps taken that day, recent alcohol consumption, time of last meal, medications/drug use, and current physical complaints, if any.

After the subject was interfaced with the monitoring system, each was isolated and seated comfortably in front of the color video monitor and provided with manual control devices which controlled the air speed (utilizing the throttle) and the altitude and pitch (utilizing the control yoke). The video screen showed the instrument cluster of the airplane along with a view from the plane's cockpit in a split screen format. In each case, the investigator was seated in an adjacent room and acted as co-pilot, communicating with the subject via an earphone/microphone headset. An overhead camera monitor provided continuous visual information concerning posture, movement, and other behaviors relevant to the task, and those related to significant artifact were noted on the simultaneously recorded EEG tracing. Subjects were requested to maintain relaxed facial muscles, limit speaking to essential conversation, and adhere to the flight protocol as closely as possible.

Each subject was required to take off from a particular airport, fly to a designated location, turn to a new heading and land at a specified airport. Each of the flight legs were designed to be completed within thirty minutes. The subject was advised that he should have successfully landed within the thirty minutes alloted for each flight leg. They were free to ask how much time was remaining during any particular flight leg. After each flight leg, a twelve-minute rest period was provided. Rest periods were occasionally longer than twelve minutes if the subject landed or crashed the simulator before the thirty minutes alloted for the leg had expired. During the rest periods, the subject was given time to look over the protocol for the next flight leg. Resting EEG data were also collected for later analysis.

Each of the seven flight legs had its own protocol which differed in starting point, turning point, designated landing airport, and specific flight criteria. Each flight leg had three phases: a departure phase, an enroute phase, and an arrival/landing phase. After take-off, the protocol required the subject to maintain the take-off heading and climb at 90 knots to a specified altitude. Once they arrived at that altitude they executed a turn to a new heading. The enroute phase required the subject to climb to a new altitude and maintain it until they began the descent for landing. Once they were over the designated turning point, they turned to a new heading and flew to the designated airport for landing. For the arrival/landing phase they were required to land on a specified runway from a specified direction. After landing they were told to await further instructions. The rest period followed a description of the next flight leg.

Data analysis is still underway in this study. The focus of initial analysis was on the comparison of EEG characteristics during good versus poor performance in the simulated flying. The multiple flight legs with differing degrees of difficulty created a sufficient variation in performance for the evaluation of EEG correlations. Completed group data are not available at the present time but several consistent relationships have emerged.

As in the previous study, EEG activity from central cortical recording sites has proven to be most useful. In particular, activity in the 8-11 Hz frequency band from left central cortex was again characterized by the most dynamic modulation in relation to performance. It was noted that the sequence of successive 16 sec. spectral density values at this frequency displayed a modulatory pattern over time approximating periodicities ranging from 0.2 to 2 cycles per minute. Moreover, this periodicity was clearly correlated with flight performance activity.

To explore this relationship systematically, profiles of the key performance variables, including air speed, altitude and heading, were compared with computer-derived templates based on actual instructions for a given flight leg. Deviations from this template exceeding a criterion level in either direction were scored as errors. Loss of control of the aircraft resulting in a "crash" led to one point in the error score for every epoch prior to expected landing. In this way, flight legs, and segments within each leg, were rated for each subject in a dimension of good to poor performance.

Corresponding periodicty in the 8-11 Hz band of EEG activity from left central cortex was displayed and subjected to both modulation and trend analysis. Modulation analysis was accomplished by subjecting the sequential spectral density values themselves to FFT analysis (Fig. 3). A consistent peak defining a periodicity between 0.2 and 0.4 cycles per minute was seen in data from vitually every subject. This periodicity was stronger and more consistent, however, during periods of good performance. Conversely, faster periodicities ranging from 1-2 cycles per minute, dominated periods of poor performance.

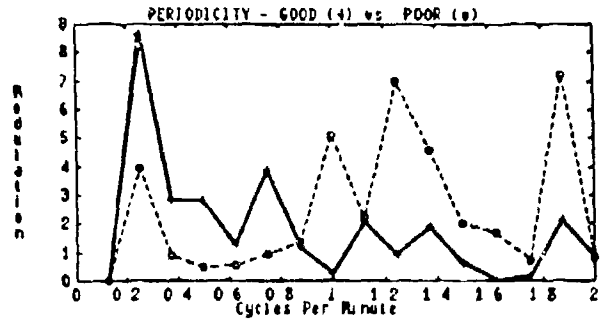


Figure 3. Modulation periodicity analysis based on FFT of successive spectral density values at 8-11 Hz from left central cortex in one subject during the enroute-landing phase of two flight legs in our Cessna simulation study. These legs were contrasted by the fact that one (solid) was rated as good performance whereas the other (dash) was rated as poor performance. Note the slower periodicity during good performance and an almost reciprocal relation to the faster periodicities during poor performance.

An additional discriminating variable was provided by regression analysis applied to the amplitude modulation of these periodicities (Fig. 4). During periods of good performance a significant positive trend was obtained. However, during poor performance, the trends observed were either negligible or negative in slope.

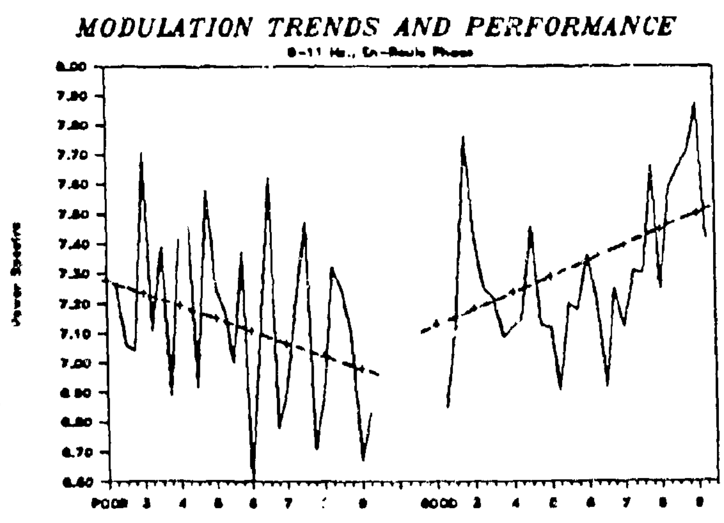


Figure 4. Power-spectral density modulation of central 8-11 Hz activity during good (segment on right) and poor (segment on left) performance in the Cessna simulation study. Modulation trends in these data were determined by linear regression analysis. A combination of slower modulation with a significant trend towards increasing amplitude (positive modulation slope) was consistently characteristic of good performance segments.)

B. In-flight Studies

1. NCH 131-H Study

Five USAF test pilots who were already part of an ongoing flight training and test program on the NC131-H Total In-flight Simulator (TIFS) were selected through the Test Pilot School (TPS) at Edwards Air Force Base (EAFB) to act as subjects in this study. All pilots were part of a TPS class that was scheduled to fly evaluation missions on the Avionics Systems Test Training Aircraft (ASTTA). All involvement with the current project was conducted on a minimal interference basis with the ongoing avionics evaluation and training program. For the current protocol, each subject was required to fly several missions, thereby providing repeated measures, albeit under different mission directives and at different times of day.

Before and after each flight, subjects completed the Profile of Mood States (POMS), which evaluates immediate subjective mood states. In addition, each subject completed questionnaire forms of a Cooper-Harper flight-oriented subjective workload assessment, as well as a card sort version of the Subjective Workload Assessment Test (SWAT) after each mission. In-flight three-point Cooper-Harper ratings were also conducted after each flight segment task was completed.

The EEG recordings employed in this study utilized the special flight vest arrangement described above. Additionally, a custom helmet liner with electrodes attached to retractable flaps over appropriate cortical sites was used. The scalp was prepared and electrode paste introduced to the site and the electrode. The flap was then closed and secured with a velcro trim. Leads from all electrodes were attached to Oxford miniature preamplifiers, also secured by velco at points between bipolar electrode sets, and cables from these units were fed into the processing and recording modules of the flight vest. A mesh cranial cap was then placed over the sealed electrode flaps, preamplifiers and cables, in order to further secure the whole assembly. This arrangement provided a fully portable monitoring system which in no way interfered with flight activity (Fig. 5). A flight helmet pre-molded to the scalp configuration for each pilot was then donned prior to takeoff. In-flight data collection included continuous EEG recordings, as well as several onboard measures. These provided recorded video images of the training station instrument panel and continuous data recordings of aircraft flight parameters.

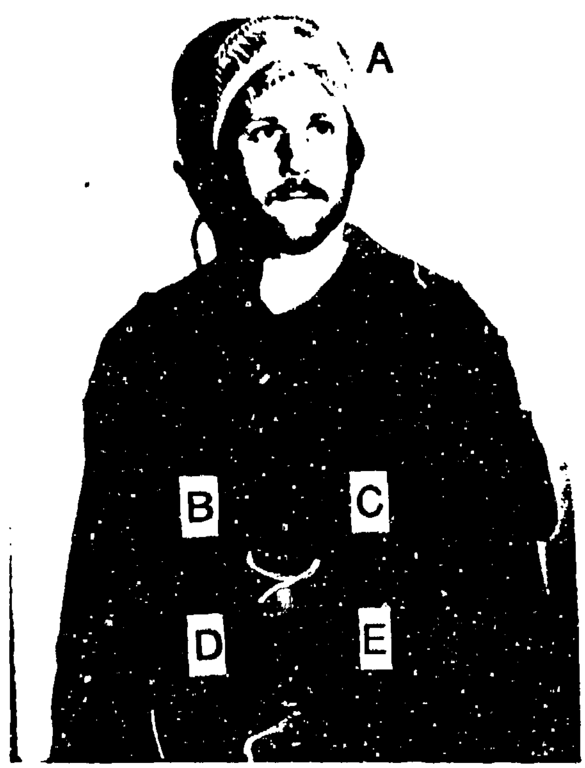


Figure 5. In-Flight portable EEG data recording system is shown here on a pilot ready to put on his pre-molded flight helmet and step to the aircraft. The special flight helmet liner (A) containing permanently mounted EEG recording electrodes at standardized placements and adjacent miniature preamplifiers, and covered by a mesh cap, is connected via secured cables to a modified flight vest. This vest contains a power supply for the preamplifiers (B), a data filtering module (C), a post-amplifier unit and battery pack (D) and a miniature FM data recorder (E). The system is activated at will by connecting the post-amplifier/battery pack unit to the recorder.

After the hookup was complete, subjects entered the aircraft (most flights included two test subjects, one scientist/observer, and the requisite engineering/technical crew) and went through the necessary preflight preparations. The observer from our staff made both voice and note recordings of activity changes, flight configuration changes, time sequence and other relevant events. All intercom dialogue was recorded on one channel of our microrecorder together with simultaneous EEG data.

Flight scenarios included either air-to-air or air-to-ground target detection, as well as the use of Instrument Navigation System (INS) and Infrared Detection System (IRDS) devices. Different scenarios involved different tasks, thereby varying workload considerably from one situation to another. All subjects were required to perform all other "normal" flight functions simultaneously with whatever additional workload tasks were involved in each scenario (i.e., there was no active copilot during data collection periods).

During the flight sequences, command pilot rotations typically occurred at least once. Thus, each flight contained several task segments and data on each of two subjects. When possible, each subject also flew different flights at different times of the day. In this way, we were able to collect data on four of the five subjects at three different points in time, morning (approx. 1000-1200 hrs.), afternoon (approx.1400-1700 hrs.) and evening (1730-2100 hrs.).

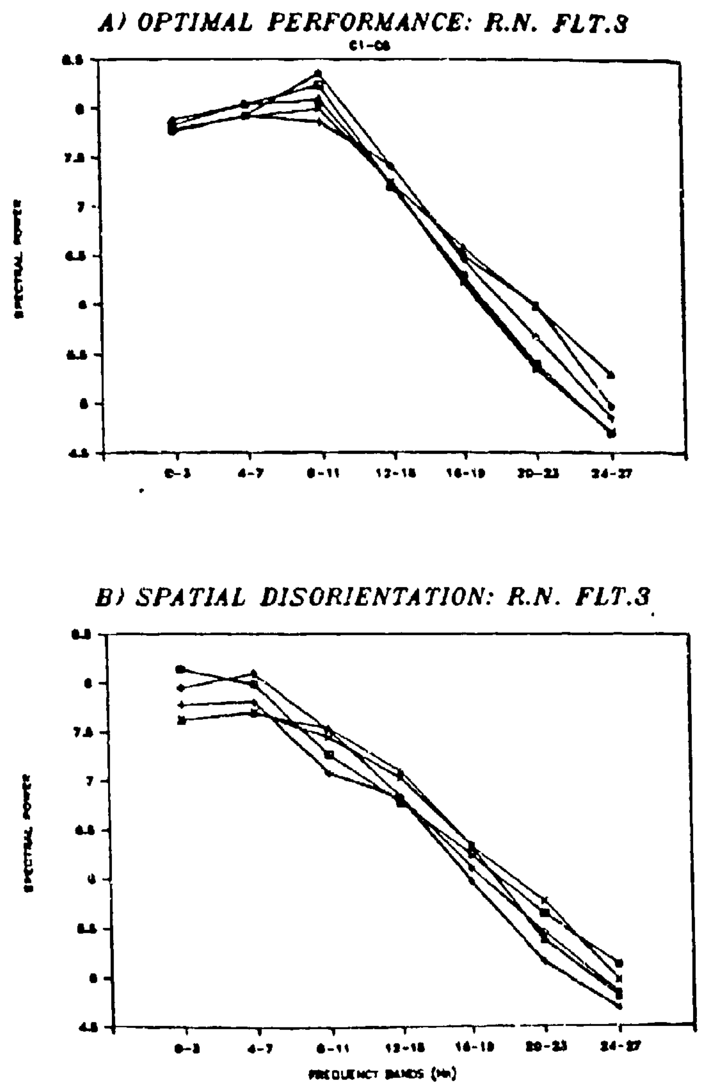


Figure 6. Power-spectral distribution curves each derived from the mean of four successive 16 sec left central cortex EEG epochs (approximately one minute of data) from a test pilot flying target missions in the NC131-H aircraft. Curves at A show data obtained during a target run lasting about five minutes where both flight and targeting functions were performed competently. Curves at B are data from the same pilot obtained during a later run. From the start of this run the pilot was confused as to the location of the target and eventually became totally disoriented.

When all of the data collected in this study are fully analyzed, it should be possible to evaluate such parameters as fatigue, time-of-day, and comprehensive performance correlations in relation to recorded EEG patterns. At present, we have succeeded in identifying specific flight segments in several pilots that were characterized by documented variations in performance, and in determining corresponding EEG configurations. For example, during an early morning flight, pilot R.N. completed a highly successful targeting run involving effective aircraft control and use of INS and IR guidance systems. Sequential 64-second spectral distribution profiles (based on the mean of four 16 sec. EEG epochs) were characterized in particular by a peak of activity at 8-11 Hz in left central cortex (Fig. 6A). Approximately one hour later, this same pilot experienced an unequivocal and verified period of spatial disorientation during an IR target identification run. Spectral profiles from left central cortex showed a marked and significant depression in 8-11 Hz activity during this sequence. (Fig. 6B). Activity in right central cortex (C2-C6) did not show significant differences in these two conditions nor did visual cortical recordings.

When data from a series of flight segments over several different flights were combined and rated on the basis of performance characteristics, several consistent findings emerged (Fig. 7). Activity in all frequency bands except 8-11 and 12-15 Hz showed no

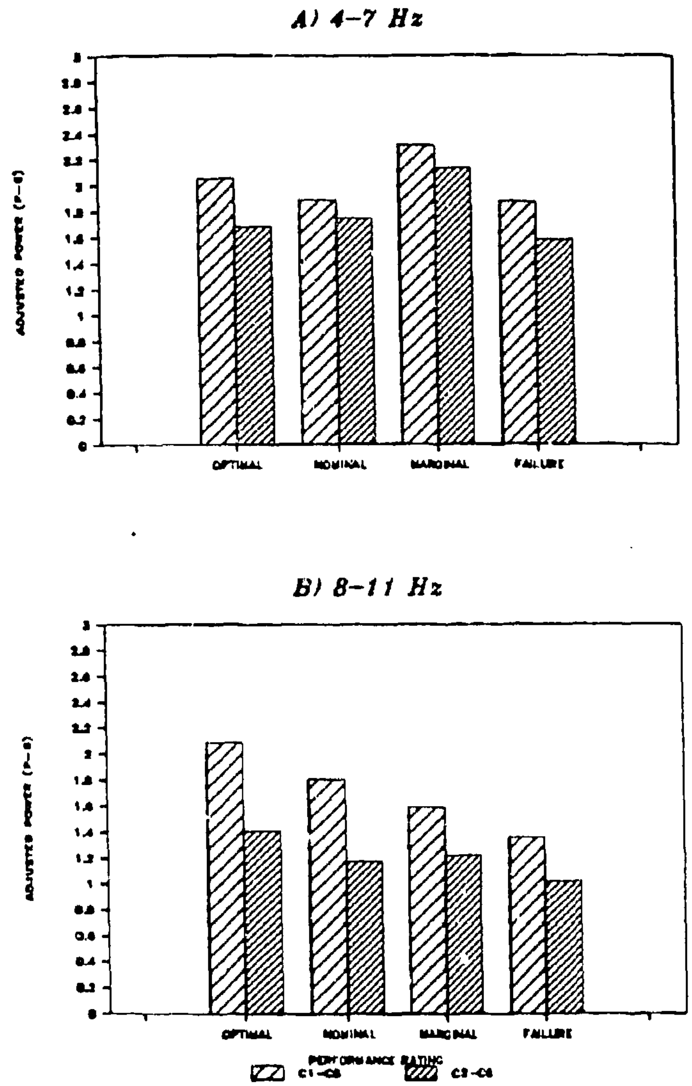
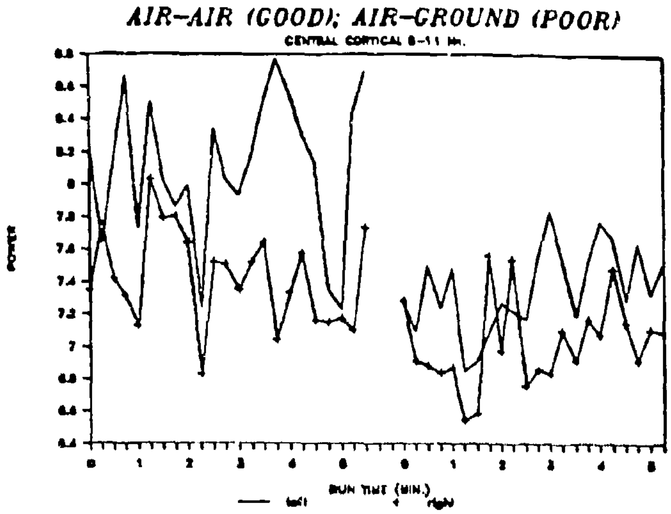


Figure 7. Mean EEG spectral power at 4-7 Hz (A) and 8-11 Hz (B) from both hemispheres is shown here for data segments recorded in four different targeting runs during which performance by the same pilot was rated from optimal to failed. Values at 4-7 Hz showed no systematic trend in relation to the dimension of performance, nor were there any significant differences between left and right hemispheres, although power on the left side tended to be higher. At 8-11 Hz, however, an essentially linear decline in power from the left hemisphere paralleled the dimension from good to poor performance. Power in right central cortex was significantly lower than that on the left during optimal and nominal performance only, and showed an overall difference only at the extremes of this dimension. The ordinate scale in this graph was adjusted to compensate for shortcomings in the Lotus graphic program.

related trends. However, in these two bands, a consistent relationship was observed. Activity at these frequencies from left central cortex (C1-C5) showed a significant linear decline from optimal to failed performance while right central activity did not. The previously noted discrepancy between left and right hemispheres was maintained across this dimension but was greatest during optimal and nominal performance.

Modulation analysis was applied also to these data (Fig. 8). Once again, optimal performance was associated with an increasing amplitude of temporal modulation in the 8-11 Hz frequency band, exclusively. Further, spectral analysis of power in this band over time indicated that intrinsic periodicity was generally slower during optimal versus failed performance. Left and right central hemisphere differences were again confirmed and were greatest during optimal performance.



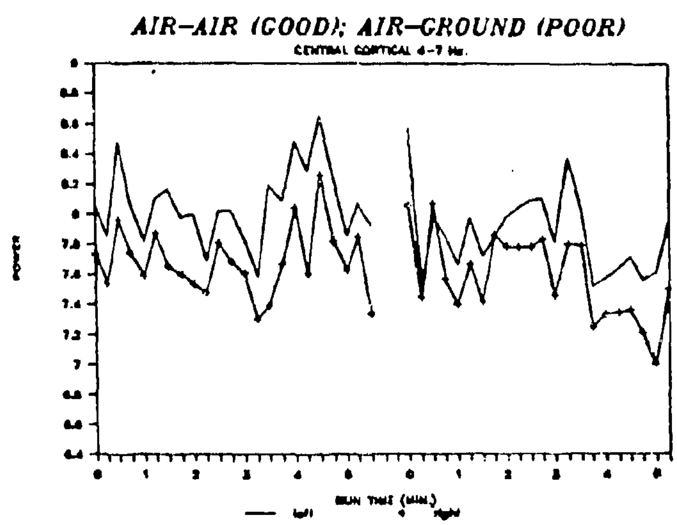


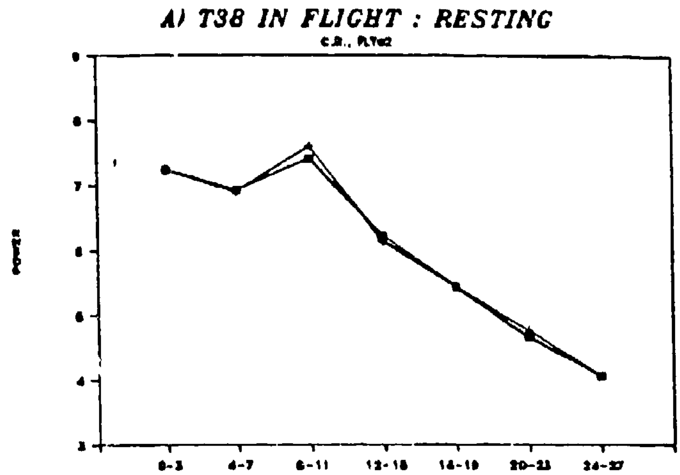
Figure 8. An example of the temporal display of EEG power modulation based on spectral density values derived from sequential 16 sec epochs of EEG data shown here for central cortical 8-11 Hz bands during good vs. poor performance samples. Both graphs show bilateral data from a good performance run (left portion of abscissa) compared with data from a different poor performance run (right portion). Note that during good performance 8-11 Hz power from the left central cortex is both elevated and more slowly modulated when compared with that from the right and with data from both hemispheres during poor performance. Hemispheric differences are reduced in the 4-7 Hz band and their amplitude and modulation do not discriminate quality of performance. These findings are functionally similar to those shown from our laboratory study in Fig. 4.

These in-flight findings support observations made in our laboratory studies suggesting that central cortical EEG patterns can be differentiated in optimal versus poor flight performance by virtue of a constellation of more-or-less consistent parameters.

These include: 1) relative power in left central 8-15 Hz activity; 2) differences in this activity between right and left hemispheres; and 3) the amplitude and period of temporal modulation in this frequency range.

2. T-38 In-flight Study

The effort to devise methods for the collection of valid EEG data in the highly dynamic environment of fighter plane operations has been a long-term component of our program. It was determined early-on that standard laboratory procedures were simply inappropriate. As suggested at the onset, the ultimate goal of this effort was to achieve a totally noninvasive, self-contained system which would provide a reliable index of pilot functional status. Over a progressive series of trials, using our own staff as passenger subjects, we were able to devise a methodology which achieved these goals within the current state of related technology, and to begin recently to collect appropriate data from Air Force pilots during actual flight operations. We are greatly indebted to the staff and officers at the Flight Test Center, Edwards Air Force Base, for this accomplishment.



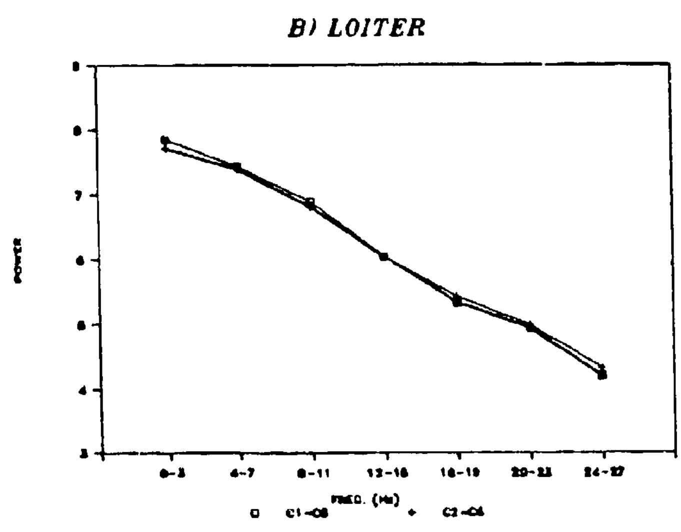
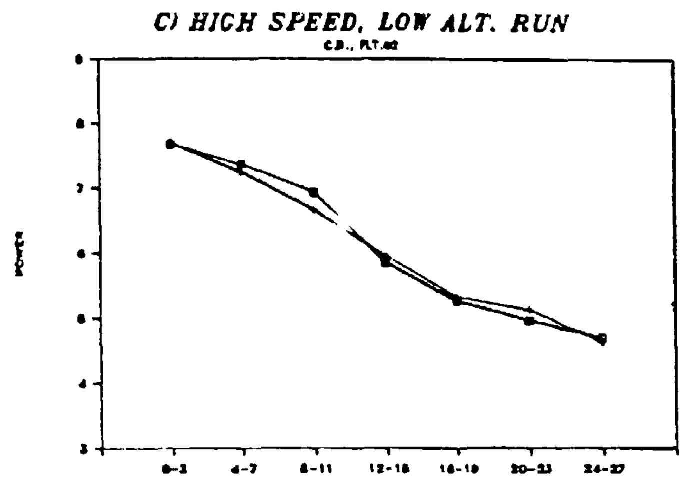


Figure 9. Mean power-spectral distribution curves calculated from left and right central cortical EEG data from an Air Force test pilot during flight segments (approximately 2-4 min. in duration) in a T-38 aircraft. During these segments the pilot was not flying the aircraft. Data at A are from a period of resting with eyes closed. Data at B are from a period of resting with eyes open during straight-and-level flight.

The system developed for this purpose was described in the previous section and used in the NC131-H study. Briefly, it consists of a specially configured flight-helmet liner cap with fixed electrodes at appropriate sites and adjacent miniature preamplifiers. Retractable flaps provide for rapid electrode attachment, with velcro seals and a mesh overcap securing everything in place. A pre-molded helmet inner-liner pad prevents the occurrence of "hot spots" when the flight helmet is put on. Leads from the electrode cap are fed unobstrusively to the previously described flight vest which contains essential data collection electronic devices. The parachute and aircraft seat belts fit over this vest and the system is configured so as not to interfere with potential ejection requirements. This entire arrangement was evaluated and approved by an appropriate Safety Review Board at the base.

Since all data collection trials are on a non-interference basis, it is necessary to extract appropriate segments from established flight profiles. Pilots are briefed in advance as to our objectives and have made every effort to cooperate within the restraints of a given specified test mission. Again, only preliminary data are available at this time from actual pilot subjects.

During a given flight, data were obtained from periods of non-operation resting, with and without attention to ongoing events (Fig. 9). Spectral analysis of such data showed a selective increase in central 8-11 Hz activity from both hemispheres when eyes are closed (Fig. 9-A). This spectral distribution peak is absent on both sides of the brain during attentive periods when the other pilot is flying the aircraft (Fig. 9-B). However, when the subject pilot flies the plane through a difficult maneuver (Fig. 10-A) activity in the lower frequency bands is increased, and particularly at 8-11 Hz in left central cortex. With maneuvers creating high G-force effects (Fig. 10- B), this



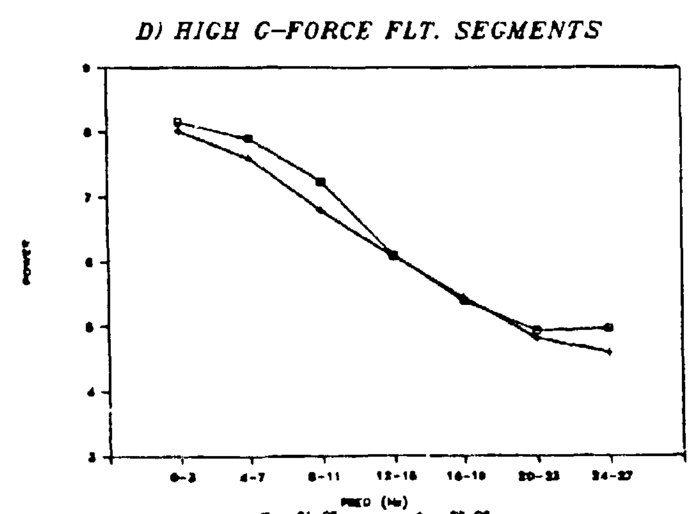


Figure 10. These graphs constitute a continuation of Fig. 9. In this case the subject pilot is flying the T-38 fighter aircraft. Data at C are from a low-altitude (approx. 100 ft.), high-speed (500 knots) flight segment, including turns with some increased G-force. Data at D are from four flight segments during which 4-5 G turns were being performed.

hemispheric discrepancy is increased as is power in the lower 4-7 and 0-3 Hz frequency bands. The latter increase is consistent with data obtained previously from non-pilot passenger subjects (23).

These findings are summarized using a different format in Figure 11. Resting activity during straight-and-level flight with eyes closed was associated with a decrease in power in the 4-7 Hz band and an increase in power at 8-11 Hz, bilaterally, in sensorimotor and visual (not shown) cortex. Demanding flight maneuvers, with some associated G-force effects, resulted in an increase in 4-7 Hz activity and a decrease in 8-11 Hz power with a discrepancy developing between left and right hemispheres in central cortex. This trend continued to some extent with high G-force maneuvers (4-5 Gs), in that power significantly increased bilaterally at 4-7 Hz and unilaterally at 8-11 Hz in left central cortex.

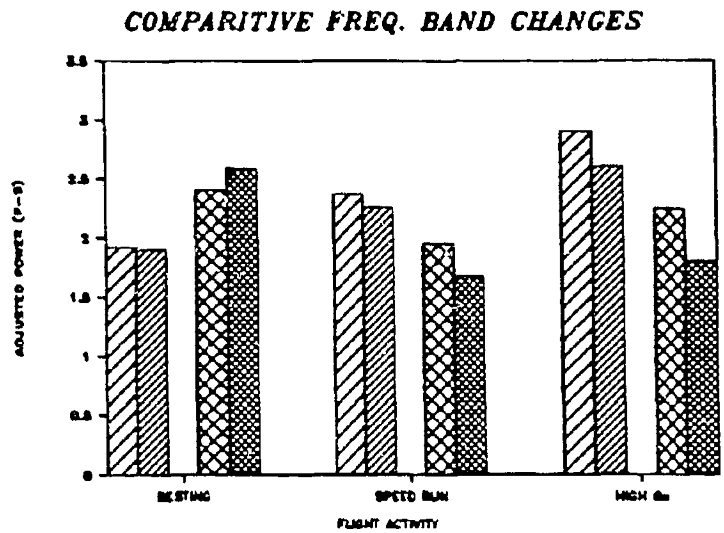


Figure 11. Comparative analysis of spectral densities at 4-7 and 8-11 Hz in left and right central cortex during three of the four flight conditions described in Figs. 9 and 10. Data from both hemispheres at 4-7 Hz are shown first during each condition (broad hatch left, close-hatch right). Data for 8-11 Hz are shown second (broad-cross left, close-cross right.). See text for discussion of these data.

Our findings to date suggest that a non-specific increase in frequencies between 1-7 Hz accompanies the imposition of significant G-force effects in a graded and parallel manner. To the extent that the pilot continues to effectively operate the aircraft, this is associated also by a specific discrepancy between left and right central cortical EEG patterns at 8-11 Hz, with power on the left greater than that on the right. Additionally, central cortical hemispheric differences appear only when the subject is actually flying the aircraft.

IV. Discussion

We have presented here a brief overview of a series of studies in various stages of completion. Accordingly, it was impossible to provide a comprehensive integration of findings. Preliminary observations, however, did disclose a consistent trend in a body of data which encompasses a number of diverse laboratory and field contexts.

As stated at the outset, our focus on the concept of background functional state and a reliance on neurophysiological constructs relating to the underlying substrates of EEG activity in task-specific neural systems is somewhat unique. It is difficult, therefore, to compare our findings with those of other groups interested in these problems. For example, studies examining event-related potentials within the EEG in relation to information processing and cognitive activity (24), while also directed to functional considerations, limit recordings to standardized midline electrode placements, a practice which precludes comparison with the hemispheric differences that proved so useful to the studies reported here. Further, EEG studies concerned with the increase in nonspecific, slower frequencies which parallels the decline of vigilance (25,26) cannot be compared with findings relating to specific frequency changes in association with increasing vigilance. Finally, there has been little in the way of extended and/or systematic EEG data collected in the context of actual military flight operations.

Data from the four EEG studies described here showed that most flight-trained individuals engaged in the visual-motor tasks associated with piloting aircraft develop a significant hemispheric discrepancy in the incidence of 8-11 Hz activity recorded from the sensorimotor (central) cortical areas, with activity in the left hemisphere exceeding that in the right. This discrepancy was present during such performance whether it occurred in the quiet, undynamic laboratory setting or in a T-38 traveling at 500 knots in a terrainfollowing exercise. It was present in both left and right handed individuals and in both younger and older adults. It was not present during resting, cognitive activity or high-performance flight if the subject was not operating the controls. Most importantly, it was attenuated or abolished during poor or failed performance when the individual was operating the controls. Time-series and trend analysis of the incidence of central 8-15 Hz activity supported these observations. A more or less periodic modulation of this activity was documented under all circumstances. However, during good performance, modulation in left central cortex was uniquely dominated by slower cycles, ranging from 2-5 minutes in period and with increasing amplitudes. Conversely, during poor performance, this modulation was faster (1-2 cycles per minute) and showed stable or decreasing amplitudes. Both period and amplitude differences between hemispheres tended to disappear as performance deteriorated.

Although increased arousal or demand generally decreased activity at this frequency, it did not abolish hemispheric differences in central cortex if the task was being successfully performed. Moreover, this discrepancy was abolished in conditions of both low and high arousal if the subject was not operating the aircraft controls. Thus, one cannot attribute the attenuation of this pattern during poor performance or disorientation to a nonspecific arousal effect.

It is possible that the unilateral facilitation of 8-15 Hz patterns was related to the so-called "en arceau rhythme" (or mu rhythm) described by Gastaut (27). However, this rhythm is dependent on the absence or suppression of movement (27,28), an unlikely requirement for the hand operating attitude control in most of our studies. Moreover, as stated above, this hemispheric discrepancy disappeared during periods of non-performance. Nevertheless, the possible relationship of these findings to the mu rhythm concept bears further consideration.

It will be recalled from our initial comments that an extensive animal literature has shown that rhythmic EEG frequencies in sensorimotor cortex are produced by ascending volleys of intrinsic, gated discharge from neurons in the specific thalamic relay nucleus projecting to this area. The amplitude of resulting EEG patterns is determined by changing levels of cortical activation. Further, oscillatory thalamic discharge is increased by either the spontaneous or imposed reduction of afferent activity in related sensory pathways. Thus, it is reasonable to propose that a unilateral increase in sensorimotor EEG rhythmic patterns reflects a decrease in the processing of somatosensory information in that hemisphere. Conversely, the attenuation of such activity implies increased functional processing. Additionally, the modulation of these events over time can be interpreted as an index of the need for such information.

The present context does not allow for a detailed discussion of these neurophysiological dynamics. However, it can be seen that they provide a basis for some speculation concerning the present findings. We would suggest that competent flight performance requires a differentiation of right and left hemisphere sensorimotor functions. It is now generally accepted that the left hemisphere functions in a primary linear, sequental and logical fashion, and is specialized for symbolic comprehension and calculation, while the right hemisphere functions in a primarily holistic, simultaneous fashion and is specialized for visual-spatial and visual-perceptual activities (29,30). Given the nature of this division of labor, our data imply that high-performance flying is improved as these underlying neurophysiological functions become more clearly differentiated. Indeed, it appears that the actual psychomotor act of aircraft control is less relevant to adequate performance than the visual-spatial processing that is ongoing. We speculate that these psychomotor tasks must become highly overlearned or near automatic behaviors (probably even subcortically maintained) while the visual- spatial environment, and therefore visual-perceptual processing, remains novel and in need of constant adaptive response.

Borrowing from the analogy of Donchin et al (31), we would assign to the right hemisphere the task of "tactical" information processing and to the left the task of "strategic" information processing. Thus, in optimal performance circumstances, the right sensorimotor cortex is continuously engaged in the spatial-perceptual task of guiding flight operations. The left sensorimotor cortex, having specified the overall objectives, does not interfere with this process except to update on a periodic basis. The more often instructions must be updated or conscious calculations made (i.e., the shorter the period of amplitude modulation), the less competent the performance. When strategic and tactical efforts become simultaneous, the quality of performance may be compromised.

Our findings in the area of G-force effects on EEG patterns are very preliminary. Once again, however, they appear to be consistent. Data from both passenger and pilot subjects have shown that the onset and increment of significant G-force effects is accompanied by a nonspecific increase in lower frequency patterns. The present data for pilots operating the aircraft suggest that this is particularly true for the 4-7 Hz band. However, regardless of this effect, if central 8-15 Hz left-right hemisphere discrepancy is maintained, competent performance is continued. The ongoing collection and interpretation of data in this context should further clarify these relationships.

References

1. Kleitman, N. Sleep and Wakefulness. 2nd Ed., Chicago, Univ. of Chicago Press, 1963.

2. McGinty, D.J., Drucker-Colin, R., Morrison, A. and Parmeggiani, P.L. Brain Mechanisms of Sleep. New York, Raven Press, 1985.

3. Drucker-Colin, Rene, Shkurovich, Mario and Sterman, M.B. The Functions of Sleep. New York, Academic Press, 1979.

4. Sterman, M.B. The basic rest-activity cycle revisited: Some new perspectives. Exp. Brain Res., Suppl. 12, 1985, 186-199.

5. Andersen, P. and Andersson, S.A. Physiological Basis of the Alpha Rhythm. New York, Appleton Century Crofts, 1968.

6. Sterman, M.B. and Bowersox, S.S. Sensorimotor EEG rhythmic activity: A functional gate mechanism. Sleep, 4(4), 1981, 408-422.

7. Andersen, P., Andersson, S.A. and Lomo, T. Nature of thalamo-cortical relations during spontaneous barbiturate spindle activity. J. Physiol. London, 192, 1967, 283-307.

8. Villablanca, J.R. and Schlag, J. Cortical control of thalamic spindle waves. Exp. Neurol., 20, 1968, 432-442.

9. Yamadori, A. Role of the spindles in the onset of sleep. Kobe J. Med. Sci., 17, 1971, 97-111.

10. Howe, R.C. and Sterman, M.B. Somatosensory system evoked potentials during waking behavior and sleep in the cat. Electroenceph. Clin. Neurophysiol., 34, 1973, 605-618.

11. Bowersox, S.S. and Sterman, M.B. Effects of somatosensory deafferentation on spectral characteristics of the sensorimotor EEG in the adult cat. Exp. Neurol., 77, 1982, 403-418.

12. Bouyer, J.J., Dedet, L., Konya, A. and Rougeul, A. Convergence de trois systemes rhythmiques thalamo-corticaux sur l'aire somethesique du chat et du babouin normaux. Rev. EEG Neurophysiol., 4, 1974, 397-406.

13. Rogeaul, A., Bouyer, J.J., Dedet, L. and Debray, O. Fast somato-parietal rhythms during focal attention and immobility in baboon and squirrel monkey. Electroenceph. Clin. Neurophysiol., 46, 1979, 310-319.

14. Gloor, P., Pellegrini, A. and Kostopoulos, G.K. Effects of changes in cortical excitability upon the epileptic bursts in generalized penicillin epilepsy of the cat. Electroenceph. Clin. Neurophysiol., 46, 1979, 274-289.

15. Gastaut, H., Dongier, M. and Courtois, G. On the significance of "wicket rhythms" (rhythms en arceau) in psychosomatic medicine. Electroenceph. Clin. Neurophysiol., 6, 1954, 687.

16. Sterman, M.B. and Wyrwicka, W. EEG correlates of sleep: Evidence for separate forebrain substrates. Brain Research, 6, 1967, 143-163.

17. Kuhlman, W.N. EEG feedback training of epileptic patients: Clinical and Electroencephalographic analysis. Electoenceph. Clin. Neurophysiol., 45, 1978, 699-710.

18. Sterman, M.B. Pilot performance modification; Symposium on Biofeedback Applications in Aerospace Physiology. Biofeedback Soc. of Calif., Monterey, Ca., Nov. 1984.

19. Harner, P.F. and Sannit, T. A review of the international ten-twenty system of electrode placement. Quincy, Mass., Grass Instrument Co., 1974.

20. Jennrich, R.I. FAST - A subroute to compute finite Fourier Transforms by the Cooley-Tukey Algorithm. Health Sciences Computing Facility, University of California, Los Angeles, 1970.

21. Pacheco, R., Perga, A. and Harper, R. Time series analysis of physiological data during sleep and waking. Proc. of the Digital Equipment Users Society, Nov. 1974, 551-556.

22. Mason, J.W. Notes on software upgrade of time-series analysis program for physiological data during sleep and waking. Pacheco et al, 1974. Mason Software Co., 1983.

23. Sterman, M.B., Dushenko, T. and Hamel, A.S. Measurement and modification of sensorimotor system function during visual-motor performance. Tech. Report #AFOSR 82-0335, 1985, Bolling AFB, Washington, D.C.

24. Donchin, E., Coles, M. and Kramer, A. The event-related brain potential as an index of information processing and cognitive activity. Tech. Report #AFOSR F4 9620-85-C-0041, 1987, Bolling AFB, Washington, D.C.

25. O'Hanlon, J.F. Vigilance, the plasma catecholamines and related biochemical and physiological variables. Tech. Report 787-2, Human Factors Research, Inc. Goleta, Ca., 1970.

26. Beatty, J., Greenberg, A., Deibler, W.P. and O'Hanlon, J.F. Operant control of occipital theta rhythm affects performance in a radar monitor task. Science, 183, 1974, 871-873.

27. Gastaut, H. Etude Electrocorticographique de la Reactivite' des rythmes rolandiques. Rev. Neurol., 87, 1952, 176-182.

28. Klass, D.W. and Bickford, R.G. Observations on the rolandic arceau rhythm. EEG and Clin. Neurophysiol., 9, 1957, 570.

29. Bradshaw, J.L. and Nettleton, N.C. The nature of hemispheric specialization in man. Behav. Brain Sci., 1981, 4, 51-91.

30. Benson, D.F. and Zaidel, E. (Eds.). The dual brain: Hemispheric specialization in humans. New York, The Guilford Press, 1985.

31. Donchin, E., Ritter, W. and McCallum, W.C. Cognitive psychophysiology: The endogenous components of the ERP. In: Callaway, E., Tueting, P., Koslow, S.H. (Eds.), Event-Related Brain Potentials in Man. New York, Academic Press, 1978, 349-411.