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THE ELECTROCORTICAL CORRELATES OF FLUCTUATING STATES OF ATTENTION DURING VIGILANCE TASKS

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Abstract

This study investigated the electrocortical correlates of attention. Sixteen subjects (seven females, nine males) engaged in a forty-minute target-detection vigilance task. Task-irrelevant probe tones were presented every 2-4 seconds. While performing the vigilance task, the subjects were asked to press a button if they were daydreaming (i.e. having a task-unrelated thought or TUT). Continuous electroencephalograms (EEG) and event-related potentials (ERPs) were recorded from the subjects during the entire task. The continuous EEG data was analyzed for differences in absolute power throughout the task as well as before and after the subjects indicated that they were daydreaming (TUT response). ERPs elicited by task-irrelevant probe tones were analyzed in the same manner.

The results indicated performance decrements as reflected by increased RT to correct detections, and decreased number of hits. Further, as the task progressed, the number of reports of daydreaming increased.

The analysis of the EEG data indicated a significant difference in the absolute power of the different frequency bands across periods. The greatest

difference was observed at the posterior parietal electrode sites. In addition, when the EEG data was converted into band ratios (beta/alpha and beta/alpha+theta), the pre-TUT conditions were found to be significantly different than the post-TUT conditions in the posterior sites. The ERP components (N1, N2, and P2) were not significantly different before and after a TUT response or across periods. However, the ERPs across periods exhibited amplitudes that were similar to those found in previous studies of vigilance and ERPs.

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In any operational setting where humans are required to monitor the activity of sensitive equipment over long periods of time, it is essential that an optimum level of attention or alertness be maintained. The operator must be attentive at all times, keeping alert for any breakdown in the system or unforeseen events (Weiner, 1984). Examples of these settings could include commercial truck-drivers to tugboat operators (Mackie, 1977), nuclear plant control workers (Rasmussen, 1981) and nurses who monitor life-support equipment (Beatty, Ahren & Katz, 1977). In such scenarios, the safety and well-being of the operator and/or others is contingent on the level of attentiveness of the operator. In other words, an operator's "readiness to respond" to emergency situations is necessary to insure the safety of others.

Commercial airline pilots represent another group of workers whose attention must be maintained at high levels. Maintaining attention, however, is not always an easy task, for today's pilots operate in settings that do not require much active participation (Hanks, 1961). In the past, pilots flew airplanes that required a great deal of manual operation, demanding a high level of pilot interaction (Potter & Foushee, 1992). But now, automated systems and computers perform many of the routine activities that were required of the pilot in previous, less sophisticated systems (Warm, 1984). Automated flight control, navigation, and systems management devices are common accoutrements of the modern air-carriers which have greatly enhanced the precision and accuracy of the aircraft. A survey compiled by the Boeing Commercial Airplane Group (1991) reflects the increased quality of today's air-carriers. The survey indicates that over the past three decades, the overall number of commercial airplane accidents has steadily decreased. The primary cause of most of these airline accidents was machine failure.

Advances in aeronautical engineering improved the quality and performance of airplanes, and accidents due to mechanical failure decreased dramatically. But the primary cause of today's airline accidents is alarming. Now, paradoxically, accidents attributed to pilot error have become the leading cause of commercial airline accidents (Potter & Foushee, 1992). It is possible that modern technology has produced cockpits that are so automated that the pilot is now relegated to the mere role of a passive monitor of an extremely accurate, self-run system. Sheridan (1978) observed that the applications of automatic flight control, navigation and systems management devices have transformed today's pilots into "systems managers". Adams, Stenson and Humes, (1961) noted that much more time is spent in an "executive" role, where the person is merely passively monitoring "dials, video screens and other sources of information for occasional 'critical' stimuli that demand decision and action". Operational situations, such as these, are conducive for lowered levels of attention because the high degree of automation decreases the cognitive demands on the individual and lowers the level of their alertness. In the event of an emergency, such as an engine failure or an imminent collision, there is an increased chance that the pilot may not respond quickly due to a decreased level of alertness. The more modern cockpits become, the more likely that problems of decreased pilot alertness and attention will be exacerbated.

Evidence of these situations comes from pilots who report their "near-accidents" to an anonymous reporting system and database called the Aviation Safety Reporting System (ASRS). In this database, pilots have indicated that many of their mistakes occur not as a result of fatigue, but from boredom and inattention.

In addition to the increased automation of the aircraft, Pope and Bogart (1992) stated that task conditions such as long periods of "quietness, droning noise and motion, monotony, repetition and familiarity" also seem to contribute to unsafe levels of awareness. Pope and Bogart (1992) refer to these situations as "hazardous states of awareness" because of the decreased ability of the pilot to react quickly in emergency situations.

Certainly, today's aircraft are excellent examples of operational settings that can, in some instances, be so automated that it jeopardizes the alertness of the operator. But, as described earlier, any situation where humans are required to passively monitor extremely automated and precise equipment over extended periods of time, the thoughts and attention of the operator may become absorbed in something other than the operation of the airplane, automobile or life-support equipment. Thus, the amount of attention available to be allocated effectively elsewhere, as in the case of an emergency, is severely diminished.

In order to develop measures to counteract these potentially dangerous operational situations, researchers must gain some knowledge about attention and inattention. Researchers have used different methods to study attention, such as tasks that assess divided, selective and sustained attention.

Selective and Divided Attention Tasks

Selective attention and divided attention tasks are two paradigms that are thought to reflect attentional capacities in humans. In selective attention tasks, subjects are asked to discriminate between incoming stimuli (Gale, 1977; Davies, 1983). The subject is instructed to attend to one of two or more stimulus attributes. Studies of selective attention tasks (Spelke, Hirst, & Neisser, 1976; Neisser & Beklan, 1975) have demonstrated that people are able to focus their attention on one of several competing stimuli.

In divided attention tasks, subjects are required to attend to two or more stimuli or stimulus attributes simultaneously. Subjects might be presented with two auditory stimuli at the same time and asked to detect specified targets. Another divided attention task could consist of the presentation of a single auditory stimulus. The subjects might be asked to discriminate between different dimensions of the tone, such as loudness or tonal quality (Davies, 1983).

Studies (Moray, 1959; Hawkins & Presson, 1986) have demonstrated that subjects can perform as efficiently under the divided attention and selective attention conditions, especially with the use of highly practiced subjects. But when the task is made more difficult (i.e. make the discriminations between dimensions more difficult), the performance under the divided attention condition deteriorates (Davies, 1983). As the amount of processing capacity reaches a critical level, one's ability to perform tasks without error decreases. In other words, attending to several things at one time is a difficult task. Kahneman (1973) theorized that the act of attending to a task represents an exertion of effort, which pulls processing resources away from the limited processing capacities of the human mind.

Vigilance and Attention

Vigilance tasks represent another method which can be used to study attention. In these tasks, researchers study the ability of individuals to "maintain their focus of attention and to remain alert to stimuli over prolonged periods of time" (Warm, 1984). Norman Mackworth (1948, 1957) was one of the first researchers to study sustained attention, or vigilance, in controlled laboratory settings. Mackworth conducted a series of vigilance studies that investigated the manner in which radar operators' performance declined over time. He observed that the longer people were required to stay "on watch", the less efficient they became at detecting critical signals. This progressive deterioration of an individual's performance is referred to as a "vigilance decrement" and occurs in long monotonous tasks which require sustained attention (Warm, 1984; Dember & Warm, 1979). The principal measures of vigilance performance include detection probability, errors of commission or "false alarms" and reaction time (RT) to correct detections or "hits" (Warm, 1984). From Mackworth's original studies to present-day studies concerning sustained attention, researchers have looked for a drop in the number of correct detections and/or a rise in the reaction time to correct detections as indications of a vigilance decrement (Buck, 1966).

Many factors impinge upon one's ability to sustain attention for long periods of time. The factors can be characteristics of the individual performing the vigilance task, as well as the characteristics of the signals that comprise the vigilance task.

<u>Individual Differences</u>

Berch and Kanter (1984) detailed numerous studies that investigated the individual differences that create variances in vigilance performance. Among the personality factors cited were those of introversion-extroversion (DiScipio, 1971), locus of control (Sanders, Halcomb, Fray, & Owens, 1976), and Type A / Type B (Lundberg, Warm, Seeman, & Porter, 1979; Perry & Laurie, 1992).

Another personality factor, boredom proneness, appears to affect vigilance performance. High scores on personality assessment questionnaires such as the Boredom Proneness Scale (Farmer & Sundberg, 1986) have been found to correlate highly with inattention and poor vigilance performance.

Subjective states and their relationship to vigilance performance have also been studied. The subject's "mental set", or expectations about the nature or purpose of the task, has been shown to affect vigilance performance (Berch & Kanter, 1984; Lucaccini, Freedy & Lyman, 1968; Jerison, 1958). Similarly, one's attitude (positive, negative, or neutral) about vigilance tasks also seems to affect their performance (Berch et al., 1984; Thackrey, Bailey & Touchstone, 1977). Bakan (1963) found that individuals who viewed the task as boring performed significantly worse than those who viewed the task as interesting.

Stimulus effects

Substantial research has examined the effects of stimulus conditions that affect vigilance performance. The duration (Baker, 1963) and intensity (Adams, 1956) of the signal have been shown to affect vigilance performance. If the duration of the stimulus presentation is decreased, the vigilance decrement will be more pronounced (Warm & Jerison, 1984), as is the case if the intensity of the signal is decreased. The event rate has also been shown to affect vigilance performance (Jerison & Pickett, 1964). If the event rate is increased, the vigilance decrement is greater because the individual is presented with more information to attend to in a given time interval (Craig, 1984; Davies & Parasuraman, 1982).

The conditions of the stimuli also affect vigilance performance indirectly, by influencing the frequency and duration of daydreaming (Antrobus, Singer, Goldstein, & Fortgang, 1970). Daydreaming, being an inward focus of attention, reduces the attention available to be allocated to the external world. Thus, the more attention is devoted to internal stimuli, the less attention will be available to devote to external, critical stimuli.

Daydreaming

The relationship between daydreaming and sustained attention has been explored in several studies (Giambra, 1993; Perry & Laurie, 1992; Giambra & Grodsky, 1989; Antrobus, Coleman & Singer, 1967; Bakan, 1963). Antrobus et al. (1967) found that subjects who scored higher on a self-report scale of frequency of daydreaming exhibited a significant decrement over trials in a signal-detection task, while those who scored low on the frequency of daydreaming scale showed essentially no change (Berch & Kanter, 1984). As the researchers expected, subjects in the high-daydreaming group indicated that they experienced significantly more daydreams during the vigilance task than did the low-daydreaming group.

Perry and Laurie (1992) conducted a vigilance study in which the relationship between Type A / Type B behavior patterns and daydreaming was investigated. They found that the Type A subjects performed significantly better and reported fewer daydreams than the Type B subjects in the vigilance task. Bakan (1963) found that the overall performance of subjects who indicated (after the task) that they were "completely lost" in daydreaming was much poorer than subjects who were not "lost" in daydreaming.

Many theories concerning the definition and purpose of daydreaming or "mindwandering" exist today. Some psychologists have suggested that daydreaming might serve to maintain the arousal level of an individual and to relieve some of their boredom (Antrobus et al., 1970; Singer, 1966a; 1966b). Similarly, Giambra (1993) suggested that daydreaming and unbidden thought-intrusions represent the "normal default mode of operation" of the conscious mind that occurs when the external world does not demand much cognitive processing or attention on the part of the individual. Giambra (1993) referred to daydreaming and mindwandering as "task-unrelated images and thoughts" (TUITs). He found that the likelihood of TUITs varies as a function of aging, hyperactivity, time of day and level of depression. Giambra (1993) also made the distinction between controlled and uncontrolled TUITs. He stated that "TUITs may occupy our awareness because they capture our attention or because we have deliberately shifted our attention from the task at hand to them."

Although not all people agree upon the definition or purpose of daydreaming, most people agree that daydreaming represents a shift of attention away from some primary mental task and toward an "unfolding sequence of private responses" to some internal stimulus (Singer, 1966a). These internal shifts of attention that define daydreaming are essential to our understanding of the relationship between attention and vigilance.

Psychophysiology and Attention

It is also important that we understand the psychophysiological factors involved in attention. In the past 50 years, enormous advances have been made in our knowledge of the brain and its role in attention. Recently, scientists have attempted to identify neurological correlates of attention using cerebral blood-flow techniques (Robinson & Peterson, 1986; Roland, 1982). In these cerebral blood-flow studies, subjects are asked to attend to various stimuli using different modalities. Blood-flow technology is based upon the fact that areas of the brain that are active consume more glucose and oxygen and require more blood to deliver these nutrients to the active areas. This flow of blood can then be seen, using temperature sensitive equipment, as it moves throughout the brain. Robinson and Peterson (1986) observed that when people paid attention to visual stimuli, blood-flow increased to the occipital lobe. When subjects were required to switch their attention from one modality to the next, increased activity was observed in the pre-frontal cortex, implicating this area of the brain in connection to shifts of attention.

Other researchers have investigated the role of the brain in the attention system using positron emission tomography (PET). In these studies, small amounts of radioactive glucose or oxygen are introduced into the body. As the radioactive material is utilized by the brain, positrons are emitted and the subsequent gamma radiation that is produced can be measured by detectors placed around the head (Posner, 1992). In this way, researchers can pinpoint the active areas of the brain.

PET studies have demonstrated that when an individual is required to maintain attention for extended periods of time, the right frontal lobe is activated (Pardo, Fox, & Raichle, 1991; Whitehead, 1991). Further, individuals who have lesions of the right frontal lobe are unable to maintain attention and alertness, even if they are given a warning signal, whereas patients with lesions in their left frontal lobe are able to remain alert (Pardo et al., 1991). This seemingly lateralized aspect of attention has been demonstrated in at least one other study. Whitehead (1991) found that reaction times in signal detection vigilance tasks tend to be quicker when the targets are presented to the left visual field (i.e. the right hemisphere).

Additional PET studies conducted by Posner and Peterson (1990) suggest another area of the brain are also control attention. Research on monkeys and humans indicated that the posterior parietal lobe is activated when a person attends to one visual field. These results are supported by studies of individuals with strokes or tumors of the parietal lobe, which demonstrate a deficit in the ability of these individuals to shift their attention to the side opposite of the lesion (Posner & Peterson, 1990).

Arousal Theory

In previous decades, scientists have hypothesized that changes in vigilance performance could be explained using measures of central nervous system (CNS) arousal level (Lacey & Lacey, 1970; Davies & Jones, 1975). One theory that has been proposed to explain why vigilance performance declines over time is arousal theory. This theory emphasizes the role of an individual's arousal level while they are engaging in a vigilance task. Arousal theory states that the monotonous nature of a vigilance task can cause a progressive decrease in CNS arousal level (Davies &

Parasuraman, 1982). As an individual's level of arousal decreases, their performance will decline accordingly.

Hebb (1958) stressed that if an individual is placed in a condition of "monotonous sensory stimulation", it is difficult for the individual to maintain a proper state of alertness (Stroh, 1977). Hebb (1958) suggested that in the beginning of a vigilance task, an individual's arousal level is high. High arousal level results in good performance wherein most of the critical events are correctly detected. But as the task continues, the vigilance task does not provide the level of stimulation that is needed to maintain attention and alertness which results in a reduction in arousal and subsequently, a decrement in performance (Stroh, 1977; Parasuraman, 1983).

EEG studies

One of the primary measures of CNS arousal level that has been used to explain changes in attention and vigilance performance is electroencephalographic (EEG) activity. A direct relationship, however, has been difficult to establish . The difficulty lies in the fact that electrocortical arousal level can decline with or without a corresponding reduction in vigilance performance (Davies, Shackleton, & Parasuraman, 1983;

Parasuraman, 1983; Gale, 1977). Moreover, studies have shown that reductions in vigilance can occur even if EEG arousal is maintained (Parasuraman, 1984; Gale, 1977).

Most EEG studies involving target detection and vigilance have examined the performance averages as indexed by the overall changes in EEG power. Yet, within an individual session, electrocortical activity fluctuates irregularly as does performance (Makeig & Inlow, 1991). Numerous vigilance studies (Davies & Parasuraman, 1982; Gale, Davies & Smallbone, 1977) indicate that subject performance usually decreases 2-3 minutes into target detection tasks and eventually reaches a plateau at which 79-80% of the targets are detected (Parasuraman, 1983). These researchers suggest that studies that focus on mean trends in EEG and performance neglect the small fluctuations in attention that tend to occur.

Another criticism of former EEG studies is that previous studies focused on the activity from a small number of electrode sites. In many of the early studies, recordings were obtained primarily from the occipital cortex using only two electrodes (Davies & Parasuraman, 1982). These limited recording sites provided an inadequate picture of the activity that occurred in the other regions of the brain (Stroh, 1977) and made it difficult to make comparisons between studies that used different electrode sites, such as over the parietal or frontal cortex. In addition, the electrodes were not always placed on the scalp in a standardized manner.

The development of the International 10-20 system, which standardized the placement of electrode sites, provided some consistency in later EEG recordings (Jasper, 1958). In addition, the use of electrode caps enables today's researchers to collect data from a wide variety of cranial locations. Other methodological inconsistencies, however, pose problems for making comparisons across earlier studies. Often, studies varied as to the type of stimulus used (auditory vs. visual), the type of reference leads (unipolar vs. bipolar), and state of the subjects' eyes (open or closed). This lack of consistency between experiments has made it difficult to reach firm conclusions about the relationship between EEG arousal and attention.

Earlier studies (Mundy-Castle, 1951; Pawlik & Cattell, 1965) focused primarily on the amount of alpha (8-12 Hz) activity recorded from the occipital cortex. Though decreases in alpha power and increases in beta power (13-30 Hz) have typically been assumed to reflect increases in electrocortical arousal, Davidson, Chapman, Chapman, and Henriques (1990) suggests that alpha power and beta power may be positively correlated with regard to levels of arousal. In addition, the effects of other frequency bands such as delta (0.5-3 Hz) and theta (4-7 Hz) on arousal are still being investigated. Specifically, Beatty, Greenberg, Deibler and O'Hanlon (1974) studied the effects of theta suppression and augmentation on performance in a target-detection task. They found that subjects who suppressed theta activity performed significantly better than those who increased the amount of theta activity. Gale (1977) found similar results, in which individuals that performed more poorly produced greater amounts of theta activity than others. Other studies (Alluisi, Coates, & Morgan, 1977; Williams, Beatty & O'Hanlon, 1975), however, found that the effects of theta regulation are not particularly strong.

Other studies have examined the decline in alertness by monitoring the changes in the EEG spectrum during the transition from awake states to Stage I sleep states (Matousek & Peterson, 1983; Townsend and Johnson, 1979). For example, Kuderian et al. (1991) found that at the beginning of all-night sleep sessions, the power in all frequency bands increased when sleep-related lapses in an auditory target detection task first occurred (Makeig, Elliot, Inlow, & Kobus, 1992). In a similar study, Torsvall and Akerstedt (1988) suggested that a decline in alertness is characterized by an increase in the amount and amplitude of alpha activity, slow eye movements and sleep spindles. However, there is substantial between-subject variability in EEG signs of drowsiness (Santamaria & Chiappa, 1987). In addition, a strong correlation between EEG signs of drowsiness and performance measures has not yet been established (Makeig, et al., 1992).

Although the effects of electrocortical arousal on attention are still being debated, for tasks that require concentration or attention over long periods of time, EEG measures do seem to be related to one's state of attention (O'Hanlon & Beatty, 1977). In an alert person, the EEG activity is small and desynchronized. During a vigil, the activity shifts to lower frequencies, indicating that a reduction in electrocortical arousal has occurred (Parasuraman, 1983).

ERP studies

Other electrocortical measures, such as event-related potentials (ERP), have been employed to assess vigilance performance and attention. Event-related potentials are brain waveforms that are elicited by sensory and cognitive stimuli. To be seen clearly, the ERP must be extracted from the background EEG by a technique called computer signal averaging, wherein a number of time-locked brain responses are averaged together to clarify the ERP waveform while diminishing the random EEG patterns and artifacts (Cacioppo, 1990). As the responses are averaged, the ERP waveform becomes more distinct.

ERP data can be defined by several methods. One method classifies the ERP according to the stimulus that produced the waveform (Andreassi, 1989). If the ERP was produced by an external sensory event, such as a auditory tone or flash of light, it is termed an exogenous ERP. Conversely, if the waveform is produced by an internal event, as in the expectation of a stimulus, the waveform is referred to as an endogenous ERP.

Another way that researchers have classified ERPs is by the shape, or morphology, of the waveform. The ERP has components that can be described by peaks and troughs that occur at characteristic latencies (Cacioppo, 1990). These latency components of the ERP have been assumed to reflect various levels of attentional states. Certain aspects of the ERP waveform have been implicated in different stages of the information processing system and are affected by the type of information processing involved, such as cognitive or perceptual processing or the type of task used, such as selective attention or divided attention tasks. The ERP also seem to be affected by a variety of stimulus characteristics such as the type of stimulus used, duration of the stimulus, probability of the stimulus and the relevance of the stimulus to the task at hand.

The negative deflection occurring about 100 ms after a stimulus presentation appears to reflect the allocation of attentional resources to a particular perceptual channel (Cacioppo, 1990). This component, referred to as N100, was investigated by Hillyard, Hink, Schwent and Picton (1973). In their study, auditory tones of two different pitches were delivered binaurally. Hillyard et al. (1973) observed that the waveform possessed a greater negative deflection (N100) when the subjects were asked to attend to the stimuli in one of the ears. The amplitude of the N100 component produced by the unattended tones remained unenhanced.

Another negative ERP component that researchers have investigated is the N200 component. This N200 component of the ERP waveform was observed by Squires, Squires and Hillyard (1975) to have a greater amplitude when the stimulus was rare, regardless of the relevance of the stimulus to the task.

The positive components of the ERP waveform have also been examined for their role in sensation, perception and attention. The positive deflection occurring around 200 msec after a stimulus presentation has been implicated in the adaptation process. If the presentation rate of a stimulus is increased, the component, called P2, will decrease in amplitude.

The most studied positive component of the ERP waveform is referred to as P300. This component is thought to be the most indicative of information processing, and occurs, despite its specific name, anywhere from 250 msec to 900 msec. The P300 seems to be affected by a wide variety of cognitive activities including decision-making, attention, discrimination, uncertainty resolution, and stimulus resolution (Andreassi, 1989).

Naatanen (1982) used evoked potentials to examine selective attention in which a series of tones were presented binaurally. When subjects heard a high tone, they were asked to press a button. Results showed that when the subjects heard the high tone, the amplitude of the N100 and P300 components increased. Using a target-detection task, Hillyard, Squires, Bauer, and Lindsay (1971) found that the amplitude of P300 was enhanced by the subject's degree of confidence in their decision. In other words, if they felt confident that the signal that they chose was a target, the amplitude of the P300 component was larger than when the subjects were not as confident in their choice.

Ford, Roth & Kopell (1976) conducted a study that investigated the effects of a task that required different levels of attention on the P300 component. They found that P300 became larger with increased attention. Pritchard (1981) stated that selective attention "appears to be a necessary condition" for the elicitation of the P300 component. The P300 component will not be produced by even low probability stimuli if the stimuli are not relevant to the task and are ignored (Andreassi, 1989).

Makeig et al. (1990) investigated the relationship between task-relevant and task-irrelevant auditory stimuli in an auditory target detection task. ERPs were recorded to assess the electrocortical correlates of the subject's readiness to detect and respond to critical signals. Makeig et al. (1990) analyzed ERPs that were elicited by unattended tones that were presented a few seconds before correct detections and missed targets. Results indicated that the ERPs elicited by task-irrelevant stimuli covaried with a measure of local error rate. Specifically, before a missed target, the N2 and P2 components were larger and the N1 component was smaller, as compared to the respective components that occurred before correct detections.

Research Purpose and Hypotheses

In this study, EEG and ERP correlates of attention were investigated. The aim was to further investigate the relationship between fluctuations in attention, vigilance performance and electrocortical activity. Subjects engaged in a forty-minute vigilance task. It was predicted that as subjects engaged in the task, their performance would steadily decrease, and their performance decrements would be reflected in the EEG record as well as by the performance data. Performance decrements were expected to be evidenced by increased reaction time (RT) to correct detections, lower probability of correct detections P(HIT) and higher probability of false alarms P(FA). Performance decrements were also expected to be reflected in the absolute power of different frequency bands of EEG activity. Specifically, as performance declined, the EEG was expected to exhibit more activity in the alpha and theta domains.

Further, vigilance decrements were also expected to be reflected by various components of the ERP waveform that are elicited by unattended auditory stimuli. The author hypothesized that as performance declined, the amplitude of the N1 would decrease, while N2 and P2 components would increase, a result that coincides with the Makeig et al. (1990) study.

This study also was designed to assess any electrocortical differences that exist between a period of daydreaming and directly after an individual redirects his/her attention to a primary task. By asking the subject to indicate occasions that they were daydreaming, the researcher was given subjective measures of the subject's state of attention at a given time. In this way, the electrocortical activity that occurred during periods of higher and lower levels of attention could be compared. When an individual experienced a task-irrelevant thought or daydream (pre-TUT), the EEG spectrum was expected to contain significantly more lower frequency, synchronous EEG that is characterized by theta (3-7 Hz) and alpha (8-12

Hz) activity. Once an individual realized that they had been absorbed in thought unrelated to the primary task and began to redirect their attention (post-TUT), the EEG spectrum was expected to begin to exhibit higher frequency, more desynchronized EEG in the beta range (13-22 Hz). In addition, the use of frequency band ratios was also expected to provide electrocortical measures of the subjects' level of attention during the task.

A significant difference between the ERP components produced by the task-irrelevant probe tones that were presented during the pre-TUT and the post-TUT periods was expected. Specifically, it was expected that while a person was engaged in a task-unrelated thought, the amplitude of the N1 component would be smaller, and the N2 and P2 components would be larger than the same components that occurred during a post-TUT period.

Thus, as stated above, the purpose of this study was to examine the electrocortical indices of attention and inattention. It was predicted that decrements in vigilance performance would be reflected in progressive cortical deactivation. It was further predicted that by analyzing the electrocortical activity that occurred during a self-reported period of daydreaming and comparing it to activity directly after this period, a better picture of the electrocortical correlates of attention and inattention would emerge.

Method

Subjects

Sixteen undergraduate and graduate students (nine males, seven females) were recruited from two medium-sized universities. All subjects voluntarily participated in the experiment. Ages ranged from 18-39 years (mean age of 25.8). Subjects were each paid $20 for their participation. Four subjects were given, in addition to the $20, extra credit in their psychology course, for their participation.

Apparatus

A Cadwell Spectrum II topographical brain mapping computer system was utilized to record EEG activity, generate the ERP waveforms and to perform the QEEG analysis. Electrocortical activity was recorded through an Electro-cap International sensor cap. The lycra sensor cap consisted of 22 recessed Ag/AgCl electrodes arranged according to the International 10-20 placement system. The cap was held on the subject's head by a chin strap and adhesive sponge pads placed on the forehead. Two earlobe electrodes were used for reference points. Conductive gel was placed into each electrode site using a dispenser tube and a blunt-tipped hypodermic needle.

An Acoustic Research Partner 570 speaker was used to present the auditory probe tones. The computer vigilance task was displayed on a Magnavox 14 inch video monitor (Model No. 9CM062 0741). All verbal instructions were delivered to the subjects through a Realistic PZ-M microphone.

Stimuli:Probe tones

The task-irrelevant auditory tones were used to simulate the probe tones used by Makeig et al. (1990). Auditory stimuli were presented through the speaker at 62 dB nHL in an ambient noise background at 45 dB nHL. The auditory tones were of two frequencies: 1098 and 568 Hz. The tones were presented in a pseudo-random order with an inter-stimulus interval between 2-4 sec. The tones were 50 msec in duration, with rise and fall times of 10 msec. The probability of occurrence of the 1098 Hz tone was 20% while that of the 568 Hz tone was 80%.

Stimuli: Vigilance Task

The stimuli in the practice trials and the vigilance task were generated by a program written by Dr. Mark W. Scerbo. In both the practice session and the main session, visual stimuli consisted of two white, vertically-oriented lines which were presented for 200 msec on a black background of the video-monitor screen.

The interstimulus interval (ISI) was four seconds or 15 events per minute. The event-rate of the target was one per minute. The size of the neutral stimuli was 2 X 72 mm separated laterally by 26 mm and subtending a visual angle of eight degrees. Critical signals were represented by an occasional 3 mm increase to the top of the pair of lines. The critical signals subtended a visual angle of nine degrees.

Procedure

EEG Recording

Data from all sessions was continuously recorded to an optical disk for off-line analysis. The EEG traces were converted to digital format. EEG signals were amplified 50k times with a 1.6-50 Hz bandwidth through Cadwell EEG amplifiers with a sensitivity of 7.5 microvolts (Uv)/ millimeter. The sampling rate was 25 mm / sec.

The Cadwell sensor cap was placed on the subject's head and a reference electrode was attached to each earlobe. The sensor cap and the reference electrodes were connected to the headbox. Electrical impedances at each electrode site were reduced to less than five kOhms. The subjects were asked to refrain from excessive blinking and movement while in the experimental chamber. The subjects were then seated in the darkened, sound-attenuated experimental chamber.

Baselines

Continuous EEG was recorded for up to three minutes during two baseline periods. In the first baseline, the subject sat quietly and stared straight ahead at the computer screen. In the second EEG baseline recording, the subjects were instructed to sit quietly and close their eyes.

Experimental Session

EEG was recorded only during the baseline periods and the main experimental session. Because of storage limitations of the Cadwell Spectrum II, the recording of the EEG was stopped every ten minutes and quickly resumed. The maximum length of time that the recording was interrupted between each period was 15 seconds. The subjects had no knowledge of any interruption of the EEG recording.

Vigilance Task

After the baseline recordings, the subjects performed two practice trials. Instructions for both the practice trials and the main session were displayed on the CRT-screen and simultaneously read aloud by the experimenter. In the first practice trial, the subjects were shown the target and the non-target pairs of lines, one after the other, in a pseudo-random manner. The subject was instructed to indicate whether the first or the second pair was the target. The subjects completed ten "forced-choice" trials in this practice section. If the subject correctly responded to seven of the ten presentations, they proceeded to the second practice session. If their performance was less than or equal to six out of the ten presentations, the forced-choice practice session was repeated until the subject reached the minimum performance level.

In the second practice trial, the subjects engaged in a ten-minute version of the experimental task. The subjects were required to press the mouse button as quickly as possible whenever they saw a target pair of lines. Responses that occurred within three seconds of the onset of the target were recorded as correct detections (HIT), and all other responses were recorded as errors of commission or false alarms (FA). After the ten-minute practice session, a non-parametric index of the subject's perceptual sensitivity (A′) was derived. If their A′ score was less than .7, the subjects were run through the forced-choice practice session again. If their A′ score was at least .7 or greater, they proceeded to the main experimental session, which lasted 40 minutes.

Task-Unrelated Thoughts

During the main session, the subjects were asked to report occasions of daydreaming or times that they found themselves to be thinking about something other than the task. The subject indicated the occasions of these task-unrelated thoughts (TUTs) by pressing the space bar on the keyboard. The subjects were informed that their primary job was to respond to the longer pairs of lines on the computer screen, but if they found themselves to be daydreaming they were instructed to press the space bar. Each TUT report was time-locked onto the EEG record.

Results

Performance Data

Subject performance data was divided into four ten-minute periods. Non-parametric measures of perceptual sensitivity, A′, and response criterion, B′′, were derived. These measures were calculated from the percentages of hits P(HIT) and false alarms P(FA) for each subject during the vigilance task. Mean reaction times (RT) for both hits and false alarms were calculated, as well as the mean number of TUT-responses made in each period.

The following analyses included the performance data from ten subjects. Six subjects were excluded from the analysis due to excessive artifact contamination of the EEG data. A one-way repeated-measures analysis of variance (ANOVA) of the performance data indicated a significant difference between the median reaction times (RT) to hits $\underline{F}(3, 27) = 16.70$, $p<.0001$ over the four 10-minute periods. No significant different was found between the median RT to false alarms. Table 1 presents a summary of the sources of variance for reaction time to hits.

Insert Table 1 here

The ANOVA indicated a significant decrease in the probability of hits over periods $\underline{F}(3, 27) = 3.79$, $p<.05$. Table 2 presents a summary of the sources of variance for the probability of hits.

Insert Table 2 here

Table 3 presents the mean performance data over the four ten-minute periods. There was no significant difference in the probability of false alarms.

Insert Table 3 here

No significant difference was found in the A′ scores over the four periods. However, the analysis did reveal a significant difference in the B′′ scores $\underline{F}(3, 27) = 5.55$, $p<.01$, which indicates that the subjects became more conservative with their responses as the task progressed. (see Table 4)

Insert Table 4 here

The ANOVA revealed a main effect for TUT responses across periods $\underline{F}(3, 27) = 2.98$, $p<.05$. Specifically, the subjects reported more TUTs in the last three periods than in the first period. Table 5 presents the source of variance for the average number of TUT responses.

Insert Table 5 here

QEEG Data

As mentioned earlier, six subjects were excluded from the analysis due to excessive artifact contamination of the EEG data. Of the remaining ten, one subject did not make any TUT responses, and therefore the TUT analysis of the QEEG data was performed on nine subjects. A maximum of twelve artifact-free epochs were collected from a thirty-second period of time prior to (pre-TUT) and after (post-TUT) each TUT-response. Each epoch consisted of 2.5 seconds of EEG data.

In some cases, subjects made several TUT responses in close temporal proximity. This made it difficult to discern if the epoch that was collected came from a post-TUT period or a pre-TUT period. Therefore, if two consecutive TUT responses were separated by less than twenty seconds, then no epochs were selected from either before or after the TUT marker. If two TUT responses were separated by twenty seconds or more, then the time was divided by two and pre-TUT and post-TUT epochs were chosen from this difference.

The changes in QEEG across the four ten-minute periods were analyzed were also examined. It was decided that an analysis of the entire period would not be as sensitive to changes in the EEG spectrum over periods. Hence, to increase the sensitivity to any period changes in EEG data, epochs were only collected during the first five minutes of each period. A maximum of 48 epochs from each subject was selected from each period.

The pre- and post-TUT epochs and the epochs across periods were subjected to Quantitative EEG (QEEG) analysis. QEEG is a type of spectral analysis that parses the data into its different frequency components (delta, theta, alpha, and beta). Each frequency band of the QEEG was analyzed separately using a one-way repeated measures ANOVA.

Pre-Post TUT: Absolute Power

The absolute power of each frequency band at F3, F4, Fz, Cz, P3, P4, and Pz electrode sites was computed. Figure 1 presents these sites as well as other sites of the recording montage used in this study. In comparing pre-TUT and post-TUT QEEG, the

Insert Figure 1 here

ANOVAs revealed no significant difference in the absolute power of the frequency bands that occurred at any of the electrode sites.

Pre-Post TUT: Frequency Band Ratios

The QEEG data from the seven electrode sites were converted into three different band ratios. The first two ratios, beta/alpha, and beta/(alpha+theta), have been used by researchers at NASA-Langley in several studies of EEG and attention. The third band ratio, beta/theta, was used by Lubar (1991) and was found to discriminate between normal children and children with ADD.

The ratios generated in the Pre-TUT and Post-TUT conditions were compared using a one-way repeated measures ANOVA. Only beta/(alpha+theta) and beta/alpha recorded at the posterior parietal sites were found to discriminate between the pre-TUT and post-TUT conditions. Significant differences were found for beta/alpha at P4 $\underline{F}(1, 8) = 12.32$, $p<.01$, P3 $\underline{F}(1, 8)$ 10.94, $p<.05$, and Pz $\underline{F}(1, 8) = 8.47$, $p<.05$. The results of this analysis are shown in Tables 6, 7, and 8.

Insert Table 6, 7 &, 8 here

Similarly, the ratio beta/(alpha+theta) was found to be significant at P4 $F(1, 8) = 10.51$, $p<.05$, P3 $F(1, 8) = 10.10$, $p<.05$, and Pz $F(1, 8) = 5.81$, $p<.05$. All other electrode sites were not found to be significant. The sources of variance for P4, P3, and Pz can be seen on Tables 9, 10, and 11, respectively.

Insert Table 9, 10, & 11 here

QEEG Across Periods

The QEEG from the first five minutes of each period were analyzed for differences in absolute power. The absolute power of each frequency band was computed from midline frontal, central, and parietal sites (Fz, Cz, and Pz). This is a commonly used array in EEG studies. The three sites were analyzed separately using a one-way repeated-measures ANOVA. The analysis revealed a significant difference in power over the four periods at all three electrodes. At the frontal electrode (Fz), the absolute power of alpha $F(3, 27) = 9.37$, $p<.001$ and beta $F(3, 27) = 3.58$, $p<.05$ was found to be significant over periods. A Newman-Keuls post-hoc test performed on the means of the frequency bands over the four periods revealed that more alpha and beta was produced in the last two periods than in the first two periods of the vigilance task. Figure 1 presents the absolute power of the four frequency bands over the four periods at Fz.

Insert Figure 2 here

At the vertex (Cz), the absolute power of theta [$F(3, 27) = 3.67$, $p<.05$)], alpha $\underline{F}(3, 27) = 6.74$, $p<.01$, and beta $\underline{F}(3, 27) = 3.33$, $p<.05$ was also found to be significant. A Newman-Keuls test performed on the frequency bands revealed that more theta was produced in the last period than the first three periods. The post hoc test also indicated that more alpha and beta were produced in the last two periods of the vigilance task. Figure 3 presents the absolute power of the four frequency bands over the four periods at Cz.

Insert Figure 3 here

Finally, at the posterior parietal site (Pz), the absolute power of alpha $\underline{F}(3, 27) = 7.22$, $p<.01$, and beta $\underline{F}(3, 27) = 4.57$, $p<.01$ was found to be significant. Figure 4 presents the absolute power of the four frequency bands over the four periods at Pz.

Insert Figure 4 here

A Newman-Keuls test indicated that a greater amount of alpha was produced in the last two periods of the task. It was also revealed that more beta was produced in the last period.

<u>ERP Data: Pre-Post TUT</u>

Due to excessive artifact contamination, the pre-TUT/post-TUT ERP analysis only included data from three subjects. ERP waveforms elicited by the task-irrelevant, high tone (1098 Hz) were generated. Only TUT responses that were separated by at least 20 seconds were included. If two consecutive TUT responses were separated by less than 20 seconds, no epochs were selected from that time period. Clean epochs were collected from a maximum of 15 seconds before and 15 seconds after a TUT-response.

Waveforms were generated at the F3, F4, Fz, Cz, P3, P4 and Pz electrode sites (see Figure 1). The amplitude (measured from zero) of the N1, N2, and P2 components of each waveform were analyzed using a one-way repeated measures ANOVA.

The results indicated no significant difference between any of the ERP components that occurred before a TUT response and after a TUT response.

ERP Data: Across Periods

As mentioned earlier, six subjects were excluded from the analysis because of excessive artifact contamination, leaving ten subjects with clean data. ERP waveforms elicited by the task-irrelevant, high tone (1098 Hz) across periods were generated. Clean epochs were chosen throughout each ten-minute period. Waveforms were generated from the midline frontal, central, and parietal electrode sites (Fz, Cz, and Pz) see Figure 1).

The amplitude (measured from zero) of the N1, P2, and N2 components from each site were analyzed separately using a one-way repeated measures ANOVA. The results indicated no significant difference in the waveform components over periods at any site. Figure 5 displays the ERP waveforms over periods at Fz, Cz, and Pz.

Insert Figure 5 here

Although the results were not significant, the ERP components at each site do attenuate in a linear fashion across the four periods, as can be seen in Figure 5.

Discussion

Performance Data

The present study has explored the relationship between vigilance performance and electrocortical activity. The study demonstrated that the subjects' performance declined as the task progressed. Although the performance decrement was not characterized by traditional measures (such as changes in A'), the decrease in the probability of correct detections, and the increase in RT to correct detections demonstrated a progressive deterioration in subject performance. The results also indicated that the subjects became more conservative over time, a finding that is common in vigilance tasks (Warm & Jerison, 1984). The fact that the subjects made significantly more TUT responses as the task progressed served as further evidence that the subjects steadily became less vigilant. The results of the performance data suggest that the monotonous nature of the vigilance task decreased the arousal level of the subjects, causing a decrease in their performance. The increased number of TUTs further suggest that the subjects engaged in this "internal stimulation", perhaps in order to relieve some of the boredom that is so much a part of vigilance tasks. But in doing so, the subjects devoted more attention away from the primary task, resulting in the performance decline that was observed. It was predicted that the performance decrement would be reflected in changes in the EEG spectrum and in the different components of ERP waveforms as the task progressed.

QEEG Across Periods

It was demonstrated that over the four periods, there was a significant increase in theta at the vertex (Cz) and a significant increase in alpha and beta at Fz, Cz, and Pz. The greatest increase observed was that of alpha power at Pz. These increases in power over periods coincide with the results of Kuderian et al. (1991) who found that power in all frequency bands increased when sleep-related lapses first occurred in a target detection task.

Pre-Post TUT QEEG

The TUTs reported by the subject during the task also provided subjective measures of the subject's level of attention at a particular moment in time. It was assumed that during a period of time preceding a TUT response, the subjects were focusing their attention on something other than the task. Likewise, it was assumed that after a TUT response was made, the subjects had re-directed their attention to the task. By examining the electrocortical data recorded directly before and directly after a TUT response, it was demonstrated that there was a significant difference in the arousal level during these two periods.

The two frequency band ratios (beta/alpha and beta/(alpha+theta)) provided significant differences between the pre-TUT and post-TUT conditions. As mentioned earlier, these ratios have been used in several studies at the NASA-Langley Research Center, and have been suggested to be related to fluctuations in attention. This study confirms that assertion.

The band ratio beta/theta, used by Lubar (1991), was not found to discriminate between the pre-TUT and post-TUT conditions. These results, then, suggest that the first two ratios are better suited for the assessment of an individual's state of attention at a particular time.

The changes in the ratios, due in large part to the changes in alpha power, that occurred in the transition from a pre-TUT to a post-TUT period coincides with previous EEG studies of attention (Mundy-Castle, 1951; Pawlik & Cattell, 1965). Another aspect of this study that coincides with previous research on attention is the finding that electrocortical activity recorded from the posterior parietal region best discriminates between higher and lower levels of attention. These results are similar to PET studies (Posner, 1992; Posner & Peterson, 1990), which found that the posterior parietal lobe was activated when subjects switched their attention to a different visual field.

In regards to the measures of absolute power, this study did not find the absolute power of the different frequency bands across the pre-TUT and post-TUT conditions to be significant. This suggests that measures of absolute power are not as sensitive to fluctuations of attention as are the frequency band ratios, and that ratios should be used as the primary electrocortical measure of attention in future studies.

ERP Data

The components of the ERPs to the task-irrelevant tones across the pre-TUT and post-TUT conditions were not found to be significant. The ERPs of the pre-TUT and post-TUT conditions contained data from only three subjects, which undoubtedly contributed to the lack of significance.

The ERPs across periods, which contained data from nine subjects, displayed components that attenuated linearly across periods. However, the differences were not found to be significant. It is possible that no significant difference was found because epochs were selected throughout the entire task. This may have reduced the sensitivity of the analysis to detect changes across the periods. The QEEG analysis avoided this pitfall, in that epochs were chosen only from the first five minutes of each period. Using this epoch selection criteria, future analysis of the ERP data may reveal significant changes over time.

Despite the results, there is one observation that can be made in regards to the ERP waveforms. None of the subjects' ERP waveforms produced by the task-irrelevant tones exhibited a P3 component. The absence of a P3 component suggests that the subjects did not attend to the stimuli. This coincides with findings of previous research involving ERPs and selective attention (Makeig et al., 1992; Beatty et al., 1974; Davies, 1964).

More research will hopefully provide a keener view of the relationship between vigilance and electrocortical activity. These electrocortical components will be instrumental in the indexing of the psychophysiological characteristics of lowered levels of attention and the possible development of a predictive algorithm to preclude these hazardous states of attention.

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Appendix A

Task Information/Consent Forms

INFORMATION ABOUT THE EXPERIMENT

The purpose of this research is to observe psychophysiological signs of alertness and attention. Understanding gained in attention research will allow the application of these signs to general aviation settings. The current experiment involves recording the brainwaves of a subject participating in several cognitive tasks.

Prior to the experimental session, a sensor cap will be placed on the subject's head to permit recording of brainwave activity, electroencephalogram (EEG). The cap consists of 22 recessed electrodes arranged according to the "International 10-20" placement system. It will be held in place by a chin strap, and adhesive sponge disks that will be attached to the forehead. Once the cap is in place, a dispenser tube with a hollow blunt tip will be used to fill each of the sensors with conductive gel. Some slight abrading of the scalp with the blunted tip will be necessary to improve the sensor contact. Sensors will also be placed on the subject's earlobes as reference points for the sensors in the cap.

There will be minimal discomfort associated with the sensor placement technique. The standard method of placement will include some slight abrasion or roughing of the skin at each location. There are no known side effects related to placement, except for slight scabbing which may occur subsequently, depending on the sensitivity of the skin.

Following sensor placement, the cap and other sensors will be plugged into a box which interfaces with the topographical brain mapping system. The subject will then be seated in a room where he will be instructed to participate in a series of tasks while brain wave activity is recorded. In the first task, the subject will be instructed to relax quietly with eyes open for a few minutes, then with eyes closed for a few minutes in order to obtain an adequate baseline of the subject. In the second task, the subject will be instructed to participate in a visual experiment. Throughout the experimental session, auditory tones will be presented in the background. The subject will be instructed to ignore these tones.

The entire experimental session will last approximately 1 hour, with approximately 30 additional minutes required for sensor placement and removal. At any time, the subject may withdraw from any of the experiments without penalty. Any information obtained from the subject will not be used to identify the subject. The subject is assured anonymity. The subject may feel free to ask questions about the procedure or the purpose of the experiment prior to and/or after the experimental session.

HUMAN ENGINEERING METHODS EXPERIMENTAL SUBJECT
VOLUNTARY CONSENT FORM

I understand the purpose of the research and the techniques to be used as explained by the investigators. I understand that electroencephalogram (EEG) recordings of my brainwaves will be made during the experimental session. I also understand that I am assured anonymity when the results are summarized and at any time I may withdraw from the experiment without further consequences to me. I understand that there are no known or expected physical or mental side effects of this research. I do voluntarily consent to participate as a subject in the experiment as it is described to me.

____

PRINT NAME

____

SIGNATURE

____

DATE

Appendix B

Task Instructions

Vigilance Task: Task-Unrelated Thought Instructions

We are now ready to begin the main session. Remember, your job is to look for the longer pairs of lines and to press the mouse button as soon as you detect a critical signal.

From time to time, your mind may wander and you may find yourself thinking about things other than the task at hand. For example, instead of concentrating on the lines you might be thinking about what you did this morning or what you might do when the experiment is finished. This is normal and to be expected. We would like to know when this happens. Whenever you realize that you were thinking about something else instead of concentrating on the longer lines, press the space bar on the keyboard.

Remember, your main objective is to detect the longer lines. However, if you do notice that you were thinking about something other than this task, press the space bar.

When you are ready to begin the main session, press the mouse button.

Table 1

Source of variance for reaction time to correct detections

Source	df	SS	MS	F Value
Period	3	160262.2260	53420.7420	16.70*
Period X Subj	27	86373.1840	3199.0068	0.00

*p<.05

Table 2

Source of variance for probability of correct detections

Source	df	SS	MS	F Value
Period	3	0.2059	0.0686	16.70*
Period X Subj	27	0.4895	0.0181	0.00

*p<.05

Table 3

Mean performance data across periods

	Period			
	1	2	3	4
Probability of Hits	0.9394	0.8398	0.7699	0.7597
Reaction Time to Hits	836.79	955.57	990.90	990.90
Response criterion (B'')	-0.4277	0.2201	0.3574	0.1825
Number of TUTs	6.5	10.4	10.5	10.9

Table 4

Source of variance for response criterion (B'')

Source	df	SS	MS	F Value
Period	3	3.6481	1.2160	5.55*
Period X Subj	27	5.9168	0.2191	0.00

*$p<.05$

Table 5

Source of variance for average number of TUTs

Source	df	SS	MS	F Value
Period	3	127.4750	42.4917	2.98*
Period X Subj	27	385.2750	14.2694	0.00

*p<.05

Table 6

Source of variance for band ratio beta/alpha at P3

Source	df	SS	MS	F Value
TUT	1	0.20208	0.20208	10.94*
TUT X Subj	8	0.14780	0.01848	0.66

TUT = Task-Unrelated Thought

*p<.05

Table 7

Source of variance for band ratio beta/alpha at P4

Source	df	SS	MS	F Value
TUT	1	0.10156	0.10156	12.32*
TUT X Subj	8	0.06597	0.00825	0.40

TUT = Task-Unrelated Thought

*p<.05

Table 8

Source of variance for band ratio beta/alpha at Pz

Source	df	SS	MS	F Value
TUT	1	0.13528	0.13528	8.47*
TUT X Subj	8	0.12774	0.01597	0.83

TUT = Task-Unrelated Thought

*p<.05

Table 9

Source of variance for band ratio beta/(alpha+theta) at P3

Source	df	SS	MS	F Value
TUT	1	0.04121	0.04121	10.10*
TUT X Subj	8	0.03264	0.00408	0.95

TUT = Task-Unrelated Thought

*p<.05

Table 10

Source of variance for band ratio beta/(alpha+theta) at P4

Source	df	SS	MS	F Value
TUT	1	0.02645	0.02645	10.51*
TUT X Subj	8	0.02014	0.00251	0.55

TUT = Task-Unrelated Thought

*p<.05

Table 11

Source of variance for band ratio beta/(alpha+theta) at Pz

Source	df	SS	MS	F Value
TUT	1	0.02762	0.02762	5.81*
TUT X Subj	8	0.03802	0.00475	1.34

TUT = Task-Unrelated Thought

*p<.05

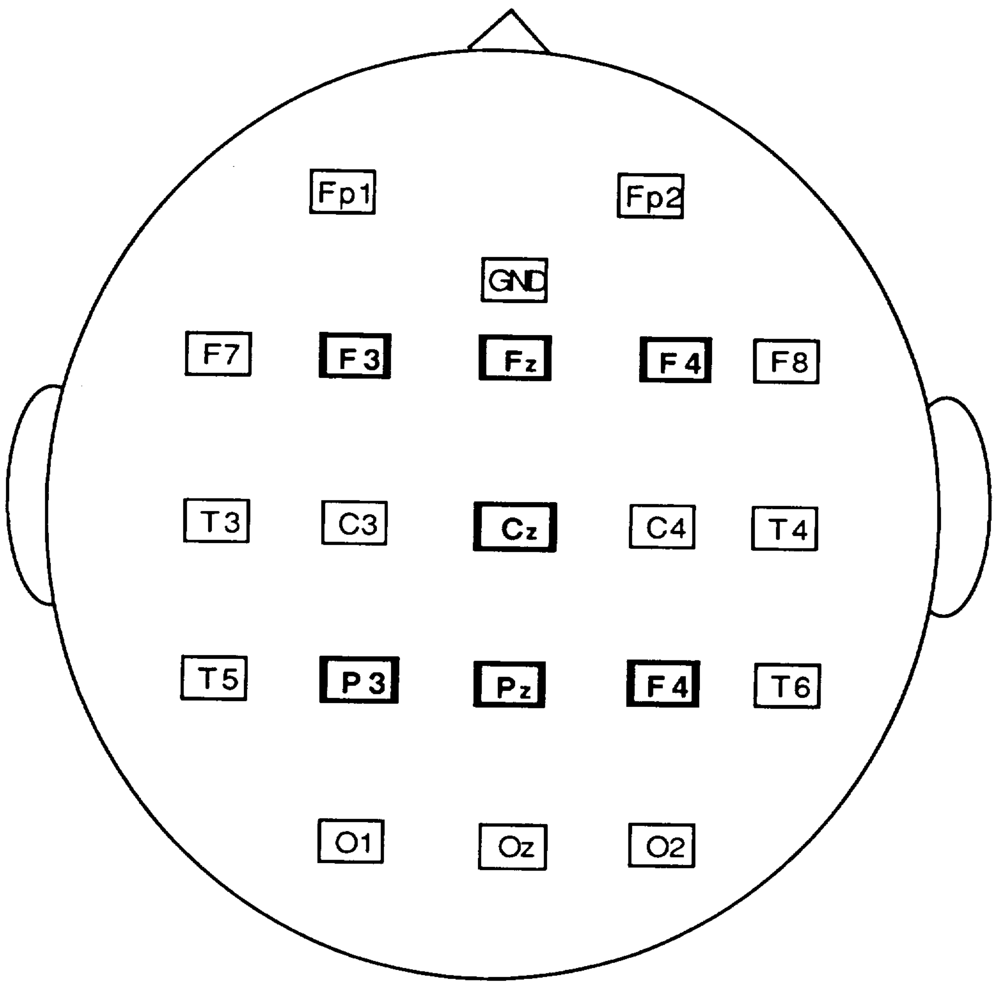

Figure 1. Recording montage organized according to the International 10-20 system

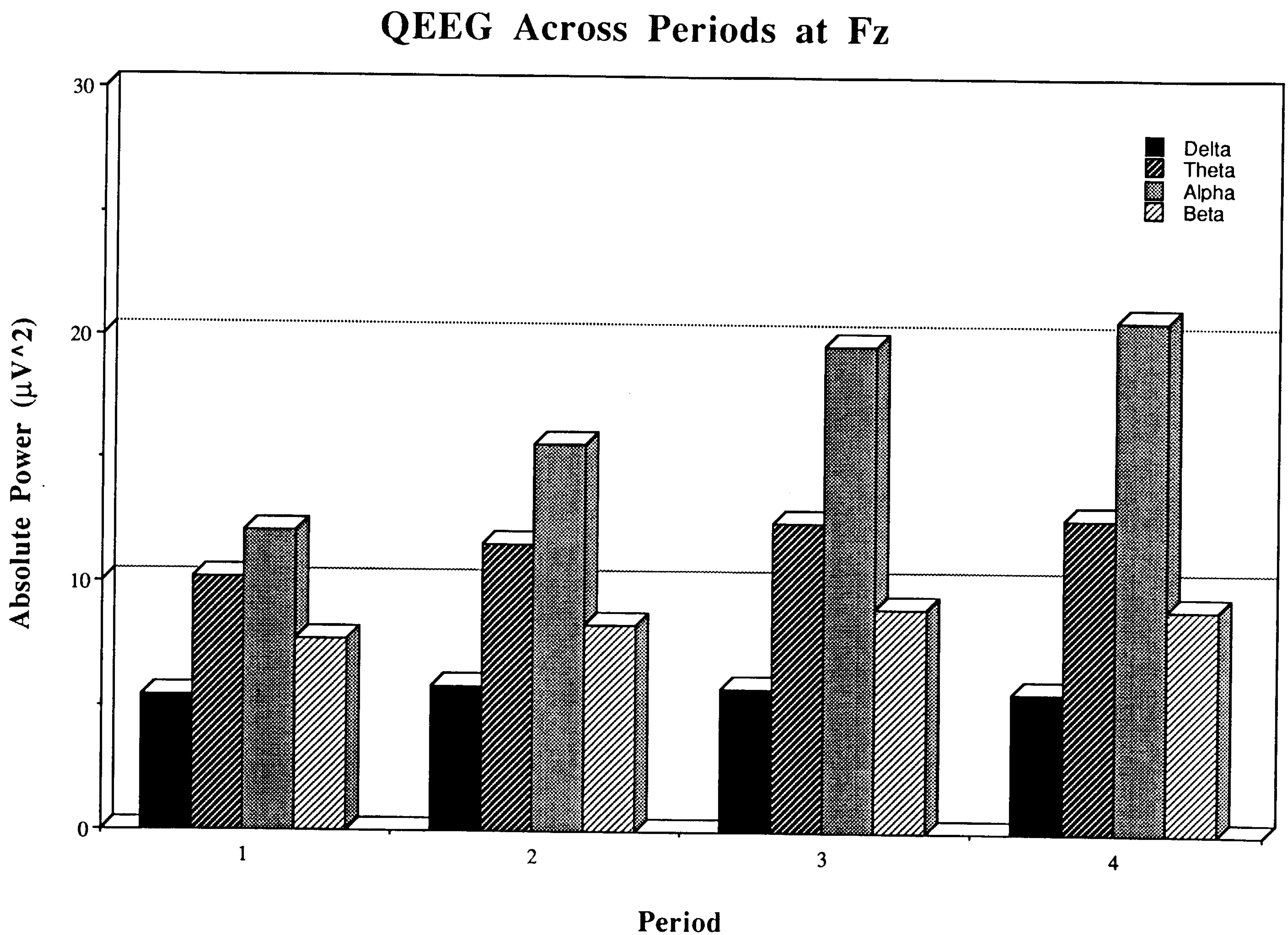

Figure 2. Absolute power of delta, theta, alpha, and beta at Fz

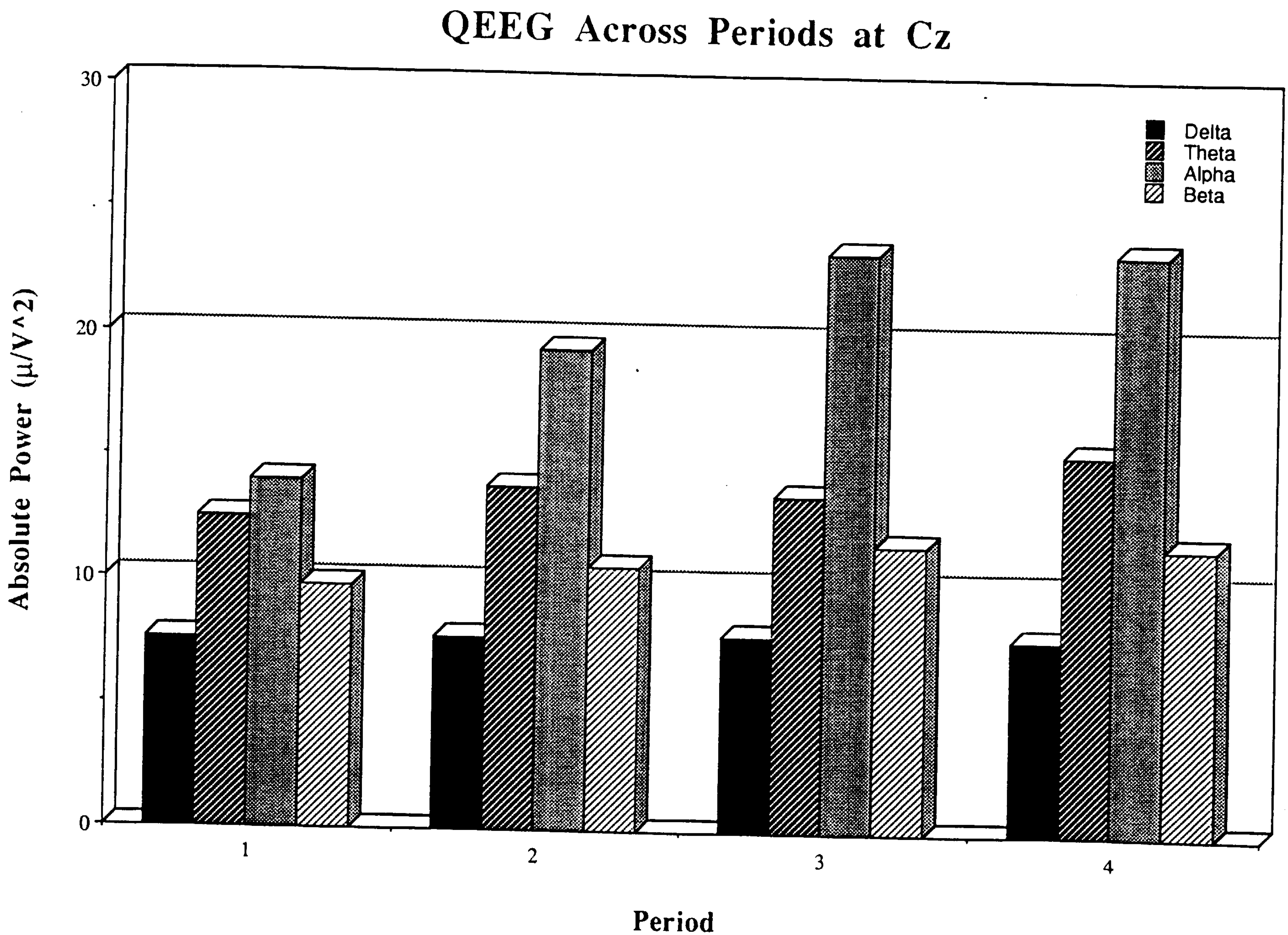

Figure 3. Absolute power of delta, theta, alpha, and beta at Cz

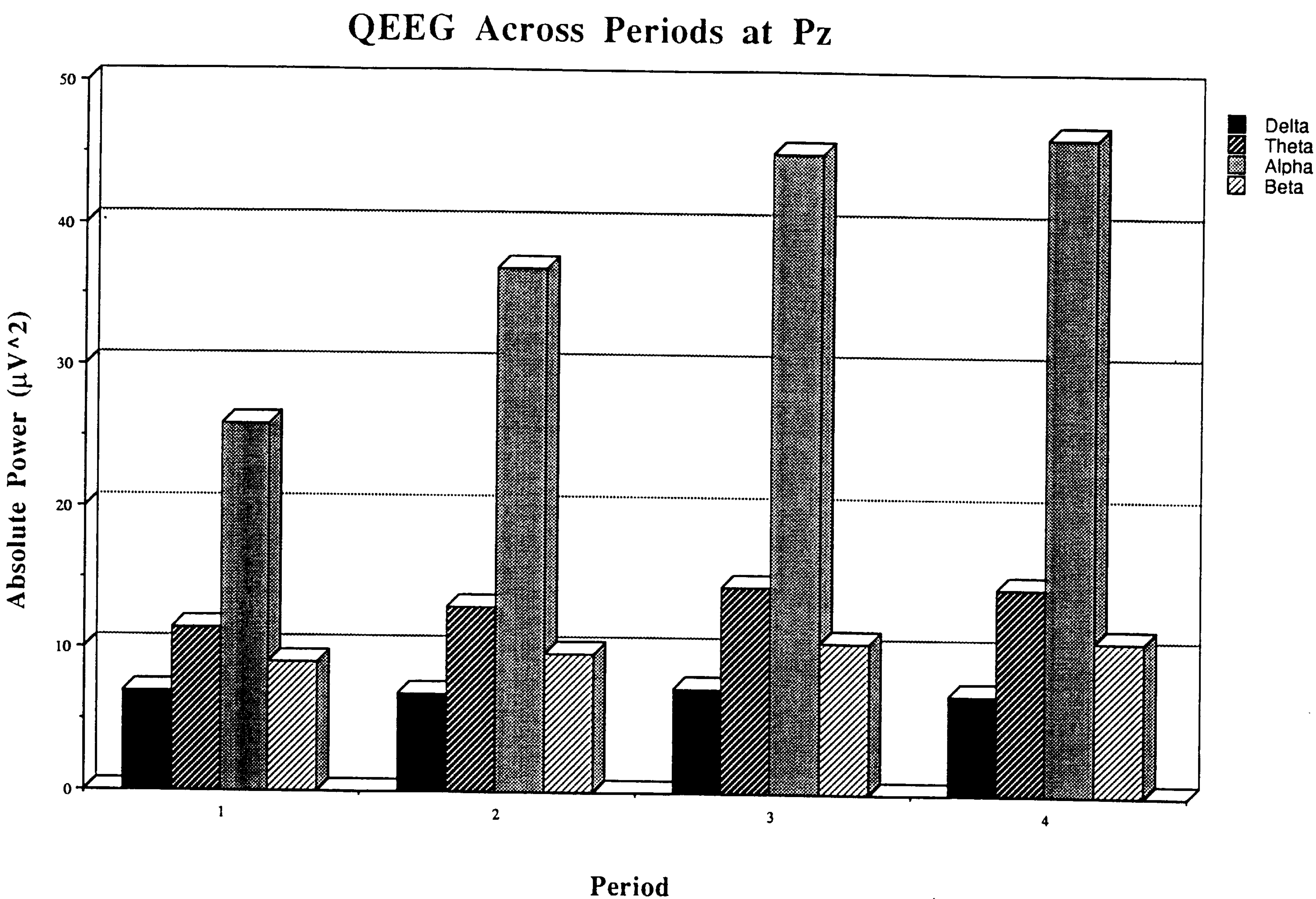

Figure 4. Absolute power of delta, theta, alpha, and beta at Pz

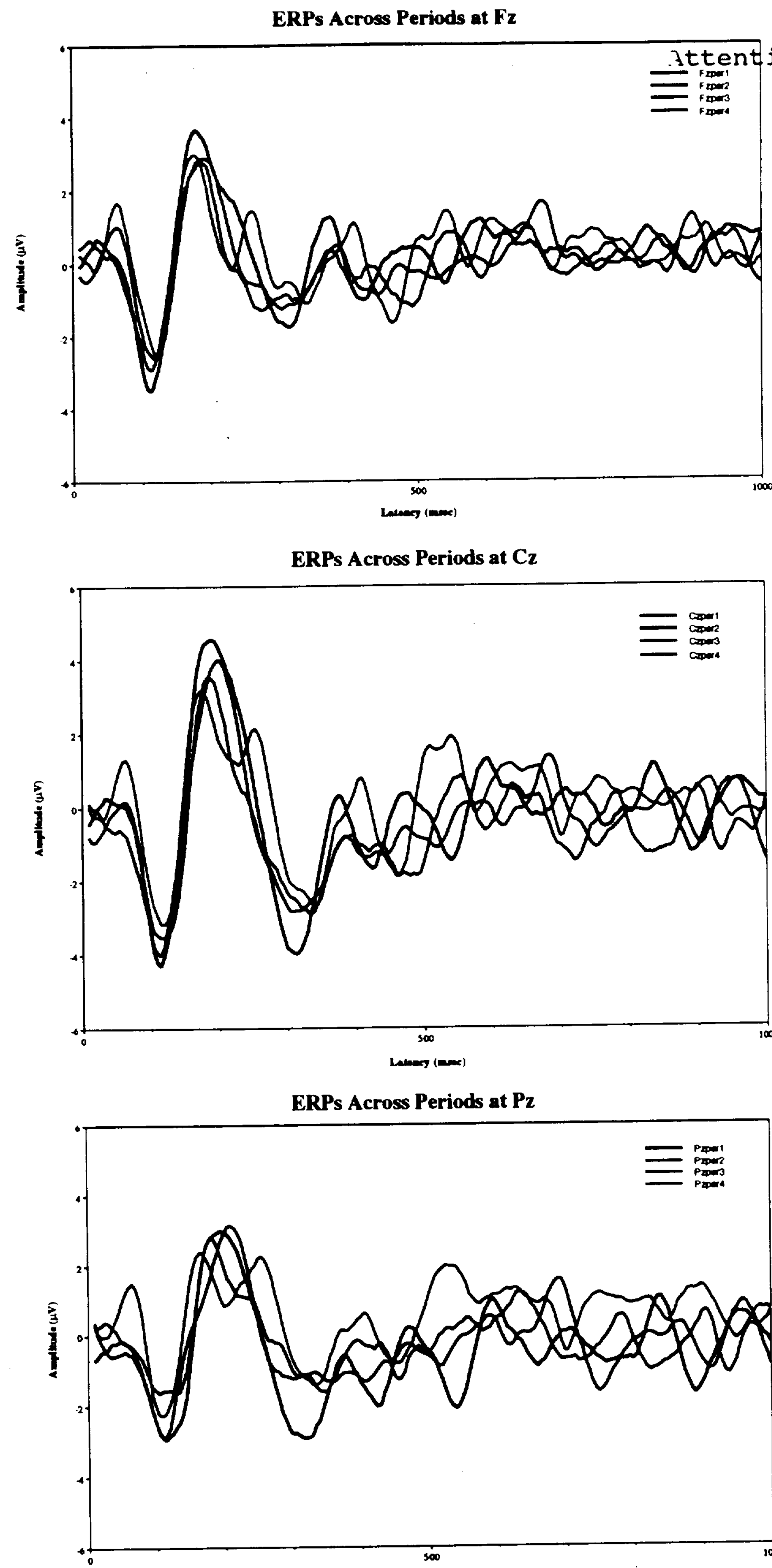

Figure 5. <u>ERPs elicited by task-irrelevant tones averaged across periods at Fz, Cz, and Pz</u>