AN ELECTROPHYSIOLOGICAL STUDY OF SELECTIVE AND SUSTAINED ATTENTIONAL PROCESSING AND AROUSAL IN THE HUMAN CEREBRAL CORTEX

by

Diana Velikonja

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ABSTRACT

The effects of increasing arousal, through caffeine and task demand, on selective and sustained attention processes were examined. The auditory oddball task exemplified selective attention processes, while the contingent negative variation task exemplified sustained attention. Caffeine was administered to 27 adults in one of two test sessions. ERPs and EEG were recorded while participants performed 3 selective attention tasks of increasing difficulty: pitch oddball, a difficult duration oddball, and a dual task; and 2 sustained attention tasks: standard auditory CNV(1), and a more challenging CNV(2) task. In the easier selective attention task, caffeine decreased the latency at which auditory information was processed. As task difficulty increased during caffeine trials, there was a shift from decreased latency to increased: allocation of attention to the auditory tones. When task difficulty increased in the no-caffeine trials, there was an increase in the amplitudes of waveforms indexing stimulus discrimination and evaluation, as well as, an increase in the latency of stimulus evaluation. For sustained attention tasks, the amplitude of the E-wave significantly increased for CNV2. A reduction in the amplitude of this component was found with caffeine.

EEG beta coherence showed a significant decrease in frontal-parietal regions between the pitch oddball and duration oddball tasks, and a significant increase in coherence between the duration oddball and dual task. For sustained attention tasks there was a significant decrease in frontal-parietal EEG alpha coherence between CNV1 and CNV2. These results support the notion of discrete attention systems located in anterior and posterior brain regions, respectively.

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INTRODUCTION

General Introduction

Through the course of the day many individuals believe that decrements in concentration and attention are associated with decreased arousal experienced as a function of a monotonous external environment, or disinterest in the task at hand. A typical strategy employed by many individuals to improve attention/concentration and enhance performance during the course of the day is the consumption of a mild stimulant such as caffeine.

The present thesis will examine whether cortically recorded event-related potentials (ERPs) are capable of measuring information processing changes within the cerebral cortex under conditions of increasing task demand and caffeine. Theoretically, the arousal-attention relationship may be characterized as an inverted-U function (attention plotted on the vertical axis and arousal on the horizontal axis) in which an individual's level of arousal can predict or account for performance proficiency. However, the interaction between moderate changes in waking state arousal and attention is not understood clearly.

In the most general sense, attention can be divided into a dual system that interacts with mechanisms of arousal: (1) a selective process which operates in modality-specific cortical areas; (2) a sustained or vigilance process which allows higher-order perceptual processing of relevant or selected stimuli. In the current investigation, selective and sustained attentional processes will be examined using auditory event-related potential paradigms. The most common phenomenon related to auditory selective attention is the "cocktail party" effect, where an individual selects from among many conversations the one that he/she wishes to attend to. This has also been referred to as early selectivity. The later stage of selective attention refers to an individual's ability to discriminate information once ***in the attended channel*** (Picton, 1988). In the current thesis the phenomenon of late selectivity will be examined. Late auditory selective attention reflects a modality-specific attention operation hypothesized to be located in posterior brain regions. On the other hand, sustained attention is operationalized as the process by which an individual maintains vigilance for an expected auditory target tone cued by an auditory warning tone. Sustained or preparatory processes are hypothesized to be located in anterior brain regions. The transfer of neuronal information between the two attentional operations, selective and sustained, is believed to be achieved at least, in part, by association fibers connecting posterior and anterior regions of the brain.

The experimental literature that will be reviewed reflects the contributions of cognitive psychology and neurophysiological research to the relationship between attention and arousal.

Theories of Attention

Multicomponent Theories

The multifaceted nature of attention is best conceptualized by multicomponent theories of attention. Thus, attention is most typically concpetualized as a process comprised of a number of components. Although there appears to be a lack of agreement in the actual number of components, the components of selective and sustained attention are consistent (Moray, 1967; Posner & Boies, 1971; Davies & Parasuraman, 1982). Mirsky et al. (1991) suggested that the essential components of attention were those that optimize the extraction of relevant information from the environment. The most common components of attention include, focus or selection (select target information), sustain (vigilance) and shift (changing selective focus).

Of particular interest to the current study are the components of selective and sustained attention.

Selective Attention

In the 1950's, cognitive psychology began to adopt the ideas and terminology used in information theory to explain human perception and information processing. It was within this framework that selective attention became operationalized as a process in which an individual chooses from a multitude of diverse incoming stimuli reflecting processes of early selectivity. The most relevant information is maintained within perceptual focus (Massaro, 1987). The ability to discriminate "attended" information has been termed late selectivity (Picton, 1988). One of the major theoretical positions regarding the selective nature of attention that emerged from the human information processing model became known as capacity theory.

Capacity theory assumes that there is a limit to a person's capacity to perform mental work (Moray, 1967). Attention is a function of the amount of capacity available at any particular time to perform one or several tasks. The processing of information is controlled by a limited-capacity store of resources equated to physiological arousal. In the capacity model, dual task interference is explained as a lack of available capacity due to the excessive demands of a task, demands which can occur (1) as a function of reaching optimal arousal level, or (2) if available capacity has been directed elsewhere through the allocation process. According to this analysis, the objects or events to which the most capacity will be allocated are those with the most meaningful perceptual attributes, thus allowing one to predict the outcome of selective attention (von Wright, 1968; Beck & Ambler, 1973).

In Kahneman's (1973) synthesis of capacity models, total mental effort is equal to the global capacity that any individual possesses to allow him/her to meet situational demands. Available capacity can change at any point and time, and every task has a certain amount of mental effort associated with it (easy = less effort and difficult = more effort). Using this model, it is possible to explain the variable interference patterns between competitive tasks by showing how effortful and intentional channelling of resources to the competing tasks could prevent performance decrements. When the demands of a situation require more mental resources than are available, even with effort, there is a cognitive overload which engenders decrements in performance.

Selection or allocation can be determined by evaluating the demand characteristics of a task on overall capacity. Hence, decrements in performance related to an over-aroused state occur because the channelling system cannot process the large number of environmental cues and over-focuses on a limited range of stimuli. In an under-aroused state, irrelevant cues are not rejected but compete with relevant cues within the channelling system (Kahneman, 1973).

The limited capacity model of attention brought together many of the salient factors from several areas of research in attention, and does explain in more realistic terms observable attentional phenomenon. In this model attention has come to be likened to a single-channel processing resource which can be allocated to service different cognitive operations (Gazzaniga, 1987; Posner, 1982). The possibility of a multiple-channel resource model has also been discussed where resources are allocated based on specific cognitive functions, with different channels likely used to process spatial versus verbal information (Navon & Gopher, 1979; Wickens, 1984). Nevertheless, whatever the nature of the specific allocational process, it is agreed that cognitive functions are limited by attentional resources, and efficiency is related to the availability of processing resources which are regulated by arousal (Parasuraman & Haxby, 1993).

It is capacity theory that will serve as the conceptual model of attention in the current study.

Sustained Attention

Vigilance or sustained attention can be defined as an alerting and sustaining process in which (1) interest in selected information can be heightened within a short period of time, and/or (2) when actions in response to selected information are maintained over a long period of time. There are two types of responses related to sustained attention which include (1) the readiness response and/or (2) on-task vigilance (the focusing of resources in anticipation of a stimulus) (Warm, 1984; Parasurman, 1984).

Historically, interest in vigilance or sustained processes has been related primarily to the area of human performance. The first influential observations occurred during the second World War when personnel monitoring radar equipment over long periods of time began to miss important radar signals (Warm, 1984). This type of decline in performance during monotonous tasks was termed the vigilance decrement. These types of decrements in performance occur because attention cannot be successfully sustained on the task at hand (Mackwork, 1950). However, the exact nature of the vigilance decrement remains a continued area of controversy. The difficulty in adequately explaining the vigilance decrement may be related to a problem of determining the degree to which psychological factors such as interest, are related to physiological factors such as arousal (Corcoran, 1965; Parasurman, 1985). Nonetheless, both factors appear to be important for sustaining attention. In fact, Mesulam (1985) incorporated both attention and arousal into his explanation of performance decrements. Essentially, he associated arousal with the efficiency which determined the efficacy of attentional processes.

Neurocognitive Theories of Attention

A major criticism of "information processing" based models of attention is their failure to identify a specific processing system. Neurocognitive theories of attention attempt to address this issue by identifying neuroanatomical correlates of the conceptual aspects of selective and sustained attention (Allport, 1989; Neuman, 1987).

Within this theoretical framework, attention is conceived of in more functional terms as a process serving to heighten the processing of information within various cognitive systems (e.g., verbal, visual, auditory etc.). For example, selective attention is still described as a product of existing processing capacity available at any particular time. The key difference is that the mechanism of selective attention resides within each cognitive system. Sustained attention resides in the executive cognitive system (anterior brain regions) and mediates the vigilance function on selected information (Cowey, 1985; Neuman, 1987; Shallice, 1988; Allport, 1989).

According to this analysis, the mechanisms of selective attention comprise the posterior system of attention, related to modality-specific mechanisms of selectivity. The posterior system is believed to be connected to an anterior attention system believed to facilitate the choice of stimuli that will be perceived. The choice of stimuli is regulated by the effects of recently stored information, generation of ideas from long-term memory, and development of complex schemata consequential to the individual (Duncan, 1980). Therefore, the anterior system, based on the current goals and concerns of the organism, selects relevant stimuli for the purpose of achieving goals, coordinating behaviour, and sustaining focus on relevant information, and directing dual task operations (Posner, 1994; Duncan, 1994; D'Esposito, Detre, Alsop, Shin, Atlas, & Grossman, 1995). The key anatomical areas related to the anterior system are believed to include the dorsolateral prefrontal cortex and anterior cingulate gyrus (Vogt, Finch, & Olson, 1992). The anatomical organization of the anterior cingulate gyrus shows extensive connections with dorsolateral prefrontal cortex and parietal areas (Goldman-Rakic, 1988).

Theories of Arousal

Subcortical Systems Mediating Arousal and Attention

Following the discovery of the orienting reflex as the foundation for conditioned responses and attending behaviours, much interest was directed toward finding the locus of an arousing or alerting system in the brain. It was the discovery of the ascending reticular activating system (ARAS) in the brainstem and the median thalamic regions and their relationship to arousal states which linked the notion of cortical arousal and consciousness to neurophysiological structures (Moruzzi & Magoun, 1949).

EEG arousal generated from the median thalamic region tended to produce a short duration arousal response resistant to habituation; while EEG arousal observed from the ARAS exhibited a longer duration arousal response prone to habituation. Based on these findings the arousal system is believed to be composed of two systems, the short duration arousal response termed phasic arousal, and the long duration arousal response termed tonic arousal (Sharpless & Jasper, 1956). Furthermore, it has been demonstrated that activation of the ARAS produces cortical activation and behavioural attention, while activation of the thalamus results in decreased arousal and behavioural inattention. As a result, it was suggested that the sleep-wake cycle is then a function of the reciprocal connectivity between thalamic and brainstem nuclei, as activity in one region will suppress activity in the other (Hernandez-Peon & Chavez-Ibarra, 1963).

Cortical Arousal

Cortical arousal can be seen as a continuum of mental state from coma through sleep, to waking state alertness, to increased levels of arousal (Thatcher & John, 1977). As mentioned earlier, it has been suggested that the system of cortical arousal can be divided into two separate systems - tonic and phasic. These systems function to heighten the efficiency of information processing by regulating available capacity (Pribram & McGuiness, 1975). The tonic arousal system regulates diurnal rhythms such as the sleep-wake and neurochemical cycles, and modulates the control of motor and behavioural responses (Claridge, 1967; Iversen, 1977). The phasic arousal system accounts for the level of efficiency accomplished within a few hundred milliseconds by an alerting stimulus, and regulates responses to novel information and environmental events (Tucker & Williamson, 1984; Posner, Inhoff, Friedrich & Cohen 1987).

Cortical Connections Related to Arousal and Attention

The connective pathways from the thalamus which extend into the orbital frontal granular cortex are believed to be related to processes of cortical inhibition (Lindsley, 1949; Weinberger, 1965; Skinner, 1971), as well as to the amplitude of evoked potentials (Dempsey & Morruzzi, 1949; Skinner, 1971) and to the slow negative potential recorded from the scalp (contingent negative variation). These frontally recorded cortical responses are believed to be the mechanisms by which attention is sustained or divided, a suggestion consistent with regional blood flow studies demonstrating increased blood flow to prefrontal areas during sustained and divided tasks in normal subjects (Roland, 1982; Corbetta, Miezin, Dobmeyer, Shulman & Petersen, 1990; Pardo, Fox, & Raichle, 1991). This evidence is also consistent with data cited by neurocognitive attention theorists who have termed this system the anterior attentional system.

The thalamus also projects sensory information to areas in the supratemporal region (auditory), occipital lobe (visual) and postcentral gyrus (somatosensory). These primary sensory areas or unimodal cortices then send information to surrounding association areas or polymodal cortices (Nauta & Feirtag, 1986). As discussed in relation to neurocognitive attentional theories, the association areas for the major sensory areas play a role in selectively filtering information processed by their respective primary sensory cortices. The efficient and successful exchange of information between frontal and posterior attentional subsystems would likely depend, in part, on the integrity of the pathways connecting frontal and posterior brain areas. This type of rapid relay function is typically ascribed to the association fiber tracts which move information between cortical areas within hemispheres (Braitenberg, 1978; Thatcher, Krause, & Hybryk, 1986), and would therefore likely be the system by which attentional information and arousal would be exchanged between frontal and posterior regions. The most prominent association fibers are the superior longitudinal fasciculus and the superior and inferior occipitofrontal fasciculi. The fasciculi are comprised of cells with long-axoned pyramidal cells which are the functional units of the feedback loops between anterior and posterior brain regions (Globus & Scheibel, 1967; Braitenberg, 1972). The superior longitudinal fasciculus (also called the arcuate fasciculus) extends as a long arc from frontal regions fanning out to the parietal, occipital, and temporal lobes. The inferior occipitofrontal fasciculus passes below the insula from the frontal lobe through the temporal lobe and back to the occipital lobe (Kolb & Whishaw, 1985).

Electrophysiology

Electroencephalogram

In 1924 a German neuropsychiatrist, Hans Berger, began recording electrical activity from the scalp of humans. He first reported the features of the alpha rhythm and the alpha blocking response (when eyes were closed) in 1929. Berger described two patterns of electrical activity; the alpha rhythm which he described as the brains "idling" pattern, later confirmed by Adrian and Mathews (1934), and the beta rhythm which he described as a frequency related to metabolic processing. Berger (1938) wrote that the alpha rhythm was the passive resting activity of the brain while the beta rhythm represented more active neural processing.

In the 1960's the development of computer technology automated EEG interpretation providing an easier method for determining the digital properties of an analog signal. Digital conversion also allowed tremendous progress to be made in the evoked potential technique in which patterns of cortical activity could be linked to stimulus presentation in visual, auditory and somatosensory modalities (Gloor, 1969; Grass, 1984).

Neurophysiological Basis of the EEG

The nervous system is composed of two types of cells, neurons or nerve cells which form the functional units of the nervous system, and glial cells which provide supportive functions to nerve cells. The neurons in the neocortex are arranged in six layers in most areas, and can be separated into two groups, the outer four layers which receive axons from other brain areas, and the inner two layers which send axons to other brain regions. The current flow through this system is predominantly determined by postsynaptic potentials (PSPs) which, depending upon which presynaptic axons are stimulated, can be depolarized or hyperpolarized causing excitatory postsynaptic potentials (EPSPs) or inhibitory postsynaptic potentials (IPSPs). The electrical activity recorded from the scalp represents mainly the sum of the graded potentials of the dendrites which are spatially and temporally summated (Creutzfeldt, Rosina, Ito, & Probst, 1969; Halgren, Stapleton, Smith, & Altafullah, 1986). Bland, Anderson and Ganes (1975) demonstrated the important relationship between unit activity and the EEG by showing how the fast bursts of unit activity in the rabbit during depolarization caused an increase in the amplitude of the graded potentials recorded from the scalp EEG. Thus, when unit activity increases the EEG rhythm speeds up. Hence, the graded potentials time or pace the unit activity and therefore an analogue property has been ascribed to the dendritic system and a digital property to the axons.

There are two types of neurons in the neocortex, stellate cells and pyramidal cells. The stellate cells are typically small and numerous. The pyramidal cells are larger with apical dendrites that ascend from the top of the cell toward the top of the cortex, and with basal dendrites that descend from the bottom of the cell. The axons of the pyramidal cells leave the cortex to reach either cortical or subcortical sites. Synaptic contact is made across the dendritic spines of the apical dendrites (Mitzdorf, 1985). Approximately two thirds of the neurons in the cortex are pyramidal cells (Stuss & Benson, 1986).

The scalp-recorded EEG reflects the electrical activity of the post-synaptic potentials (PSPs) generated in the dendrites of the pyramidal cells in the cerebral cortex as they respond to cortical and subcortical inputs. The spatial and temporal summation of the PSPs, or far field potentials, are conducted through the cortex toward the scalp where they are recorded (John, 1977). Changes in the surface recorded EEG are a product of the PSPs, while relatively little or no contribution is provided by action potentials which produce a closed-field potential that does not travel through extracelluar space (Mitzdorf & Singer, 1978).

EEG Frequencies

The firing of the post-synaptic potentials produces rhythmic patterns of activity. This rhythm is a compilation of the various rates at which large groups of neurons fire. Various ranges of frequencies have been grouped together based on their clinical significance (Niedermeyer, 1993).

The dominant frequency range that is found in normal adults ranging in age from about 18 to 60 years of age occurs in what has been termed the alpha frequency (Cooper, Winter, Crow, & Walter, 1965) which ranges from 8 to 12 Hz (cycles/second) with an average frequency of 10 Hz, and is found predominantly under conditions of relaxed wakefulness when the eyes are closed. It has a developmental course such that by early adulthood 70% of EEG activity should occur continuously in the alpha range when the eyes are closed in a resting state (Matousek & Petersen, 1973). The alpha rhythm is recorded maximally over posterior head regions including occipital, parietal and posterior temporal regions (Adrian & Mathews, 1934), and is blocked by afferent input such as light (when eyes are open) and to a lesser extent by other afferent inputs such as auditory, somatosensory input and mental activities (Gloor, 1971). The effect of afferent inputs are to increase the firing rates of the PSPs resulting in faster frequency waves being recorded at the scalp.

The signal amplitude of this rhythm varies greatly between individuals ranging between 20 and 60 microvolts in most individuals (Simonova, Roth, & Stein, 1967). Dominant posterior alpha is indicative of synchronized neuronal activity which is functionally associated with reduced cortical activity; desychronization of this rhythm is observed with increased vigilance or stimulation which is characterized by low voltage fast activity (Niedermeyer, 1993).

Frequencies above 12 Hz are classified as beta activity which decreases dramatically after 35 Hz (Berger, 1938). This type of activity is observed maximally over the frontal and central regions of the head. Beta activity is greatly influenced by pharmacological agents especially barbiturates and minor tranquilizers (Niedemeyer, 1993). Beta is found most prevalently in frontal and central regions, and it's rate of activity corresponds with cerebral blood flow in these regions (Ingvar, 1987).

The pontine portion of the ascending reticular formation strongly influences cortical synchronized activity (Magni, Moruzzi, Rossi & Zanchetti, 1961), while the mesodiencephalic portion of the ascending reticular formation regulates desynchronizing effects (Moruzzi & Magoun, 1949). This regulation of cortical EEG synchronization likely accounts for the many fluctuations in EEG amplitudes, especially those related to levels of vigilance and arousal. It is the beta bandwidth activity that most closely reflects hightened states of vigilance and arousal.

The frequencies occurring below 8 Hz are considered slow wave activity. The theta rhythm is classified as those frequencies occurring between 4 to 7Hz and has developmental importance in infancy and childhood (maturational slowness), and in sleep or other low arousal states (Rugg & Dickens, 1982). Frequencies occurring below 4 Hz are classified as delta bandwidth activity with a distribution primarily observed through posterior frontal and temporal areas. It occurs in very small amounts, less than 10% of the EEG during waking state arousal (Neidemeyer & Lopes Da Silva, 1993).

In the current study normal electrophysiological processes will be discussed in relation to changes in waking state arousal therefore the activity of alpha and beta rhythms will be reported.

EEG Measures

Any complex waveform may be reduced into a distribution of individual sine waves consisting of varying frequencies, amplitudes, and phases. Conversely, the spectra of individual sine waves may be summed together to reconstruct the original signal (Glaser & Ruchkin, 1976). Thus, given that the EEG is a complex waveform, recorded epochs of electroencephalographic activity can be reduced mathematically to a series of simple sine waves described in terms of frequency, power, and phase.

Spectral analysis is a method of decomposing the EEG signal into its constituent wavelength components by evaluating raw data using the principles of the Fourier transform (Glaser & Ruchkin, 1976). The resultant distribution of a power spectrum analysis is a histogram measure of component sine wave amplitude across sampling frequency. This process defines the amount of power (amplitude squared) for each frequency range (Dummermuth, 1977). Following the calculation of a Fourier transform for a given sample of EEG data as recorded from each electrode placed over the scalp, it then becomes possible to determine the amount of power contained in each frequency bandwidth from each electrode (Lopes da Silva, 1993).

A related variant of spectral analysis is "coherence" or "cross-spectral analysis" of the EEG. In essence, the coherence function provides an indication of the similarity or "shared activity" between generators of electroencephalographic activity from spatially different cortical regions (Otnes & Enochson, 1972; Lopes da Silva, Pijn, & Boeijinga, 1989). Moreover, EEG coherence may be calculated within individual EEG bandwidths (e.g., alpha, beta) to measure the degree of similarity in electrocortical activity for a specific frequency bandwidth between proximal and/or distal cortical sites.

In the present study EEG coherence is defined as the cross correlation of EEG power calculated as a time series between two epochs of EEG activity and is mathematically comparable to a cross-correlation distribution (Glaser & Ruchkin, 1976). The coherence coefficient provides a measure of the synchrony or phase similarity between the EEG activity calculated between two electrode sites. Interhemispheric coherence measures the activity between cerebral hemispheres using homologous electrode sites (e.g., left and right occipital lobes). Intrahemipheric coherence compares EEG activity from the same cerebral hemisphere using electrodes placed over different cortical regions, such as the left frontal and left occipital lobes (Beaumont, Mayes, & Rugg, 1978).

More specifically, when the EEG is compared between anterior and posterior sites, it is assumed that the coherence function reflects the activity of long-range fiber systems connecting various cortical regions (e.g., callosal fiber tracts, fasciculi). A high coherence function between distal sites would indicate a greater similarity in EEG activity and a higher degree of cortico-cortico communication. Conversely, a lower coherence coefficient between distal electrode sites would likely indicate dissimilar EEG activity and fewer cortico-cortico connections (Thatcher et al, 1986).

One advantage of the coherence function over power spectra analysis is that coherence has been shown to be a more sensitive index of functional relationships between cortical regions during cognitive tasks both in normal and pathological states. For example, in a number of studies examining EEG activity during cognitive tasks in normal and schizophrenic participants, the EEG coherence function provided more detailed information about regional activation patterns related to task demands than did power spectral analysis (Michelogiannis, Paritisis, & Trikas, 1991; Kuda, Maber, Buchsbaum, Escobar, & Ralph, 1991; Morrison-Stewart, Williamson, Corning, Kutcher, & Merskey, 1991; Morrison-Stewart, Velikonja, & Corning, 1996).

Neurophysiology of the Event-Related Potentials

The evoked potential (EP) arises from synchronized neural activity occurring as a function of events processed in primary sensory areas. The presentation of a sensory stimulus results in changes in the activity of the post-synaptic dendrites, which respond by producing faster frequency activity, and the resulting activity is the evoked waveform. The various components of the waveform represent different stages in the processing of the stimulus (John, Ruchkin, & Villegas, 1964). The stages of processing reflect both peripheral and cortical processing of the stimulus (Donchin, Kramer, & Wickens, 1986). The actual waveform elicited is a function of the conditions under which a stimulus is presented and therefore identification of evoked waveforms are a direct function of the experimental paradigms used to elicit them.

Event-Related Potentials

The event-related potential (ERP) is associated with changes in brain electrical potentials in response to an event or stimulus (Picton, 1988). Unlike the EEG, ERPs can only be elicited under specific experimental conditions. Therefore, the ERP serves to capture the response of the central nervous system (CNS) to the evoking stimulus by time-locking stimulus presentation to the CNS response. Stimuli from different modalities produce a different scalp distribution of components.

ERPs are classified as exogenous and endogenous, distinguishing the response of the sensory system to the physical characteristics of the stimulus versus the response to the psychological significance of the stimulus, respectively. The endogenous potentials, which occur approximately 100 milliseconds following stimulus presentation, are related to the cortical processing of modality-specific stimuli (e.g., visual, auditory, somatosensory). However, cortical processing is similar for all stimuli regardless of modality (e.g., similar components are found for infrequent target stimuli regardless of modality of stimulus presentation) (Regan, 1989; Morris, Luders, Dinner, Lesser, & Wyllie, 1989).

ERP Measurement

As the ERP is recorded, background "noise" or brain activity not related to the experimental task is also recorded making the evoked signal difficult to observe. The presence of a consistent signal elicited by the experimental conditions leads to the conclusion that there are specific groups of cells that respond to each occurrence of the stimulus presented in the experimental condition. Some fluctuation does exist in the evoked response due to biological variability (variations in the composite response of groups of cells), and individual variability in response to experimental conditions. The effects of such fluctuations result in variations in the amplitudes and latencies of the evoked waveform complex. Background noise and individual variability factors are typically handled through signal extraction methods, the most popular of which is the signal averaging technique. By averaging the evoked response across the trials in the experimental condition, the signal can be strengthen by improving the signal-to-noise ratio. The degree to which the averaged signal can be considered an unbiased estimate depends on three conditions: 1) whether the signal is accurately time-locked to stimulus presentation (signal is stationary); 2) the signal is related to the event (is not a random event); 3) that a linear relationship exists between background noise and the signal (noise cancels out while signal is additive). When such conditions are met, averaging serves to reduce signal-to-noise ratios and produces a good estimate of the evoked signal (Ruchkin, 1971; Glaser & Ruchkin, 1976)

When the aforementioned condition are met the averaged EP a reliable signal; however, these conditions are subject to violation. The first condition assumes that the waveform is homogeneous. However, with highly variable data sets, some degree of heterogeneity is unaviodable. Furthermore, the evoked response itself can be variable to the same stimulus. Finally, although the background EEG (one source of noise) is assumed to be independent of the stimulus, it does change as an individuals state changes over the course of the testing session. For example, if an individual becomes increasingly drowsy during testing, larger amplitude alpha frequency EEG can be observed over individual trials. The aforementioned factors can serve to distort the averaged evoked waveform (for review see Ruchkin, 1988). Some of these difficulties are addressed using filtering techniques prior to averaging which attempt to reduce the activity in the high and low frequency ranges. However, this does not always address potentials which occur within the frequency range of the signal such as slower potentials.

An alternative to the averaging technique which serves to circumvent some of the difficulties of waveshape distortion is single-trial analysis. Since it is difficult to assume that each signal is stationary, variability in component latencies (latency jitter) remains an important factor to consider in ERP analysis (Fabiani, Gratton, Karis, & Donchin, 1987). Different techniques exist by which to perform single-trial analysis which include, most commonly, template-matching versus peak-picking methods. Template-matching involves computing the cross-correlation between a sinusoid template and the filtered single-trial for all points in which each component is expected to occur. It is also possible to use the cross-covariance as this calculation considers component amplitudes as well (Coles, Gratton, Kramer, & Miller, 1986). On the other hand, with the peak-picking method the experimenter chooses components as occurring at the point of maximal amplitude within a particular latency window. Comparative studies typically demonstrate that peak-picking results in greater reductions in signal-to-noise ratios and is also more reliable than template methods (Smulders, Kenemans, & Kok, 1993).

Auditory Event-Related Potentials

The endogenous components of the event-related potential elicited by auditory stimuli (AEP) are termed the long latency components of the slow potential according to classification systems (Davies, 1976). More specifically the latter components of the AEP reflect the cortical processing of the auditory stimulus which is a waveform composed of a series of positive and negative waveforms. Components are elicited by rare tones and are defined by their latencies: 100 milliseconds post-stimulus presentation a negative wave appears which is termed the N1, defining the direction of wave deflection occurring at a particular latency; at approximately 200 milliseconds a positive peak appears called the P2; another negative peak occurs at about 250 milliseconds called the N2; and then at about 300 milliseconds another positive peak appears called the P3. There is evidence to suggest that multiple generators produce the early components, N1 and P2, which include the superior temporal plane of the primary auditory cortex and the lateral aspect of the temporal cortex (Vaughn & Ritter, 1970; Knight, Hillyard, Woods, & Neville, 1980; Wolpaw & Wood, 1982; Wood & Wolpaw, 1982; Scherg, Vajsar & Picton, 1989). The generators of the later potentials, N2 and P3, are still controversial. Early theories described the hippocampus as an important generator site (Halgren, Squires, Wilson, Rohrbaugh, Babb, & Crandall, 1980); however, more recent studies have correlated lesions of the temporal parietal junction with diminished P3 amplitude, and lesions of the inferior parietal lobule with diminished N2 amplitudes (Selemon & Goldman-

Rakic, 1988; Woods, Knight & Scabini, 1993; Singh & Knight, 1993).

The four AERP components are recorded maximally from the vertex sites, N1 and P2 have a maximal mid-frontal distribution, while N2 and P3 are maximally recorded at central and posterior midline sites. The first three components have amplitudes ranging between 1 to 10 microvolts while the P3 ranges up to 20 microvolts (Starr & Don, 1988).

Auditory ERPs and Arousal

One factor affecting the morphology of the AERP is an individual's state of arousal. Typically, increases in arousal are associated with increases in component amplitudes (Haider, Spong, & Lindsley, 1964). As individuals are falling asleep N2 (Weitzman & Kreman, 1965) and P2 show increased amplitudes while the N1 and P3 become attenuated (Segalowitz, Ogilvie, & Simons, 1990). Of particular importance is that significant changes in arousal level, as with sleep, also produce significant increases in the latencies of all components. In the awake state it is the amplitude of the N1 component which appears to be sensitive to changes in state, as its amplitude tends to decrease with habituation to the presenting stimulus. While this effect has been linked to the orienting response (Naatanen & Gaillard, 1983), strong evidence exists for linking the orienting response with attentional factors similar to those affecting P3 amplitude (Donchin, 1981; Roth, Ford, Krainz, & Kopell, 1978). Nonetheless, changes in AERP component amplitudes and latencies reflect decreases in arousal related to sleep onset.

Auditory ERPs and Attention

In order for an ERP complex to be associated with selective attention, at least two types of stimuli must be presented, an "attended" stimulus and an "ignored" stimulus. The stimuli must also appear in an unpredictable order to prevent anticipatory responses (Hillyard & Picton, 1979; Naatanen, 1975). The stimuli that should be "attended" versus "ignored" must be distinguishable along some dimension. In auditory paradigms the acoustic stimuli are varied typically in their pitch. This difference in pitch between stimuli must remain constant within a condition (Moller, 1974). In order to further link attentional processes to an ERP paradigm, concurrent behavioural responses are often required of participants, providing a measure to demonstrate the preferential processing of the attended stimulus (Hillyard & Hansen, 1986).

Investigations of attention using AERP paradigms typically attempt to define the stages of information processing. During a selective auditory task, the early negativity recorded for "attended" tones has an amplitude greater than that observed for tones that are ignored (Woods, 1990). The early auditory negativity or N1 component is associated with early stimulus feature analysis, task performance (Nataanen & Picton, 1987); and the amplitude difference between N1 in "attend" and "ignore" conditions, termed the negative difference wave (Nd), is an effect associated with early stimulus selection - or "cocktail party effect" (Hillyard, Hink, Schwent, & Picton, 1973). The early positive component (P2) is also associated with early selection processes as it's amplitude can also be enhanced in "attend" conditions (Naatenen, 1990). Although the P2 component is typically linked with the N1 component in attention paradigms, during decreases in arousal it can be dissociated from N1 and shows similar features of amplitude enhancement as N2 (Segalowitz et al., 1990). The later components, N2 and P3, are elicited in attend conditions and are associated with perceptual processing (Hillyard, 1982). Enhancement of N2 occurs in conditions emphasizing stimulus discrimination (Sams, Paavilainen, Alho, & Naatanen, 1985), while P3 is associated with processes of further stimulus evaluation (Picton & Hillyard, 1988).

The P3 has also been related to changes in the allocation of attention as a function of perceptual processing. In order to vary attentional allocation somewhat independently of arousal, experimenters attempt to change stimulus features such as frequency of targets tones, inter-stimulus-interval, addition of distracting targets, dual tasks, and probability (Picton & Hillyard, 1988; Regan, 1989). In a review of this literature Kramer and Spinks (1991) concluded that P3 amplitude increases as more attention is directed toward a particular stimulus feature. In the case of target probability, low probability (stimuli to be attended) targets elicit a larger P3 amplitude, hence the link between P3 amplitude and novelty (Squires, Wickens, Squires, & Donchin, 1976). Although such paradigms attempt to maintain arousal at a fairly constant level, this is an implied condition not directly measured.

ERPs Related to Expectancy and Preparation

ERPs related to states of expectancy and preparation are recorded as brain potentials which occur more slowly than the brain potentials related to immediate sensory processing (AERP). When Walter (1964) decided to switch to longer time constants during recordings he found that during the 1 second interstimulus interval between a warning stimulus and an imperative stimulus (requiring a response), a sustained negative potential occurred. It was Walter who named this slow negativity as the contingent negative variation (CNV). The critical association which elicits the CNV is the reliable advent of the imperative stimulus following the warning signal. The lower the probability of this association, the greater the reduction in the amplitude of the CNV (Walters, Cooper, Aldridge, McCallum, & Winter, 1964).

Although elicited in a similar manner, the motor readiness response (RP), also termed the Bereitschaftspotential (BP) is different from the CNV (Kornhuber &

Deecke, 1965). A significant distinction between the two potentials is that the CNV is recorded maximally at the vertex while the RP has a clear lateralized distribution recorded maximally over regions contralateral to the hand involved in the motor response.

Another important factor mediating the degree of negativity of slow potentials is the amount of attention allocated to the imperative stimulus versus attention to distracting stimuli (Walters, 1964). Walter proposed that the underlying cognitive construct mediating this response was "expectancy", while others have proposed that motivation to respond to the imperative stimulus is most important (Knott & Irwin, 1973). Currently, the most commonly accepted interpretation of the psychological construct underlying the CNV has been that of attention defined in this paradigm by Hillyard and Galambos (1967) as the process of preparation to either receive information or to elicit an action. Investigations into the attentional construct have shown that distraction is related to attenuation of CNV amplitude (McCallum, 1967; McCallum & Walter, 1968; Tecce & Hamiton, 1973). Based on these findings Tecce (1976) proposed that CNV amplitude had a positive monotonic relationship to sustained attention to the imperative stimulus, and an inverted-U relationship to arousal. Although it has been shown that distraction causes attenuation of CNV amplitude, it has not been demonstrated experimentally that the converse is true.

The CNV has been conceptualized as a process of sustaining focus or awareness of an impending stimulus which reaches maximum capacity when the decision to respond is executed (McCallum, 1993), however, the response is not contingent upon a motor response (Walter, 1964; Donchin, Gerbrandt, Leiffer, & Tucker, 1972), but rather the association between imperative and warning stimuli.

Integrating Theories of Cortical Arousal and Attention

Arousal and Performance

The earliest theory attempting to explain the relationship between performance and arousal was the Yerkes-Dodson law, characterizing the curvilinear relationship (inverted-U shape) of performance to increasing levels of arousal (Yerkes & Dodson, 1908). This principle implied that an optimal level of arousal was associated with optimal performance efficiency, which is represented as the top of the curve in the inverted-U function (Duffy, 1962). While agreement exists about the inverted-U shaped function in relation to arousal and performance, the source of performance decrements at either end of the arousal continuum remain controversial. Some have argued that arousal level alone explains performance decrements (Easterbrook, 1959; Hockey, 1984; review see Parasuraman & Davies, 1984), while others propose that arousal causes distractibility (Tecce & Hamilton, 1973; Tecce, 1978, 1979) or an over-focusing of attentional resources (Naatanen, 1973; Kahneman, 1973).

Measurement of Attention and Arousal

The performance-arousal hypothesis set out by Yerkes and Dodson serves at the very least to explain a very observable phenomena: performance decrements at either end of the arousal continuum. Subsequent criticisms of the model focus on the relationship of the attention phenomena to performance, such as the difference between tasks under automatic versus controlled processes (Schneider & Schiffrin, 1977). Another important factor involves individual differences in arousal related to situational and personality factors (Gale & Edwards, 1986). It is clear that attention is an important component in performance, and that attention and arousal processes are theoretically and phenomenologically closely related. What remains unclear is the nature of the relationship between arousal and attention/performance during the waking state (top of the inverted-U shaped function).

Cognitive Studies

Cognitive paradigms, for the most part, attempt to explain the arousal-attention relationship during the waking state by altering arousal level while maintaining attentional demand at a constant level. Under such paradigms, variables believed to alter arousal level experimentally include stimulus strength, background noise, anxiety, social pressure and crowding (for review see Jennings, 1986). Easterbrook (1959) reviewed the effect of increasing emotional arousal on performance and explained performance effects as related to an incremental restriction in the range of cues available to perform the task. He attempted to demonstrate that performance could be optimized by introducing a few critical cues during heightened emotional arousal. However, during complex tasks, emotional arousal distorted the critical cues causing declines in performance. Hebb (1955) believed that performance decrements in the face of changing arousal levels may be a function of the "energizing" of competing responses. Tecce and Cole (1976) interpreted the existing literature as confirming Hebb's hypothesis that distraction causes performance decrements.

Of central importance is the effect of altering arousal using environmental means. Kryter (1970) argued that background noise, when used to increase arousal, was ineffective in maintaining elevations in arousal because adaptation to noise occurs quickly. Hence, the results of many such studies are still controversial as some studies report improvements in performance of selective attention tasks during noise conditions (Hockey, 1970a, 1970b; Broadbent, 1971), as well as improvements in overall performance efficiency (Thayer & Carey, 1974; Poulton, 1979), but these results have not been demonstrated consistently (Forester & Grierson, 1978).

Pharmacological Studies: The Effects of Stimulants

Caffeine

The current study focuses on the effects of moderate increases in arousal on attention utilising caffeine as it is the most commonly used mild stimulant. Since many individuals use caffeine in order to increase attention/performance abilities, this stimulant is a good candidate to examine how moderate increases in arousal during the waking state affect attention/performance.

Once ingested, caffeine is quickly and completely absorbed into the bloodstream from the gastinal intestinal tract, and reaches maximum plasma concentrations within 30 to 120 minutes, and has a metabolic half-life from 2 to 10 hours (Horning, Nowlin, Leitratanangkoon, Kellaway & Zion, 1977; Blachard & Sawers, 1983; Rall, 1985). There is a strong correlation between maximum plasma levels and dosage, concentrations below 200 mg have maximal effects at about one hour post-administration, while concentrations of about 360 mg reach maximum plasma levels at about two hours post-administration. In fact, caffeine concentrations in plasma and in the brain are proportional to dosages administered one hour prior according to animal models (Kaplan, Greenblatt, Leduc, Thompson, & Shader, 1989). For example, caffeine crosses the blood-brain-barrier immediately, and has been demonstrated to reach the same concentrations within the cerebral spinal fluid as those in blood plasma within 4 to 8 minutes, and remain at this level for at least one hour. Thus, plasma concentrations of caffeine may be a good indicator of brain concentrations in both human and nonhuman species (Thithapandaha, Maling, & Gillette, 1972; Teschemacher, Herz, Hess, Novoczek, 1968).

The most current theory regarding the manner in which caffeine exerts its effect on the central nervous system suggests that caffeine acts as an antagonist on adenosine receptors. Adenosine has a suppressing function on a number of biological systems including blood pressure, renin release, catecholamine release, urine output, lipolysis, intestinal peristalisis, respiration and central nervous system activity, responses consistent with decreased arousal. Caffeine acts as a stimulant by blocking the adenosine receptors to endogenous adenosine (Daly, Bruns, & Snyder, 1981; James, 1991). It is speculated that the effects of caffeine, which relate to psychological and motoric processes, are regulated through the increased utilization of cortical noradrenaline, dopamine, and serotonin in thalamic, limbic, and motor regions. Although the models of caffeine uptake are based on animal models, they do serve as some indication of the systems likely affected in humans as well (Kirch, Taylor, Gerhardt, Benowitz, Stephen & Wyatt, 1990; Reith, Sershen, & Lajtha, 1987).

Attempts to demonstrate increases in brain electrical activity in response to caffeine have varied across paradigms. In the animal literature, where dosages of caffeine exceed what is commonly consumed by humans, dramatic effects on the central nervous system have been demonstrated. For example, dosages of up to 100mg/kg (30 times normal human intake) cause increases in cortical EEG amplitude in animals (Arushanian & Belozertsev, 1978), and increases in electrophysiological activation in the reticular formation (Hirsh, 1984).

In humans the effects of caffeine on EEG recordings show a tendency toward a pattern of cortical arousal in which there is attenuation of high amplitude, low frequency activity and/or increases in beta bandwidth activity (Goldtein, Murphee, & Pfeiffer, 1963; Sucl, Brozek, & Cmiral, 1974; Pollock, Teasdale, Stern & Volavka, 1981). There has also been a report of increased slow wave activity in response to caffeine (Clubley, Bye, Henson, Peck & Ridding, 1979), a response typically associated with decreased arousal.

Few studies exist examining the effects of caffeine on evoked brain responses and the results from these studies are controversial. Klein and Salzman (1975) found decreased amplitudes in the earlier components of the visual evoked potential in males, while female subjects demonstrated increases in the amplitudes of these earlier components. There have also been reports of enhancement of the amplitude of the late negative and positive components, changes associated with attentional processes, only when subjects were in a fatigued condition (Lorist, Snel, Kok & Mulder, 1994). Wolpaw and Penry (1975) found that caffeine administration was related to a small but significant amplitude decrease in the earliest component (N1) of the auditory evoked potential. They also found that subjects did not demonstrate the overall decrease in amplitude of the earlier components which typically occur over long testing sessions, an effect believed to represent some type of resistance to habituation and fatigue.

The effects of caffeine on the amplitude of the CNV have also been examined. Some reports include increases in CNV amplitude (Ashton, Millman, Telford & Thompson, 1974), while others have found no significant effect of caffeine on the amplitude of the CNV (Janssen, Mattie, Plooij-Van Gorsel & Werre, 1978). When the CNV was divided between its earlier (orienting response) and the later (expectancy) components, it was reported that caffeine was related to increases in amplitude for the orienting portion of the CNV which diminished in the second hour of testing (Munte, Heinze, Kunkel & Scholz, 1984).

Behavioural reaction time studies tend to suggest that caffeine is associated with improved performance on a number of measures. Caffeine administration has been associated with decreases in stimulus detection time (Roach & Griffiths, 1987;

Connors, 1979), and improved target detection (Zwyghuizen-Doorenbos, Roehrs, Lipschutz, Timms, & Roth, 1990; Hasenfratz and Battig, 1992; Lorist et al., 1994). Other studies have shown that caffeine improves psychomotor performance, ratings of alertness, and increases in pulse and sublingual temperature (Zwyghuizen-Doorenbos et al., 1990).

Comments and Criticisms

Many of the inconsistencies apparent in the aforementioned studies addressing the effects of caffeine on electrophysiological and behavioural measures can be attributed to problems with methodology. First, in most cases the reported studies neither address or take comprehensive steps to account for individual differences in reactions to caffeine. Factors such as drug up-take as a function of body weight, habitual use and reactivity, food intake prior to testing, and time of day are all factors which mediate drug effects. In many cases a single dosage of caffeine is chosen for participants (e.g., 300mg), although the effect of such a dosage will vary according to body weight. The degree to which such factors are not controlled can change an individual's reaction to any pharmacological substance and create variability in reaction to the drug. This problem is further compounded when between-subject designs are used (a placebo group versus drug group) because differences in reactions to the drug will vary across individuals and across experimental groups.

With regard to task analysis, the attentional construct is often broadly defined within these studies. Thus, specific hypotheses about how or which aspects of attention will most likely be affected by mild stimulants and their potential interactions are not discussed. For example, the specific process of attention, selective or sustained, is not defined, nor is the effect that arousal should have on specific processes delineated. In doing so, the constructs of attention and arousal are often discussed in an overlapping manner within paradigms so that it becomes unclear which specific measures refer to either attention or arousal.

In order to address how changes in arousal affect attentional processes in a more systematic manner, a series of studies will now be discussed that attempt to address the aforementioned difficulties found in previous research. The following studies incorporated event-related potential measures into their experimental paradigms. The was done because (1) the experimental paradigms were based on definable attentional phenomena such as selective and sustained processes: and, (2) the ERP provides measures sensitive to changes in states of arousal and manipulations of attention. However, this relationship has been somewhat controversial across various ERP paradigms. Therefore, the general intention of the following studies was to find methods by which arousal and attention could be manipulated without confounding the two processes, and to determine, using more carefully defined constructs, if correlates of arousal and attention could be assigned to ERP measures in a more consistent manner.

In the first study, arousal was manipulated by testing participants while they were falling asleep. At the same time participants performed the standard auditory oddball ERP task. This study found systematic reductions in the latencies of all four ERP components (N1, P2, N2, P3), and significant increases in the amplitudes of the middle components (P2 and N2) (Segalowitz et al., 1990). However, in this study both processes of attention and arousal were confounded because attention and arousal decreased simultaneously as individuals fell asleep. Therefore, a subsequent study was designed in which arousal was manipulated during the waking state, thus preventing the possibility of a simultaneous change in attention during a decreasing state of arousal. In this study, arousal was manipulated by administering caffeine to awake participants while they performed (1) a selective attention task (the standard auditory oddball ERP task) and (2) a sustained attention task (the standard CNV task). The results of this study showed significant decreases in the latencies of all four components (N1, P2, N2, P3) of the AERP (Velikonja & Segalowitz, 1993). No changes in AERP amplitude were found. Moreover, no changes in the auditory CNV were found (Velikonja & Segalowitz, 1992). These results were replicated in a single case study with a participant who suffered from chronic low arousal and who was prescribed amphetamines by her physician. Using the same ERP paradigm, significant reductions in the latencies of the AERP components were found with amphetamine (Velikonja & Segalowitz, 1994).

Another aspect of the aforementioned caffeine study was the attempt to control individual participant factors overlooked in previous studies. These factors included providing caffeine doses based on each participant's body weight, determining each participant's reactivity to caffeine, assessing arousal level (diurnal rhythm), and time of day effects were controlled by testing all subjects within a similar time frame in the morning; between-subject variability and expectations were controlled by testing each participant on two separate occasions in a blind administration. It was also the intention of the caffeine study to clearly define the processes of attention that were to be examined by defining them within ERP paradigms so as not to confound processes of attention with arousal. A significant interaction was found between diurnal rhythm and drug condition, such that participants who felt their best doing activities in the morning showed significantly larger reductions in latency with caffeine than did participants who felt at their best when doing activities in the evening (Velikonja & Segalowitz, 1993).

The decrease in latencies with caffeine mirrored the increase in latencies found in the sleep onset study, suggesting a dissociation between the amplitude and latency components of the AERP. Essentially, latency appeared to be related to changes in arousal. It is interesting to note that caffeine administration was not related to increases in attentional processing (changes in amplitude) although participants reported using caffeine for just that purpose.

Therefore, the first important finding is that the latency measure of the AERP is correlated with changes in arousal. Latency increased when participants were falling asleep and decreased during caffeine administration. Second, a moderate increase in arousal (caffeine) did not affect the amplitude of the AERP and the CNV which are assumed to be a measure of attentional processing during these simple tasks. However, in the ERP literature the relationship between attention and measures of amplitude have been inconsistent. Using the capacity model of attention as a framework, attention allocation has been typically associated with the amplitude of the P3 and capacity (arousal) with the amplitude of the N1 (Donchin, Kramer, & Wickens, 1986; Gopher & Donchin, 1986; Kramer & Spinks, 1991; Hinko, van Voorhis, Hillyard, & Smith, 1977; Parasuraman, 1978). In these studies attentional allocation has been manipulated by attempting to increase attentional demand by using dual task paradigms. However, when a distraction framework or a dual task paradigm is utilized (Israel, Chesney, Wickens, & Donchin, 1980; McCarthy & Donchin, 1981; Ragot & Renault, 1981; Magliero, Bashore, Coles, & Donchin, 1984; Ragot, 1984) selective processes are no longer isolated. Attention becomes divided and additional cognitive processes become activated depending on the nature of the secondary or distraction task.

Similarly, previous attempts to examine increased sustained processes have also relied on a divided task framework. The assumption in these paradigms has been that since distraction results in decreased CNV amplitude (see McCallum, 1988; and Tecce, 1976, for reviews), an increase in sustained processes should elicit a corresponding increase in CNV amplitude. However, such an effect has never been demonstrated experimentally.

Therefore, to assess whether attentional allocation in selective and sustained attention tasks are related to changes in AERP amplitude, a more systematic approach to increasing task demand is required. This particular question can be examined within the context of the paradigms used in the aforementioned caffeine and amphetamine studies, and is the foundation for the present thesis. In doing so the relationship between arousal, as reflected in AERP latency, can be examined during increasing attentional demand in both selective and sustained attention paradigms.

The Present Investigation

Rationale

Important criticisms about the relationship between waking state arousal and attention focus on the importance of specific task demands in relation to arousal. This is a complex interaction as different tasks carry different demands on resources with some tasks requiring a greater or lesser amount of effort or resource than others. Moreover, the interaction is compounded by the aspect of task performance that is emphasized, for example, speed versus accuracy of performance (Robbins & Everitt, 1989). Therefore, the nature of optimal arousal level and performance must be defined to consider interactions between the demands on attention with the level of arousal.

The results from the caffeine and AERP studies demonstrated that moderate increases in arousal enhanced the speed of information processing in a selective attention task. However, when performance demands are low, as with the standard auditory oddball, response times are typically emphasized. Hence, caffeine-induced increases in arousal could not be shown to affect either attention allocation or sustained processes (vigilance) (Velikonja & Segalowitz, 1992). The present study was designed to examine the interaction between moderate increases in arousal and task demand (increasing task demand or perceptual processing). Emphasis will be placed on examining attention and arousal in the waking state using electrophysiological measures.

Objectives

The present investigation was designed to extend the findings of the original caffeine experiments performed in our lab. The intention of the proposed investigation is to examine interactions between moderate increases in waking state arousal and task demand. To this end the experimental conditions from the original caffeine studies were duplicated; however, the primary objective was to examine how a similar, moderate increase in arousal would affect the processing of a task requiring considerably more demands on attention than required in our previous work. The hypothesis under consideration was the relationship between arousal and attention when attentional demand is increased.

A novel approach to manipulating attentional demand during task performance will be incorporated into the present study. In previous research, task difficulty was varied by adding dual task conditions or distraction tasks. In the present study attentional demand was manipulated first, by adding a more difficult version of the simple standard auditory oddball task and then a dual task condition. Thus, by examining attention under simple, difficult and dual task conditions with and without a moderate increase in arousal, the nature of the relationship between attentional demand and arousal will be elucidated within what has been termed the optimal range of arousal and performance, or the top of the inverted-U shaped function.

The final objective of this study is to examine whether the technique of EEG coherence can measure the proposed relationship between anterior and posterior systems of attention during ERP attentional paradigms. This is a logical choice of metrics since EEG coherence provides a comparison of activity between specified electrode sites and a correlation function can be determined concerning the degree of similarity of activity between these sites. Therefore, the degree similarity of activity between anterior and posterior systems during different tasks can be assessed directly. The use of this technique is supported in theory by the anatomical pathways that are believed to send information between sustained anterior processes and selective posterior processes. This is accomplished through the long fiber tracts connection anterior and posterior brain regions. These fiber tracts are composed of long axoned pyramidal cells which produce far-field potentials that are recorded easily at the scalp as electroencephalographic activity. A more detailed discussion of electrode sites will be presented in the methods section.

Description of the Present Study

Two variants of the oddball auditory event-related potential task were developed to examine selective attention processes. The first task, was the standard oddball paradigm, which required participants to discriminate a target tone differing in pitch from a standard tone. Participants indicated detection of the target by pressing the space bar on a computer key board. This task was designed for easy target detection and elicits the standard AERP waveform. The second oddball paradigm was designed to increase the difficulty of stimulus discrimination. In order to challenge the participants' ability to discriminate among stimuli, the nature of the target stimulus was changed from a variant in pitch to one of stimulus duration. Target and standard tones of identical pitch were presented; however, the duration of the target stimulus was decreased to a level where discrimination from the standard tone would present a challenge to the participant. The objective of this manipulation was to increase the attentional resources required to execute the task accurately. The dual task was developed to study both sustained and selective attention processes simultaneously. The sustained portion was a visual tracking task, and the selective attention portion was the difficult version of the target discrimination task (i.e., discriminating the tone of shorter duration).

The initial sustained attention task was the standard CNV in which participants relied on a warning tone to anticipate the onset of the target tone. As in our previous study, the participants responded to the target tone by pressing the space bar on a computer key board. A challenging version of this task required participants to respond to the target tone within 200 milliseconds. Participants were instructed that each time they met the challenge and responded successfully to the target tone they would receive a monetary reward. In theory, participants would have to increase their anticipation and monitor sustained processes more intensely in order to respond to the target tone within the specified time frame and collect the reward.

The unique aspect of the current protocol was that task difficulty was manipulated by building on the difficulty of simplier tasks.

In summary, the present study was conceived to examine the interaction between arousal and attentional demands in the waking state. This research is an attempt to take a more comprehensive look at the top of the inverted-U shaped function used to describe optimal arousal and performance. It is proposed that such a relationship can be examined more accurately in the paradigm described above. However, the actual effect of increasing anticipatory/sustained processes directly by making the task more challenging has not previously reported in the literature.

The second part of this study was exploratory in nature, and involved assessing EEG coherence between posterior and anterior electrode sites to determine whether this measure was sensitive to the task demands of the paradigms presented above and furthermore, to assess the functional association between proposed anterior and posterior attention systems.

Hypotheses and Predictions

Participants

Participants were categorized on a number of variables including diurnal rhythm (preferred time of day at which peak activity level is achieved), reactivity and habitual use of caffeine, and arousal level at the time of testing. These data were collected because, according to the pharmacological literature, these variables may produce significant between-subject variability. If necessary, homogeneous subgroups will be identified within the participant sample. With regard to the diurnal rhythm variable, it was hoped that an equal division between individuals who considered themselves to be more active in the morning versus those who considered themselves to more active in the evening would be recruited so that interactions between caffeine and circadian rhymicity could be examined. In our previous caffeine study, individuals who considered themselves to be morning types demonstrated an even greater reduction in AERP latencies in response to caffeine than did individuals who considered themselves to be evening types during morning test sessions. It is hoped that this effect will be replicated in the current study.

Selective Attention Tasks

Easy Oddball Auditory Event-Related Potential Task

During the standard oddball task, caffeine administration should have the effect of systematically decreasing the latencies of the four AERP components, while no significant effects should occur for the amplitudes of these components. These effects would represent a replication of previous results using a similar experimental paradigm (Velikonja & Segalowitz, 1993, 1994). Hence, caffeine should increase the speed at which target stimuli are processed during a simple auditory discrimination task.

Difficult Duration Oddball Auditory Event-Related Potential Task

The effect of caffeine on AERP measures of information processing during a more difficult discrimination task should result in an increase in component amplitudes. This hypothesis is based on the prediction that an increase in arousal will be directed toward more attentional resources being allocated (amplitude) to the efficient performance of a demanding attentional task. Additionally, it is believed that the largest effects of amplitude will occur for the N1, P2 and N2 components since greater target discrimination demands would require heightened target detection and discrimination abilities. In essence, this reflects the subjective purpose for which most individuals consume caffeine which is to increase attention/concentration abilities in order to enhance the processing of the difficult characteristics of the task at hand.

Dual Task - Duration Oddball Auditory Event-Related Potential and Visual Tracking Tasks

Traditionally, dual tasks have been used to assess the effects of increased task difficulty on the components of the ERP elicited during the standard oddball task. Particular focus has been placed on the effects related to the P3 component. The results from these studies demonstrated that when the second task is made easier there is no effect on the amplitude of the P3 (a simple task); however, when the perceptual demands of the second task are more demanding there are significant reductions in P3 amplitude (Israel et al., 1980; Magliero et al., 1984). In the present study it is the first task, the auditory oddball, that was designed to be as challenging as the second task, visual tracking. Thereby, attention should be equally divided between both tasks. Accordingly, the effect of increasing arousal during the dual task condition will be an enhancement of all stages of information processing, since more resources will have to be allocated to stimulus detection, discrimination, and evaluation in order to meet the demands of this task in a divided attention condition. Thus, a moderate increase in arousal, through the administration of caffeine, will be related to increased component AERP amplitudes.

Amplitude and Latency Analyses Between Selective Attention Tasks

It is hypothesized that changes in AERP morphology will be related to changes in task difficulty. Compared to the easy pitch oddball AERP task, the duration oddball task should result in an increase in the latencies and the amplitudes of the four AERP components. In the dual task condition, an even greater increase in the latencies and the amplitudes of the four AERP components should occur due to the progressive increase in attentional demand across tasks.

Sustained Attention Tasks

Standard Contingent Negative Variation (CNV) Task

It was hypothesized that caffeine administration would not affect the amplitude of the CNV waveform during the standard presentation of this task. This hypothesis is based upon previous findings (Velikonja & Segalowitz, 1992).

Challenging Contingent Negative Variation (CNV) Task

The effect of a moderate increase in arousal, through caffeine administration, should result in an increase in CNV amplitude which would reflect a compound effect between increased endogenous arousal (due to the stimulating effects of the task) and an increase in arousal through a pharmacological intervention. Hence, an increase in arousal related to caffeine may add to the effect of increased arousal related to the task to produce optimal allocation of attention.

Changes in CNV Amplitude Related to Task Difficulty

An overall significant increase in CNV amplitude between the easy and challenging versions of this task is hypothesized. This prediction would follow the logic of previous research in which it has been presumed that if distraction decreases CNV amplitude, then increasing sustained processes should be related to a significant increase in CNV amplitude.

Behavioural Reaction Time

Behavioural reaction times (time to press a computer space bar upon detection of a target tone) were collected for each task. For the dual task, accuracy of performance on the visual tracking task will also be recorded.

Easy Selective Attention Task (pitch oddball AERP task)

The literature suggests that there is a correlation between AERP latency and behavioural response times during the standard oddball paradigm (Kutas, McCarthy, & Donchin, 1977). Thus, if there is a decrease in the component AERP latencies related to caffeine administration (first hypothesis), then caffeine administration should result in a decrease in the response time to target ones. Hence an increase in the speed at which information is processed may also result in an increase in response speed to target stimuli.

Difficult Selective Attention Tasks (duration and dual duration oddball AERP tasks)

Since no change in AERP latencies are predicted for this task with caffeine administration, behavioural reaction times should also not differ as a function of caffeine. Similarly, no effects related to behavioural reaction time are predicted for caffeine during the dual duration oddball task.

An additional behavioural measure will be attained for the dual task related to the accuracy of visual tracking. This measure will be the number of milliseconds that the participant cannot maintain the computer mouse on the target. It is predicted that an improvement in accuracy will occur when participants are in the caffeine condition. Therefore, since caffeine is predicted to improve sustained processing with regard to corresponding brain potentials, then a similar improvement is predicted for the accuracy of visual tracking.

Changes in Behavioural Reactions Between Selective Attention Tasks

An incremental increase in behavioural reaction times should occur as task difficulty increases. Thus, reaction times will be longer for the duration oddball task relative to the pitch oddball task, while the greatest increase in response times will be observed in the dual duration oddball task.

Sustained Attention Tasks - Standard CNV and Challenge CNV

As previously mentioned caffeine is associated with improvements in target detection in sustained attention tasks as well. A decrease in the time to respond to target stimuli in the CNV task are also predicted.

For the challenge CNV task the effect of caffeine administration on reaction times will likely not change. This is predicted because one of the objectives of this task is for participants to respond to the target tones upon detection or within 200 milliseconds. It is predicted that a ceiling effect with respect to response times will occur for this task.

EEG Coherence

It is hypothesized that EEG coherence would be lower during tasks with unitary attentional demands (e.g., pitch and duration selective attention tasks and sustained attention tasks). The EEG activity in frontal versus posterior sites should be more dissimilar since posterior based selective and anterior based sustained processes will be operating exclusively, and less "shared neuronal activity" will be apparent between these regions. During the dual task, in which both anterior and posterior attentional systems should be active, an increase in EEG coherence between frontal and posterior sites should occur. These hypotheses represent an exploratory look at the sensitivity of the EEG coherence measure in examining the proposed functional relationship between anterior and posterior attentional systems.

METHOD

Participants

Participants in this study were recruited from a first year psychology course and received course credit for their participation. A total of 30 individuals participated in this study, however, the data from 27 were complete and could be used in further analyses. Participants were non-smokers, as nicotine reduces the half-life of caffeine (James, 1991), were free from all medications, and were without any history of major head injuries or psychiatric illnesses.

Procedure

For two weeks prior to each partcipants' scheduled date of testing, they were asked to fill out a diary of caffeine consumption (see Appendix A). Participants were to mark in the provided spaces the type of caffeine product they consumed as well as the number of caffeine products consumed for each hour of the day over the designated 14 days. From the information provided in these diaries, each participant's habitual daily consumption of caffeinated products was estimated in units of milligrams per day based on estimations of the caffeine content in the products consumed (Benowitz, 1990).

The study was a within-subject design so each participant was tested twice over a two-week period, and was blind to the drug condition. All testing was performed in the morning at either 7:30 am or 9:00 am, and participants were asked to refrain from eating or drinking anything, except water, from midnight prior to both days of testing.

Upon entering the lab, participants were given a cup of water-processed decaffeinated coffee which in one condition had powdered caffeine dissolved in it. They were asked to drink it over a 5 minute period, and were then given a series of three questionnaires, one related to their reactivity to caffeine (see Appendix B), another inquiring about their current level of arousal (see Appendix C), and finally one related to their diurnal patterns of activity (Appendix D). When both the questionnaires and coffee were completed, subjects were taken into a shielded room for electrophysiological testing.

At least one half-hour passed between coffee administration and electrophysiological recordings. In combination with the lack of food intake prior to testing, close to maximal blood plasma levels of caffeine should have been reached for each participant in the caffeine trials (Birkett, 1986). This protocol was repeated for both testing sessions for each participant.

The caffeine was a tasteless and colourless powder (BDH Chemicals Inc., Toronto, Ont.) administered in an amount based on the participant's body weight (3mg/kg). This particular dosage was chosen as it represented an amount of caffeine similar to that found in a regular cup of coffee (Benowitz, 1990). The amount of caffeine allotted to each participant was based on the individual's body weight in order to keep the rate of metabolism of the drug similar for each person. Caffeine/no caffeine administration was counterbalanced between participants to control for order effects.

Electrophysiological Testing

Electroencephalograph recordings were obtained from all participants. Gold-plated electrodes (Grass Instrument Co.) were positioned according to the International 10/20 system of electrode placement using a linked-earlobe monopolar montage with a mastoid reference. Electrodes were placed at the following sites: FZ, CZ, PZ, F3, F4, T5, T6, P3, and P4 (See Appendix E). Odd numbered leads refer to positions over regions of the left hemisphere, even numbered leads to positions over homologous right hemisphere regions, and Z-labelled leads to positions over mid-line regions. The alphabetical portion of the site designations refers to the cortical region the electrodes are placed, F to the frontal lobe, T to the temporal lobe and P to the parietal lobe. Electrodes were fixed on to the scalp, which was cleaned using a pumice paste (prepared by a pharmacy), using EC-2 electrode cream (Grass Instrument Co.) to ensure good conduction. Artifacts related to eye movements were monitored with a bipolar electrode montage using the outer canthus and the orbital ridge of the right eye. Records with eye movement artifacts were excluded post-acquisition using a +/-100 microvolt window, low-voltage eye movements were excluded by visual inspection of the raw electroencephalograph record during single-trial analysis.

EEG data were filtered between 0.5 Hz and 30 Hz. The time constant was set for 3 seconds. The sampling rate was 400 Hz, and the sampling interval was 2.5 milliseconds.

The data from 6 of the electrode sites (mid-line and frontal sites) were collected on-line using a computerized acquisition program (MQE), while the data from the other five electrode sites (temporal and parietal sites) were recorded onto magnetic FM tape and were later digitized using the MQE computerized acquisition program. All recordings were backed-up on magnetic FM tape which are stored in the Brock University Electrophysiology Laboratory.

The records were divided into sites that would be used for ERP analyses which included all mid-line sites (Fz, Cz and Pz) and into those sites that would be used for quantitative EEG analyses (F3/F4, T5/T6, P3/P4). Each set of records contained eye movement recordings so that both ERP and EEG records could be checked for eye movement artifacts.

Cognitive Event-Related Potential (ERP) Tasks

All participants performed the cognitive electrophysiological testing protocol in the same order. The initial step of the protocol consisted of baseline resting EEG in which subjects sat still for two minutes with their eyes open staring at a blank computer screen. This was followed by 5 auditory cognitive ERP tasks.

Selective Attention Tasks

Task 1 (Easy): The first cognitive ERP task was the standard auditory oddball task in which high-pitched tones (1500 Hz) were to be selectively attended and responded to from low-pitched tones (1000 Hz). Participants were required to respond to the high-pitched tones (rare targets) by pressing the space bar on a computer key board, and were told to ignore the low-pitched tones (frequent non-targets). Since participants were required to selectively attend to the high-pitched tones and because the distinction between the tones was simple, this was considered an easier selective attention task.

Task 2 (Difficult): The auditory oddball paradigm was also used in the second task, but instead of having participants make a distinction in tone pitch, they were asked to distinguish between the duration of two tones. The tones were presented at the same frequency ratio of targets to non-targets as in the pitch oddball task. The duration oddball task was made a more difficult task relative to the standard oddball by reducing the difference in the duration of the two tones to a rate that would be considered challenging by each participant. This was done during pretesting by initially setting the task to be at a moderate level of difficulty (short target tones at 100 ms duration; long non-target tones set at 150 ms duration). If participants could distinguish these tones at a 90% or better accuracy rate, then the duration of the longer non-target tones was reduced to a rate at which the participant achieved between 70% and 80% accuracy, to as short as 125 ms. Thus, the difference in tone duration was set accordingly for each participant so that the task became challenging but not impossible for them to perform.

Behavioural responses were recorded during both the pitch and duration oddball tasks which included reaction time to the target stimulus, correct number of hits to target stimuli, and the number of target stimuli missed.

Sustained Attention

Task 3 (Easy): The first sustained attention task was the standard auditory Contingent Negative Variation (CNV) task. Participants heard a warning tone (S1) of 100 ms duration and 800 Hz which signalled the coming of the stimulus tone (S2) of similar duration and 1500 Hz, 2.3 seconds later, to which they were asked to respond by pressing the space bar on a computer keyboard. Further instructions were given that S1 was to be used to anticipate the coming of S2 but that responses should not be made prior to hearing S2 or a buzzer would sound. Each S1-S2 pair was presented at variable intervals (between 5 and 9 sec.), but the time between the tone pairs remained the same. Since the only requirement of this task was to anticipate and respond to the S2 tone, this was considered a simple sustained attention task.

Task 4 (Challenge): A more difficult version of the standard CNV paradigm was created with the intention of increasing the participant's attentional allocation. Additional instructions were provided to participants following the standard CNV instructions: (1) Participants were told that they should try to respond to the S2 tone within 200 ms; and (2) each time they did respond to the S2 tone within 200 ms, they would receive a monetary reward of $0.25. A tone beep signalled a successful response to S2. This version of the CNV task was defined as a more challenging sustained attention task.

Behavioural responses were recorded for both versions of the CNV task which included reaction times to the S2 tone, the number of misses and hits, and anticipations recorded as responses to S2 prior to hearing the tone.

Selective and Sustained Attention

Task 5 (Dual Task): The final task combined both the difficult selective attention task (Task 2) with a new sustained attention task. The latter task was a visual tracking task called Box Chase which was performed on a computer screen. Subjects were asked to keep a 1 mm dot, which they guided with a computer mouse, within a 2 cm x 2 cm randomly moving box. The computer recorded the total number of milliseconds that the dot was not kept within the box. Prior to testing, subjects were allowed to practice the task until they felt comfortable tracking the box. They used their dominant hand for the tracking task and their non-dominant hand to respond to the short duration tones (Task 2). The two tasks were to be performed with equal accuracy.

Behavioural reaction times were recorded for the duration oddball and for the Box Chase task. The mean amount of time that the dot was not kept in the box was recorded, along with the number of 1-second units during which the dot remained inside the box.

ERP Collection and Scoring Procedures

Auditory Oddball Tasks

For each of the oddball tasks (pitch and duration) frequent non-target tones were presented 240 times while rare target tones were presented 40 times. All oddball stimuli were presented at an average inter-stimulus interval of 1.5 seconds (range of 1.2 sec. to 1.8 sec., a variation initiated to reduce monotony). The amplifier filtered frequencies from 0.05 Hz to 30 Hz. The time constant was set for 3 seconds. The sampling rate was 400 Hz, and sampling interval was 2.5 milliseconds. The intensity of tones was set at 60 dB sound pressure level, and were delivered from a free field speaker. Target tones occurred at 1500 Hz while non-target tones occurred at 800 Hz.

The continuous EEG record for each oddball task was run through a program which parsed the continuous record into 1100 millisecond segments starting at 100 ms pre-stimulus. The segments were then stored in separate files containing ERPs for target and non-target stimuli. The files containing the ERPs for target stimuli were then scored for the four major ERP components (N1, P2, N2, P3) by single-trial analysis using a computer assisted peak-picking program. The N1, P2, N2 and P3 components were scored as the largest peaks appearing within specific latency parameters. For the pitch oddball tasks, the N1 was scored between 75 and 150 ms, the P2 between 175 and 250 ms, the N2 between 200 and 300 ms and the P3 was scored between 250 and 500 ms. The average latency for each component increased for the duration auditory oddball tasks (Tasks 2 and 5). For the duration tasks, the N1 was scored between 75 and 200 ms, P2 between 175 and 300 ms, N2 between 200 and 350 ms and P3 between 350 and 800 ms.

In the single-trial analysis, trials were rejected using two criteria: (1) alpha bandwidth activity (8-12 Hz) and, (2) the presence of eye or other movement artifacts. A file was created with the overall mean and standard deviation for each individual component. These means and standard deviations were then used in further statistical analyses. A minimum of 15 individual trials had to be accepted for each task for the ERP data to be included for analysis.

Contingent Negative Variation

The time between the onset of the warning stimulus (S1) and the onset of the target stimulus (S2) was constant at 2300 ms for each of 30 trials in each condition. The continuous records containing the CNV data were then placed through a program that digitized these data at 100 Hz for 3000 ms starting 200 ms prior to the warning stimulus. The 30 individual trials were then stored in a separate file and were run through an averaging program which divided each trial into five separate epochs, then calculated the area for each epoch and then averaged the areas for the epochs across the trials that were not rejected due to artifact. A minimum of 10 trials out of the possible 30 trials had to be accepted for the CNV data to be included in further analyses.

The amplifier filtered data from 0.01 Hz to 30 Hz. The time constant was set for 10 seconds. The sampling rate was 100 Hz, and sampling interval was 10 milliseconds. Target tones occurred at 1500 Hz and warning tones occurred at 800 Hz.

Measures and Statistical Analyses

Analyses of Event-Related Potential Components

The latency and amplitudes for each of the four major components (N1, P2, N2, P3) were analyzed separately for each of the oddball tasks in a mixed repeated measures analysis of variance with 2 between-subject variables, diurnal rhythm (morning versus evening types) and session (caffeine administration either first versus second session), and one within-subjects variable (drug condition of caffeine versus no-caffeine). The latency and amplitude for each component was placed into separate analyses for each of the three oddball conditions, producing a total of 24 repeated measures ANOVAs for this section of the analysis.

A further 2 x 3 repeated measures analysis of variance was performed with Condition (caffeine versus no-caffeine) and Tasks (pitch, duration, duration during visual tracking) to assess differences in the amplitudes and latencies of the four components between the three tasks.

Analysis of the Contingent Negative Variation

The five epochs of the CNV were divided into the two major components of the CNV, the O-wave and the E-wave. Epochs 1 and 2 were averaged together to make the O-wave component and epochs 3, 4 and 5 were averaged together to make the E-wave component. Each component was treated separately in a mixed analysis of variance with 2 between-subject variables (diurnal rhythm and session) and two within-subject variables (condition and the two CNV tasks). This analysis was performed separately for the O-wave and E-wave components.

Behavioural Data

Behavioural Event-Related Potential Data

The behavioural measures compiled from the three oddball tasks included reaction times, and true negatives (the number of trials subjects correctly did not respond to). The behavioural measures computed from the CNV tasks included reaction time, number of hits, misses and anticipations of S2 before presentation.

Repeated measures analysis of variance were conducted for each of the behavioural measures separately, with diurnal rhythm and session as between-subject variables and condition as a within-subject variable. For the CNV behavioural data, CNV type (standard versus challenge) was added into the repeated measures analysis.

For the tracking task the mean number of times that the participants did not keep the dot in the box was recorded, and the number of 1-second units related to tracking errors.

EEG Coherence Analysis

Coherence is a measure of the similarity between two EEG signals within a frequency bandwidth. It measures the degree to which two comparative cortical areas are producing similar patterns of activity within a particular frequency. Thus, coherence is a measure of the degree of spectral similarity and, presumably, in the underlying neuronal activity of the two areas (Dimont & Beaumont, 1974).

Coherence analysis was performed within two bandwidth frequencies, alpha and beta, for each of three pairs of electrodes. The alpha bandwidth frequency was chosen because in adults it contains the most overall EEG power, and is very sensitive to changes in brain activation (John & Thatcher, 1980). The beta bandwidth frequency was chosen because it is observed maximally in the frontal lobe regions and is also sensitive to changes in activation particularly in anterior brain areas (John, 1977). Two types of comparisons were performed, inter-hemispheric coherence which would require analysis between the following electrode configurations: F3/F4, T5/T6, P3/P4. Changes in coherence between different tasks would demonstrate changes in lateralized brain activity. Intra-hemispheric comparisons, which are comparisons within each hemisphere between anterior and posterior sites, would require the following configurations: F3/P3, F3/T5, F4/P4, F4/T6. Changes in coherence between tasks in this analysis would reflect the similarity in activity between anterior and posterior brain regions during cognitive activation or during attentional tasks.

Statistical Analyses

Repeated measures analysis of variance were conducted between the coherence functions for the resting state and tasks tapping selective attention processes (pitch, duration, duration and visual tracking), and between the resting state and both versions of the CNV task. The within-subject measure was condition - caffeine verus no-caffeine. This analysis was performed for both inter-hemispheric and intra-hemispheric montages.

RESULTS

Participant Data

Demographics. Of the 30 participants tested, 27 subjects had enough artifact-free data that could be used in further analyses. Participants ranged in age from 19 to 30 years of age (mean=20.3, s.d.=3.4), 18 of whom were female and 9 of whom were male. All participants were enrolled in a first-year psychology course at Brock University, where this study was conducted.

Diurnal Rhythm. Diurnal rhythm was assigned as a categorical variable and was determined from the participant's own ratings of when they prefer to perform most activities (morning versus evening) as indicated on the Horne/Ostberg questionnaire of morningness and eveningness. Based on their reports, 16 participants rated themselves as morning types, or people who function best first thing in the morning, while 11 participants rated themselves as evening types, or individuals who function best later in the day.

Reactivity to Caffeine. Participants were also asked to report whether they felt that caffeine acted as a stimulant for them during different times of the day. The times of day included the morning, afternoon and evening. Twenty-four of the 27 participants reported that caffeine acted as a stimulant for them at all three times of the day, and 3 participants reported that caffeine had no effect on them at any time of the day.

Habitual Caffeine Use. Habitual use was measured as the approximate amount of caffeine consumed per day as calculated from the caffeine diaries, which included any beverage or food containing caffeine. Twenty-three of the participants consumed daily amounts of caffeine between 100 - 300 mgs., and 4 subjects consumed between 400 to 500 mgs of caffeine daily.

Arousal Level. Participants were also asked to rate their quality of sleep from the night prior to testing. Five participants rated their sleep as poor while 22 rated their previous night's sleep as good or adequate. When asked to rate their level of alertness prior to testing, 25 participants rated themselves as alert or feeling good prior to testing and 2 participants rated themselves as feeling drowsy.

Therefore, in general the participants in this study were homogenous with regard to their age, reactivity to caffeine, habitual use of caffeine, and their level of arousal upon entering the laboratory setting.

Event-Related Potential Data for Selective Attention Tasks

Pitch Oddball Task

Component amplitudes and latencies were analyzed in 2 (Condition: caffeine/no caffeine) x 2 (Diurnal: morning vs evening types) x 2 (session when caffeine administered) mixed repeated measures analysis of variance with Condition as the repeated measure. The early ERP components, N1 and P2, were scored at the Cz electrode site where they maximally appear. The later N2 and P3 components were scored at the Pz electrode site were they maximally appear. Similar statistical effects were obtained for the N2 and P3 components at the Cz electrode site.

There were no significant effects for diurnal rhythm or session, and therefore the results reported below will refer to effects related to experimental condition and/or task type.

Latency Analysis. Significant main effects of condition were found for all ERP component latencies: N1 ($F_{1,23}=11.00$, $p<0.005$), P2 ($F_{1,23}=10.78$, $p<0.005$), N2 ($F_{1,23}=11.72$, $p<0.005$) and P3 ($F_{1,23}=21.00$, $p<0.001$). In each case the latencies were significantly shorter in the caffeine condition than in the no-caffeine condition (see Table 1 for mean latency values also see Figure 1).

Amplitude Analysis. There was one significant main effect of amplitude for condition which occurred for the P2 component ($F_{1,23}=10.78$, $p<0.005$) (see Table 1 for mean amplitude values). This increase in P2 amplitude occurred for the no-caffeine condition (see Figure 1). This was an unusual finding which was not found in our previous studies (Velikonja & Segalowitz, 1993, 1994).

Complex Selective Attention Tasks: Duration Oddball

Latency Analysis for Duration Oddball Task. There were no significant treatment effects for latency for the N1, P2 and N2 components. There was a significant main effect for the P3 component ($F_{1,23}=12.05$, $p<0.005$). These results suggest that caffeine administration is related only to a reduction in the latency of the evaluation phase of difficult auditory target discrimination (see Table 2 for mean latency values also see Figure 2).

Amplitude Analysis for Duration Oddball Task. There were significant main effects of amplitude for condition for the N1 ($F_{1,23}=6.07$, $p=0.05$), P2 ($F_{1,23}=31.98$, $p<0.001$) and N2 ($F_{1,23}=10.44$, $p=0.005$) components. These results indicate that caffeine administration is related to a significant increase in the amplitudes for the stimulus detection and stimulus discrimination phases of auditory information processing (see Table 2 for mean amplitude values).

Dual Duration Oddball Task

Latency Analysis for Duration Oddball and Visual Tracking. There were no significant effects for latency during the dual task (see Table 3 for means and Figure 3).

Amplitude Analysis for Duration Oddball and Visual Tracking. There were significant main effects for condition for the caffeine N1 ($F_{1,23}=5.27$, $p<0.05$), P2

($F_{1,23}$=47.94, $p<0.001$), N2 ($F_{1,23}$=9.73, $p<0.005$) and P3 ($F_{1,23}$=14.94, $p<0.001$) amplitude components. These results indicate that component AERP amplitudes were significantly greater when participants were administered caffeine (see Table 3 for means and see Figure 3).

Amplitude and Latency Between Oddball Tasks

Component amplitudes and latencies were analyzed in 2 (Condition: caffeine/no caffeine) x 3 (Task-Type: pitch, duration, dual duration) repeated measures analysis of variance. The mean amplitudes and latencies are presented in Table 4 for the three selective attention tasks for the caffeine and no-caffeine conditions. Figure 4 depicts the configurations of the AERP during the three tasks for the caffeine condition, while Figure 5 depicts the configuration of the AERP components for the no-caffeine condition.

N1 Component. There was no significant difference between the latencies for the N1 component between the pitch, duration and the dual duration tasks. There was a significant interaction of amplitude for task-type and condition ($F_{2,52}$=7.71, $p<0.005$). The amplitudes for this component were significantly higher in the two duration oddball tasks during the caffeine conditions.

P2 Component. There were no differences for the P2 latency between the three selective attention tasks.

There was a significant two-way interaction between condition and task-type for the amplitude of the P2 component ($F_{2,52}$=14.78, $p<0.001$). In the caffeine condition the amplitude of this component was greater for the more difficult tasks, duration and dual duration tasks, relative to the P2 amplitude in the pitch oddball task.

N2 Component. In the caffeine condition, there was a larger increase in latency for the N2 component for both duration oddball tasks relative to the pitch oddball task as indicated by a significant 2-way interaction ($F_{2,52}=27.09$, $p<0.001$). Although the latencies increased as task difficulty increased in the no caffeine condition as well.

With respect to N2 amplitude, there was also a significant increase during the more difficult duration oddball tasks with caffeine administration ($F_{2,52}=51.53$, $p<0.001$) relative to the N2 amplitude recorded during the pitch oddball task, while in the no-caffeine conditions the three tasks produced similar N2 amplitudes.

P3 Component. There was a significant reduction in P3 latency during the pitch oddball task in the caffeine condition relative to the P3 latencies in the duration oddball tasks ($F_{2,52}=48.83$, $p<0.001$).

The amplitude of the P3 component increased significantly during the more difficult duration oddball tasks relative to the P3 amplitude recorded during the pitch oddball task ($F_{2,52}=15.51$, $p<0.001$).

In summary, when target discrimination is made more difficult and caffeine is administered, increases in AERP latency and amplitude are found across components suggesting a shift in AERP waveform configurations. This change in AERP configuration is related to increased task difficulty and to increases in arousal.

Event-Related Potential Data for Sustained Attention Tasks

Contingent Negative Variation (CNV) Tasks

O-Wave Components of the Standard and Challenge CNV: There were no significant effects found for the amplitude of the O-wave component between the standard and challenge CNV tasks. There were 27 participants who had complete data set and were included in this analysis.

E-Wave Components of the Standard and Challenge CNV: There was a significant main effect for condition ($F_{1,23}=10.07$, $p<0.005$), and a significant two-way interaction for task by condition ($F_{1,23}=5.42$ $p=0.05$).

Simple effects testing showed that there was a significant increase in E-wave amplitude between the caffeine and no-caffeine conditions for the Challenge CNV task ($t=2.19$, $p=0.037$). However, there was no significant difference between the caffeine and no-caffeine conditions for the standard CNV task. The significant effect of task showed that there was a significant increase in E-wave amplitude between the standard and Challenge CNV in the no-caffeine conditions ($t=-3.64$, $p=0.001$). In fact, the amplitude of the E-wave for the challenge CNV is almost double that recorded for the standard task in the no-caffeine conditions (see Table 5).

There was no significant difference in the E-wave components during the standard CNV task between the caffeine and no-caffeine conditions (see Figure 6). This result is a replication of our previous work done (Velikonja & Segalowitz, 1992), indicating that during a simple sustained attention task caffeine has no significant effect on the amplitude of the CNV.

BEHAVIOURAL DATA

Oddball Tasks: Selective Attention

There were no significant effects for any of the behavioural data recorded during the pitch oddball task between the caffeine and no caffeine conditions (see Table 6 for means). However, there was a trend toward shorter reaction times with caffeine administration.

For the reaction time data collected during the duration oddball task there was a significant main effect for condition ($F_{1,26}=5.06$, $p<0.05$), in which participants responded faster to the target tones during the caffeine condition (567.41 ms versus 593.20 ms).

The behavioral measures recorded for the duration oddball portion of the dual task showed a trend toward a significant reduction in reaction times in the caffeine condition. Participants responded faster to the target tones in the caffeine condition ($p<0.07$) (597.50 ms versus 631.07 ms).

There were no significant effects for diurnal rhythm or session for the behavioural data for the three selective attention tasks.

CNV Tasks: Sustained Attention

Analyses of the behavioural data computed from the CNV tasks resulted in a number of effects. For a summary of the mean values of behavioural data see Table 7.

Participants responded significantly faster to the target tones in the no-caffeine condition than in the caffeine condition during the standard CNV (234.20 ms versus 313.68 ms) ($t=6.21$, $p<0.005$).

There was no significant difference in response times to the target tone related to condition for the Challenge CNV. The very similar reaction times between the caffeine and no-caffeine conditions likely represents a ceiling effect for response times to this task, since participants attempted to respond within one-fifth of a second to the target tones.

Anticipatory responses were calculated as the number of times subjects pressed the space bar prior to hearing the target tone. The actual numerical value derived for this analysis represents the proportion of anticipatory responses made during the entire task (the number of anticipatory responses divided by the total number of responses). Participants made proportionately more anticipatory responses in the no-caffeine condition than they did in the caffeine condition ($F_{1,26}=10.11$, $p<0.005$). No significant differences were found between conditions related to anticipatory responses for the Challenge CNV task.

Target miss rates were calculated as the proportion of the total responses that were missed (the number of misses divided by total number of responses). During the standard CNV task participants had a higher proportion of misses in the caffeine condition relative to the no-caffeine condition ($t=2.49$, $p<0.05$). No significant differences in misses were found as a function of condition during the Challenge CNV task.

EEG Coherence Data for Selective Attention Tasks

Of the 27 participants in this study the data from only six had enough artifact-free data to ensure reliable EEG coherence values. Further, for these six participants the data from the resting state (eyes open) condition could not be aligned between electrode montages as they were recorded onto different media (computerized and FM tape). Consequently, data from six additional participants were collected using the same experimental paradigm in order to collect resting state data for the EEG coherence analysis.

The results presented below include the data collected during the attention tasks for those participants in the first sample for whom resting state data could not be used, and the resting state data as well as the data for the attentional tasks for the additional six participants. Thus, following results will include the analysis of the resting state data of the 6 additional subjects and then that of the 6 participants from the original study.

EEG coherence was analyzed for the alpha and beta bandwidths using intrahemispheric (anterior versus posterior brain regions) and interhemispheric (right versus left hemisphere brain regions) electrode comparisons.

EEG Coherence for Selective Attention Tasks

Overall there were no significant effects in EEG coherence related to caffeine, thus the results discussed below will focus on changes in EEG coherence between the different selective attention tasks and the two sustained attentional tasks in the no-caffeine condition.

EEG coherence is always higher between spatially proximal electrode sites. Visual inspection of the EEG coherence values indicated that EEG coherence between frontal-parietal leads were considerably higher than the EEG coherence values found between frontal-temporal leads regardless of condition or task. Therefore, a higher degree of similarity in EEG activity exists between frontal-parietal areas than between frontal-temporal areas. Similarly, visual inspection of the EEG coherence values between homologous (right versus left) electrode sites, indicated that a higher degree of similarity in EEG activity was found between homologous frontal and parietal leads than was found for homologous temporal leads.

All analyses between the resting condition and the simple selective and sustained attention tasks were performed for the 6 subjects with resting state data inclusive. The analyses performed between the attention tasks were done using the data from all 18 participants.

Intrahemispheric Alpha Coherence (Anterior and Posterior Leads): The comparison between the resting state and the pitch oddball task showed that there were no significant differences in EEG alpha coherence between anterior and posterior leads. Similarly, there were no significant changes in EEG alpha coherence between anterior and posterior leads when compared between tasks (pitch, duration, and dual task duration). The alpha EEG coherence values were relatively similar across all tasks (see Table 8 for means and Figure 7).

Interhemispheric Alpha Coherence (Right and Left Hemisphere Leads): There were no significant changes in EEG alpha coherence between homologous right and left hemisphere leads for frontal, parietal and posterior temporal leads when the resting state values were compared with the pitch task (see Table 9 for mean EEG alpha coherence values). Similarly, there were no significant changes in EEG alpha coherence between homologous electrode leads between the three attention tasks (see Figure 8).

EEG Beta Coherence for Selective Attention Tasks

Intrahemispheric Beta Coherence (Anterior and Posterior Leads): There was no significant difference in EEG beta coherence between anterior and posterior lead between the resting state and pitch task. There was no significant difference in EEG beta coherence between the resting state and pitch oddball task. However, there was a significant main effect of task ($F_{2,22}=6.14$, $p=0.028$) for the EEG beta coherence for the frontal-parietal leads (see Table 10 for mean EEG beta coherence). The pattern of changes in EEG beta coherence between tasks shows that there a significant decrease in EEG beta coherence occurred between the pitch task and the duration task. The next comparison was between the duration task and the dual task. Here there was a significant increase in EEG beta coherence between the two tasks. The difference between the pitch and the dual task was also significant for the frontal-parietal comparisons. This pattern of changes in EEG beta coherence between tasks would support the hypothesis of increased differentiation of EEG activity between frontal and parietal areas during increasingly difficult modality-specific posterior attentional tasks (pitch versus duration oddball). However, when both frontal and posterior attentional systems are active, during the dual task condition, an increase in EEG beta coherence between frontal-parietal areas occurred.

No significant changes in EEG beta coherence were found for the frontal-posterior temporal comparisons across any of the conditions (see Figure 9).

Interhemispheric Beta Coherence (Right and Left Hemisphere Leads): There were no significant changes in EEG beta coherence between homologous frontal, parietal and temporal leads across tasks (see Table 11 for mean coherence values and Figure 10).

EEG Coherence for Sustained Attention Tasks

Intrahemispheric Alpha Coherence (Anterior and Posterior Leads): There was no significant difference in EEG alpha coherence between the resting state and the pitch task. However, there was a significant main effect of task ($F_{1,11}=6.06$, $p=0.034$) for the EEG alpha coherence values. There was a significantly lower EEG alpha coherence for the frontal-parietal comparisons in the standard CNV task than in the challenging CNV task (see Table 12 for mean EEG alpha coherence values). This pattern of effects would suggest that there is a greater degree of differentiation in activity between frontal and parietal sites as the sustained attention task became more challenging (Figure 11). This pattern of results was also consistent with the notion of increased regional activation with increasing task difficulty.

Interhemispheric Alpha Coherence (Right and Left Hemisphere Leads): There were no significant changes in alpha coherence values when comparing values for the easy and challenging CNV tasks (see Table 13 for mean EEG alpha coherence values) for the frontal-parietal and frontal-posterior temporal leads (see Figure 12).

EEG Beta Coherence for Sustained Attention Tasks

Intrahemispheric Beta Coherence (Anterior and Posterior Leads): There were no significant changes in EEG beta coherence between tasks for either the frontal-parietal or frontal-posterior temporal leads (see Table 14 for mean EEG beta coherence values). Thus, no changes in activity in the beta bandwidth occurred between anterior and posterior leads as a function of changes in task difficulty (see Figure 13).

Interhemispheric Beta Coherence (Right and Left Hemisphere Leads): There were also no significant changes in EEG beta coherence between tasks for homologous electrodes leads at frontal, parietal or temporal sites (see Table 15 for mean EEG beta coherence values). These results indicate that no changes between EEG beta coherence occurred between homologous right and left hemisphere leads as a function of task difficulty (see Figure 14).

DISCUSSION

The results from this study demonstrated that caffeine improved the speed at which auditory target information was processed during what may be considered an easy selective attention task. As task difficulty increased, caffeine started to affect mechanisms associated with attentional processing. A somewhat different pattern of results were found for the sustained attention tasks. During the easy sustained attention task, caffeine did not affect attentional processes, an effect similar to that found for the easy selective attention task. However, when the sustained attention task became more challenging, the effect of caffeine was to decrease the allocation of attentional resources. The results summarized above represent the effects that can be attributed to an exogenous source of arousal, caffeine. A second source of arousal, termed endogenous, are related to increases in task difficulty or demand. The results obtained related to task demand were as follows: For the AERP components, task demand (1) increased the speed at which stimulus discrimination and evaluation occurred, and (2) increased the attentional resources for the evaluation stage of target auditory information processing. For the CNV, increasing the challenge of the task resulted in an almost two-fold increase in expectancy-related sustained attention.

Finally, analysis of the EEG coherence during tasks of selective and sustained attention provided support for the suggestion that these processes can be localized in posterior and anterior brain regions, respectively.

Participants

Based on the self-reported diary of caffeine consumption and the questionnaires administered immediately prior to electrophysiological testing, the 27 participants in this study were a fairly homogeneous group with regard to age, reactivity to caffeine, use of caffeine, level of arousal (reporting a good night's sleep), and general alertness.

With respect to diurnal rhythm, 68% of the participants reported a preference for morning activity while 32% reported a preference for evening activity. In previous studies on the effects of caffeine on AERPs (Velikonja & Segalowitz, 1993), participants who considered themselves to be "morning types" demonstrated a greater reduction in AERP latencies on the pitch oddball task than did "evening types". In the present study, no significant effects were found for diurnal rhythm.

One possible explanation for the difference in effects related to diurnal rhythm is that participants in the current study tended to rate themselves less strongly as morning or evening types than did the participants in the previous study. The Horne/Ostberg questionnaire divides the morning and evening categories into strong and intermediate subtypes. The intermediate subtype includes individuals who feel best when activities extend from the morning into the afternoon. In the current study, most participants placed themselves at the intermediate level of diurnal type, as opposed to the participants in the previous caffeine study who reported themselves to be more strongly diurnal in each category.

Consistent with the findings of the previous caffeine study (Velikonja & Segalowitz, 1993), there were no significant interactions between the effects of session and the behavioural and/or electrophysiological variables. Each participant in the present study was tested on two occasions. The order of caffeine administration (e.g., caffeine and no-caffeine) was counter-balanced so that half the subjects received caffeine in their first session while the other half received caffeine in their second session.

The Effect of Caffeine on Selective Attention - Auditory Evoked Potentials

Easy Oddball Task (Pitch Discrimination)

The results from the simple selective attention task replicated the findings from the previous caffeine study (Velikonja & Segalowitz, 1993). In summary, caffeine administration was related to a systematic and significant decrease in the latencies of all four AERP components. Thus, the findings from previous and present studies confirm the suggestion that a moderate increase in arousal through caffeine administration causes an increase in the speed at which auditory target stimuli are processed by the brain during a simple pitch discrimination task.

With respect to AERP amplitude, the results from the present study did not quite replicate the findings from the previous caffeine study. In the previous study, no significant changes in evoked potential amplitude were found for the AERP components. In the present study, however, a significant effect for the amplitude of the P2 component of the AERP was found, with it being greater in the no-caffeine condition than in the caffeine condition. It is difficult to infer the functional significance of this result since the P2 component is closely associated with the N1 component especially during the waking state. Taken together, the N1-P2 complex is considered an index of stimulus detection (Naatanen, 1992). However, stimulus detection was not challenged in the simple oddball task, in other words, no experimental manipulation was made related specifically to the P2 AERP component in this task. Therefore, it is difficult to assess this finding within the context of the current paradigm. One possible explanation is that the increase in P2 amplitude may have been a chance finding. Another possibility was that the unusually low amplitude found for this component in this condition (see Table 1) was a function of the AERP analysis method.

Difficult Oddball Task (Duration Discrimination)

The second, more challenging, selective attention task required participants to discriminate between the duration of non-target and target stimuli. Results from the difficult oddball task demonstrated that caffeine administration reduced significantly the latency of the P3 component and increased significantly the amplitudes of the N1, P2 and N2 components.

As discussed previously, the stages of cortical processing reflected by the AERP components include stimulus detection or attentiveness (N1-P2), stimulus discrimination or categorization (N2), and stimulus evaluation (P3). Thus, when target discrimination became more of a challenge, caffeine increased attentiveness during the stimulus detection (N1 and P2) and stimulus discrimination (N2) stages of information processing. Next, the observed increases in evoked potential latency (P3) suggests that faster stimulus evaluation also occurred. Therefore, when auditory tones become more difficult to discriminate, the effect of caffeine is to increase resource allocation to the stimulus detection and categorization phases of information processing. Following the heightened detection and discrimination responses, mechanisms related to evaluation of the stimulus then speed up. This has not been found in other studies examining the effects of increased task difficulty on the configuration of the AERP. The reasons for these differences will be explored in more detail later in the discussion.

Combined Selective and Sustained Attention Task (Dual Task)

The combined selective and sustained attention tasks required the participants to perform simultaneously the difficult oddball task (duration oddball) and a visual tracking task (box chase). The effect of caffeine on the AERP components during the dual tasks was a significant increase in the amplitude of all four AERP components. The significant increases in AERP component amplitudes suggest an overall improvement in the allocation of attentional resources to all stages of cortical processing of the auditory stimulus.

Summary of Results for the Selective Attention Tasks

In summary, the effect of caffeine on AERP component latencies and amplitudes varies as task demands change. When simple auditory discrimination is required, caffeine improves the speed at which auditory information is processed in the cortex. With a more challenging auditory discrimination task, the speed of stimulus evaluation is enhanced, and more resources are allocated to the effortful detection and discrimination of auditory stimuli. Finally, when attention was divided between difficult selective and sustained tasks there was an increased allocation of effort to all stages of information processing.

The Effect of Caffeine on Sustained Attention:

Auditory Contingent Negative Variation Tasks

The CNV tasks were divided into their two major components, the O-wave (orienting) and E-wave (expectancy). No significant effects occurred for the O-wave component of the CNV in either task or condition. Therefore, a discussion of the results pertaining to the E-wave alone will follow.

Easy Sustained Attention Task (CNV)

The results for the CNV task replicated the null findings of the previous caffeine study (Velikonja & Segalowitz, 1992): Caffeine administration did not affect the amplitude of processing negativity during the sustained attention task.

Challenging Sustained Attention Task (CNV)

When participant motivation was enhanced and monetary incentive added, caffeine caused a significant decrease in expectancy negativity. However, the significant interaction between task and condition suggests that the combined effect of caffeine and increased arousal due to task demand may have created a state of over-arousal. This point will be addressed in further detail below.

Behavioural Reaction Times

Reaction Times for Selective Attention Tasks

Although statistical significance was found for the reaction times in the duration oddball task only, when taken together with the results from the remaining selective attention tasks, this does suggest a strong trend toward overall faster behavioural responses following caffeine consumption (see Tables 1, 2, 3, and 6). When the effect of caffeine on cortical processing speed is compared with the increase in behavioural reaction times, the concomitant motor responses to target stimuli were smaller in magnitude. This suggests a differential between cortical processing relative to task difficulty and participant reaction time.

By comparing the behavioural reaction times to the latencies of the later components of the AERPs (N2 and P3) for the three selective attention tasks, it becomes evident that participants took longer to respond to the target tones as task difficulty increased. This increase in reaction time across tasks can be taken as a behavioural index that task difficulty did increase with the more demanding selective attention tasks. Another important aspect of the differences in reaction times across tasks was that they suggest that participants responded to the target tones in each task at different stages of stimulus processing. For the pitch oddball task, participants pressed the space bar to target tones within a time frame closer to the stimulus evaluation stage (P3), whereas for the two duration oddball tasks participants pressed the space bar much later following stimulus evaluation. These findings can be examined within the context of the speed/accuracy trade-off discussed by Kutas et al. (1977). They found that when speed was emphasized during an oddball task behavioural reaction times occurred prior to the latency of the P3, and when accuracy was emphasized subjects responded after complete stimulus evaluation (following peak onset of P3).

Within the context of the current paradigm it is possible to assess these differences in response times relative to the processes of stimulus evaluation. During the pitch oddball task where auditory discrimination was easier, there is an inherent emphasis on response speed as very little mental effort is required for accuracy. In this condition, behavioural response times were closer to the latency of the P3. In the more difficult discrimination tasks (duration and dual duration) more emphasis or effort is channelled toward accuracy, and thus response times occur much later following stimulus evaluation. Although speed and accuracy were not manipulated in a similar manner as in the work of Kutas et al. (1977), the degree of processing related to task demand is a plausible context by which to interpret the current results.

Reaction Times for Sustained Attention Tasks (CNV)

For the easy CNV task participants responded to the target tones more quickly without caffeine than with caffeine. This contrasts the trend toward decreased response times found during the easy selective attention task (pitch oddball). Therefore, caffeine may be related to a reduction in motor-based anticipation in response to auditory target stimuli during a simple sustained attention task.

The reaction times for the challenging CNV task were similar for the caffeine and no-caffeine conditions. This result likely represents a ceiling effect in motor response times due to the shorter time in which participants were encouraged to respond to target stimuli.

Effects of Task Difficulty on AERP Configuration

Selective Attention Tasks (No-Caffeine Conditions)

The effects of increased task difficulty on the configuration of the AERP can be examined by comparing the changes in the latencies and the amplitudes between selective attention tasks for each component (see Table 4 for mean values).

First, the effect of task difficulty alone can be examined by comparing the latencies and amplitudes across tasks in the no-caffeine conditions. For the AERP components associated with stimulus detection (N1 and P2) there was no change in the amplitudes and the latencies as a function of task difficulty (values compared in no-caffeine conditions alone). On the other hand, the AERP components associated with late stimulus processing (N2 and P3) showed significant increases in latency related to task difficulty. These findings suggest that more effortful processing is required to discriminate and evaluate difficult-to-detect auditory target stimuli. With regard to amplitude, only the P3 component was significantly greater in the more difficult tasks (duration and dual duration tasks) relative to the simple attention task (pitch oddball). This finding indicates that the greater the demands placed on a participant's ability to discriminate selected auditory stimuli, the more effort will be required to evaluate the target stimulus.

Therefore, increases in task difficulty, including an additional task (dual task condition), cause longer latencies of the N2 and P3, and increased P3 amplitude. These findings have not been reported in previous studies in which task difficulty has been manipulated. The difference being that, in the present study, task difficulty was made more challenging by reducing the difference in tone duration whereas in others studies, the pitch of the target and non-target tones was varied. The most common finding associated with the latter studies has been an increase in P3 latency only

(Ritter, Simson, & Vaughn, 1972; Squires, Donchin, Herning, & McCarthy, 1977; McCarthy & Donchin, 1981; Pfefferbaum, Ford, Johnson, Wenegrat, & Johnson, 1983; Magliero et al., 1984; Polich, 1987).

One possibility for the additional changes in the later AERP components found in the present thesis (increased N2 latency and P3 amplitude) may be related to differences in stimulus attributes (pitch versus duration). However, effects related to differences in stimulus attributes are most commonly observed in the early stages of information processing (N1 and P2), and therefore would not account for the present findings.

Another explanation for the current results may be related to task difficulty. One of the inherent strengths of the present study is that difficulty was treated as a subjective phenomenon by requesting that each participant provide a self-reported estimation of when the tones became "difficult" to discriminate. Thus, difficulty level was assessed by each participant individually since task difficulty can be a subjective phenomenon.

Without a doubt, the task of pitch discrimination can be made more challenging by decreasing the pitch between target and non-target tones, as done in the aforementioned studies. However, individuals vary in their ability to discriminate pitch particularly if they have inherent musical ability or training. This may introduce a confound into the experimental design because an individual may find pitch discrimination easy even though this discrimination is made more difficult relative to an easier discrimination. Consequently, the results of the studies looking at pitch discrimination may have shown that a longer evaluation time was required for making a more difficult pitch discrimination but the effects of task difficulty or effort may have been washed-out by variability between participants with regard to pitch acuity. At the very least, the idea of what is considered a difficult discrimination would vary between individuals.

It is suggested that the additional increases in N2 and P3 latency and P3 amplitude reported in the current study may reflect the effects of increasing the effort required to make a subjectively more effortful discrimination. This was evident in the degree of variability in tone duration that was used across participants as some considered a discrimination between 150 versus 100 milliseconds to be difficult while others found that a further reduction to 120 versus 100 milliseconds made the task challenging.

Selective Attention Tasks (Interactions Between Task Difficulty and Caffeine)

The addition of caffeine or an increase in cortical arousal generated even greater changes in AERP configuration than was obtained in the no-caffeine conditions (see Table 4). No significant effects of latency were found for the earlier components (N1 and P2), but a significant change in the latencies of the N2 and P3 were found with caffeine administration when compared to the no-caffeine condition. The significant decrease in the latencies of these later components indicated an increase in cortical processing speed during stimulus discrimination and evaluation with caffeine. The amplitudes of all the components were significantly higher in the more difficult tasks versus the simple pitch task with caffeine. The significant increase in amplitude across components indicated more effortful processing of auditory stimuli that are difficult to discriminate.

Overall, it was evident that caffeine does enhance attentional processing. For simple tasks, caffeine increases systematically cortical processing speed. During more difficult tasks caffeine enhances attention and accelerates the later stages of information processing. It also increases the speed of motor responses during these tasks. Thus, caffeine does improve attentional performance and motor output during selective processing, which are the very reasons for which we typically consume products containing caffeine.

Changes in CNV Configuration as a Function of Task Difficulty

The changes observed in the configuration of the CNV between the easy and challenging versions of the task demonstrated significant effects in the E-wave component. The amplitude of the E-wave in the difficult version of the task, without caffeine, was almost two times larger relative to the amplitude of this component derived during the easy condition. This is the first time that such a change in the E-wave component has been demonstrated, that is, increasing sustained attention demands increased the amplitude of the E-wave of the CNV. This finding confirms previous suggestions that increased sustained/prepatory processes should result in an increase in amplitude (Tecce, 1976).

Waking State Arousal and Performance

The portion of the curve at the top of the inverted-U function describing the relationship between arousal and performance (Easterbrook, 1959) is the point at which optimal arousal is associated with peak performance. However, what is not explained by the simple function are the complexity of factors affecting performance during the waking state. A variety of explanations have been proposed to help define how specific arousal factors affect performance. These include moving the inverted-U shaped function to incorporate higher arousal levels (as would be drawn on the abscissa) for simple tasks given that at higher levels of arousal performance is not typically disrupted; creating stress conditions to change arousal state; examining arousal changes at different levels of sleep deprivation (Revelle, Anderson, & Humphreys, 1983; Gale & Edwards, 1986); looking at how a number of diurnal and situational variables affect arousal temporally (Gale, 1977); and explaining performance decrements during complex tasks in terms of dual arousal mechanisms (Broadbent, 1971).

Perhaps a more informative model of arousal and performance during the waking state should define specific arousal factors and assess the context of how performance is measured. During the waking state we use a variety of methods to increase our arousal when we feel that our performance on any particular task is declining. A common method by which many individuals attempt to quickly and moderately increase arousal is through caffeine consumption. Thus, in the current context the influences on arousal systems would be related to exogenous arousal through a stimulating agent, caffeine. Another influence on arousal systems are internal factors related to the increase in task demand which will be termed endogenous arousal. In the current experiment performance is broadly defined within the attentional construct as selective and sustained processes. Within each set of tasks the effects of increasing challenge or demand were examined by dividing selective and sustained tasks according to difficulty. Increasing difficulty not only affects the demand characteristics of the task but is also believed to be an internal source of arousal, although, such processes are difficult to quantify. Within the current paradigm exogenous arousal (caffeine related) is kept at a similar level across tasks. Performance demands and arousal are examined during the normal waking state within what can be described as the optimal range of arousal/performance according to the inverted-U shaped model.

The results from both selective and sustained attention tasks suggest an interesting model of arousal and attentional performance. This model ties together elements of capacity theory and the inverted-U shaped model to explain the mechanisms of cortical information processing, their interaction, and their relationship with mechanisms of arousal. The notion of a pool of resources and the allocation of these resources is derived from capacity theory. The pool of available resources is the total amount of capacity available to perform a task. Available resources would therefore be the amount of cortical arousal or energy that can be directed or allocated during the performance of a task. Based upon specific task requirements, and assuming that levels of cortical arousal are of fundamental importance to the performance of any task, the allocation mechanism directs available resources to the functions of task performance most appropriately served.

Two functions to which allocation can be directed, based upon ERP measures, are the speed at which a task is performed and the amount of effort required to complete the task successfully. Changes in the allocation of resources can be affected by the specific demands placed on the system by the task at hand and the overall mental state as defined by cortical arousal. Based on capacity theory, cortical arousal can influence the amount of resources made available to the system. According to the current analysis, this should increase the availability of resources that can be allocated to either of the functions (speed and effort) defined in this study. In other words, cortical arousal affects the size of the pool of available resources which determines how much resources are available to be allocated to, in the current paradigm, speed or effort.

Within the context of the current study the effect of increasing arousal, and hence the pool of available resources, when performing a simple discrimination task is that the increase in available resources are allocated to the speed at which target auditory information is processed. The simple discrimination task requires little effort to perform accurately, therefore, directing more resources to effortful processing may not be useful or necessary for accurate task performance. However, when the discrimination of selected information is made more difficult, then the result of increasing the available pool of resources by increasing cortical arousal (caffeine) is for the resources to be allocated differentially between effortful processing and speed. During this task the increase in available resources were allocated to the increase in the effortful detection and discrimination of target auditory stimuli (N1-P2-N2). Following the heightened detection and discrimination of the stimuli, faster processing is then allocated to the evaluation stage (P3). Finally, when difficult target discrimination is required in conjunction with a sustained attention task (box chase), then the increase in resources are allocated to the more effortful processing of target stimuli at all four stages of cortical information processing (N1-P2-N2-P3). Additional resources are not directed to the faster processing of stimuli likely because effective information processing when attention is divided cannot be achieved at a faster cortical processing speed.

Therefore, an increase in available resources is allocated toward increased efficiency (speed) in information processing when target discrimination is made easy, and less emphasis is required for accuracy. As accuracy or difficulty is increased the increase in available resources (through caffeine) are allocated more toward the effortful processing of target stimuli.

In the current study accurate task performance (correct responses to target stimuli) was maintained within the optimal range of performance (top of the inverted-U shaped function). However, increases in effortful processing of target stimuli as a function of increased arousal (caffeine) were most closely associated with improvements in the speed of behavioural reaction times. Therefore, where more effort was allocated to the stages of information processing, the better the speed at which participants responded to target stimuli. Hence, increases in amplitude are more closely associated with improved reaction times.

Although, it is difficult to quantify endogenous arousal related to a task, it is possible within the current study to at least examine the concept of endogenous arousal within the context of task difficulty. Thus, changes related to task difficulty incorporate what would likely be an increase in endogenous arousal. The aforementioned model can therefore be used to examine changes in AERP morphology related to task difficulty found for individual components between tasks in the no-caffeine conditions.

By increasing the difficulty of a task, an increase in the resources available to perform the task should also occur. According to the results of this study, in order to perform a more difficult discrimination task, presumably, the increase in available resources are allocated to slower stimulus discrimination and evaluation (N2 and P3) and to the more effortful evaluation of the stimulus (P3). Therefore, if increased task difficulty is related to an increase in the pool of available resources, the increase in resources would appear to be allocated to effortful evaluation and an increase in the time required to discriminate and evaluate the target auditory stimuli. If we accept that increases in arousal related to task difficulty can be allocated to speed and effortful processing functions, then it can be argued that the addition of an exogenous source of arousal (caffeine) causes an even greater increase in available resources which are allocated to improving the speed and increasing effortful information processing.

In the sustained attention task, no measure of speed related to sustained processing could be derived. Only the degree of increased effort, indexed by amplitude. During a simple expectancy-related sustained attention task, an increase in exogenous arousal (caffeine) had no effect on cortical sustained processes. Hence the increase in the pool of available resources are not directed or allocated to increased effort (similar to those results obtained for the simple selective attention task). However, participants did give behavioural responses to the target stimuli more quickly without caffeine, suggesting that in fact during a simple sustained attention task caffeine may impede motor responsivity.

In the more challenging version of the CNV task, caffeine reduced the expectancy-related sustained processes. Therefore, when the pool of available resources were increased through caffeine during a challenging sustained attention task, the increase in resources were not allocated to more effortful sustained processing. In fact the decrease in CNV E-wave amplitude suggests that cortical sustained processes were starting to decrease. This result may be interpreted as the point at which cortical sustained processes may have reached a level of over-arousal or maximal firing potential. To examine this hypothesis more closely it is important to re-examine the effect of increased challenge on the morphology of the CNV during the no-caffeine conditions. As mentioned previously, the CNV task was made more challenging (1) by decreasing the response time to the target tone and (2) by adding a monetary incentive if responses could be made within the reduced time frame. The effect of making this task more challenging was an almost two-fold increase in the amplitude of the E-wave portion of the CNV in the no-caffeine condition. Therefore, the effect of increasing task demand, incorporating endogenous arousal, would be an increase in the pool of available resources which were allocated to sustained processes (effortful processing). The further increase in available resources through caffeine administration was related to a significant reduction in the E-wave of the CNV compared to the no-caffeine condition.

At this point it is possible to introduce the concept of limits or upper boundaries to the attention and arousal systems. According to theories concerning the inverted-U function, external limits or upper and lower boundaries related to arousal level for successful task performance is reflected in overt behaviour (decline in performance). Arousal has been defined in terms of cortical processes which are internal systems. If internal cortical mechanisms foreshadow overt behaviours then it possible to suggest that the internal limits on optimal arousal likely precede the limits on overt optimal performance. Internal limits are set around the pool of available resources which are affected by the state of arousal and task demands for every individual. Varying that state of arousal or task demand to a high enough level creates the limits of behavioural performance. The CNV results may reflect the onset of the internal limits of optimal arousal level which will at some point begin to affect behavioural performance. Hence, the addition of caffeine when participants were already in a heightened state of arousal may have triggered the point at which too many resources were allocated to the task, a point which would eventually reduce the levels of successful task performance.

In summary, the increase in available resources or mental capacity attained through a moderate increase in arousal (caffeine) are believed to be allocated to different information processing functions based on the demands of the task (speed during easy tasks and effort as tasks become more difficult). During the challenging CNV task, caffeine acted to decrease the expectancy-related sustained process.

The effect of increasing available resources through task-related increases in arousal during the selective attention tasks permitted allocation to be focused on more effortful stimulus evaluation and longer stimulus discrimination and evaluation processing time. If we accept that ERP amplitude is related to effortful processing or attention, then the effect of increased demand is to allocate an increase in resources to those aspects of the information processing chain which are required to perform the task successfully. Since performance levels were maintained at a high level throughout the tasks, this particular hypothesis could not be tested directly. However, according to capacity theory, the effect of increasing task demand would be to also increase the pool of available resources which were allocated to increased effortful processing.

If the interpretation of the current data are accepted, then it is proposed that the increase in available resources attained by increasing task demand are allocated to the functions of cortical information processing that would allow for successful execution of the more demanding tasks.

EEG Coherence Analyses

The coherence function used for this study may be defined as the cross correlation of EEG power calculated as a time series between two epochs of EEG activity (Neuroscan Co.). Numeric values for the coherence function range between zero and one, with a coherence coefficient of one indicating perfect phase harmony between the two EEG samples. Typically, EEG coherence is calculated on data filtered for a specific EEG bandwidth, such as alpha or beta.

The coherence function provides a general measure of overall synchrony between EEG activity recorded from two electrode sites. For example, an increase in coherence between two EEG samples from a baseline to a conditioned state indicates that the two waveforms have become more synchronous or "in-phase" with the change of state. Another way of looking at this phenomenon is that the EEG activity has demonstrated an increase in shared activity within the specified frequency bandwidth (i.e., alpha or beta). A decrease in coherence, on the other hand, indicates that EEG activity within the alpha (or beta) bandwidths for the sampled data has become less synchronized with the change of state. Thus, a decrease in the coherence differential indicates less shared activity between recorded EEG activity.

Depending on the direction of change, when EEG coherence is compared across cognitive tasks, it may be shown that two brain sites are either working more closely together or differentiating such that one site becomes more active in performing the task than the other. When changes in EEG coherence occur in one specific bandwidth and not in another, it is an indication of the frequency range at which the activity most closely related to the task is occurring. For example, in the selective attention tasks, significant change in coherent activity was found in the beta bandwidth. Therefore, during the selective attention task, changes in the beta EEG frequency could be associated with the performance of the specific task.

With respect to the present findings, alpha and beta bandwidth EEG coherence functions were calculated for frontal/parietal, frontal/posterior-temporal, and left/right hemisphere electrode comparisons. As reported previously, no significant changes for interhemispheric (right-left) EEG coherence were found with respect to either alpha or beta coherence. Moreover, there were no significant effects of task on intrahemispheric EEG coherence for the frontal and posterior temporal comparisons. Similarly, caffeine had no significant changes on EEG coherence. However, significant differences in EEG coherence measured between frontal-parietal electrode sites were found for the selective, the dual task and sustained conditions. Therefore, the following discussion will focus on these findings.

Selective Attention Tasks

No effect of selective attention tasks in EEG alpha coherence were found. Moreover, no significant difference was found in EEG beta coherence between frontal-parietal sites in the resting state condition as compared with the pitch oddball task. Therefore, EEG coherence between frontal- parietal sites did not differ between the resting state and the pitch oddball task.

However, a significant reduction in frontal-parietal EEG beta coherence occurred in the difficult version of the selective attention task. The significant reduction of EEG beta coherence for the difficult task would indicate that the frontal-parietal EEG activity had differentiated from each other. Thus, selective processing of auditory information during a challenging discrimination task may be characterized by less synchronized cortical activity.

During the dual attention task, where both selective and sustained tasks were being performed simultaneously, there was a significant increase in frontal-parietal EEG beta coherence. This would indicate that frontal and parietal brain regions were working in a more synchronous manner to perform the dual task. This pattern of results is consistent with the proposition of distinct cortical regions related to the different processes of attention (D' Esposito et al., 1995; Posner, 1994). The decrease in EEG beta coherence during the difficult selective attention task may be taken to imply that one cortical area is assuming a greater role in the performance of the task. The increase in EEG beta coherence during the dual attention task suggests that two cortical areas, frontal and parietal, were more engaged to perform a more challenging task requiring the synchronization of cortical resources.

Finally, the fact that changes occurred only in the beta bandwidth and not alpha indicate that frequency of EEG activity most closely associated with the execution of these tasks occurred within the beta frequency band. These patterns of activity occurred similarly for right and left hemisphere frontal-parietal electrode comparisons, suggesting that the activity of the attentional systems are bilateral in nature.

Sustained Attention: CNV Tasks

The frontal-parietal EEG coherence during the resting condition and CNV tasks showed significant changes between conditions in the alpha bandwidth. No changes in beta coherence were noted during the sustained attention tasks. Again significant changes occurred only for frontal and parietal leads for both the right and left hemispheres. There were was no significant changes between the EEG alpha coherence between the resting state and the easy CNV task. However, there was a significant decrease in EEG alpha coherence between the resting state, the easy CNV task and the challenging CNV task. The significant decrease in EEG alpha coherence during the challenging CNV task would indicate that the EEG activity in the alpha frequency range between frontal and parietal areas became more dissimilar. Thus, EEG alpha activity desynchronizes between frontal and parietal sites during a challenging sustained attention task. Again this would indicate a differentiation in activity between the frontal and parietal areas.

The results of the EEG alpha coherence found across sustained attention tasks also supports the notion of separate attentional systems. The decrease in alpha coherence indicates that the activity within the frontal and parietal areas are differentiating and the activity in one area may be assuming a greater role in performing the task. According to neurocognitive theories of attention, this would imply that the frontal area is assuming a greater role in the performance of the sustained attention tasks. Similarly, the effects found for the duration oddball task would imply that the parietal area is taking a more active role in the discrimination of target tones. Finally, the results found for the dual task would indicate that both the frontal and parietal regions are similarly engaged while performing tasks tapping sustained and selective processes. Therefore, the results of the current study would support the notion of dual attentional systems.

EEG Coherence Effects Related to Electrode Distance

Of note were the differences in mean EEG coherence values between the different sites. The EEG coherence values for the frontal-posterior temporal comparisons were much lower for both alpha and beta bandwidths than the values derived for the frontal-parietal comparisons. This may be, in part, related to the greater inter-electrode distance between the frontal and posterior temporal areas relative to the inter-electrode distance between the frontal and parietal sites. EEG coherence values are usually higher between areas spatially closer together. This was evident from the high EEG coherence values observed for the interhemispheric comparisons between frontal and parietal sites. These were central sites and thus closer together. The interhemispheric posterior temporal comparisons also had lower coherence values because these sites also happen to be spatially far apart.

The frontal-parietal EEG coherence values indicate that there is a greater amount of shared activity between these cortical areas, relative to the posterior temporal connections. The frontal and parietal areas are also the ones which are most closely associated with attentional processes, relative to posterior temporal areas, a finding supported by the current study.

In the current EEG coherence analysis it was found that changes in sustained attention occurred within the alpha bandwidth and changes in EEG coherence during the selective attention tasks occurred in the beta bandwidth, suggesting that the electrocortical activity of the two attentional operations occur within different defined bandwidth frequencies. Thus, it is possible that the neuronal systems that fire during sustained processes do so at a slower rate than do neuronal systems that fire during selective processes (Skinner & Lindsley, 1971). This finding is consistent with the neurophysiological properties of brain potentials recorded during expectancy-related sustained processes and those recorded during immediate sensory processing. As mentioned previously, brain potentials recorded during sustained operations occur more slowly than do those recorded during sensory processing which have been related to selective operations. The effect of performing a sustained attention task may cause the general pattern of neuronal activity to fire within the alpha bandwidth range. Similarly the occurrence of faster brain potentials related to sensory processing (selective operations) may cause the general pattern of neuronal activity to fire within the beta bandwidth. The current findings may be suggestive of just such differences related to EEG activity as a function of the frequency at which brain potentials related to a task occur. This also points to the importance of examining the activity across more than one bandwidth during EEG coherence to determine at what frequency changes occur during specific tasks.

To summarize the findings from the EEG coherence analysis, the patterns of activity found during the different attentional tasks would indicate that as attentional demand increases in unitary tasks (difficult selective and sustained tasks), the activity in cortical areas associated with selective and sustained processes differentiate in activity as more demand is placed on them to perform the specified attentional operation. However, when the operations of both systems are combined during a dual task situation the activities between the two cortical areas, believed to mediate the different attentional systems, located in anterior and posterior brain regions, become more synchronous.

Attention and Arousal Systems

The results of the current EEG coherence analysis are consistent with the notion of separate attentional operations located in different cortical areas proposed by neurocognitive theorists. Within the context of neurocogntive theories of attention the two attentional processes examined in this study, selective and sustained, have proposed areas of localization. The sustained operation regulates an individual's ability to heighten interest in selected information and maintain attention over a period of time. According to Posner's hypothesis the sustained attention operation is part of an anterior attentional system (Posner & Petersen, 1990). The regions of the frontal lobe that are presumed to be related to such functions are the dorsolateral prefrontal cortex (DPC) and anterior cingulate gyrus. The F3/F4 electrodes are placed over the DPC, which presumably would have provided the largest contribution to the activity recorded from these electrode sites. Another function attributed to the anterior attention system, in conjunction with regulating sustaining processes, is to direct the requirements of dual tasks (Posner, 1994, D'Esposito, 1995). Therefore, the effects observed for the F3/F4 sites may have provided the maximal activity of the proposed anterior attention system.

The posterior attentional system, which regulates the selectivity of modality-specific information, is believed to include auditory association cortex and multimodal association areas in the inferior parietal lobe (Woods, Knight, & Scabini, 1993). Lesions in the inferior parietal lobe tend to produce a neglect for auditory signals in contralateral space, and dissociation from auditory cues presented in contralateral space (De Renzi, Gentilini, & Barbieri, 1989; Farah, Wong, Monheit, & Morrow, 1989). Hence, there is good reason to believe that the task-related effects found in the current study for the P3/P4 electrodes may represent the activity of parietal areas associated with the later stage of auditory selective attention.

A further supposition of neurocognitive theorists is that the anterior attention system has primacy over the functioning of the posterior attentional system. According to Posner and colleagues the anterior system is the executive attention system. It has what could be described as a command function which operates through the reticular activating system to "alert" relevant frontal areas to the presence of an important stimulus. The frontal sites that are alerted depend upon the cognitive functions which are relevant to the perception of the specific stimulus. The relevant cognitive functions "interpret" the stimulus based upon the goals, concerns, memories etc., of the individual, and "activate" relevant posterior attention systems to select the stimulus features to be further processed by frontal cognitive systems (Posner et al., 1988). The executive anterior attention system, as termed by Posner, has been described within a similar framework by others using different terminology such as the Supervisory Attentional System (Shallice, 1988) or as part of the Executive System (Baddeley, 1986). Common to all the aforementioned systems is that they are believed to depend on the frontal lobe and function to activate and inhibit the operations of various cognitive subsystems (e.g., memory functions, verbal processes, visual processes, etc.). This frontal system is believed to hold a command function which directs the behaviour of an individual through a process of activation and/or inhibition of various cortical areas.

The Functional Nature of EEG Coherence

The purpose of the coherence study was to determine whether EEG coherence could provide a functional assessment of the operations of the proposed anterior and posterior attention systems. Important evidence for regional specificity of different attentional operations has been shown through imaging technologies such as Positron Emission Tomography (PET) (Corbetta et al., 1991; D'Esposito et al., 1995). Although the use of PET has demonstrated that posterior and anterior cortical regions are activated during specific attention related tasks, the activation of these areas does not demonstrate that a functional relationship exists between the two areas during specific attention-related tasks. On the other hand, EEG coherence provides a measure of the shared electrocortical activity from specific cortical regions. The current study is the first known attempt to use EEG coherence to assess the functional relationship between the anterior and posterior attentional systems during tasks that relate specifically to selective and sustained attention, as well as, during a dual task tapping into both selective and sustained operations. The present results would support the contention of two *functionally* separate attention systems primarily related to selective versus sustained operations, and the joint functioning of these systems during a dual task designed to activate both systems.

The differences found in EEG coherence between the easy and difficult versions of each task type do suggest the importance of the effort required to process stimuli in the relationship between cortical regions. Changes in neuronal response to the same stimuli in easy and difficult visual selective attention tasks have been shown with animals. Spitzer, Desimone and Moran (1988) showed that the amount of attention devoted to a stimulus affected the response of neurons in the inferior temporal association cortex differently during an easy task than during a difficult task. Specifically, similar neurons respond to easy and difficult to detect stimuli, but with more difficult stimuli there is a greater intensity of response. Therefore, it is possible to speculate that neurons related to the selection of auditory stimuli fire with a greater intensity during a difficult selective attention task.

The finding that the greatest changes in EEG coherence were observed during the more challenging versions of each task type may be examined within the context of effort and arousal. Interestingly, there were no significant changes in EEG coherence activity related to the exogenous source of arousal (caffeine), suggesting that EEG coherence is not sensitive to the effects of caffeine on cortical activity. The increase in speed and effort of information processing observed with caffeine on the AERP are not changes that can be picked up during spectral EEG coherence analysis.

Criticisms of the EEG Coherence Study

The exploratory nature of this study has provided the opportunity to demonstrate that EEG coherence is sensitive to manipulations of attention. However, it is difficult to conclude that the frontal and parietal sites are the only areas that are active during selective and sustained attention tasks based solely on the design of the current study. In the current study only 6 electrode sites namely bilateral, frontal, parietal and posterior temporal, could be used for analysis. Therefore, the conclusions of this study are restricted to the results found using only those electrode sites. In order to make more conclusive statements about cortical areas that are active during various attentional tasks the inclusion of more sites would be important.

The changes between the resting state EEG coherence and that recorded during the easier versions of both selective and sustained tasks were not significantly different. However, one reason for the lack of difference between resting and easy conditions is that in the data for the resting condition included only six of the 12 participants. When the results from the six participants who had complete data sets were similar to those reported with the 12 subjects were found, but these changes were not statistically significant. It was only when the data from the 12 participants was used did the differences between the pitch, duration and dual duration versions of the tasks reach statistical significance. Therefore, data for the resting state with an equal number of participants would provide a more reliable assessment of EEG coherence in a baseline or resting state. However, the data provided in the current analysis can be used an approximation of resting state EEG coherence activity for the alpha and beta bandwidths.

Future Research

The results of the EEG coherence analysis support the use of this measure to assess the functional relationship between cortical regions using attention paradigms. Further research should attempt to replicate the findings of the current study using similar attention paradigms, and consider a number of methodological improvements.

One of the limitations of the current study was that only six electrode sites were used, restricting the extent to which conclusions could be made with regard to the number of brain regions that may be involved during the performance of attention tasks. Specifically, the anterior-posterior comparisons should include anterior temporal, occipital and central comparisons with frontal regions. The anterior temporal (T3/T4) comparisons would help to determine whether this cortical region may also be sensitive to aspects of late auditory selective attention. Since the generators of the early AERP components are believed to be located in superior temporal areas, it is likely that this region may be sensitive to the manipulations of increasing demand in auditory attention paradigms. The activity of the occipital region (O1/O2) would allow for the assessment of the contribution of visual cortical areas to a visual sustained attention task. Another important comparison would include lateral frontal areas (F7/F8) which may have provided greater specificity with regard to the regions of the frontal lobe most sensitive to sustained attention processes. Finally, the inclusion of the central electrodes (C3/C4) can be used as controls sites to which no specific activity related to auditory manipulations of attention would be predicted.

Similarly, the application of a high density montage to analyze the EEG power would provide additional information regarding the regional changes in EEG power during the performance of different attention tasks. For example, during the selective attention tasks changes in EEG beta coherence were observed across the difficult tasks. Hence, of interest would be whether regional changes in the amount of beta activity across related cortical regions, frontal and parietal, also occur. Similarly, during sustained attention tasks changes in EEG alpha coherence were also observed. The possibility of concomitant changes in the amount of alpha activity across affected regions would also be of interest. This type of analysis may also serve to help explain the changes in the EEG coherence across the different bandwidths. Changes in EEG coherence are not necessarily related to changes in EEG power across bandwidths, but changes in EEG power would provide additional evidence for activation of either specific cortical regions or global shifts in underlying brain activity.

In the current analysis the alpha and beta bandwidths were defined broadly. Alpha included the entire 8 to 12 Hz frequency range and beta the entire 13 to 25 Hz frequency range. It would be interesting to examine within each bandwidth the frequency range most closely associated with the changes in phase (increase and decrease in EEG coherence) observed in the current study. This could be done by examining EEG coherence changes within the low and high alpha and beta frequency ranges. For example, are changes in EEG alpha coherence during sustained attention related more to desychronization in the low alpha (8 to 10 Hz) or high alpha (10.5 to 12 Hz) activity. In conjunction with the power spectra analysis this may serve to provide further explanation of the changes in EEG coherence. The patterns lower coherence during the difficult selective attention task between frontal and parietal areas may be a function of (1) increased high or low beta activity in the parietal region while no change occurred in the frontal area or (2) a change in high or low beta in the frontal area and changes in high or low beta in the parietal areas. A more complete explanation of regional changes in EEG activity could be explained using such analyses.

Further research should be designed to help explain the nature of the changes in EEG coherence between cortical regions during unitary and dual attention tasks.

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APPENDIX A

DIARY OF CAFFEINE CONSUMPTION

Journal of Daily Caffeine Use

In the following chart you should write the date of everyday that you will monitor your caffeine use in the boxes marked Day 1 etc. In the legend below are letters which correspond to different ways in which caffeine may be ingested. For each hour of the day mark in the letters which correspond to whatever form of caffeine you may ingest within that hour. Therefore, if you have a coffee at 9:00 am on Day 1, put a C in the corresponding box, if you have two coffees write in C C in the box.

Legend:
C= coffee T= tea HT= hot chocolate CH= chocolate M= cold or other remedies containing caffeine
S= soft drinks P= caffeine pills (dose) O= other caffeinated substances (specifiy on back of page)

Journal - For Two Weeks

Week 1	12am	1	2	3	4	5	6	7	8	9	10	11	12pm	1	2	3	4	5	6	7	8	9	10	11	12
Day																									
Day																									
Day																									
Day																									
Day																									
Day																									
Day																									

Journal - For Two Weeks

Week 2	12am	1	2	3	4	5	6	7	8	9	10	11	12pm	1	2	3	4	5	6	7	8	9	10	11	12
Day																									
Day																									
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Day																									
Day																									
Day																									

APPENDIX B

REACTIVITY TO CAFFEINE QUESTIONNAIRE

CAFFEINE STUDY

Please fill out the following questionnaires carefully and accurately.

NAME:__________________________________ PHONE NUMBER:__________/__

Age:______ Sex:______ Height:______(ft/inches) Weight:______(lbs)

In which year of study are you currently enrolled?
______1st
______2nd
______3rd
______4th
______other (specify)

Are you a _____full time student?
_____part time student?

Are you currently employed? _____yes _____no

If yes, how many hours per week? _____hrs

Do you work shifts? _____mornings ______evenings _____nights

Did you get a reasonably good nights sleep? _____yes _____no

Have you taken any stimulants (ie.coffee) since midnight last night? __yes __no

Have you had anything to eat since you woke up this morning? __yes __no

Do you smoke? ___yes ___no

If you were to consume caffeine in the morning, how would it effect you?
it would make me tired _____
it would wake me up _____
I need it to wake me up _____
I do not quite feel awake until I have some _____
it would make me feel irritated and edgy _____
it would make me feel nauseous _____
it would make me feel hyper _____
it does not effect me
In what form do you usually consume caffeine at this time? _____

If you were to consume caffeine in the afternoon, how would it effect you?
it would make me dozy _____
it would make me feel livelier _____
I need it to get me through the afternoon _____
I feel dozy unless I have some _____
it would make me feel irritated and edgy _____
it would make me feel nauseous _____
it would make me feel hyper _____
it doe not effect me _____
In what form do you usually consume caffeine at this time? _____

If you were to consume caffeine in the evening, how would it effect you?

it would make me tired _____
it would make me feel livelier _____
I need it keep me awake through the evening _____
I feel dozy unless I have some _____
it would make me feel irritated and edgy _____
it would make me feel nauseous _____
it would make me feel hyper and I would have trouble falling asleep ___

it does not effect me _____

In what form do you usually consume caffeine at this time? ______

APPENDIX C

STANFORD SLEEPINESS SCALE

Stanford Sleepiness Scale

Instructions: Choose the value which best describes your present state of sleepiness.

1. feeling active and vital, alert, wide awake.
2. functioning at a high level, but not at peak, able to concentrate.
3. relaxed, awake, not at full alertness, responsive.
4. a little foggy, not at peak, let down.
5. fogginess, beginning to lose interest in remaining awake, slowed down
6. sleepiness, prefer to be lying down, fighting sleep, woozy.
7. almost in reverie, sleep onset soon, lost struggle to remain awake.

APPENDIX D

HORNE/OSTBERG QUESTIONNAIRE

HORNE/OSTBERG QUESTIONNAIRE TO DETERMINE MORNINGNESS/EVENINGNESS

Instructions:

1. Please read each question very carefully before answering.
2. Answer all questions.
3. Answer questions in numerical order.
4. Each question should be answered independently of the others.
5. All questions have a selection of answers. Choose one answer only.
6. Please answer each question as honestly as possible. Both your answers and the results will be kept in strict confidence.

1. Considering only your own feeling best rhythm, at what time would you get up if you were entirely free to plan your day?

5am_____ 6am_____ 7am_____ 8am_____ 9am_____ 10am_____ 11am_____ 12pm____

2. Considering only your own feeling best rhythm, at what time would you go to bed if you were entirely free to plan your own evening?

8pm_____ 9pm_____ 10pm_____ 11pm_____ 12am_____ 1am_____ 2am_____ 3am____

3. If there is a specific time at which you have to get up in the morning, to what extent are you dependent on being woken up by an alarm clock?

not at all dependent_____ slightly dependent_____ fairly dependent_____

very dependent_____

4. Assuming adequate environmental conditions, how easy do you find getting up in the morning?

not at all easy_____ not very easy_____ fairly easy_____ very easy_____

5. How alert do you feel during the first half hour after having woken in the morning?

not at all alert_____ slightly alert_____ fairly alert_____ very alert___

6. How is your appetite during the first half-hour after having woken in the morning?

very poor_____ fairly poor_____ fairly good_____ very good_____

7. During the first half-hour after having woken in the morning, how tired do you feel?

very tired____ fairly tired____ fairly refreshed____ very refreshed_____

8. When you have no commitments the next day, at what time do you go to bed compared to your usual bedtime?

seldom or never later____ less than one hour later____
one to two hours later____ more than two hours later____

9. You have decided to engage in some physical exercise. A friend suggests that you do this for one hour twice a week and the best time for him is 7am to 8am. Bearing in mind nothing else but your own feeling best rhyt[illegible], how do you think you would perform?

would be in good form____ would be in reasonable form____
would find it difficult_____ would find it very difficult_____

10. At what time in the evening do you feel tired and as a result in need of sleep?

8pm____ 9pm____ 10pm____ 11pm____ 12am____ 1am____ 2am____ 3am____

11. You wish to be at peak performance for a test which you know is going to be mentally exhausting and lasting for two hours. You are entirely free to plan your day and considering only your feeling best rhythm, which one of the four testing times would you choose?

8am-10am_____ 11am-1pm_____ 3pm-5pm_____ 7pm-9pm_____

12. If you went to bed at 11pm at what level of tiredness would you be at that time?

not at all tired____ a little tired____ fairly tired____ very tired___

13. For some reason you have gone to bed several hours later than usual, but there is no need to get up at any particular time the next morning. Which one of the following events are you most likely to experience?

will wake up at usual time and not fall back to sleep_____

will wake up at usual time and doze thereafter_____

will wake up at usual time but fall back to sleep_____

will not wake up until later than usual_____

14. One night you have to remain awake between 4am and 6am in order to carry out a night watch. You have no commitments the next day. Which alternative will suit you best?

would not go to bed until watch was over_____
would take a nap before and sleep after_____
would take a good sleep before and nap after_____
would take all sleep before watch_____

15. You have to do two hours of hard physical work. You are entirely free to plan your day and considering only your feeling best rhythm, which one of the following times would you choose?

8am-10am_____ 11am-1pm_____ 3pm-5pm_____ 7pm-9pm_____

16. You have decided to engage in hard physical exercise. A friend suggests that you do this for one hour twice a week and the best time for him is between 10pm and 11pm. Bearing in mind nothing else but your own feeling best rhythm, how well do you think you would perform?

would be in good form_____ would be in reasonable form_____

would find it difficult_____ would find it very difficult_____

17. Suppose that you can choose your own work hours. Assume that you worked a 5 hour day (including breaks) and that your job was interesting and paid by results. Which five consecutive hours would you choose?

12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11

midnight am noon pm

18. At what time of day do you think you reach your feeling best peak?

12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11

midnight am noon pm

19. One hears about morning and evening types of people. Which one of these types do you consider yourself to be?

definitely a morning type_____

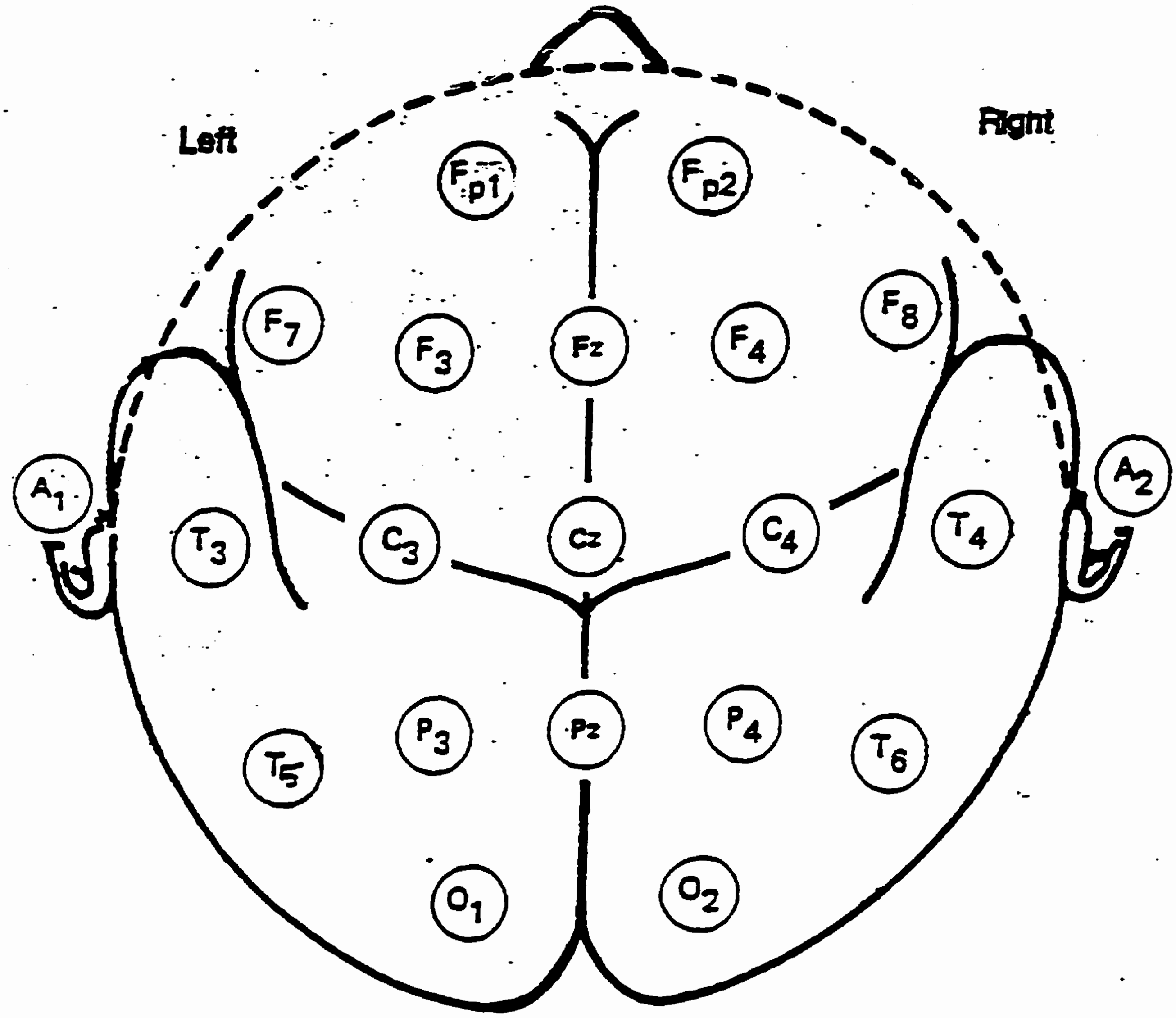
more a morning type than an evening type_____

more an evening type than a morning type_____

definitely an evening type_____

APPENDIX E

EEG MONTAGE



EEG Electrode Placements According To International 10/20 System

APPENDIX F

TABLES

Table 1. MEAN LATENCY AND AMPLITUDE OF AERP COMPONENTS FOR THE STANDARD ODDBALL TASK

	Latency		Amplitude	
	Caffeine	**No-Caffeine**	**Caffeine**	**No-Caffeine**
N1	114.13	126.12 **	-11.13	-11.22
P2	182.58	208.25 **	3.97	7.15 **
N2	240.82	288.98 **	-9.04	-10.41
P3	337.02	408.98 ***	12.71	12.38

* $p<0.05$
** $p<0.005$
*** $p<0.001$

Latency values in milliseconds
Amplitude values in microvolts

Table 2. MEAN LATENCY AND AMPLITUDE OF AERP COMPONENTS FOR THE DURATION ODDBALL TASK

	Latency		Amplitude	
	Caffeine	**No-Caffeine**	**Caffeine**	**No-Caffeine**
N1	117.25	122.85	-13.98	-11.83 *
P2	207.52	213.95	11.99	6.17 **
N2	310.05	330.66	-14.15	-9.96 **
P3	463.19	479.24 **	18.91	16.32

* $p<0.05$
** $p<0.005$
*** $p<0.001$

Latency values in milliseconds
Amplitude values in microvolts

Table 3. **MEAN LATENCY AND AMPLITUDE OF AERP COMPONENTS FOR THE DUAL TASK DURATION ODDBALL**

	Latency		Amplitude		
	Caffeine	**No-Caffeine**	**Caffeine**	**No-Caffeine**	
N1	115.53	122.24	-14.92	-12.28	*
P2	207.03	207.32	12.77	5.77	**
N2	323.18	335.52	-14.60	-10.64	**
P3	472.15	488.52	19.61	15.74	**

* $p<0.05$
** $p<0.005$
*** $p<0.001$

Latency values in milliseconds
Amplitude values in microvolts

Table 4. **MEAN LATENCY AND AMPLITUDE COMPARISON BETWEEN AERP COMPONENTS FOR STANDARD ODDBALL, DURATION ODDBALL AND DUAL TASK DURATION ODDBALL (COMPARISON OF AERP MORPHOLOGY BETWEEN TASKS)**

	Standard		**Duration**		**Dual Task**	
	Ca	**NC**	**Ca**	**NC**	**Ca**	**NC**
N1						
Latency	114.1	126.1	117.2	122.8	115.5	122.2
Amplitude (**)	-11.1	-11.2	-13.9	-11.8	-14.9	-12.2
P2						
Latency	182.5	208.2	207.5	213.9	207.0	207.3
Amplitude(***)	3.9	7.1	11.9	6.1	12.7	5.7
N2						
Latency (***)	240.8	288.9	310.0	330.6	323.1	335.5
Amplitude (***)	-9.0	-10.4	-14.1	-9.9	-14.6	-10.6
P3						
Latency (***)	337.0	408.9	463.1	479.2	472.1	488.5
Amplitude (***)	12.7	12.3	18.9	16.3	19.6	15.7

* $p<0.05$
** $p<0.005$
*** $p<0.001$

Ca = Caffeine Condition
NC = No-Caffeine Condition

Latency values in milliseconds
Amplitude values in microvolts

Table 5. AMPLITUDES FOR EASY AND CHALLENGE CNV TASKS

Standard CNV	Caffeine	No-Caffeine
O-Wave	5.49	5.89
E-Wave (**)	7.49	5.04

Challenge CNV	Caffeine	No-Caffeine
O-Wave	5.57	5.56
E-Wave (**)	7.13	9.36

*	$p<0.05$	
**	$p<0.005$	CNV values in microvolts
***	$p<0.001$	

Table 6. BEHAVIOURAL FOR DATA SELECTIVE ATTENTION TASKS

	Oddball	Duration *	Dual Task
Caffeine	386.42	567.41	597.50
No-Caffeine	394.98	593.20	631.07

* p<0.05 Values represent mean reaction time in milliseconds

Table 7. BEHAVIOURAL DATA FOR CNV TASKS

	Caffeine	No-Caffeine
Reaction Time		
CNV Easy	313.68	234.20 **
CNV Challenge	190.41	189.67

Values represent mean reaction time in milliseconds

	Caffeine	No-Caffeine
Anticipation		
CNV Easy	0.34	1.24 *
CNV Challenge	2.62	3.55
Misses		
CNV Easy	0.44	0.06 *
CNV Challenge	0.06	0.13

* p<0.05
** p<0.005 Anticipation and Misses are proportional values
*** p<0.001

Table 8. INTRAHEMISPHERIC EEG ALPHA COHERENCE FOR SELECTIVE ATTENTION TASKS (ANTERIOR-POSTERIOR LEADS)

No Caffeine Condition	Resting	Standard	Duration	Dual Task
F3/P3	0.32	0.34	0.24	0.26
F4/P4	0.33	0.30	0.22	0.25
F3/T5	0.10	0.07	0.08	0.07
F4/T6	0.17	0.10	0.10	0.11

Caffeine Condition	Resting	Standard	Duration	Dual Task
F3/P3	0.36	0.32	0.29	0.29
F4/P4	0.39	0.27	0.30	0.29
F3/T5	0.09	0.08	0.09	0.11
F4/T6	0.09	0.10	0.09	0.10

Table 9. INTERHEMISPHERIC EEG ALPHA COHERENCE FOR SELECTIVE ATTENTION TASKS (RIGHT AND LEFT HEMISPHERE LEADS)

No Caffeine Condition	Resting	Standard	Duration	Dual Task
F3/F4	0.34	0.37	0.37	0.37
P3/P4	0.39	0.35	0.36	0.38
T5/T6	0.05	0.05	0.04	0.06

Caffeine Condition	Resting	Standard	Duration	Dual Task
F3/F4	0.40	0.41	0.39	0.35
P3/P4	0.40	0.43	0.40	0.46
T5/T6	0.04	0.05	0.06	0.07

Table 10. INTRAHEMISPHERIC EEG BETA COHERENCE FOR SELECTIVE ATTENTION TASKS (ANTERIOR-POSTERIOR LEADS)

No Caffeine Condition	Resting	Standard	Duration	Dual Task
F3/P3	0.20	0.21	0.16	0.30 *
F4/P4	0.20	0.24	0.17	0.29 *
F3/T5	0.12	0.12	0.11	0.13
F4/T6	0.13	0.12	0.09	0.07

Caffeine Condition	Resting	Standard	Duration	Dual Task
F3/P3	0.21	0.20	0.15	0.29 *
F4/P4	0.19	0.20	0.17	0.31 *
F3/T5	0.10	0.10	0.11	0.12
F4/T6	0.12	0.12	0.10	0.11

* $p<0.05$

Table 11. INTERHEMISPHERIC EEG BETA COHERENCE FOR SELECTIVE ATTENTION TASKS (RIGHT AND LEFT HEMISPHERE LEADS)

No Caffeine Condition	Resting	Standard	Duration	Dual Task
F3/F4	0.25	0.26	0.25	0.25
P3/P4	0.40	0.40	0.38	0.45
T5/T6	0.10	0.13	0.12	0.16

Caffeine Condition	Resting	Standard	Duration	Dual Task
F3/F4	0.22	0.18	0.19	0.20
P3/P4	0.39	0.41	0.40	0.40
T5/T6	0.09	0.09	0.11	0.13

Table 12. **INTRAHEMISPHERIC EEG ALPHA COHERENCE FOR SUSTAINED ATTENTION TASKS (ANTERIOR-POSTERIOR LEADS)**

No Caffeine Condition	Resting	CNV-Standard	CNV-Challenge
F3/P3	0.25	0.23	0.16 *
F4/P4	0.32	0.28	0.17 *
F3/T5	0.10	0.12	0.12
F4/T6	0.11	0.10	0.13

Caffeine Condition	Resting	CNV-Standard	CNV-Challenge
F3/P3	0.29	0.21	0.18 *
F4/P4	0.33	0.29	0.15 *
F3/T5	0.11	0.11	0.13
F4/T6	0.09	0.10	0.12

* $p<0.05$

Table 13. **INTERHEMISPHERIC EEG ALPHA COHERENCE FOR SUSTAINED ATTENTION TASKS (RIGHT AND LEFT HEMISPHERE LEADS)**

No Caffeine Condition	Resting	CNV-Standard	CNV-Challenge
F3/F4	0.42	0.40	0.40
P3/P4	0.39	0.40	0.45
T5/T6	0.10	0.15	0.14

Caffeine Condition	Resting	CNV-Standard	CNV-Challenge
F3/F4	0.39	0.39	0.40
P3/P4	0.43	0.44	0.43
T5/T6	0.10	0.10	0.11

Table 14. **INTRAHEMISPHERIC EEG BETA COHERENCE FOR SUSTAINED ATTENTION TASKS (ANTERIOR-POSTERIOR LEADS)**

No Caffeine Condition

	Resting	CNV-Standard	CNV-Challenge
F3/P3	0.23	0.23	0.26
F4/P4	0.27	0.25	0.29
F3/T5	0.11	0.09	0.09
F4/T6	0.11	0.11	0.12

Caffeine Condition

	Resting	CNV-Standard	CNV-Challenge
F3/P3	0.25	0.27	0.27
F4/P4	0.28	0.29	0.28
F3/T5	0.09	0.06	0.07
F4/T6	0.08	0.08	0.12

Table 15. **INTERHEMISPHERIC EEG BETA COHERENCE FOR SUSTAINED ATTENTION TASKS (RIGHT AND LEFT HEMISPHERE LEADS)**

No Caffeine Condition

	Resting	CNV-Standard	CNV-Challenge
F3/F4	0.35	0.35	0.33
P3/P4	0.37	0.38	0.42
T5/T6	0.10	0.05	0.07

Caffeine Condition

	Resting	CNV-Standard	CNV-Challenge
F3/F4	0.33	0.36	0.34
P3/P4	0.35	0.34	0.38
T5/T6	0.05	0.04	0.04

APPENDIX G

FIGURES

Figure 1. AERP Components For Pitch Oddball

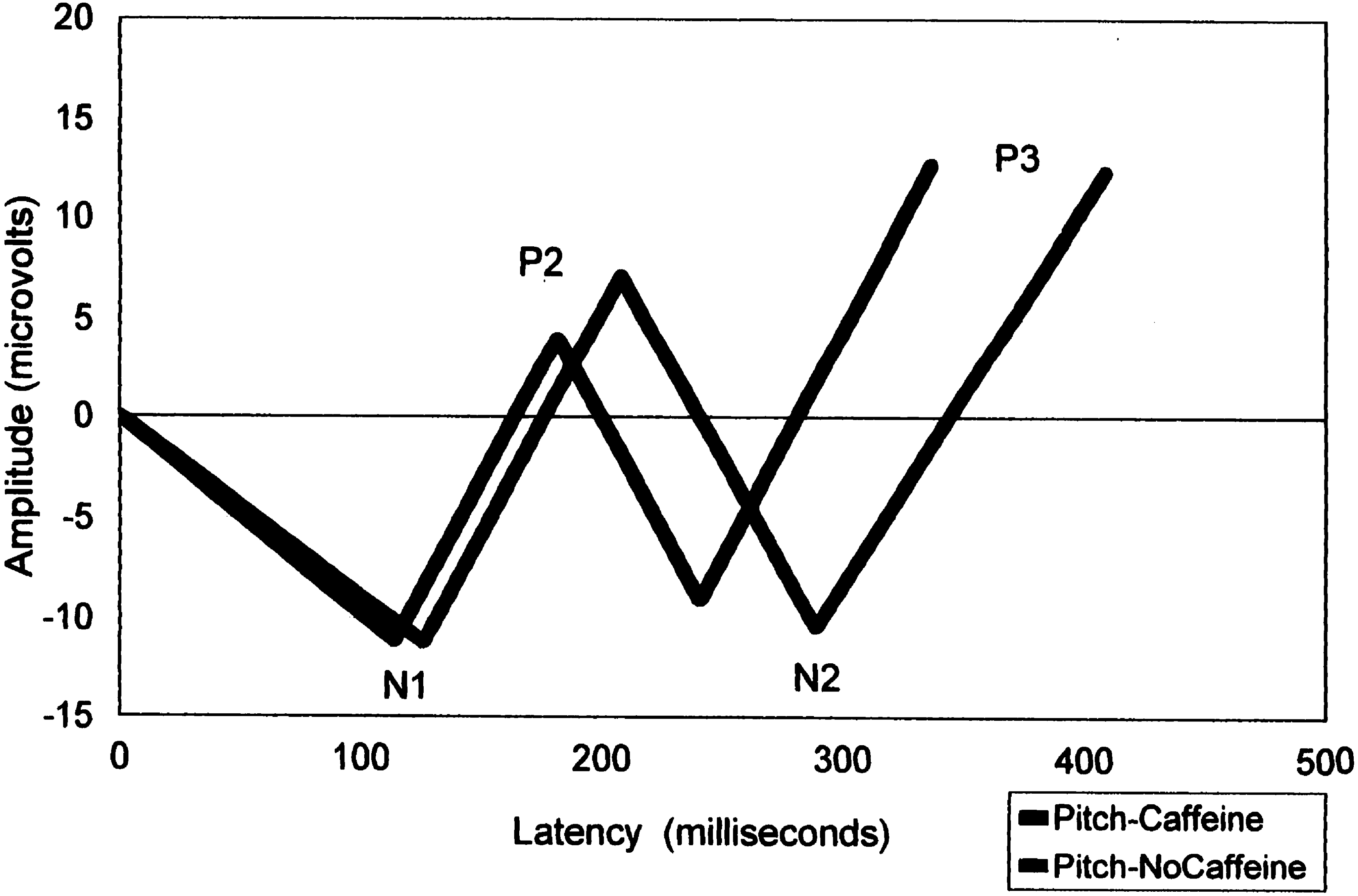


Figure 2. AERP Components For Duration Oddball Task

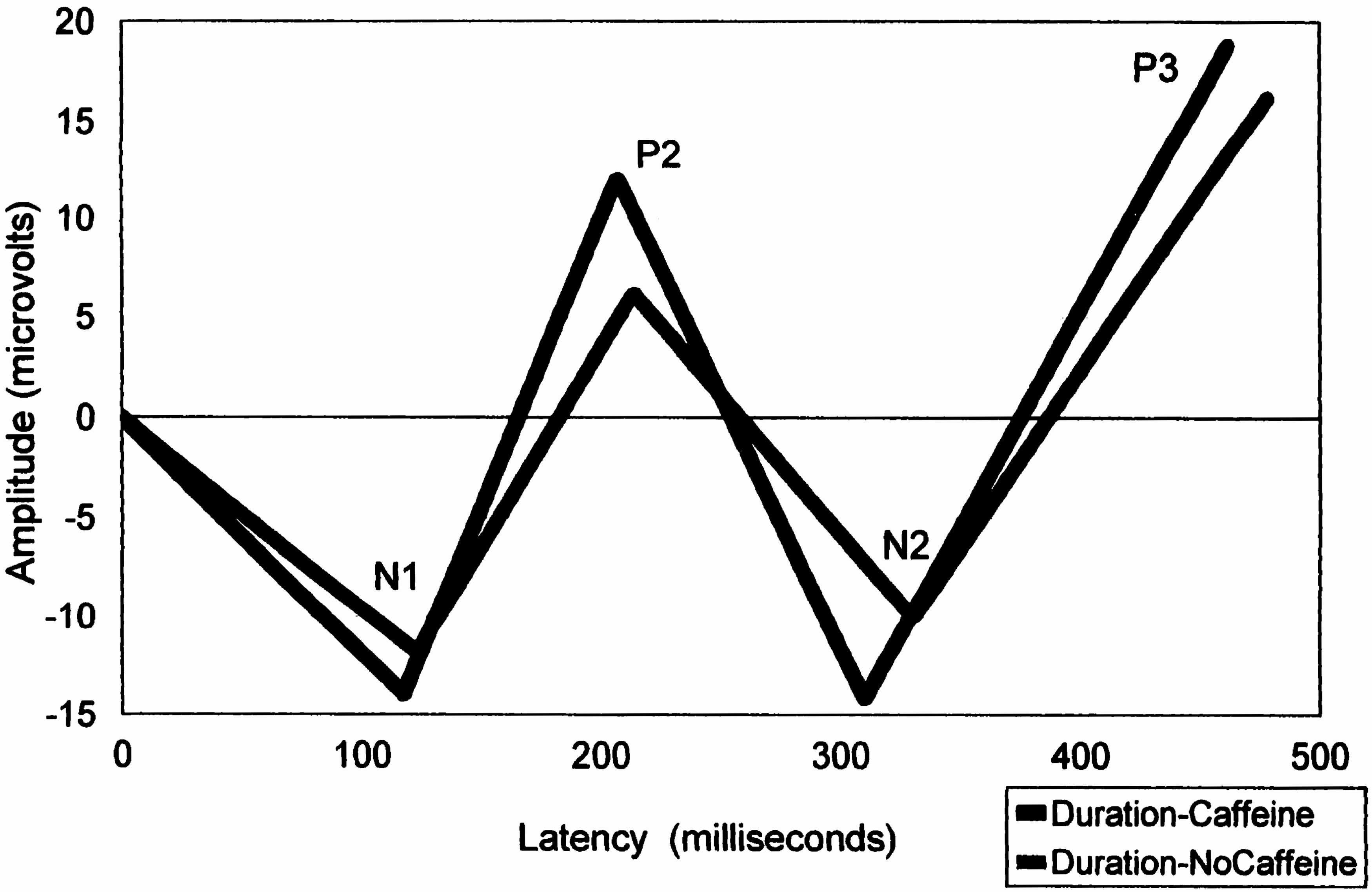


Figure 3. AERP Components For the Dual Task Duration Oddball

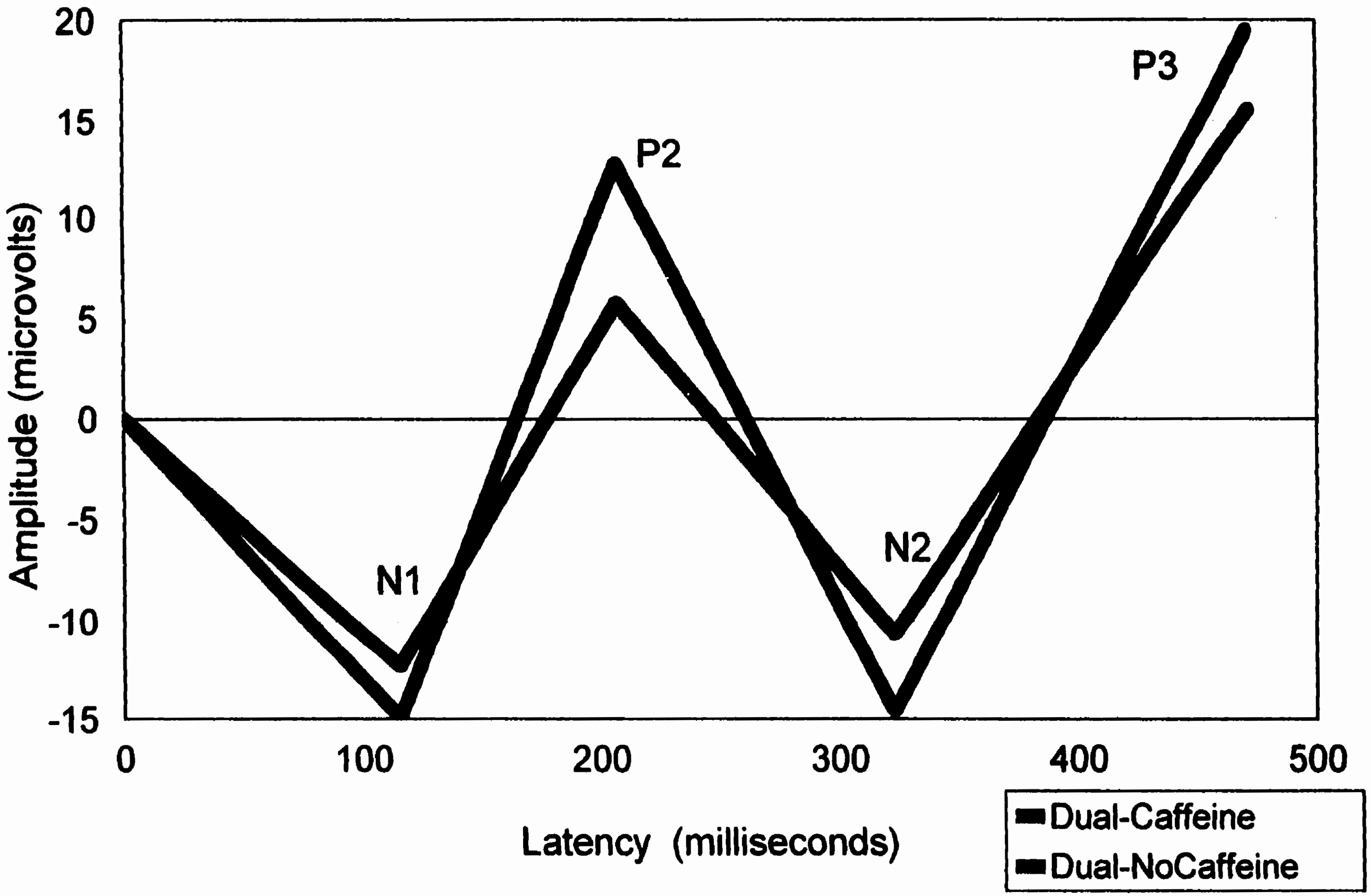


Figure 4. AERP Components For Selective Attention Tasks

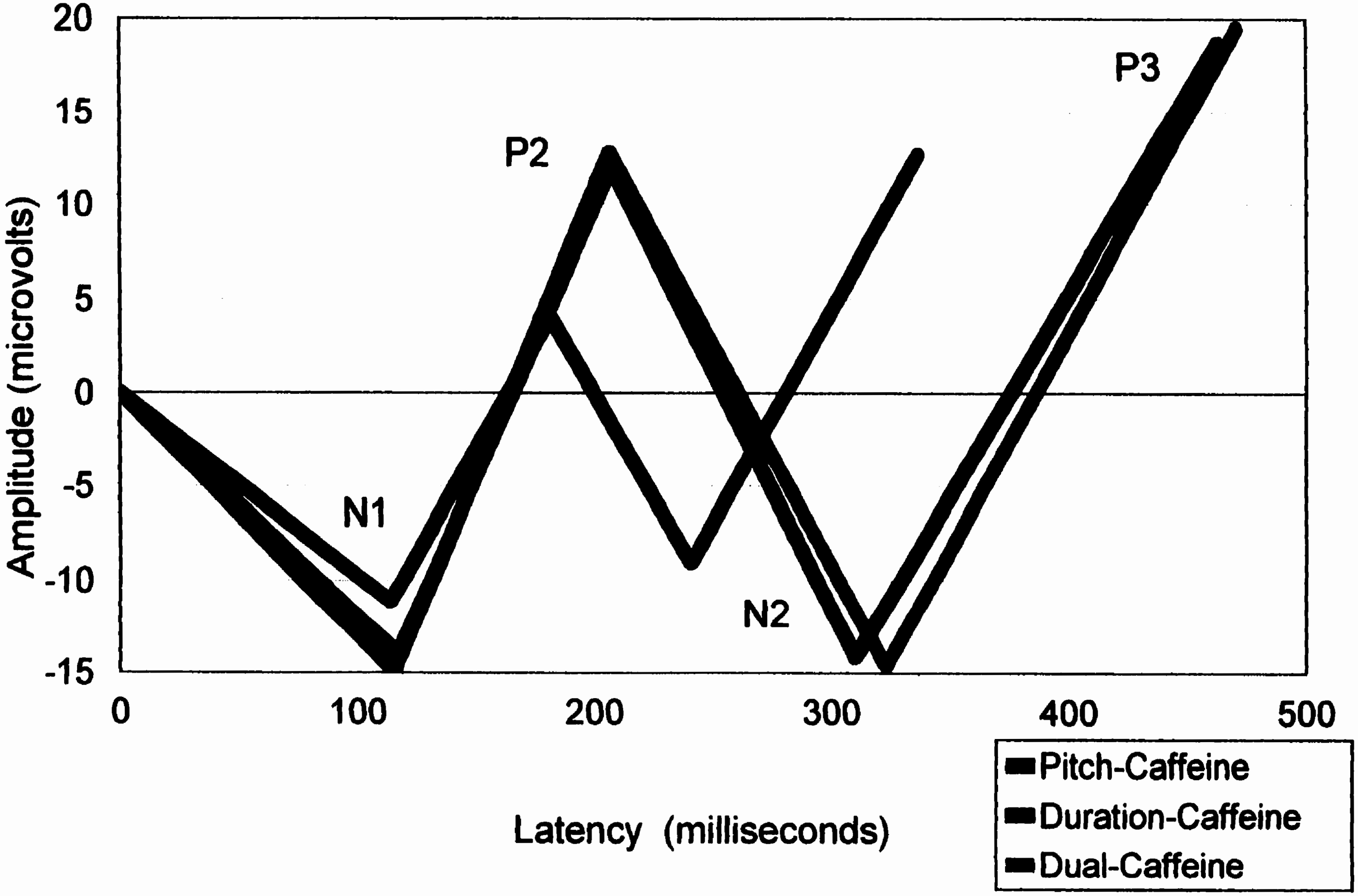


Figure 5. AERP Components For Selective Attention Tasks (No-Caffeine)

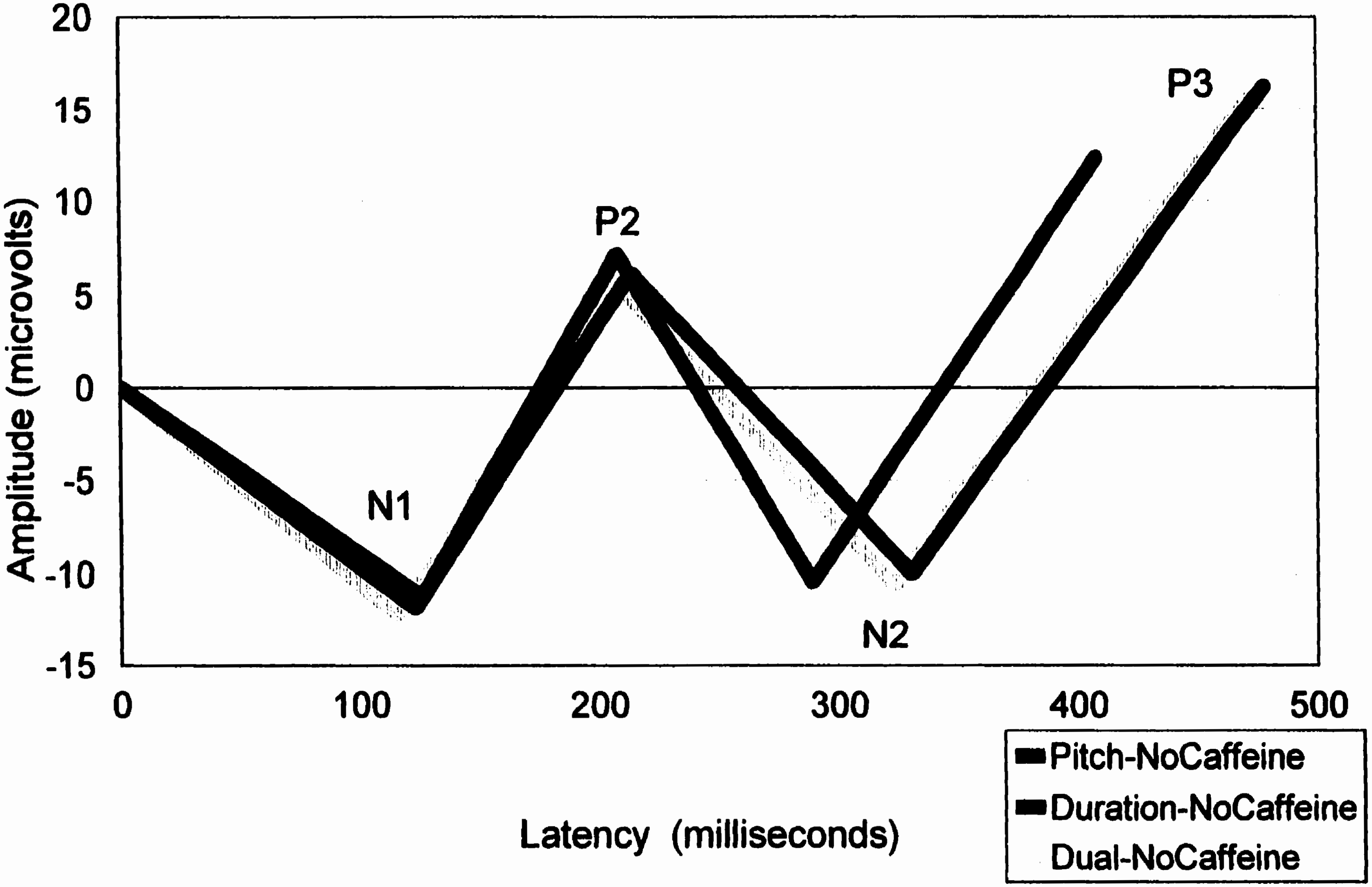


Figure 6. CNV: Caffeine x Instruction Type

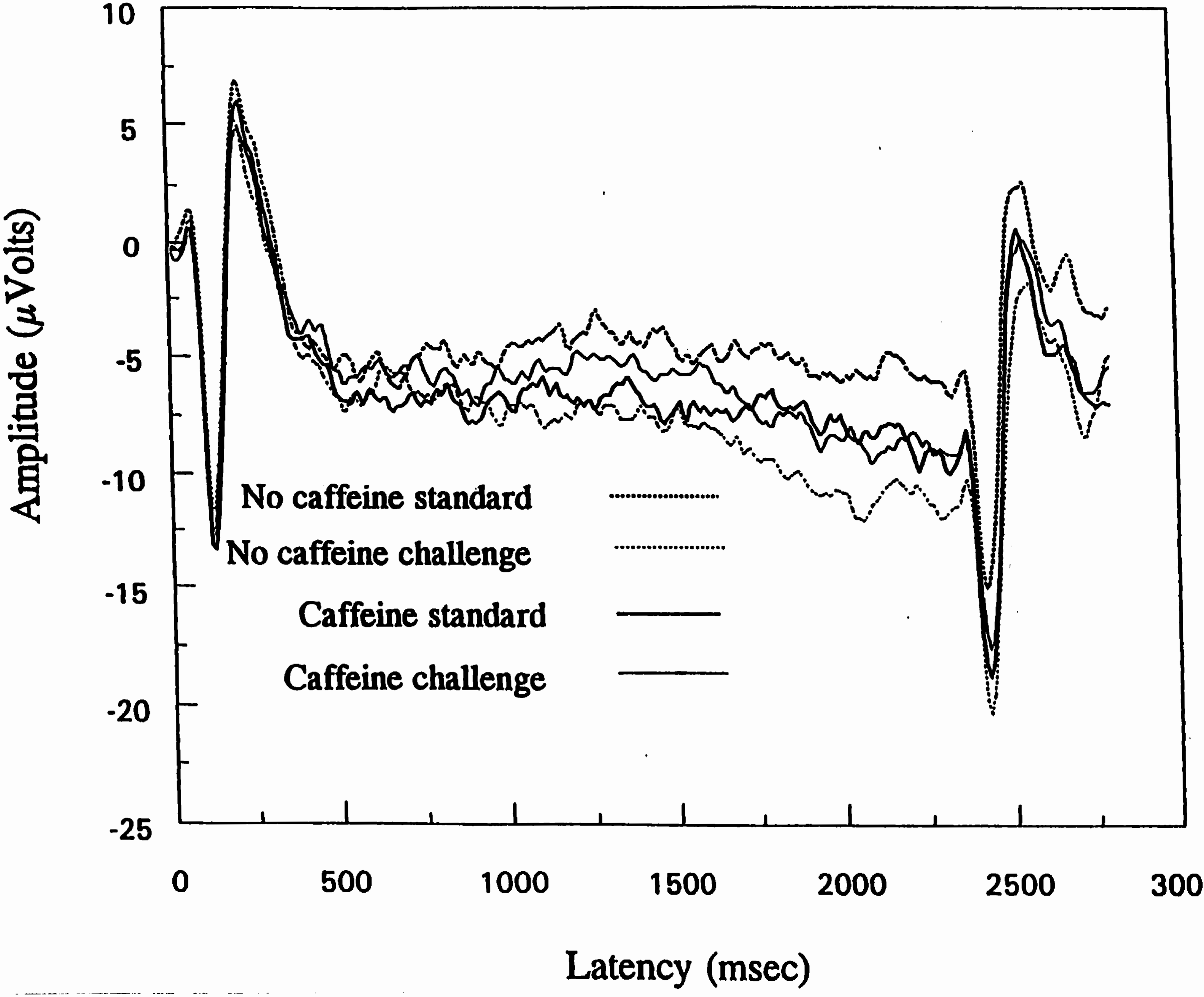


Figure 7. **INTRAHEMISPHERIC EEG ALPHA COHERENCE (Anterior-Posterior Leads)**

Selective Attention Tasks
No-caffeine

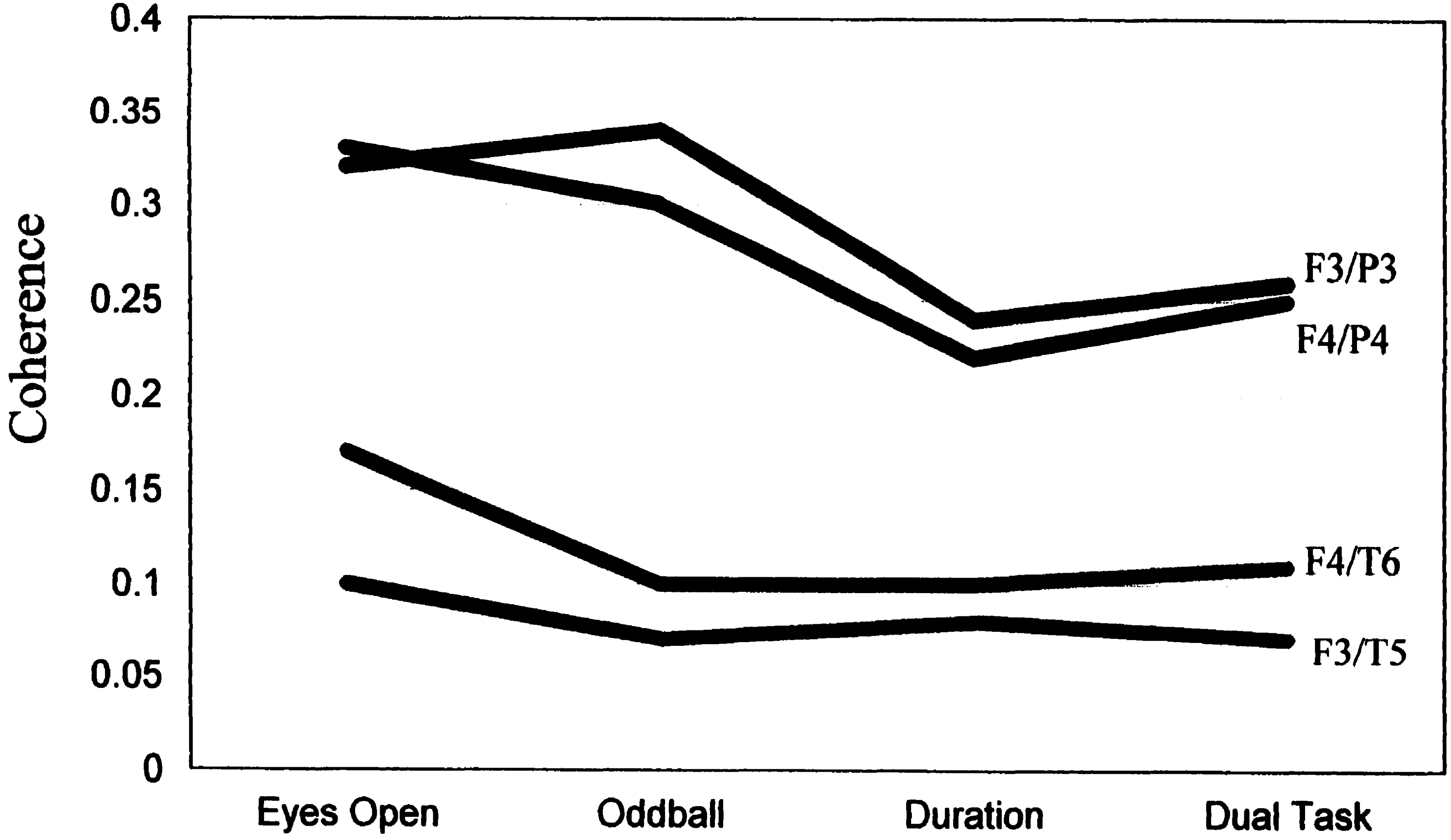


Figure 8. **INTERHEMISPHERIC EEG ALPHA COHERENCE**
(Right and Left Hemisphere Leads)

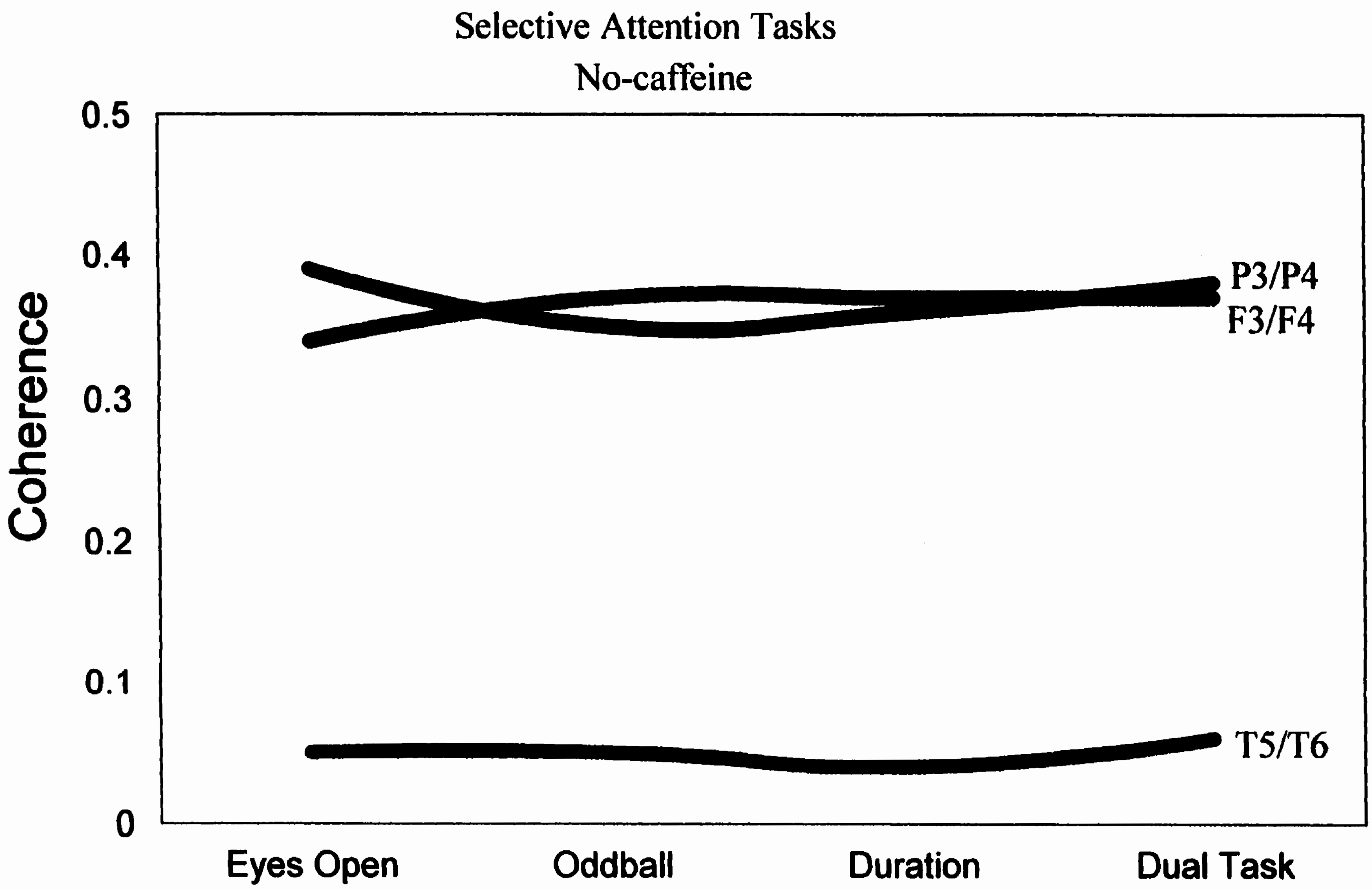


Figure 9. **INTRAHEMISPHERIC EEG BETA COHERENCE (Anterior-Posterior Leads)**

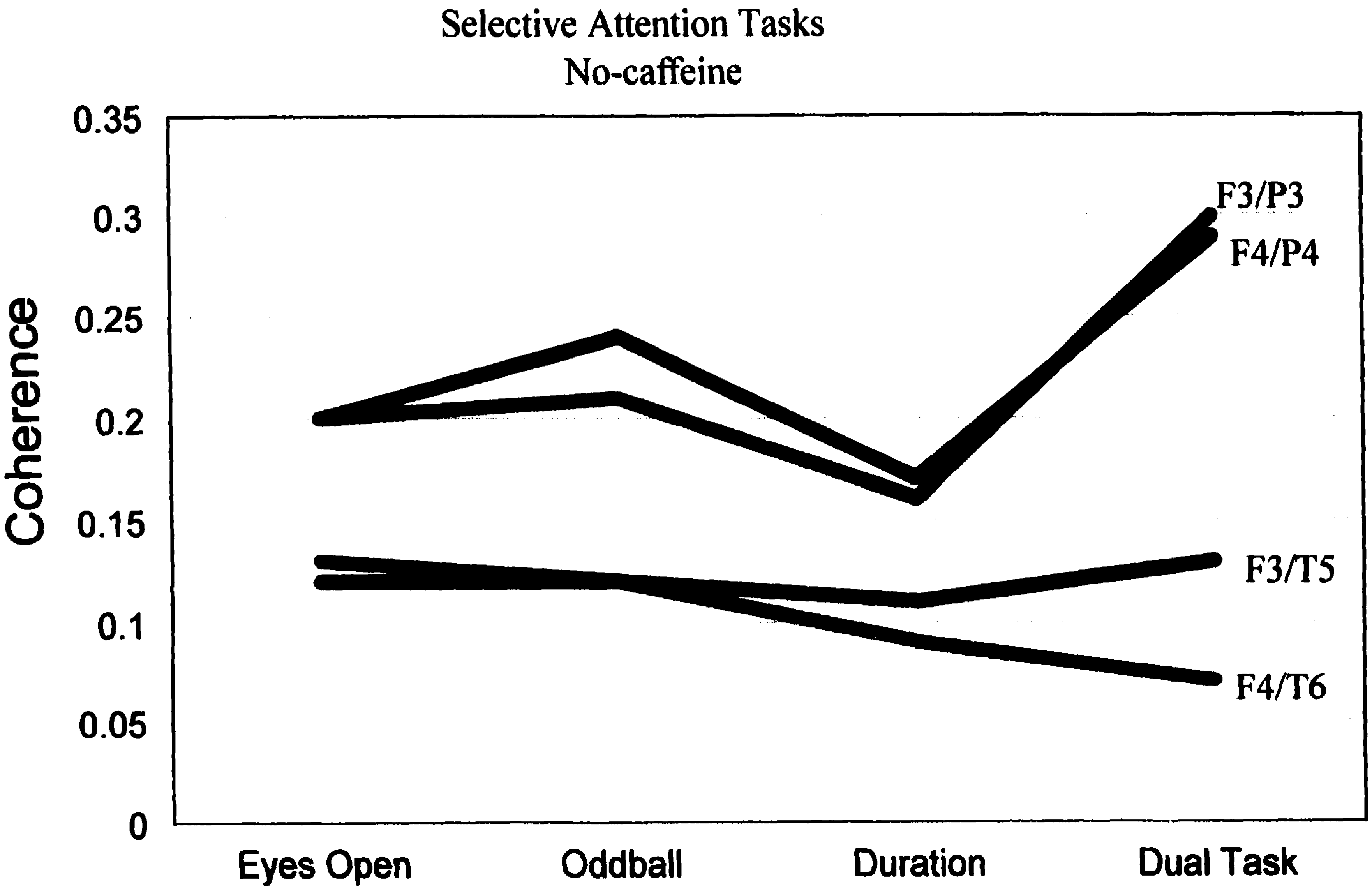


Figure 10. **INTERHEMISPHERIC EEG BETA COHERENCE (Right and Left Hemisphere Leads)**

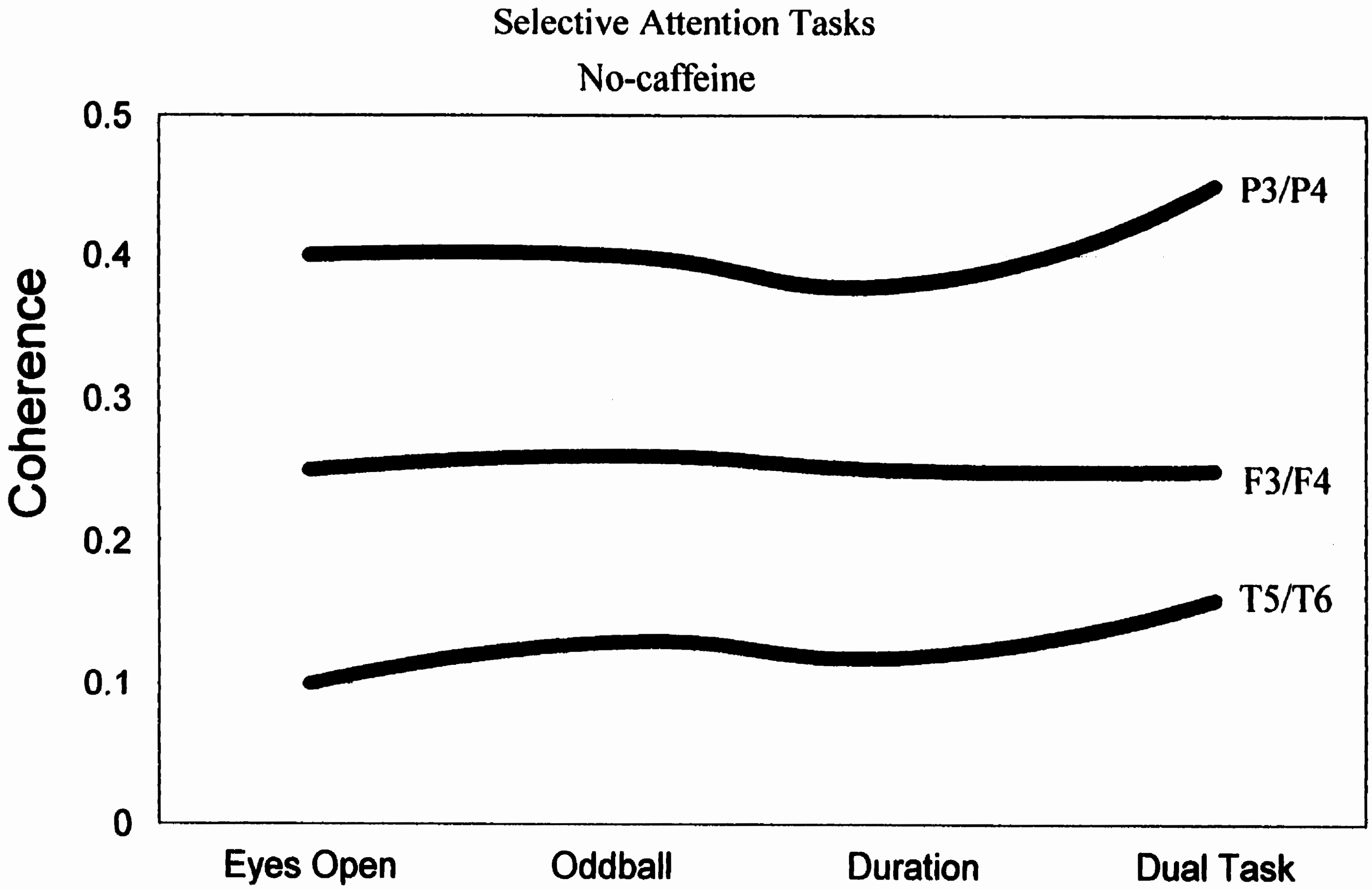


Figure 11. **INTRAHEMISPHERIC EEG ALPHA COHERENCE**
(Anterior-Posterior Leads)
Sustained Attention Tasks
No-caffeine

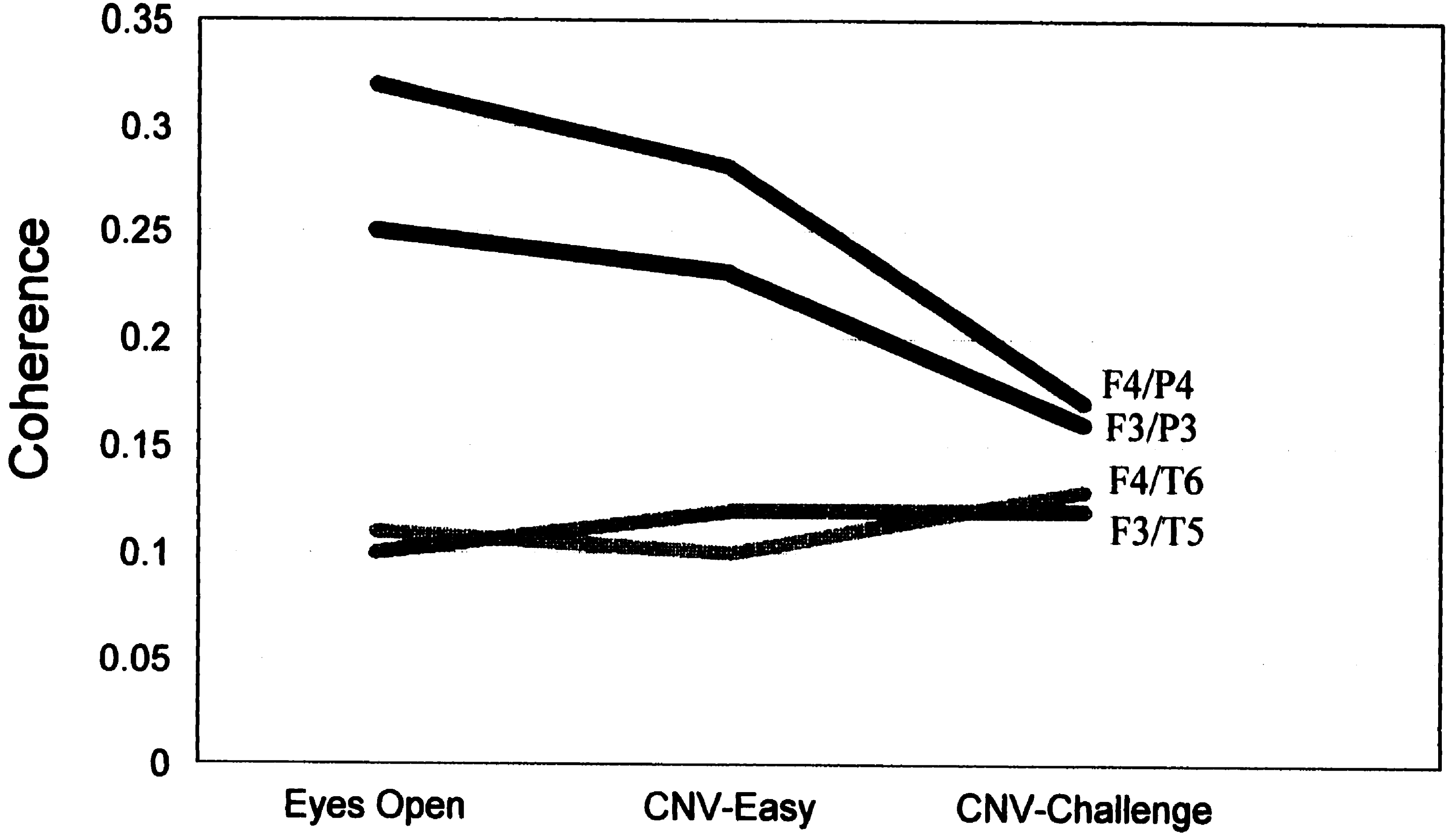


Figure 12. **INTERHEMISPHERIC EEG ALPHA COHERENCE (Right-Left Hemisphere Leads)**

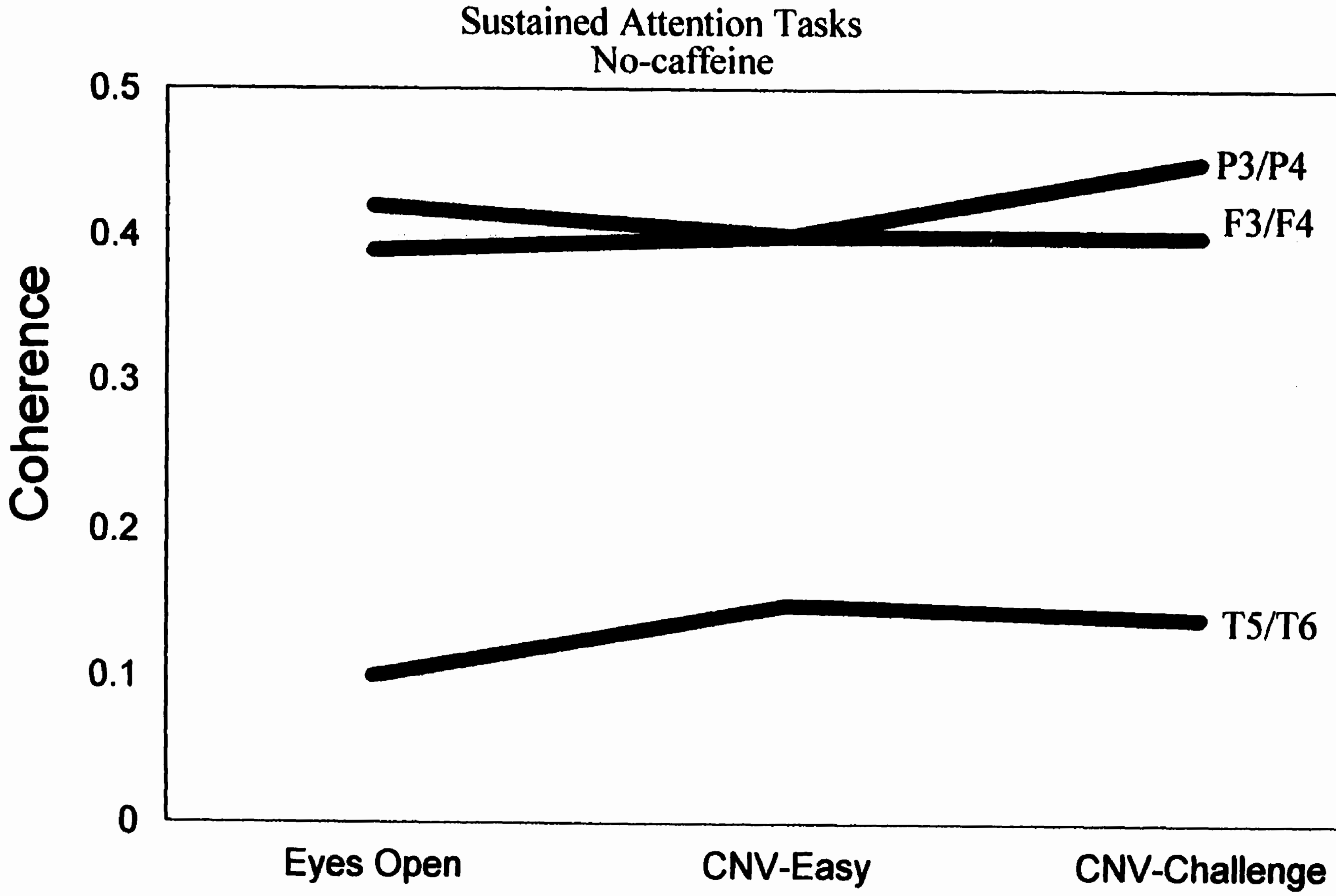


Figure 13. **INTRAHEMISPHERIC EEG BETA COHERENCE (Anterior-Posterior Leads)**

Sustained Attention Tasks

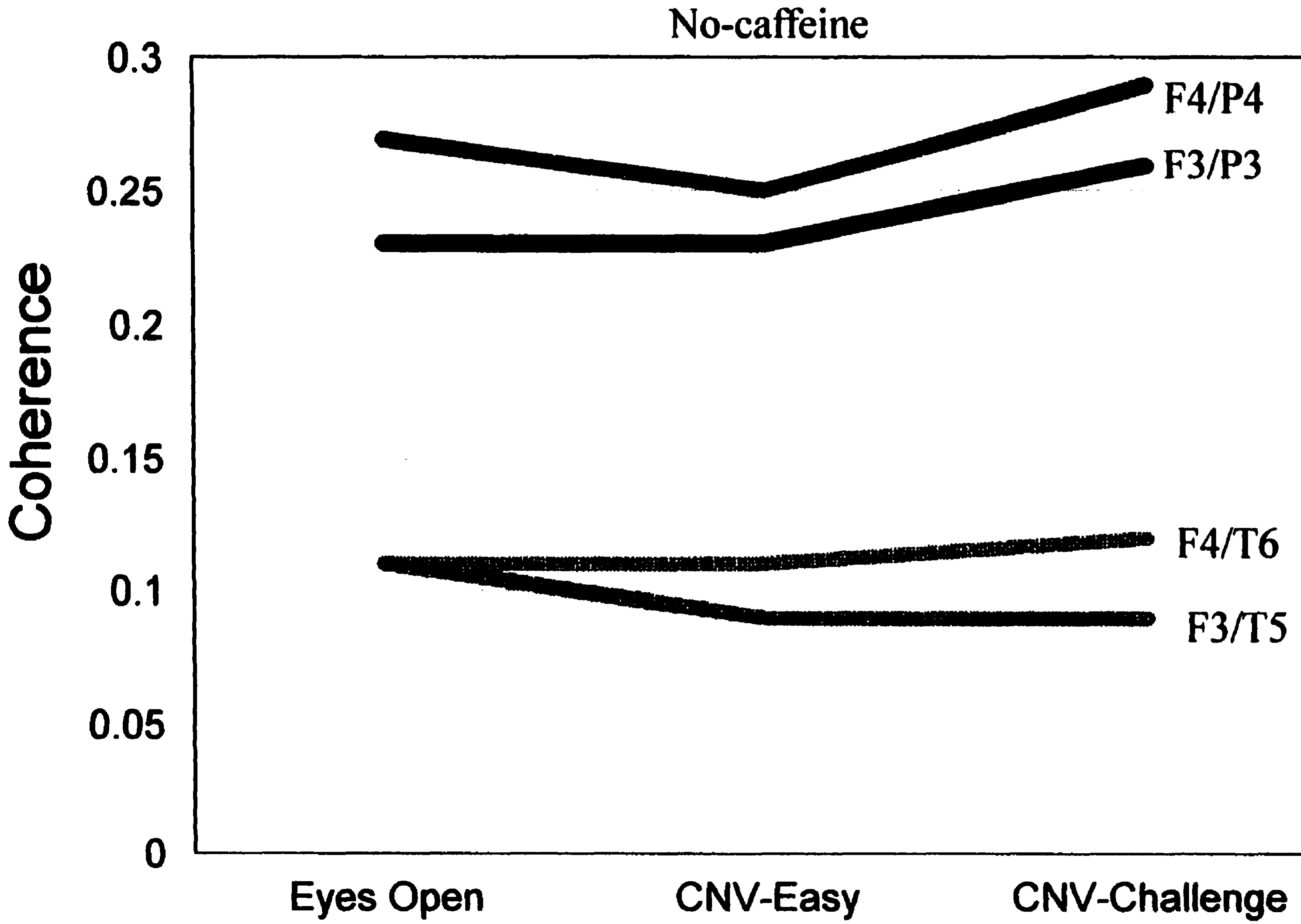


Figure 14. **INTERHEMISPHERIC EEG BETA COHERENCE (Right-Left Hemisphere Leads)**

Sustained Attention Tasks
No-caffeine