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Confirmatory Factor Analysis of Quantified Electroencephalogram Measured During a Continuous Performance Test: A Confirmation of Neurocognitive Systems

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CONFIRMATORY FACTOR ANALYSES OF QUANTIFIED ELECTROENCEPHALOGRAM MEASURED DURING A CONTINUOUS PERFORMANCE TEST: A CONFIRMATION OF NEUROCOGNITIVE SYSTEMS

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Abstract

In the University of Rhode Island's psychophysiology laboratory we are constructing a quantitative neuropsychological test that could be used in the assessment of human brain dysfunction. To this end we have collected the quantified electroencephalogram (QEEG) of 102 participants while they performed an eyes-closed, auditory, continuous performance test (CPT). Using the principal component procedure and 40 QEEG variables, Weiler (1993) and Arruda et al., (1994) derived two measurement models; suggesting the existence of seven to eight neurocognitive systems, including a theoretically meaningful right hemisphere, "Attention" component that appears fundamental to the brain's performance of a vigilance/attention task. The present study sought to confirm the existence (construct-related validity) of the seven and the eight component measurement models using an independent sample of 106 participants and the confirmatory factor analysis procedure. The results of this study confirmed the existence of a reduced seven component measurement model, strongly suggesting the existence of five neurocognitive brain systems, including the right hemisphere attention system referred to above. Component scores were then derived for each of the five component measures using the QEEG obtained from a subsample of participants while they performed a 23 minute CPT (i.e., attention task). The results of this study suggest that the right hemisphere beta wave component is a measure of a right hemisphere attention system. Changes in task demands were associated with varying levels of both the right hemisphere beta component and attention, as defined by behavioral performance. To the author's knowledge, the five component measurement model represents the first successful confirmation of a QEEG measurement model (i.e., component/factor structure) using an independent sample.

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Introduction

In the University of Rhode Island's psychophysiology laboratory we are constructing a quantitative neuropsychological test that could be used in the assessment of human brain dysfunction. During the past four years we have collected the quantified electroencephalogram (QEEG) of 102 participants while they performed an eyes-closed, auditory, continuous performance test (CPT). The CPT was chosen because it is thought to be a relatively simple cognitive task (i.e., requiring a limited number of cognitive strategies), and could be performed by a variety of clinical populations. All participants possessed no history of neurological condition, birthing complications, or loss of consciousness greater than two minutes. We believe this newly developed neuro-behavioral probe (Gur, Erwin, & Gur, 1992) could be used to successfully discriminate between the $QEEG_{cpt}$ of clinical and control groups.

The primary purpose of the present study was to establish the construct-related validity of the measurement models (i.e., neurocognitive systems) previously obtained by Weiler (1993) and Arruda, Valentino, and Gold (1994). Using the principal components analysis procedure, Weiler and Arruda et al. parsimoniously described 40 QEEG measures that were obtained from the 102 controls. The results from these two experiments suggest the existence of seven to eight neurocognitive systems, including a theoretically meaningful right hemisphere, "Attention" component, that appears fundamental to the brain's performance of a vigilance/attention task (i.e., CPT). The present study attempted to confirm the existence (construct-related validity) of the seven and the eight component solutions by applying the derived measurement models, as described by Weiler and Arruda et al., to the QEEG data obtained from a recently collected participant group (Experiment 1). In addition to examining the statistical fit of the

measurement model, a follow-up study was conducted to assess the criterion validity of the right hemisphere component (Attention System). Because the right hemisphere component is thought to index a brain system involved in attention, its association with concomitant performance was evaluated as participants performed the test over an extended period of time (i.e., at stages of decreasing vigilance) (experiment 2).

To provide the reader with a broader, theoretical perspective within which to place the present investigation and its use of a vigilance/attention paradigm, a brief discussion of the various attentional models, both cognitive and neural, is presented below.

Models of Attention

The study of attention was thrust into the mainstream of scientific inquiry during WWII when it became advantageous to understand, and to maximize the performance of radar operators while searching for enemy submarines (Mackworth, 1948). It was determined that radar operators were missing a significant number of enemy targets within 30 minutes after their shift had begun. Since the time of Mackworth, social and biological scientists have identified three subtypes of attention: a) selective b) divided, and c) sustained (i.e., vigilance). While selective attention may be defined as the ability to consciously focus (visually, auditorilly, tactily) on a single part of the environment, divided attention refers to the simultaneous processing of two competing environmental stimuli. Sustained attention, as defined here, may be considered the prolonged maintenance of selective attention. Theories of sustained attention are usually constructed to account for the performance decrement so frequently seen while people perform a prolonged attention task.

Because so much of the research involving the phenomenon of attention has been conducted in the neurosciences and in the area of cognitive psychology, one can easily find both cognitive and neural models of attention. Hence, an attempt was made to briefly discuss the cognitive and neural models of selective, divided and sustained attention.

Selective Attention: Cognitive

Because most cognitive theories of selective attention vary in their degree of semantic automaticity, it is important to first understand what is meant by automaticity. By definition (Posner & Snyder, 1975) a process is considered automatic if it satisfies the following three criteria: a) it is unintentional, b) it is unconscious, and c) it doesn't interfere with any other process. While selective attention may not satisfy some or all of these criteria (agreed upon by all models), the automaticity of semantic processing is still unknown. Hence, the cognitive theories of selective attention diverge on the degree to which they consider semantic processing to be automatic.

Early Selection Filter Theory (Broadbent, 1958) This theory postulates that all sensory information is taken into the organism serially through channels, and that at any point in time, a channel may be selected for further semantic processing. It is at the level of the filter that a bottleneck occurs, as not all of the stimuli move on for further processing. This theory also holds that all sensory information receives automatic physical processing, while only those stimuli (channels) that are filter selected experience the more extensive semantic processing. Semantic processing here is thought to require attention (i.e., the filter). A major problem with this theory, however, is the breakthrough of the unattended. Even though we might not be attending to a particular sensory channel it is still possible for those ignored stimuli to grab our attention (passive

attention). Hence, the semantic processing of ignored channels must somehow occur.

Early Selection Filter Attenuation Theory (Treisman, 1960) This theory, like that of Broadbent's Early Selection Filter Theory, suggests that all sensory information receive automatic physical processing, but unlike Broadbent's theory, postulates that even ignored channels are capable of receiving minimal semantic processing. Thus, while attended channels receive full semantic processing, ignored channels still receive minimal automatic semantic processing. Treisman believed that this minimal seepage of semantic information may be enough to cause the breakthrough of the unattended. That is to say, this reduced information may sometimes be sufficient to activate highly primed entries in the "mental dictionary". Treisman further suggested that a valence or an emphasis could be placed on certain words within this mental dictionary and that this weighting may occur through instructions, genetics or learning.

Late Selection Filter Theory (Deutsch & Deutsch, 1963) Unlike Broadbent's Filter Theory, Deutsch and Deutsch believed that all stimuli automatically receive both physical and semantic processing. Thus, if one were to try to envision this model one would see that the filter is pushed back in the processing scheme, allowing for both semantic and physical processing of stimuli. This is very different from the early selection filter models whose filters are situated early on in the processing. One problem with this theory is the fact that not all stimuli (attended and ignored) possess the same ability to semantically prime. Indeed, attended stimuli have a much greater ability to cause semantic priming than do ignored stimuli. This finding suggest that semantic processing does somehow rely on selective attention and isn't necessarily automatic at all.

Feature-Integration Theory of Vision (Treisman, Sykes & Gelade, 1977) This theory is based on the visual modality and posits that all stimuli are broken

down and processed according to their separable parts. Furthermore, all processing is thought to occur in parallel. Once separated, the separable parts are registered in their appropriate feature map according to the area of visual space that they had been extracted from. Treisman also asserts that there may be a master map of extrapersonal space that possesses the ability to focus a spotlight of attention on any area of the visual field. It is believed that once this spotlight is focused on a particular area of the visual field that all of the separable features that have been registered in that particular visual field, across all feature maps, will be correctly put together. Those separable features which fall outside the spotlight will tend to be put together improperly.

Selective Attention: Neural

Posner (1992) Posner put forth a neural model of selective attention which consists of three distinct neural attention systems: a) a posterior attention (PA) system, b) an anterior attention (AA) system, and c) a right hemisphere arousal (RHA) system. Posner posits that is the interplay between these three systems that makes for successful selective attention behavior.

The PA system resides within the parietal cerebral cortex and is responsible for the covert shift of selective attention. The posterior system does this by sending afferents to both the superior colliculus, which is responsible for the overt shift of attention (eyes and head), and the pulvinar, which is responsible for locking in attention and filtering out extraneous visual noise. The posterior system is also thought to enhance the readiness of primary sensory cortices prior to their receiving afferents.

The AA system either resides in or involves the cingulate cortex and is responsible for the successive discrimination of stimuli and targets. Positron emissions tomography (PET) studies have shown that this region becomes

increasingly active when the presentation rate of targets is increased, irregardless of sensory modality.

The RHA system involves the right frontal cerebral cortex, and possibly the right hemisphere in general. It is thought to be highly dependent upon norepinephrine (NE) and is believed to be responsible for the maintenance of attention during prolonged attention tasks.

Mesulam (1981) Mesulam's neural theory of selective attention involves four fundamentally different representational maps of extrapersonal space that are thought to be located in the following four areas of the brain: a) the superior parietal cortex, b) the frontal eye fields of the cerebral cortex, c) the cingulate cortex, and d) the ascending reticular activating system.

Superior parietal cortex: In the superior parietal cortex polymodal sensory information (highly processed and integrated sensory information) is registered in the appropriate location within its map of extrapersonal space. Each hemisphere is believed to contain a map of extrapersonal space for both the left and right visual fields. However, each hemisphere has a preference for sensory information from the contralateral visual field. Hence, sensory information doesn't have direct access to this region, instead sensory information initially passes through the primary sensory, unimodal associational, and then polymodal associational cortex before finally reaching the superior parietal cortex. By this time the sensory information has been thoroughly integrated (visual + auditory + tactile) and gives a complex representation of extrapersonal space. This area of the cortex also sends and receives information from the frontal eye fields (& superior colliculus), the cingulate cortex (& basal forebrain), and the reticular group (intralaminar nucleus, locus coeruleus, reticular formation).

Cingulate cortex: The cingulate cortex is thought to contain a representation of extrapersonal space on which varying degrees of valence or

significance may be placed. The importance assigned to an area of extrapersonal space may vary either with internal states, such as hunger, or with learning. Hence, for a hawk extrapersonal space below its line of site may be of more significance than extrapersonal space above its line of site, as prey usually appear below and not above the bird. This difference in valence may be even more accentuated during times of hunger. Furthermore, the cingulate cortex can influence the complex polymodal sensory processing that occurs at the level of the superior parietal cortex, by placing varying levels of importance onto its extrapersonal sensory map.

Frontal eye fields: As with the cingulate and the superior parietal cortices, the frontal eye fields also contain maps of extrapersonal space. However, these maps contain specific motor programs designed to explore specific sections of extrapersonal space. These motor programs are invoked through specific efferents from the superior parietal cortex and its corresponding map.

Reticular group: The function of the reticular group is one of maximizing the performance of the above mentioned systems.

Tucker (1981) Tucker postulates that a neurochemical dichotomy once existed between the left and the right halves of protoreptilian brain. He further theorizes that this dichotomy has had a great impact on more recent brain structures, and that even today, this ancient dichotomy has a profound influence on higher order behaviors such as selective attention. Accordingly Tucker believes that the left cerebral hemisphere is responsible for the focusing of attention (i.e.,a redundancy bias), while the right cerebral hemisphere is responsible for the expansion of attention (i.e.,a novelty bias). Underlying this attentional dichotomy is a neurochemistry dichotomy which involves both dopamine (DA) and NE. Tucker believes DA and NE to be more highly represented in the left and in the right hemispheres, respectively. Thus, the two hemispheres are always trying to

maintain a constant equilibrium between focusing and expanding attention. Indeed, whether one or the other predominates depends upon both the internal state of the organism (e.g. hunger: focused attention) or the state of the environment (e.g. danger: expansion of attention).

Vigilance: Cognitive

Inhibition Theory (Mackworth, 1948) Mackworth believed that performance decrement was purely a function of extinction. He believed that performance behavior decreased because it is rarely reinforced during a prolonged vigilance condition such as the task which a radar operator must perform.

Expectancy Theory (Deese, 1955) This theory postulates that people are capable of producing probability estimates of the occurrence of future targets, but that these estimates are always systematically lower than the actual. Furthermore, it is the discrepancy between the estimated and the actual probabilities that end up reducing a participant's confidence, causing a participant to become more conservative in their responding (i.e.,fewer hits and false alarms with time on task). While this seems plausible it is still hard to understand why more time on task doesn't serve to increase a participant's subjective estimated probabilities, making them more accurate and confident with time on task.

Signal Detection Theory (Egan, Greenberg & Schulman, 1961) . This theory breaks performance down into two independent measure: d' (sensitivity) and β (criterion). d' is a measure of perceptual sensitivity and is a function of the detectability of a stimulus and the integrity of the participant's sensory system. β is a measure of how conservative (high β) or liberal (low β) a person is in their decision to respond to a stimulus as a target. If a person performs vigilance task with a slow presentation rate d' will remain the same during the course of the task while β will systematically increase. With fast presentation rates, however, both d'

and β change, with d' decreasing and β increasing. The decomposition of raw performance into d' and β assumes not only that the stimuli are near threshold, but that both targets and non targets are normally distributed. While these assumptions may be met with a sensory tasks such as tones or light flashes, they are not met with more cognitive task such as tasks that use letters or words as stimuli.

Vigilance: Neural

Habituation (Groves & Thompson, 1970) This theory states that the performance decrement is a function of the decreased neural representation of a stimulus due to its repeated presentation. Hence, the sensory apparatus within the nervous system habituates to the repeated presentations of a stimulus, causing a reduction in its neural representation. Evidence put forth by Krulewitz, Warm and Wohl (1975), however, suggest that habituation is not responsible for performance decrement. Krulewitz used a reversed presentation paradigm where stimuli were presented at either a fast or a slow rate first, and then at a slow or a fast rate last, respectively. If habituation theory were correct, any change in the presentation rate should have a positive effect on performance and the performance decrement should be attenuated. Krulewitz et al., however, found that performance got worse for those subjects who were used to a slow presentation rate and who had to then perform using the fast presentation rate.

Arousal Theory (Duffy , 1932) This theory holds that arousal is a continuum which ranges from coma or deep sleep to hyper vigilance or hyper-arousal, and that the relationship between arousal and performance is curvilinear in nature. Hence, with extreme level of arousal (coma or hyper vigilance) performance suffers, while high performance is a function of some moderate levels of arousal. While certainly intuitive, this theory has received mixed support. Physiological

measures of arousal such as EEG have exhibited inconsistent relationships with performance. Thus, while alpha levels (EEG) do increase with time spent performing a vigilance task (i.e.,performance decreases), it also increases when there's no performance decrement at all. Similarly, it also appears that alpha increases while a person does nothing at all.

Divided Attention: Cognitive

While most of the cognitive theories of selective attention (filter theories) were structural in nature (i.e.,serial processing and limited in capacity), cognitive theories of divided attention (resource theories) rely on the concepts of parallel processing and limited capacity. Furthermore, although the filter theories were presented under the heading of selective attention they could easily have been presented here. Structural theories, such as Broadbent's and Treisman's, would explain the simultaneous performance of two tasks as having been accomplished by the quick switching of the filter from one task to the other. The resource theories would explain the same phenomenon by suggesting that the tasks are performed in parallel.

Divided attention tasks usually require a person perform two tasks simultaneously. People experience more or less trouble performing the two tasks depending upon the types of task being performed.

Single Resource Theory (Moray, 1969) This theory suggests that there are attention resources or pools that may be tapped into while a person performs two tasks simultaneously (parallel processing). It was further suggested that the use of attentional resource by one task will serve to either reduce or to increase the amount of attentional resource available for the other, depending upon whether the former task requires more or less attentional resource, respectively. This theory, however, does not account for the performance decrement seen using tasks that

simultaneously engage the same, or adjacent brain regions. Research suggests that it is not just the difficulty of the two task which determines the level of interference, but also how close the two task come to engaging the same brain region (Näätänen, 1992). Similar tasks (e.g. verbal-verbal) will cause more interference than will dissimilar tasks (e.g. verbal-spatial).

Multiple Resource Theory (Wickens & Kessel, 1979) This theory suggests that instead of one resource or pool that multiple pools exist for various cognitive modalities. Unfortunately, while this theory would predict perfect time sharing between tasks of different modalities, perfect time sharing is never actually realized. In fact, there is always some interference as a result of performing two separate task simultaneously (Näätänen, 1992).

Experiment 1

The Applications of PCA to QEEG Data: A Look at Previous Literature

The principal components analysis (PCA) procedure has been used in QEEG research as a way to statistically reduce the dimensionality of the original QEEG measures (**p**) to a smaller set of theoretically interesting component variables (**c**), where **c<p**. The component variables (i.e., latent constructs), which in the case of QEEG may be measures of different neurocognitive systems, are thought to account for the observed correlations amongst the original measured QEEG variables. Parsimony can then be achieved by linearly combining the original QEEG scores possessing the highest loadings for that component or brain system.[1] The new component scores, which are weighted linear composites of the

[1] The term loading refers to the correlation between a measured variable and a component variable.

original QEEG measures, can then be used to reliably (Tabachnick & Fidell, 1989) investigate brain-behavior relationships with QEEG.

The application of the PCA procedure to QEEG data has had a short and unproductive history. PCAs involving QEEG have been performed with small sample sizes, and have resulted in solutions that are both unreliable and highly unstable. Researchers who use the PCA procedure to investigate QEEG are often unfamiliar with some of the more pressing methodological and statistical issues concerning the PCA procedure. More distressing still is the fact that derived solutions are never independently confirmed using the data from an independent sample.

Two of the more frequently used PCAs are the spatial, and the reduced-N. In a spatial PCA the dependent variables are usually spectrally analyzed QEEG measures that are obtained at various regional derivations. Spatial PCA frequently requires that QEEG be sampled from a very large group of participants (**n**). In a reduced-N PCA the different regional derivations are substituted for **n** and the spectrally analyzed QEEG measures are treated as dependent variables. While the reduced-N PCA may require fewer participants, the results from these analyses may be unreliable, and indeterminate due to the resulting case dependencies. The spatial PCA, on the other hand, is free of these methodological difficulties, but requires that QEEG measures be taken from a relatively large number of participants. Unfortunately, the gathering of QEEG measures, while easily obtained and abundant once the electrode placements have been completed, is often very time consuming (e.g. >1.5 hours/participant). One result of this inherent time commitment is an over reliance on smaller, more unstable samples by studies that employ QEEG. Indeed, these samples are frequently so small ($n<10$) that their use with most univariate analyses, and certainly all multivariate analyses, is very questionable.

While the results of previous research involving PCA and QEEG are not directly comparable to the proposed analyses of the present study or to those of Weiler (1993) and Arruda et al. (1994), a brief description of the literature will be given below (Bente, 1979; Duffy, Jones, Bartles, McAnulty, & Albert, 1992; Gasser, Mocks, & Bacher, 1983; Lorig & Schwartz, 1989; Gasser, Jennen-Steinmetz, Sroka, Verleger, & Mocks, 1988; Ott, McDonald, Fichte, & Herrmann, 1982; Schenk, Filler, Ranft, Zerbin, Dokk, Haverkorn, Lemke, & Windelschmidt, 1982; Sponheim, Clementz, Iacono, & Beiser, 1994). These studies had several shortcommings including: (1) small sample sizes, (2) complex task paradigms, (3) resting paradigms, (4) questionable methodological practices, and (5) unipolar montages.

Bente (1979) measured the QEEG from a single electrode placed over the right occipital area of 11 participants while they performed a resting/Viloxazine task and a pursuit tracking task/Viloxazine task. Bente then performed a reduced-N PCA with the 32 spectrally analyzed frequency bands (1Hz/frequency band) as dependent measures, and the factorial combination of participants (11), conditions (2), and time epochs (5) as cases (N=110). Bente's reduced-N PCA produced a five component solution which accounted for 91% of the variance in the original measures. The components were as follows: (1) 30Hz +, (2) 9Hz +/ 3Hz -, (3) 13Hz +, (4) 17Hz -, and (5) 7Hz +/ 11Hz-. Bente then performed a Hotellings T^2 using the five components as dependent measures and the two task conditions as between subjects factors. Finding a significant differences between the two conditions using component two, Bente suggested that this component may be a vigilance component. However, because of case dependencies and the lack of information regarding extraction and rotation, Bente's five measurement model should be considered unreliable and certainly suspect.

Gasser et al (1983) sampled the spectrally analyzed QEEG (i.e., delta, theta, alpha, beta1, beta2) of 31 healthy children whose ages ranged from 10 to 13 years in order to investigate mental retardation and learning disabilities in children. The participants were asked to rest with their eyes closed while QEEG was recorded at the following eight derivations: (1) F_4, (2) F_3, (3) C_4, (4) C_3, (5) C_Z, (6) P_Z, (7) O_2, and (8) O_1. All derivations were referenced to linked ears. A PCA, using the eight derivations as dependent measures, was performed separately for each frequency band. Gasser et al. reported finding a three component solution, ignoring the single component solution suggested by the Kaiser Rule, which accounted for 93% of the variance in the original measures. Axes were not rotated and the components were thought to be representative of all frequency bands. The first component accounted for 82% of the variance and appeared to represent generalized spectral band activity across all derivations. The second component accounted for 9% of the variability and appeared to discriminate the antero-posterior axes. The third component accounted for 3% of the variance and appeared to discriminate the centro-parietal derivations from the frontal derivations. However, the three component solution must be considered unstable, and therefore invalid, due to the small case to variable ratio used by Gasser et al. (.66:1).

Ott et al. (1982) performed a single PCA on seven QEEG measures and six psychometric variables obtained from 60 male participants. The QEEG (total power, theta, alpha1, alpha2, beta1, and beta3) was measured from the O_2-A_2 derivation during an eyes closed resting condition. All six psychometric measures were taken twenty minutes later when each participant completed a series of six behavioral tests: (1) simple reaction time test, (2) pegboard test, (3) continuous addition test, (4) aiming test, (5) flicker fusion frequency test, and (6) a tapping test. Using the Kaiser Rule (i.e., eigenvalue > 1) and a varimax rotation, Ott et al.

reported finding a four component solution that accounted for 65% of the variance observed in the original measures. The first component accounted for 27% of the variance and consisted primarily of delta, negative alpha$_1$, beta$_1$, beta$_3$, and negative total power. The second and third components accounted for 19% and 11% of the variance, respectively, and consisted of mostly behavioral measures. The fourth component accounted for 8% of the variance and consisted of theta, and negative alpha$_2$. Despite this interesting finding, the component solution is probably unreliable due to case dependencies and the use of the Kaiser Rule to extract components comprising the solution.[2]

In 1982, Schenk et al. recorded 34 spectrally analyzed frequency bands, ranging from .5Hz to 32.8Hz, from the heads of 41 male participants during an eyes closed resting condition. All recording were made from two bipolar derivations (C$_4$-P$_4$, and P$_4$-O$_2$). Using a PCA and a varimax rotation, Schenk et al. identified a five component solution that could account for 85% of the variance. The first comprised 20% of the variance and consisted primarily of fast alpha and medium beta. The second component accounted for 24% of the variance and consisted of fast delta/theta and slow alpha /beta. The third component consisted of fast beta and also accounted for 24% of the variance. The fourth and the fifth components consisted of delta and medium beta, respectively, and accounted for 9% and 7% of the variance. Once again, because such a small sample was used (.60:1), the results from this study must also be considered unreliable.

In a replication of their earlier findings and in order to develop a meaningful topographic distribution of band power that would be valid across age groups, Gasser et al (1988) sampled the spectrally analyzed QEEG (i.e., delta, theta, alpha beta$_1$, beta$_2$) of 158 healthy children whose ages ranged from 6 to 17 years. The participants were asked to rest with their eyes closed while QEEG was

[2] Using the Kaiser rule usually results in the over extraction of components.

recorded at the following eight derivations: (1) F_4, (2) F_3, (3) C_4, (4) C_3, (5) C_Z, (6) P_Z, (7) O_2, and (8) O_1. All derivations were referenced to linked ears. A PCA was conducted using the eight derivations as dependent measures for each frequency band. Gasser et al. reported finding a three component solution which accounted for 95% of the variance and which was identical to the three component solution they had found earlier. The components were unrotated and representative of all frequency bands. The first component accounted for 80% of the variance and appeared to represent generalized spectral band activity across all derivations. The second component accounted for 10% of the variability and appeared to discriminate the antero-posterior axes. The third component accounted for 4% of the variance and appeared to discriminate the centro-parietal derivations from the frontal derivations. This apparent replication of an earlier 3 component solution can be accounted for by the fact that both solutions were left unrotated.

In an experiment designed to better understand the relationship between the alpha frequency, beta frequency, and EEG arousal, Lorig and Schwartz (1989), using period analyzed EEG, had participants perform 20 different cognitive and perceptual tasks[3] . EEG was measured at four scalp locations (F_7, T_5, F_8, and T_6 referenced to linked mastoids). Two of the tasks required mental arithmetic, six tasks required mental imagery, four were eyes closed resting, and eight were odorant tasks. Period analysis was performed on EEG taken from each electrode derivation (4), of each epoch (3), of each task (20) and of each subject (10). Lorig and Schwartz performed two reduced-N PCAs for each electrode derivation with the 15 frequency bins as the dependent measures, and the factorial combination of participants (10), conditions (10), and time epochs (3) as cases (N=300).

[3] Period analysis of EEG is a time domain technique which quantifies the frequency of waves occurring in different wave band frequencies. In the present experiment, 15 frequency bins were constructed with midpoints of 1Hz, 3Hz, 5Hz, 7Hz, 9Hz, 11Hz, 13Hz, and 15Hz. The entire frequency range was 4.3Hz to 64Hz.

Conditions were 10, as the 20 original conditions were matched for category and were divided into two equal groups of ten. Lorig and Schwartz reported finding six reliable components: (1) primary component/left anterior, (2) secondary component/left anterior, (3) primary component/left posterior, (4) secondary component/left posterior, (5) primary component/right anterior, and (6) primary component/right posterior. Components were deemed reliable if a significant relationship (r) was found between the loading values of the actual and the replicated PCA. The primary components of both the left and the right anterior region were made up of frequency bins ranging from 5.8Hz to 8.0Hz and were negatively associated with reports of boredom. The primary component of the right anterior region consisted of the 4.3Hz and the 21.3Hz bins and was positively associated with boredom. The primary component of the left posterior region was comprised of the 5.3Hz to 6.4Hz and the 8.0Hz to 12.8Hz bins and was positively associated with embarrassment and excitedness. The secondary component of the left posterior region was comprised of the 4.3Hz and the 7.1Hz bins and was not significantly correlated with any state. The primary component of the right posterior region was comprised of the 4.3Hz, 5.8Hz-7.1Hz, and the 12.8Hz-16Hz bins, and was negatively associated with reports of alertness and tenseness.

Using the unipolar derivations Cz, C3, and C4, Sponheim et al. (1994) compared the resting QEEG (i.e., delta, theta, alpha, beta) of 102 schizophrenic patients (44 first-episode, 58 chronic) with the resting QEEG of 102 normal controls. While no significant differences were found between first-episode and chronic schizophrenics, Sponheim et al reported that schizophrenics, irregardless of disorder duration, exhibited significantly more delta and theta, and far less alpha than did controls. Sponheim et al. then performed a series of three PCAs using the $QEEG_{Cz}$ from schizophrenics, normals, and schizophrenics/normals combined. The results suggested the existence of (1) a beta component, and (2) an

"augmented low frequency-diminished alpha component" which accounted for approximately 74% of the variance observed in the original measures. The two components were then used in subsequent univariate analyses where only the "augmented low frequency-diminished alpha component" reliably discriminated between clinical and controls groups. Schizophrenics possessd augmented low frequency-diminished alpha component scores that were significantly higher than those of controls.

In one of the more promising studies examined thus far, Duffy et al., (1992) performed two unrestricted spatial PCAs on the eyes-open (EO) and the eyes-closed (EC) $QEEG_{resting}$ data taken from 202 healthy adult participants, ages 30 to 80 years. Bipolar recordings were made according the International 10-20 system and resulted in formation of 1536 spectral variables (64 spectral frequencies, ranging from 0.5Hz to 32.0Hz in increments of .0.5Hz, x 24 channels). Using a variable to case ratio of 7.6 to 1, Duffy et al. extracted 20 orthogonal components whose eigenvalues ranged from 1.11 to 18.46 for the EC condition, and from 1.32 to 10.6 for the EO condition. Of the 20 components initially extracted for both conditions, only 9 and 8 components, respectively, were considered real and not artifactual: **EC1**-central slow beta, **EC2**-fronto-central fast beta, **EC3**-posterior delta, **EC4**-central theta, **EC5**-fast occipital beta, **EC6**-classic alpha, **EC7**-biposterior alpha and 2nd harmionic, **EC8**-bianterior slow alpha, **EC9**-central beta; **EO1**-posterior beta, **EO2**-central slow beta, **EO3**-bifrontal beta, **EO4**-central alpha, **EO5**-parietal delta, **EO6**-bilateral central beta, **EO7**-classic alpha, **EO8**-central beta.

Of the remaining artifactual components derived from the EC condition, two were located in the left and in the right temporal regions, respectively, and were comprised entirely of fast frequency beta . As both components were temporally derived, Duffy et al. concluded that each was merely a measure of

mastoid muscle movement. However, both components proved as effective at discriminating age, sex, and clinical status (i.e., dementia) as were those components considered "real". Moreover, the two EC components closely resemble the temporal beta components derived by Weiler (1993) and Arruda et al. (1994) while using an eyes-closed CPT procedure.

In contrast to the methods used by those studies previously reviewed, our laboratory has taken a much more methodical approach in its utilization of QEEG. Using the necessary sample sizes, we have sought to establish both the reliability (i.e., temporally and internally) and the validity (i.e., construct-related and criterion-related) of our QEEG measures (Valentino, Arruda, Weiler, Teixeira, & Gold, 1991; Weiler, 1993; Weiler, Willis, Arruda, Gold, & Valentino, 1992). The result has been the construction of two new measurement models that are both temporally reliable and internally consistent.

The AP6 and AP5 Measurement Models

Weiler (1993) performed a series of spatial PCAs using the QEEG data obtained from 102 normal participants while they performed an auditory CPT. These analyses resulted in the formation of ten, orthogonally rotated measurement models. Of the ten measurement models defined, four were derived from relative power (RP) QEEG, three were derived from log10(RP/(1-RP)), two were derived from absolute power (AP) QEEG, and one measurement model was derived from log10(AP). The AP for a frequency band (e.g. delta, 1-3Hz) was defined as the area bounded by the sine-wave formation, averaged across a two minute epoch. RP was defined as the proportion of AP that a frequency band, at each derivation, possesses in relation to the total power (i.e., AP summed across all five frequency bands) measured at each derivation. Weiler analyzed both AP and RP because of the on-going disagreement within the literature as to which of the two

electrophysiological measures is optimal for measuring cortical functioning. Additionally, log10(RP/(1-RP)) and log10(AP) transforms were included due to their normalization properties (Gasser, Bacher, & Mocks, 1982).

Using theoretical and statistical criteria, Weiler evaluated the utility of each measurement model. Measurement models were deemed useful if they were: a) deemed stable as evidenced by the number and the size of the variable loadings (Anderson & Rubin, 1956; Velicer & Fava, 1987, 1990; Zwick & Velicer, 1986), b) interpretable with respect to the current literature on attention (construct-related validity), c) reliable as measured by six minute, test-retest Pearson Correlations (r_{tt}), and d) predictive of behavioral performance (criterion validity). As a result of these four criteria, measurement models based upon RP EEG were deemed undesirable. RP measurement models were less reliable and far less interpretable than were the measurement models based on AP EEG (Weiler, 1992). The log10(AP) measurement model, while reliable, lacked sufficient interpretability. The most promising measurement model was the 8-component (AP8), (Figure 1). The AP8 possessed r_{tt} ranging from .71 to .95, with an average r_{tt} of .85. The AP8 solution also contained an intuitively appealing right hemisphere beta component.

Weiler chose to orthogonally rotate each component solution because they were to be used in subsequent multivariate analyses (i.e., multiple regression analyses). The use of orthogonal predictors enabled Weiler to make a clear determination of the contribution made by each component in explaining observed performance. However, because the decision to orthogonally rotate the component solutions was made for the convenience of interpretation, the orthogonally rotated AP8 measurement model, while apparently valid, may not have been the only valid absolute power (AP) solution. Moreover, as these measures of electrocortical activity were derived from the same brain, it may have been

unreasonable to assume that the components were independent. To address this issue, a pilot study was conducted using the same data and criteria as was used by Weiler (1993), however, an oblique rotation was performed (Arruda, et al. 1994). The results from this pilot study suggested a seven component solution (AP7) whose component's r_{tt} ranged from .74 to .96, with an average r_{tt} of .85 (Figure 2). The AP7 component solution was identical to that of the AP8 component solution except for the abscence of a frontal alpha component and the presence of a reduced occipital slow wave component (compare components 1 of AP8 and AP7).

Based on the findings of Weiler (1993) and Arruda et al., (1994), Experiment 1 examined the statistical fit of both the orthogonal AP8 and the oblique AP7 measurement models using the data obtained from a newly acquired sample. To my knowledge, there has never been an attempt to confirm the existence of a previously derived QEEG measurement model on a separate group of participants using the confirmatory factor analysis (CFA) procedure. Moreover, previously derived component/factor structures have been based on complex cognitive task paradigms or have been constructed using questionable methodologies. The measurement models proposed by Weiler (1993) and Arruda et al. (1994) were obtained from a large sample of participants who performed a relatively simple cognitive task. If the QEEG measurement models prove to be valid measures (i.e., stable across samples), they may represent measures of underlying neurocognitive systems, and therefore may be used to reliably discriminate between and among clinical (neurological) and control populations. The component solution that exhibited the best overall fit,was used in subsequent multivariate and univariate analyses (Experiment 2).

The present study avoids the problems of previous studies by: (1) using an adequate sample size (N = 106), (2) using a simple cognitive task paradigm, and (3) confirming and extending the findings of previous research (Arruda et al.,

1994; Weiler, 1993). Experiment 1 examined the statistical fit of two competing measurement models (orthogonal AP8-Weiler, 1993; oblique AP7-Arruda et al., 1994) on a newly acquired participant sample.

Hypotheses and Predictions

It was hypothesized that the measurement model proposed by Arruda et al. (1994) best represents the electrocortical activity in the normal human brain as it performes a CPT.

(1) It is predicted that both measurement models (orthogonal AP8-Weiler; oblique AP7-Arruda et al.,) will possess an adequate fit with the data, as assessed by absolute (Satorra-Bentler Scaled χ^2 statistic, χ^2/df, Root Mean Square Residual), and relative (comparative fit index) measures of fit, but that the oblique AP7 model will exhibit absolute and relative fit values that are both lower and higher, respectively.

Methods

Participants

One hundred and six (N=106) participants (39 men and 67 women) were recruited from a general psychology course (PSY113) and a junior level perception course (PSY385) at URI. Due to the large number of cases needed for the proposed study, a decision was made to combine the $QEEG_{cpt1}$ taken from a variety of protocols that had included CPT1 as a condition.[4] Participants earned credit towards their final course grade in return for their participation. The ages of the participants ranged from 18 to 26, with an mean age of 19.4 (SD = 1.4). Participants were all right handed as assessed by a modified version of the

[4] Of the 106 participants used in the present study (Experiment 1), 47 were recruited from Experiment 2.

Edinburgh Handedness Inventory (Oldfield, 1971) (Appendix A). All participants were free of any neurological conditions, birthing complications, or loss of consciousness more than two minutes (Appendix B). This protocol has been reviewed and accepted by URI Human Subjects Review Board.

Apparatus

Bipolar recordings were gathered, using the International 10-20 system (Jasper, 1958), from eight sites:Fp1-F7, Fp2-F8 (frontal region); F7-T3, F8-T4 (fronto-temporal region); T3-T5, T4-T6 (temporal region); T5-O1 and T6-O2 (temporal-occipital region) (Figure 3). A ground electrode was placed in the middle of the forehead. High- and low-pass filter settings were 0.5 Hz at 18dB/octave rolloff and 50 Hz at 24 dB/octave rolloff; gain = 10 000. Signals were digitized (sampling rate = 200/s, with 12 bit precision) and a spectral analysis was performed (FFT point every 0.4 Hz, 2.5-s segments) using a Sentinal 8 System designed by Axon (Haupauge, NY, USA). For the present study absolute power was calculated for delta(1-3.5 Hz), theta (3.5-7.5 Hz), alpha (7.5-12.5 Hz), beta1 (12.5-17.5 Hz) and beta2 (17.5-25.0 Hz). All impedance levels were less than 15 Kohm.

Participants listened to a computer generated audio tape consisting of randomly-arranged letters of the alphabet. Participants were instructed to press a button, which they held in their right hands, whenever they heard any letter read consecutively (twice in a row). Performance accuracy was recorded.

Procedure

After reading and signing an Informed Consent sheet, participants were asked to complete a questionnaire regarding their medical histories, their hand preferences, and their moods. Participants then sat in a comfortable chair while

electrodes were placed. Upon the successful completion of all electrodes participants were given the following instructions:

> For the first phase of this experiment we ask that you sit quietly with your eyes closed; your arms in your lap and your legs extended outward. After resting for a period of approximately three minutes we will ask that you perform a task which will constitute the second phase of our experiment. The task will require that you listen to a computer generated audio tape in which letters of the alphabet are spoken randomly, one immediately after the other. It will be your job to press the button once, using your right hand, for each time you hear the same letter spoken twice consecutively (e.g., d d within the sequence: a b d d k). Please keep your eyes closed throughout the entire procedure (both phases) and try not to move in your seat. Prior to the actual task we will have you complete a short trial run in order to make sure that you understand the task at hand. The actual task will run for a period less than ten minutes and I will let you know when you have completed the task. We will verbally signal you when we are about to begin the second phase.

The participants relaxed for approximately two minutes and 45 seconds, while a two minute sample of artifact free QEEG was taken. The actual QEEG recording began 45 seconds into the resting period (Resting). Upon the completion of the resting condition, participants were then informed that the trial sequence would commence. The trial sequence lasted for 20 seconds and insured that all participants could hear the letters and understand the directions of the task. After the trial period ended, and it was clear that the participant had a good understanding of the task, participants began performing the actual task for approximately 10 minutes. During the task, two 2-minute samples of both artifact free QEEG and behavioral performance were recorded at 45 seconds (CPT1), and 6 minutes and 45 seconds (CPT2) for all of the participants. For 47 of the participants EEGs were also recorded at 12 minutes and 45 seconds (CPT3) and at

18 minutes and 45 seconds (CPT4). However, only the data obtained from CPT1 were used in the confirmatory factor analyses.

Statistical Analyses

Because of the relatively small sample size being used for this type of statistical procedure, an attempt was made to reduce the number of parameters comprising each model (i.e., measurement model). Reductions in model size were accomplished by: (1) excluding the frontal slow wave components from all further analyses (i.e., AP8 components 2 and 7; AP7 components 4 and 6), and (2) restricting the number of variables used to define any one component to three. Variables were chosen for exclusion based upon their univariate skewness and kurtosis. The frontal slow wave components were chosen for exclusion because they are thought to contain slow wave eye movements. As both measurement models were reduced in size, the orthogonal AP8 and the oblique AP7 were subsequently referred to as the orthogonal AP6 and the oblique AP5, respectively (Figures 4 and 5). To eliminate the undue influence of variables possessing larger variances, all univariate measures were z-score transformed ($\underline{M} = 0$, $\underline{SD} = 1$) prior to all CFA procedures. Residuals were not allowed to correlate.

Estimation Procedure. Using the component solutions obtained by Weiler (1993) and Arruda et al. (1994), two confirmatory factor analyses, using the elliptical reweighted least squares procedure (ERLS, EQS, Bentler, 1985), were performed using the data obtained from the new sample of 106 participants (i.e., CPT1 data). ERLS is a non-normal estimation method that is robust to violations of skewness, providing relatively unbiased estimates of non-normal data parameters, standard errors, and goodness-of-fit indices (Sharma, Durvasula, & Dillon, 1989). However, because extreme levels of kurtosis may produce standard error estimates that are systematically smaller, resulting in t-ratios that are

artificially inflated (Harlow, 1986; Sharma et al, 1989), only the robust standard error estimates (corrected standard errors, Bentler, 1985), and their resulting probabilities were considered in the present study. The corrected standard error procedure produces estimates that are both reliable and accurate as they relate to actual sampling variability (Chou et al,, 1991).

Fit Indices. The overall fit of each component solution was evaluated using several fit indices (Marsh, Balla, & McDonald, 1988). One such fit index is the Satorra-Bentler Scaled χ^2 statistic. The Scaled χ^2 statistic is a robust, absolute measure of fit that is ideal for non-normal data (Chou, Bentler, & Satorra, 1989; Chou et al., 1991). While a smaller, nonsignificant χ^2 is indicative of a good fit between the model and the data, such a result is often unreasonable due to the enormous statistical power often enjoyed by such tests. Hence, even the slightest descrepancy between the proposed model and the data will result in a rejection of the null hypothesis, and the conclusion that there exists an **inadequate** fit between a proposed model and the data. As a result, it is convention to examine the ratio of a χ^2 to its degrees of freedom (df), with a ratio of 2 to 1 representing an adequate fit. The χ^2**/df** index has also proven to be quite invariant under a variety of sample size conditions (Marsh et al., 1988).

An additional absolute measure of fit is the Root Mean Square Residual (RMR) (Jöreskog & Sörbom, 1989). While it has previously been assumed that an RMR less than .05 represents the adequate fit of a model, Marsh et al., (1988) has reported finding a strong inverse relationship between sample size and RMR magnitudes (r^2=.55), with an RMR of .12 representing a perfect fit for a sample size of 100.

A third fit index to be used in this study is the comparative fit index (CFI, Bentler, 1990). The CFI is considered a normed fit index, as its scores range from 0 to 1.0. Higher CFI values indicate greater model fit, with a CFI greater than .90

indicative of an excellent fit between the proposed model and the data. The CFI is particularly valuable to the present study as it is derived with reference to the null model and its magnitude has been demonstrated to be relatively independent of sample size (Bentler, 1990).

Alpha Coefficients. Alpha coefficients (Cronbach, 1951), a measure of internal consistency, were calculated for each component, and averaged for each component solution . Those component solutions evidencing sufficient internal consistency, i.e., >.80, were considered reliable and deserving of further experimental consideration (Carmines & Zeller, 1979).

Results

The Orthogonal AP6 Measurement Model

A condition code was detected, indicating the generation of an impossible parameter estimate and the inability of the EQS program to produce a tenable solution using the parameter constraints established (i.e., the model as it was proposed). As a result, the questionable parameter estimate was automatically constrained to a lower-bound value, and a constrained solution was subsequently derived. Based on the three measures of fit, the artificially constrained, orthogonal AP6 measurement model provided an **inadequate** fit to the data, $\chi^2(135) = 308.36$, $\chi^2/df = 2.28$, CFI = .788, RMR = .228. The elliptical reweighted least squares estimates were obtained for the factor loadings and the error variances of the 18 QEEG variables representing the six components (Table 1). All factor loadings were statistically significant ($p < .001$), ranging from .402 to 1.0, with a mean loading of .807.

In order to determine whether the sample size used in the previous analysis contributed to the detected condition codes, a second CFA was conducted using the combined samples of Weiler (N = 102) and Arruda (N = 106). This resulted in another constrained solution, as an additional condition code was detected. The constrained, orthogonal AP6 measurement model once again provided an ***inadequate*** fit to the data, $\chi^2(135) = 319.71$, $\chi^2/df = 2.37$, CFI = .795, RMR = .192, suggesting that the proposed model may be either incomplete or untenable.

Using the 18 QEEG variables analyzed in the two previous CFAs and the 106 sample, coefficient alphas were calculated for each component of the orthogonal AP6 measurement model. The coefficient alphas were .77, .75, .81, .93, .86, and .82, respectively. The average alpha level for the AP6 measurement model was .823.

The Oblique AP5 Measurement Model

The oblique AP5 measurement model provided an **adequate** fit to the data, $\chi^2(80) = 183.04$, $\chi^2/df = 2.29$, CFI = .918, RMR = .058. The elliptical reweighted least squares estimates were obtained for the factor loadings and the error variances of the 15 QEEG variables representing the five components (Table 2). All factor loadings were statistically significant ($p < .001$), ranging from .369 to .999, with a mean loading of .81. Pearson Correlation coefficients were calculated for all component pairs (Table 3). Component correlations had a mean of .36 and ranged from .15 to .63. Of the original ten pairwise correlations, only seven were statistically significant at the $p < .005$ level of significance, using a one-tailed test and a Bonferroni adjustment (Figure 6).

Using the 15 QEEG variables previously analyzed in the AP5 CFA, coefficient alphas were calculated for each component comprising the oblique AP5

measurement model. The coefficient alphas were .77, .75, .81, .86, and .93, respectively. The average alpha level for the AP5 measurement model was .824.

As any comparsion involving the Null model solution may be considered unrealistic (i.e., too strict), and therefore inconsequential, a decision was made to examine the fit of four additional measurement models: (1) 1 factor measurement model, (2) oblique, AP5 random measurement model, (3) orthogonal, AP5 random measurement model, and (4) an orthogonal AP5 measurement model. The single factor measurement model was chosen as the covariation amongst the observed QEEG measures could reasonably be attributable to a single factor such as the brain. The oblique, AP5 random measurement model was chosen as it would provide a measure of fit for the oblique, AP5 measurement model (a favored model based on the findings of the present experiment) when it's observed measures were randomly reassigned to it's five factors. The orthogonal version of the AP5 random measurement model was included as it complemented the oblique solution. The orthogonal, AP5 measurement model was chosen because it represented the closest approximation to the oblique, AP5 measurement model.

As can be seen in Table 4, the oblique, AP5 measurement model proved far superior to all other models proposed. The present results further validate the oblique, AP5 measurement model, and are strongly suggestive of underlying neurocognitive systems.

Discussion

The Oblique, AP5 Measurement Model

As predicted, the oblique, AP5 measurement model possessed a χ^2/df, a RMR, and a CFI that were both smaller and larger, respectively, than those of the orthogonal, AP6 measurement model. The fact that all component measures were derived from the same brain, and therefore highly correlated, would account for

the oblique AP5 measurement model's superior fit. It is interesting to note that each of the four orthogonal models entertained produced condition codes, suggesting further that the oblique solution may be superior to the orthogonal solution when the measures are QEEG. Moreover, the oblique, AP5 measurement model, with its small sample size and distributional abnormalities, produced fit indices that were acceptable even by the conventional, often stringent, standards put forth by more traditional survey research. As no previous research has ever successfully validated the existence of a QEEG measurement model using an independent sample and the CFA procedure, the present finding comes as an tremendous breakthrough for the use of QEEG as both a clinical and a research tool. A path diagram of the oblique AP5 measurement model can be seen in Appendix C.

In addition to validating the proposed AP5 measurement model, the present results also suggest the existence of five neurocognitive brain systems. If true, the newly developed AP5 measurement model, being a reliable quantitative measure of said systems (Arruda et al., 1994; Weiler, 1993), could conceivably be used in the diagnosis of various brain pathologies. However, more research and development will be necessary before the AP5 measurement model can be used for such diagnostic purposes.

The oblique AP5 measurement model, representing a meaningful reduction (i.e., 88% reduction) in the number of original QEEG measures, should also prove invaluable to small N research. Having fewer, more reliable and valid measures of brain activity should allow research with sample sizes as low as 25 to reliably investigate brain-behavior relationships using multivariate analyses such as the multivariate analysis of variance (MANOVA) or multiple regression. Likewise, reliable measures also increase the statistical power of analyses.

The Orthogonal, AP6 Measurement Model

The prediction that both measurement models would possess an adequate fit with the data was not supported by the results of the present study. The orthogonal AP6 measurement model produced fit indices that were unsafisfactory even by the more liberal standards associated with non-normal data. More troubling still was the presence of condition codes for the CFAs performed on both the single (N = 106), and the combined (N= 208) samples. The condition codes signaled the inability of the ERLS procedure to derive acceptable parameter estimates for the proposed orthogonal, AP6 measurement model even when doubling the sample size. In both instances, ERLS moved to artificially constrain those unacceptable estimates to more acceptable values and proceeded to generate best solutions. However, these best solutions still possessed an inadequate fit to the data. As a result, the orthogonal, AP6 measurement model is considered untenable, and will not be included in future analyses (i.e., used in Experiment 2).

Internal Consistency and Coefficient Alphas

Coefficient alphas derived for both the orthogonal, AP6 measurement model and the oblique, AP5 measurement model were deemed satisfactory using the > .80 criterion established by Carmines and Zeller (1979). The orthogonal AP6 model and the oblique AP5 model possessed coefficient alphas of .823 and .824, respectively. This suggests that both measurement models are comprised of components that are internally reliable. However, as the AP6 measurement model exhibited an inadequate fit to the newly acquired data sample, only the AP5 measurement model can be considered worthy of further experimental consideration.

The Oblique AP5 Component Correlations

Pairwise component correlations resulted in an interesting pattern of component relationships (Figure 6). Most interesting for the purposes of the present and subsequent study is the covariation observed between the theoretically meaningful right hemisphere beta component and each of the four remaining slow and fast wave components. Such comparisons, while only descriptive, may serve to further define the role of all five components.

R Hemisphere Beta Component and L Hemisphere Beta Component. One possible interpretation of the strong, positive relationship found between the right (C2) and the left (C3) hemisphre beta components ($r = .625$), is that both components index attentional processes. This interpretation, however, conflicts with the findings of cerebral blood flow, metabolism, reaction time, and quantified electroencephalogram which strongly suggests that the right cerebral hemisphere, and not the left, plays an important role in the attentional process (Posner & Petersen, 1990; Valentino et al, 1993; Weiler, 1993; Whitehead, 1991).

Assuming that contractions are always bilateral, a second interpretation of the relationship may be that both components index mastoid muscle movement (Duffy et al., 1992). This interpretation, however plausable, would still only explain approximately 39% of the variance in either component (r^2), leaving a remaining 61% to be explained by other means. Hence, it is conceivable that one or both components additionally measure something other than muscle artifact. A test of this hypothesis was conducted when the left hemishere beta component was used as a covariate in subsequent, hierarchical multiple regressions (Experiment 2).

As the CPT likely possessed both a verbal and an attentional element, a third interpretation of the strong relationship between the left and the right beta components may represent the concurrent processing of language and attention by

the left and the right cerebral hemispheres, respectively. Hence, we would expect the measures of these two hemispheric processes to be highly correlated.

R Hemisphere Beta Component and Frontal Beta Component. The most sensible interpretation of the strong, positive correlation (r = .498) found between the right hemisphere beta component and the frontal beta component (C5) is that both components are measures of the same attention system (Mesulam, 1981; Posner, 1992). Indeed, both Posner and Mesulam have speculated and given justification for the existence of just such a system. If true, then the use of the frontal beta component as a covariate in subsequent heirarchical multiple regressions (Experiment 2) should necessarily reduce the predictive strength of the right hemisphere beta component when regressed on behavioral performance.

R Hemisphere Beta Component and Posterior Slow-Wave Components. As both slow wave components (C2 and C4) may measure electrocortical arousal (Davies & Parasuraman, 1982; O'Hanlon & Beaty, 1977), their strong association with the right hemisphere beta component (C2) (r_{C1} = .266; r_{C4} = .403) may represent the close interplay between general arousal and the right hemisphere attention system.

Conclusion

The AP5 measurement model has proven to be both reliable and valid measure of electrocortical activity. To my knowledge, the AP5 measurement model represents the first, and only, successful confirmation of a QEEG measurement model (i.e., component/factor structure) using an independent sample. Being reliable and possessing construct validity, the AP5 measurement model may be of significant clinical value in the diagnosis of brain dysfunction. If true, the EEG/CPT procedure, using the AP5 measurement model, would represent

an inexpensive, less invasive alternative to some of the more traditional diagnostic techniques presently being used.

Experiment 2

To extend the findings of Experiment 1, five component scores, comprising the AP5 measurement model, were examined over the course of a 23 minute CPT. Of particular interest was the behavior of the RHAC (C2) and concominant performance. Results from the previous study and those of metabolism, blood flow, reaction time (RT), and quantitative electroencephalogram (QEEG) suggest that the RHAC may be a measure of a right hemisphere attention system. However, because of the enormous variability, and the inconsistency with which experimental tasks have been chosen in those studies of attention and vigilance, the exact role of the right cerebral hemisphere is still unknown. In addition, much of this research has been correlational in nature and no direct attempt has been made to systematically manipulate the right hemisphere attention system. At the very least, however, it can be safely assumed, based on the findings of such studies, that the right cerebral hemisphere serves an important and unique role both in attention and in vigilance. The consensus from the results of these studies support the concept of an "Attention" system that is located in the right cerebral hemisphere (Jutai, 1984).

A Model of Attention (Posner)

The right hemisphere attention system was first incorporated into a formal model of attention by Posner in 1992. In the model, Posner (1992) postulated the

existence of three separate, yet associated attention systems within the brain. The first of the three systems has been termed the Posterior Attention System. Posner has suggested that the Posterior Attention System, which consists of both cortical and sub cortical areas, is involved in both covert orienting and the selective activation/inhibition of the appropriate cellular groups. The major structures involved in the Posterior Attention System are thought to be: a) the left and the right posterior parietal lobes, b) the pulvinar, and c) the superior colliculi (Mountcastel, 1978; Petersen, Robinson, & Morris, 1987; Wurtz, Goldberg, & Robinson, 1980).

The second attention system referred to by Posner is the Anterior Attention System. The primary role of this attention system is said to be the successive discrimination of incoming stimuli. A principal brain structure implicated as a major contributor in the anterior attention system is the anterior cingulate gyrus (Posner, Petersen, Fox, & Raichle, 1988).

A third, and a much more significant attention system for the present study, is the Arousal Attention System. The Arousal Attention System, as described by Posner and Petersen (1990), lay within the right cerebral hemisphere (i.e.,cortex), and has the primary responsibility of maintaining an alert state. By maintaining an alert state, the Arousal Attention System is thought to facilitate the efficient engagement of both the Anterior and the Posterior Attention Systems when environmental events deem their participation necessary (Posner & Petersen, 1990). While all three of the attention systems, as previously detailed by Posner, have been based upon a visual task paradigm, recent findings from cerebral blood flow studies suggest that both the Anterior Attention System and the right hemisphere Arousal Attention System play a significant role in the performance of visual, auditory and tactile vigilance tasks (Petersen, Fox, Posner, Mintun, & Raichle, 1988; Roland,1982, 1985).

A Right Hemisphere Attention System?

Cerebral Blood Flow and Glucose Metabolism

Recent advances in nuclear medicine have allowed researchers to take "snapshots" of the functioning human brain. Frequently, PET is the method used to "photograph" distributions of a radioactively labeled substance within the brain while a person performs a cognitive task. In order to trace cerebral blood flow a radioacitvely labeled tracer is placed into the blood stream either by injection (i.e.,radioactive isotope) or by inhalation (^{133}Xenon). The tracing of glucose metabolism in the brain is done by injecting radioactively labeled glucose into the blood stream. Because it is assumed that those brain regions that are most important for a particular cognitive task will use relatively more blood and glucose, the distribution of radioactively labeled substances is used to infer function of brain regions.

Pardo, Fox, and Raichle (1991) performed a CBF-PET study in which 23 participants (9 females, 14 males) where asked to perform both a visual (i.e.,light intensities) vigilance task and a somatosensory (i.e.,touch) vigilance task. Prior to each task participants received dosages of radioactively labeled solution intravenously (i.e.,$H_2{}^{15}O$ technique). Pardo et al. reported finding an enhanced activation (i.e.,increased blood flow) in both the right prefrontal and the right superior parietal cortices regardless of each task's stimulus modality. The results from this study support the concept of a right hemisphere attention system.

Haier, Siegel, Nuechterlein, Hazlett, Wu, Paek, Browning, and Buchsbaum (1988) had 30 right handed males perform a visual (i.e.,numbers) CPT after they had been injected with a radioactively labeled glucose solution (i.e.,fluoro-2-

deoxyglucose). Working under the assumption that the most active brain cells would absorb the most radioactively labeled glucose, Haier et al. reported finding an increased rate of glucose metabolism in the right hemisphere only.

Roland (1982) examined the regional CBF (rCBF) of 10 normal participants who were injected with a radioactive isotope (i.e., ^{133}Xenon) prior to performing: a) a visual (i.e., ellipses) selective attention task, b) a somatosensory (i.e.,shapes) selective attention task , and c) an auditory (i.e., tones) selective attention task. The major finding from this study was the consistent increase in blood flow, and presumably activation, of the right hemisphere and of the superior mesial frontal region (i.e., the cingulate area). Taken together, the findings from this study suggest the involvement of both a right hemisphere attention system and the Anterior Attention System, respectively, in performing a variety of CPTs.

In 1990, Buchsbaum, Nuechterlein, Haier, Wu, Sicotte, Hazlett, Asarnow, Potkin, and Guich, using the F-2-deoxyglucose technique, examined the regional brain metabolic rate of patients with schizophrenia (n=13) and of normals (n=37) while they performed a visual (i.e., numbers) CPT. While all of the schizophrenic patients, and half of the normal group actively performed the CPT, the other half of the normals were required to passively view the same visual stimuli presented in the CPT. Buchsbaum et al. reported finding significantly higher metabolic rates in both the right posterior frontal and the right parietal/temporal regions of the controls that had actively participated in the CPT than in the same cortical regions of both the passive controls and the patients with schizophrenia. In fact, Buchsbaum found the metabolism rate of the whole right hemisphere to be greater than the metabolism rate of the left hemisphere when controls actively participated in the CPT and not when the controls passively participated.

Cohen, Semple, Gross, Nordahl, DeLisi, Holcomb, King, Morihisa, and Pickar (1987) performed an experiment in which 16 patients diagnosed with

schizophrenia and 27 normal controls performed a 35 minute auditory (i.e., tones) CPT after having been injected with F-2-deoxyglucose. Cohen et al. reported a significant negative correlation between the metabolic rate of the middle prefrontal cortex (i.e., cingulate area) of normals and performance. The results from this study, while not suggesting the involvement of a right hemisphere attention system, does lend some support to the concept of an Anterior Attention System.

Deutsch, Papanicolaou, Bourbon, and Eisenberg (1987) described the results of a metaanalytic study in which they examined the data from 121 rCBF scans. The scans were taken under a variety of experimental conditions and protocols which included verbal and spatial tasks presented both auditorily and visually. Deutsch et al. focused primarily on the asymmetry (i.e., hemispheric) of blood flow and reported finding a consistent right frontal asymmetry. It was concluded that the right hemisphere plays a greater role in attention or vigilance than has been previously thought.

In 1988 Cohen, Semple, Gross, Holcomb, Dowling, and Nordahl examined the glucose metabolism (i.e., MET-PET) exhibited by 52 normal controls while they rested or performed either a continuous auditory discrimination task or a somatosensory task. Significantly higher and lower metabolic rates were found in the right middle prefrontal cortex and in the anterior cingulate/superior posterior parietal cortices, respectively, when participants performed the continuous auditory discrimination task. Moreover, they reported finding a significant positive relationship between the metabolic activity in the right middle prefrontal cortex and performance accuracy.

The accumulation of results obtained from studies of brain metabolism and brain blood flow lend support to the concept of a right hemisphere attention

system. However, due to the poor temporal resolution[5] of the PET scan procedure, the role of this hypothesized right hemisphere attention system is still quite unclear.

Reaction Time

RT has also been used to better understand the roles of the two cerebral hemispheres in attention. Underlying this research is the premise that a cerebral hemisphere which is intimately involved in the attention process should have the unique capability of quickly processing information that is in immediate need of attention. Conversely, damage to a cerebral hemisphere that is closely involved in the attention process should produce RTs that are very slow. The paradigm often used in this area of research may either involve the presentation of visual stimuli to the left and to the right cerebral hemisphere of "normals" or the bilateral presentation of visual/auditory stimuli to individuals with unilateral (i.e.,left or right) cerebral brain damage.

In 1970, Jeeves and Dixon performed a RT study in which 30 normal participants were asked to respond as quickly as they could to visual stimuli that were presented to either their left cerebral hemisphere (i.e.,right visual field) or to their right cerebral hemisphere (i.e.,left visual field). Participants were divided into three groups of 10 and were asked to respond to each visual stimulus with either their left hand, their right hand or both hands, respectively. Jeeves and Dixon reported finding that those participants who received visual stimulation initially in the right hemisphere responded faster than those participants who received the same information initially in the left hemisphere. Indeed, they found a right hemisphere advantage in RT regardless of hand used.

[5] Typically, the radioactively labeled tracer is measured over a 20 to 30 minute period (i.e., collapsed across time). This would be analogous to taking a photograph using a 20 to 30 minute exposure time.

Heilman and Van Den Abell (1979) had 24 normal participants respond to a centrally located RT stimulus after the presentation of either a left warning signal (WS), a right WS, or no signal at all. Heilman and Van Den Abell reported finding a significant reduction in RT for both the left and the right responding hand when the WS was presented in the left visual field (i.e.,presented to the right hemisphere). The same reduction in RT was not found for WS presented in the right visual field.

In a direct replication of Heilman and Van Den Abell's 1979 study, however, Nieves, Linz, Hynd, Connor, and Shapiro (1987) failed to find any support for the thesis that the right hemisphere mediates attention bilaterally. Nieves et al. had three separate groups of normal participants (i.e.,9, 13, and 18 year old) perform the same visual selective attention task as that used by Heilman and Van Den Abell (1979). For all three groups Nieves et al. reported finding no reliable difference in RT reduction between subjects who were presented with the left visual field WS and subjects who were presented with right visual field WS.

Whitehead (1991), in two separate experiments, had 15 and 24 normal participants perform a sustained visual attention task where participants were expected to press a button that represented the presence/location of an asterisk presented to either their left or to their right cerebral hemisphere. Using reaction times (RT) as the primary dependent measure, Whitehead reported finding a right hemisphere processing superiority under conditions of sustained attention. Despite the indirect nature of these findings, the right hemisphere (i.e.,left visual field) RT advantage obtained appears to support the concept of a right hemisphere attention system.

In a study designed to examine the RT of patients with left and right cerebral damage, Renzi and Faglioni (1965) had 166 patients perform a simple visual RT task that involved the pressing of a button once for each time a stimulus

light was presented. Renzi and Faglioni found the RTs of patients with right cerebral lesions to be significantly longer than the RTs of patients with left cerebral lesions. In fact this phenomenon held regardless of which hand the participant used.

Using simple RT and an auditory vigilance task, Howes and Boller (1975) examined the processing speeds of normals (younger n=16; older n = 16), left cerebral hemisphere patients (n=28), and right cerebral hemisphere patients (n=21). While both patient groups exhibited RTs that were significantly higher than those of the control groups, the right hemisphere patients possessed RTs that were significantly higher than the RTs of the left hemisphere patients. Furthermore, Howes and Boller found participant RTs to be independent of lesion size or lesion type.

It can be inferred from the RT literature that the right cerebral hemisphere may play a basic role in the attention process. Indeed, the participation of the right cerebral hemisphere in attention appears robust (Benton, 1986; Jutai, 1984) despite the lack of support found by some researchers (Nieves, Linz, Hynd, Connor, & Shapiro, 1987; Verfaellie, Bowers, & Heilman, 1988).

Electroencephalogram

The study of attention through QEEG has often revolved around the behavior of certain brain wave frequencies in relation to task demands. For the present line of research, task demands are attentional in nature. Two of the most widely used frequency bands in attention research are the alpha (7 to 13 Hz) and the beta (14 to 35 Hz) frequency bands. It is convention to view an abundance of alpha wave activity as indicating relative brain inactivation, while a predominance of beta wave activity (i.e.,wave desynchronization) as an indicate of brain activation.

Marquis, Glass and Corlett (1984) examined the alpha power of 12 normal participants at the occipital regions while the participants performed a visual vigilance task. Additionally, each participant experienced five different levels of task difficulty. They reported that the right occipital region exhibited the greatest alpha suppression in relation to the other cortical region. Indeed, Marquis et al. also reported finding that increased alpha suppression in the right occipital region was associated with increased task difficulty.

In another study done by Heilman and Van Den Abell (1980) 12 normal participants responded to a centrally located RT stimulus after the presentation of either a left warning signal (WS), a right WS, or no signal at all. In addition to measuring RT, Heilman and Van Den Abell also made bipolar QEEG recordings from the following montages: F3-C3, C3-P3, P3-O1, F4-C4, C4-P4, and P4-O2. In accord with the results of previous RT experiments, Heilman and Van Den Abell reported finding a significant reduction in RT for warning stimuli that were presented in the left visual field. Heilman and Van Den Abell also found a propensity for the right parietal lobe to desynchronize (i.e.,an abundance of beta) for warning stimuli that were presented both in the right and in the left visual field, while the left parietal lobe only desynchronized for warning stimuli presented in the right visual field. Based upon these findings it was suggested that the right parietal lobe may be dominant for attention (Heilman and Van Den Abell, 1980).

In 1990 Clayton and Friedman had 16 normal participants perform both a speech and a music sustained attention task while measuring QEEG from the following montage: C3-Cz, C4-Cz, F7-T3, F8-T4, T3-T5, T4-T6, P3-O1, P4-O2. Clayton and Friedman reported finding the greatest increase in beta activity, relative to the opposite cerebral hemisphere, in the right frontal cerebral cortex. The increase in right frontal beta activity was evident both in the speech task,

which is presumably a left hemisphere task, and in the music task, which is supposedly a right hemisphere task.

Shepherd (1982) made bipolar recordings from O1-P3, and O2-P4 while 40 normal participants performed an auditory vigilance test (i.e.,the Bakan Test). Contrary to the findings of previous research, however, Shepherd reported finding no significant hemispheric differences in theta (4 to 6 Hz), alpha (low, medium, and high), or beta. Still, Shepherd's failure to find any significant difference in QEEG between the two cerebral hemispheres may be legitimately brought into question, as Shepherd also failed to find a significant performance decrement.

In 1993, Valentino, Arruda and Gold, examined the QEEG of 27 good and 27 poorer performers while they performed a ten minute CPT. Participants were considered poorer performers if they made four or more omission errors in CPT2 (7^{th} to 10^{th} minute) than during CPT1 (2^{nd} to 5^{th} minute). Good performers consisted of participants who made fewer than 1 additional omission error during CPT2 than during CPT1. Eight bipolar recordings were measured from the following channels: Fp1-F7 and Fp2-F8 (frontal region); F7-T3 and F8-T4 (fronto-temporal region); T3-T5 and T4-T6 (temporal region); T5-O1 and T6-O2 (temporal-occipital region). Most notable was the finding of a significant difference in the predominance of high frequency beta (i.e., beta2) between good and poorer performers. For the poorer performers, a decline in performance was accompanied by a decline in temporal beta2 power. This suggests that the temporal lobes, both right and left, may play a significant role in the attention process.

Weiler (1993) examined the decline of both performance and QEEG while 102 normal controls performed a ten minute, auditory CPT. Eight bipolar recordings were measured from the following eight channels: Fp1-F7 and Fp2-F8 (frontal region); F7-T3 and F8-T4 (fronto-temporal region); T3-T5 and T4-T6

(temporal region); T5-O1 and T6-O2 (temporal-occipital region). Of the eight component scores derived, two were comprised of anterior slow waves, two were comprised of left and right hemisphere beta (respectively), one was comprised of frontal alpha, one was comprised of frontal beta, and two were comprised of posterior slow waves. The results of two standard multiple regressions suggested that a significant relationship existed between the changes seen in the right hemisphere beta component, as measured between CPT1 and CPT2, and performance decrement.

Results from EEG, together with the findings from studies of brain metabolism, blood flow, and RT, strongly suggest that the right cerebral hemisphere plays an important role in attention processing. As the RHAC was both derived and confirmed using an attention task paradigm (i.e., CPT), it is conceivable that the RHAC is a reliable measure of the right hemisphere attention system.

Hypotheses and Predicictions

It is hypothesized that the RHAC is a valid index of the right hemisphere attention system, and as such, should behave in a predictable manner during the course of a CPT. For the purposes of the proposed study participants had performed a resting condition, followed by a 25 minute CPT, during which four evenly spaced measurements of QEEG and behavioral performance were taken (i.e., CPT1, CPT2, CPT3, CPT4). For the purposes of this experiment, resting, CPT1, CPT2, CPT3, and CPT4 constitute the five levels of the repeated measures component TRIAL. The following predictions are made:

(1) The RHAC will significantly increase, moving from RESTING to CPT1.

(2) The RHAC will exhibit a significant decrease, moving from CPT1 to CPT4.

(3) Significant differences in QEEG power will be found between the RHAC and the left hemisphere component during CPT.

(4) Changes in the RHAC (i.e., CPT1-CPT2 change; CPT2-CPT3 change; CPT3-CPT4 change) will be significantly correlated with, and predictive of, changes in concominant behavioral performance (i.e., detection latencies & proportion of correct responses)

(5) Behavioral performance (i.e., detection latencies & proportion of correct responses) will also exhibit a significant decrease, moving from CPT1 to CPT4.

Methods

Participants

Forty-seven participants (12 men, 35 women) were recruited from a general psychology course (PSY113) and a junior level perception course (PSY385) at URI. Participants earned credit towards their final course grade in return for their participation. The ages of the participants ranged from 18 to 24, with an mean age of 18.94 (SD = 1.24). Participants were all right handed as assessed by a modified version of the Edinburgh Handedness Inventory (Oldfield, 1971). All participants were free of any neurological conditions, birthing complications, or loss of consciousness greater than two minutes. This protocol has been reviewed and accepted by The URI Human Subjects Review Board.

Apparatus

A description of the apparatus can be found in Experiment 1.

Procedure

A description of the basic procedure can be found in Experiment 1. However, in order to test the hypotheses and predictions made in experiment 2,

two additional CPTs (i.e., CPT3 and CPT4) were added. Hence, QEEG and behavioral performance was measured at 45 seconds (CPT1), 6 minutes and 45 seconds (CPT2), 12 minutes and 45 seconds (CPT3), and 18 minutes and 45 seconds (CPT4).

Component Scores

Component scores were derived by the unit weighting, and averaging of all observable QEEG variables loading on a component (i.e., three variables per component score). The averaging procedure was chosen as it produced component scores that were of the same metric as the original observable variables.

Performance Measures

Behavioral performance was operationally defined as the average detection latency (DL), as measured in milliseconds (msec.), during a two minute epoch. A DL was operationally defined here as a button press coming within 1000 msec (1 second) of a target presentation. Errors of omission (i.e., target presentation and no response) were given a default DL of 1000 msec. Detection latency has been used as a measure of performance for some time and has proven to be a reliable and sensitive measure of vigilance loss (Davies and Tune, 1970).

The Omission Error Index (IO = omissions/omission opportunities) was used as an additional behavioral performance measure. For ease of interpretation the IO was subtracted from 1.0, representing the proportion of correct hits. A response was considered an omission error if a participant fails to respond within 1000 msec. of the presentation of a target.

Statistical Analyses

Analysis of Variance (ANOVA) on the RHAC. A one-way ANOVA was conducted using the RHAC as a dependent measure and TRIAL as a repeated measures component. As it may be unrealistic to assume that all variances are equal (i.e., the homogeneity assumption), all simple and main effect tests were subjected to the Greenhouse-Geisser df adjustment[6] . (Predictions 1 & 2)

Two-Way Analysis of Variance. A two-way, repeated measures ANOVA (2 x 5 x S) was conducted using the left hemisphere beta component and the RHAC as the two levels of the repeated measures component HEMISPHERE, and RESTING, CPT1, CPT2, CPT3, and CPT4 as the five levels of the repeated measures component TRIAL. Because it could be argued that the RHAC, being comprised of beta wave frequencies, is simply an index of high frequency muscle movement, the left hemisphere beta component was also included in the analysis. All simple effect, main effect, and interaction effect tests were subjected to the Greenhouse-Geisser df adjustment.(Prediction 3)

Multiple Regressions. In the spirit of model building, six hierarchical regressions were performed using the proportion of change in component scores (i.e., CPT1-CPT2, CPT2-CPT3, and CPT3-CPT4) as predictors and the proportion of change in behavioral performance as the criterion (i.e. hit-decrement, DL-decrement). The proportion of change was defined by the following formula: (Pre-Post) / ((Pre+Post)/2). In all six analyses the right hemisphere component was forced into the equation last, using all of the remaining components as covariates. (Prediction 4)

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[6] To avoid the use of decimals, the **unadjusted** degrees of freedom will be reported with all F values. However, all probability levels will correspond to the **adjusted** degrees of freedom. This will be true for all of the Greenhouse-Geisser adjustments made.

In order to more fully define and describe each component, six simple multiple regressions were also performed using the same predictors and criterion variable as mentioned above. The resulting squared semi-partial correlations (sr^2) provided a measure of the proportion of performance variance that each component accounted for independent of the contributions made by the remaining components.

Analysis of Variance on Performance. Two, one-way ANOVAs were conducted using DL and the proportion of correct hits as the dependent measures and TRIAL as a repeated measures component. However, because performance was the dependent measure of interest, the repeated measures component TRIAL only possessed four levels (CPT1, CPT2, CPT3, CPT4). The main effect test of TRIAL was subjected to the Greenhouse-Geisser df adjustment. (Prediction 5)

Analysis of Variance on Remaining Components. Separate, one-way ANOVAs were conducted using the remaining components (i.e., C1, C4, and C5) as dependent measures and TRIAL as a repeated measures component. All three main effect tests were subjected to the Greenhouse-Geisser df adjustment.

Results

Predictions 1 & 2

The means and standard deviations for all of the component and performance measures can be found in Table 5. The predictions that the RHAC would show both a significant increase, and a significant decrease, moving from RESTING to CPT1, and from CPT1 to CPT4, respectively, were supported by the results of the present experiment. Following a significant overall main effect for TRIAL, $\underline{F}(4,184) = 8.79$, $p < .01$ (Table 6), post hoc comparisons using Tukey's honestly significant difference (HSD) test revealed significant differences between RESTING ($\underline{M} = 4.08$, $\underline{SD} = 3.41$) and CPT1 ($\underline{M} = 6.37$, $\underline{SD} = 4.72$); RESTING

and CPT2 ($\underline{M}$ = 5.78, $\underline{SD}$ = 4.63); CPT1 and CPT3 ($\underline{M}$ = 4.62, $\underline{SD}$ = 3.57), and between CPT1 and CPT4 ($\underline{M}$ = 4.68, $\underline{SD}$ = 4.15). No significant differences were found between (1) RESTING, CPT3 and CPT4, and (2) CPT1 and CPT2 (Table 7).

Prediction 3

The prediction that significant differences would be observed between the RHAC and the left hemisphere component during the CPT was supported by a significant interaction effect between TRIAL and HEMISPHERE, $\underline{F}(4,184)$ = 4.04, $p < .01$ (Table 8). Follow-up simple main effect tests revealed marginally significant differences between the RHAC and the left hemisphere component during both CPT1, $\underline{F}(1,46) = 3.22$, $p = .08$), and CPT2, $\underline{F}(1,46) = 3.57$, $p = .07$), but not during RESTING , CPT3 or CPT4 (Figure 7). When an adjustment was made for hemispheric group differences at RESTING, the RHAC was found to be significantly larger than the left hemisphere component during both CPT1, $\underline{F}(1,45)$ = 4.94, $p = .03$), and CPT2, $\underline{F}(1,45) = 9.12$, $p = .004$), but not during CPT3 and CPT4 (Figure 8).

Prediction 4

The results of the multiple regressions (i.e., 6 Standard, 6 Heirerarchical) do not support the prediction that the RHAC would be significantly correlated with, and predictive of, changes in concominant behavioral performance (i.e., change in hits and in DL). As can be seen in Tables 10, 13, 16, 19, 22, and 25, the RHAC did not account for a significant proportion of the variance in either hit-decrement or DL-decrement when the predictive effects of the remaining components were partialed out. The mean squared semi-partial correlation (sr^2) found between the

RHAC and both measures of performance decrement was .01,and ranged from 0.0 to .09.[7] (Tables 11, 14, 17, 20, 23, 26),

More interesting was the apparant lack of relationship between RHAC change and performance decrement even prior to the extraction of covariance between the remaining components and performance decrement (Tables 9, 12, 15, 18, 21, and 24). Pearson Product-Moment Correlations between RHAC change and hit-decrement ranged from -.05 to .28, with a mean value of .11. Pearson Correlations between RHAC change and DL-decrement ranged from 0.0 to -.17, with a mean value of -.06. These correlations, while in the right direction, were still quite small. In fact, the RHAC only accounted for approximately 8% and 3% of the variability observed in both hit-decrement, and DL-decrement, respectively.

The Posterior Slow Wave Components. A strong relationship was found betweeen both posterior slow wave components and performance decrement. Pearson Correlations involving hit-decrement ranged from .22 to .61 for C1 (M = .41), and from .16 to .46 for C4 (M = .35). Correlations involving DL-decrement ranged from .04 to -.39 for C1 (M = -.21), and from .02 to -.34 for C4 (M = -.22). However, when the effects of the remaining components were held constant, the proportion of variance accounted for by each of the slow wave components was exceedingly low (mean sr^2_{c1} = .07, mean sr^2_{c2} = .02).

Prediction 5

Proportion of Correct Responses. The prediction that a significant decrease in the proportion of correct responses would be found, moving from CPT1 to CPT4, was supported by a significant main effect for TRIAL F(3,138) = 22.79, p < .01 (Table 27). Post hoc analyses using Tukey's HSD test revealed significant mean differences in the proportion of correct responses for all, but the CPT2-CPT3

[7] Otherwise known as Change in RSQ in the Heirarchical Regression solution.

pairwise comparison (Table 28). Early CPTs (e.g., CPT1) exhibited a greater percentage of correct responses than did subsequent CPTs (e.g., CPT2) (Figure 9).

DL. The prediction of a significant DL decrement, moving from CPT1 to CPT4, was supported by a significant main effect for TRIAL $F(3,138) = 27.74$, $p < .01$ (Table 29). Post hoc pairwise comparisons using Tukey's HSD test revealed significant DL differences between CPT1-CPT2; CPT1-CPT3, and CPT1-CPT4. No other significant differences were found (Table 30). CPT1 possessed DLs that were significantly shorter than those of CPT2, CPT3, and CPT4 (Figure 9).

Condition Effects on Remaining Components.

Posterior Slow Wave Component I (C1). A non-significant main effect for TRIAL was found, signifying relatively little change in the power of the slow wave component over the course of the TRIAL, $F(4,184) = 2.82$, $p = .06$ (Figure 10).

Posterior Slow Wave Component II (C4). No significant main effect was found for TRIAL, which suggests a lack of change in the slow wave component over the course of the TRIAL, $F(4,184) = .92$, $p = .41$ (Figure 10).

Anterior Fast Wave Component (C5). Once again, the main effect for TRIAL was not significant, which indicates that there was relatively little change in the fast wave component over the course of the TRIAL, $F(4,184) = .11$, $p = .82$ (Figure 11).

Left Hemisphere Beta Component (C3). A significant main effect for TRIAL was found, indicating that C3 QEEG power levels varied with the different TRIAL conditions, $F(4,184) = 3.77$, $p < .05$. However, a post hoc Tukey HSD test revealed no signficant mean differences in QEEG power between any of the five TRIAL conditions (i.e., resting, CPT1, CPT2, CPT3, CPT4) (Table 31).

Test-Retest Reliability

Six, twelve, and eighteen minute test-retest reliabilities were calculated for all component and performance measures using the Pearson Product-Moment Correlation (Table 32). With the exception of those reliabilities calculated for C2 and C3 at eighteen minutes, all five component measures demonstrated excellent test-retest reliability. Of the two performance measures used, only the DL demonstrated adequate test-retest reliability. Test-retest reliabilities for the proportion-of-hits ranged from .50 (18 min.) to .58 (12 min.), with a mean score of .55. Test-retest reliabilities for DL ranged from .62 (18 min.) to .79 (6 min.), with a mean score of .70.

Discussion

Predictions 1 & 2

As predicted, the RHAC (C2) proved exceedingly sensitivity to changes in TRIAL conditions. In addition to showing a signficant increase in power, moving from resting to CPT1, the RHAC also showed a significant decrease in power moving from CPT1 to CPT4. The remaining components proved insensitive to changes in TRIAL. These results stand in contrast to the assertion by Davies and Parasuraman (1983) that the only prerequisite for a shift from higher to lower EEG frequencies (i.e., decrement in beta freqencies, increase in delta, theta, alpha frequencies) is that the experimental situation be monotonous and prolonged. In the present experiment, components comprised of fast (C3 & C5) and slow (C1 & C4) wave frequencies showed no such increase or decrease, respectively, with time spent on TRIAL (23 minutes). These results are consistent, however, with those of Valentino et al, (1993) and Weiler (1993).

Using task paradigms identical to that of the present study , both Valentino et al, (1993) and Weiler (1993) reported finding a significant increase in the level of temporal beta2 power, as participants moved from resting to CPT1. Valentino et al, (1993) also reported finding that a decline in performance was strongly associated with a decline in temporal beta2 power.

Prediction 3

Support for the hypothesis that the RHAC is a reliable and valid measure of the right hemisphere attention system comes from the finding that the RHAC (C2) and the left hemisphere beta component (C3) behaved quite differently over the course of the CPT. While the power levels of the left hemisphere beta component remained relatively stable across the five TRIAL conditions, RHAC power levels increased sharply with the onset of the CPT, and then decreased as behavioral performance declined. The RHAC also exhibited CPT3 and CPT4 power levels that were statistically identical to that of resting, representing a return to baseline. Previous research that has examined the attention phenomenon using measures of metabolism, blood flow, RT, and QEEG appear to support this interpretation of the present results (Benton, 1986; Buchsbaum et al, 1990; Clayton & Friedman, 1990; Cohen et al, 1988; Deutsch et al., 1987; Heilman & Van Den Abell, 1979; Heilman & Van Den Abell, 1980; Howes & Boller, 1975; Jeeves & Dixon, 1970; Jutai, 1984; Marquis et al., 1984; Pardo et al, 1991; Petersen et al., 1988; Posner, 1992; Posner & Petersen, 1990; Renzi & Faglioni, 1965; Roland, 1982, 1985; Valentino et al, 1993; Weiler, 1993; Whitehead, 1991).

By contrast, this finding does not support the supposition by Duffy et al., (1992) that all measures comprised of temporal beta are solely a measure muscle artifact. The RHAC, while similar to the left hemisphere beta component during resting, CPT3, and CPT4, was significantly different from the left hemisphere beta

component during periods of maximum attention (i.e., CPT1 and CPT2). In the present experiment, level of attention was operationally defined as the proportion-of-hits and the level of DL. Interestingly, it was Duffy et al, (1992) who reported that measures comprised of fast frequency beta could reliably discriminate the age, sex, and clinical status of participants.

Prediction 4

The prediction that the RHAC would be significantly correlated with, and predictive of, changes in behavioral performance was not supported by the results of the multiple regressions. The RHAC accounted for less than 9% of the variance in performance decrement when the influence of the remaining five component structures were removed. These results are consistent with those of Weiler (1993), however.

Weiler performed a series of standard multiple regressions using the change in component scores as predictors and the change in performance as the criterion. Of particular interest were the results of the AP8, and the AP12 multiple regressions. In both solutions, the RHAC accounted for less than 4% of the variability observed in performance change. However, unlike the findings of the present study, contributions made by the RHAC were statistically significant at the .05 level (Weiler, 1993). This apparant discrepancy between the results of the present study and those of Weiler could conceivably have been a function of statistical power, as the sample size in the present study was 47 and the sample size used by Weiler was 102.

Similar to the present results, Weiler did not find significant effects for either the AP8 and the AP12 multiple regressions. With the exception of two multiple regression equations (CPT2-CPT3 change and CPT3-CPT4 change) tested in the present study, all of the remaining multiple regression equations

failed to predict change in performance to any significant degree. A post hoc appraisal of statistical power revealed power levels ranging from .12 to .56 (M = .35) for the non-significant multiple regressions, and from .85 to .99 (M = 92) for the two significant multiple regressions. Power levels for the two multiple regressions performed by Weiler were .56 (AP8) and .77 (AP12) (M = .67).

One explanation for the apparent lack of statistical power, and subsequent non-significant results, revolves around the reliability of the change scores used. Indeed, research suggests that the combination of two unreliable measures will produce a third that is much more unreliable (Willis & Goodwin, 1987). A post hoc evaluation of the test-retest reliability of component and performance change scores revealed reliabilities that were exceedingly low, ranging from .02 to -.43 for the components, and from -.06 to -.35 for the performance measures (Table 33). In fact, the most acceptable reliabilities came from those change measures used in the two significant multiple regressions. These findings are in agreement with those of Weiler (1993) who attributed the non-significance of his multiple regressions to the use of unreliable omission error change scores.

Prediction 5

The results of the present study also support the prediction that performance would decline with increased time on task. As the proportion-of-hits declined, moving from CPT1 to CPT4, DLs increased. The primary importance of this finding was merely to demonstrate that the TRIAL manipulation actually had taken affect. Hence, the attention level of participants, as operationally defined in the present experiment as the proportion-of-hits and DLs, did decline.

Test-Retest Reliabilities

Test-retest reliabilities for all five component scores were excellent, suggesting further that the oblique, AP5 measurement model could be used to reliably discriminate between and among clinical and control groups. These results are in strong agreement with those of Arruda et al., (1994). Using an independent sample of 102 participants, Arruda et al., found six minute, test-retest reliabilities ranging from .74 to .96 ($\underline{M}$ = .85). In the present experiment, six minute, test-retest reliabilities ranged from .77 to .97 ($\underline{M}$ = .90). With the exception of the 18 minute, test-retest reliabilities calculated for the RHAC and the left hemisphere beta component, the remaining test-retest reliabilities were exceptional.

Test-retest reliabilities calculated for the proportion-of-hits and DL were modest. While the reliabilities averaged in the low 70s for DL, the mean reliability score for the proportion-of-hits was .55. Six minute, test-retest reliabilities for DL and proportion-of-hits were .79 and .56, respectively. These results are in agreement with those of Halperin et al., (1991) who reported finding moderate five month, test-retest reliabilities for hit reaction times (range: .65 to .74). Similarly, Weiler (1993) found one-week, test-retest reliability for the proportion-of-hits to be extremely low (r_{tt} = .37). More troublesome was the finding that the conversion of whole scores to change scores resulted in a 55% reduction in the test-retest reliability in all measures. This finding is in strong agreement with Willis and Goodwin (1987). As both the proportion-of-hits and DL lack the necessary level of reliability, future research utilizing such measures must seek to elevate the statistical power of tests by necessarily increasing the sample sizes used.

Conclusion

Unlike the remaining component scores, the RHAC proved extremely sensitive to changes in task conditions. As changes in task conditions were also associated with varying levels of attention, the present findings suggest that the RHAC may be a reliable and valid measure of the right hemisphere attention system. Unfortunately, the use of unreliable change scores made the verification of a direct relationship between the RHAC and behavioral performance difficult.

High test-retest reliabilities for the RHAC and remaining components suggests that the oblique, AP5 measurement model could be used to reliably discriminate between and among clinical and control populations. For instance, as we now presently have a database consisting of 208 men and women, ages 18 to 25 years old, the RHAC could conceivably be used to identify young adults in this age group who suffer from attention deficit disorder (ADD).

Appendix A

Handedness Inventory
QEEG Study
Adapted from the Edinburgh Inventory

Have you ever had any tendency toward left-handedness?
Yes No
Is anyone in your family left-handed (i.e., parents, siblings)?
Yes No
If you are left-handed, do you write with an inverted hand posture?
Yes No

Please indicate your preference in the use of hands in the following activities by putting + in the appropriate column. Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, put ++. If in any case you are really indifferent, put + in both columns.

Please try to answer all of the questions, and only leave a blank if you have no experience at all of the object or task.

Right	Left	
		Writing
		Drawing
		Throwing
		Scissors
		Comb
		Toothbrush
		Spoon
		Hammer
		Striking a match (match)
		Opening a book (lid)
		Dealing cards
		Which foot do you prefer to kick with?
		Which eye would you use to look through a telescope?

Group_____ #_____

Appendix B

Informed Consent

Subject/Patient Name_____ Institution_____

Location_____

I have been asked to take part in a research project (described below). I should feel free to ask questions of the researcher. If I have more questions later, Dr. Valentino, the person mainly responsible for the study (792-4233), will discuss them with me. I may participate in the study or I may change my mind and withdraw at any time by contacting Dr. Valentino (792-4233). I understand that I will not receive payment for my participation, nor will I be penalized in any way if I withdraw.

Researchers at the University of Rhode Island Dept. of Psychology are conducting a study to observe changes in the electroencephalogram (EEG) during different tasks. As part of this study, I will be asked to sit for an EEG recording session. Up to 16 electrodes will be placed against my scalp and held there by a comfortably fitted headband. The electrodes are flat metal disks about 1/4 inch in diameter. Another may be taped on my forehead above my eye. A drop of electrode cream will be placed under each electrode. This procedure may take up to 45 minutes. Under no circumstances will electricity ever pass from the recording equipment to my body.

During the actual EEG recording session, which may last up to 30 minutes, I understand that I will be asked to perform a simple mental task, such as listening for letters or sounds and signifying by pressing a button.

After the recording session, the EEG technician will remove the electrodes. He/She will remove most of the electrode cream with water, but I may want to wash my hair when I get home. The cream is not harmful, but it is a little messy.

As part of this study, I may also be asked to fill out brief forms regarding personal information, such as my health, handedness, skills, etc.

This study will provide knowledge about how the brain processes information and where the processing may take place. This knowledge will help clinicians to do a better job recognizing abnormal EEG patterns.

My privacy will be protected during the course of the study. Though the computer disk on which my records are stored may contain a label with my Social Security number, my data will always be labled with a number code available only to Dr. Valentino. I will not be identified in any publication of this study.

If I am not satisfied with the way the study is performed, I may discuss my complaints with Dr. Valentino or with the Psychology Department Chairperson, Dr. Janet Kulberg (792-2193), anonymously, if I choose. In addition, I may contact the office of the Vice Provost for Research, 70 Lower College Road, University of Rhode Island, Kingston, R.I., telephone: (401) 792-2635.

I have read the Consent Form. My questions have been answered. My signature on this form means that I understand the information and I agree to participate in this study.

Signature_____ Date_____

[redacted]_____ Date_____

Investigator [redacted]_____ Date_____

C_____

1. Have you ever had a head injury? a. yes
b. no

If answer to #1 was "yes", answer questions 2-6, if "no" skip to # 7.

2. Were you seen in a hospital for your head injury? a. yes
b. no

3. Approximate date(s) of head injury(s)?
_____;_____;_____

4. Did you lose consciousness during the head injury? a. yes
b. no

5. Did you have amnesia (can't remember what happened) for a time before the head injury? a. yes
b. no

Approximately how long in minutes_____

6. Did you have amnesia (can't remember what happened) for a time after the head injury? a. yes
b. no

Approximately how long in minutes_____

7. Have you ever lost consciousness anytime other than a head injury?
a. yes
b. no

Please describe_____

8. Have you ever or anyone in your immediate family ever had a neurological disorder such as: epilepsy, Tourette's syndrome, Parkinson's disease or attention deficit disorder?
a. yes
b. no

Please describe

If answer to #8 was "yes", then answer #9, if "no" skip to #10.

9. How far removed from yourself was the relative with a neurological condition?

a. myself
b. sibling
c. parent
d. grandparent
e. aunt/uncle

10. When was your most recent use of of caffeine?

a. <4 hours ago
b. 4 to 12 hrs
c. 12 to 24 hrs
d. more than 1 day
e. never

11. When was your most recent use of of tobacco?

a. <4 hours ago
b. 4 to 12 hrs
c. 12 to 24 hrs
d. more than 1 day
e. never

12. Have you or anyone in your immediate family ever been diagnosed as having attention deficit disorder, dyslexia, or a learning disability?

a. yes
b. no

Please describe_____

If answer to #12 was "yes", then answer #13, if "no" skip to #14.

13. How far removed from yourself was the relative with a neurological condition?

a. myself
b. sibling
c. parent
d. grandparent
e. aunt/uncle

14. Are you currently taking any medications?

a. yes
b. no

If yes, what medication _____
Dosage per day _____

What do you take this medication for?

5. Have you ever been treated or hospitalized for psychiatric reasons such as depression, schizophrenia, bipolar disorder or anxiety?

a. yes
b. no

6. Has anyone in your immediate family ever been treated or hospitalized for psychiatric reasons such as depression, schizophrenia, bipolar disorder or anxiety?

a. yes
b. no

17. Have you ever been treated for drug or alcohol problems?

a. yes
b. no

18. Are you aware of any birthing complications associated with your birth?

a. yes
b. no

please describe _____

19. Did you have any prolonged periods of high fever as an infant?

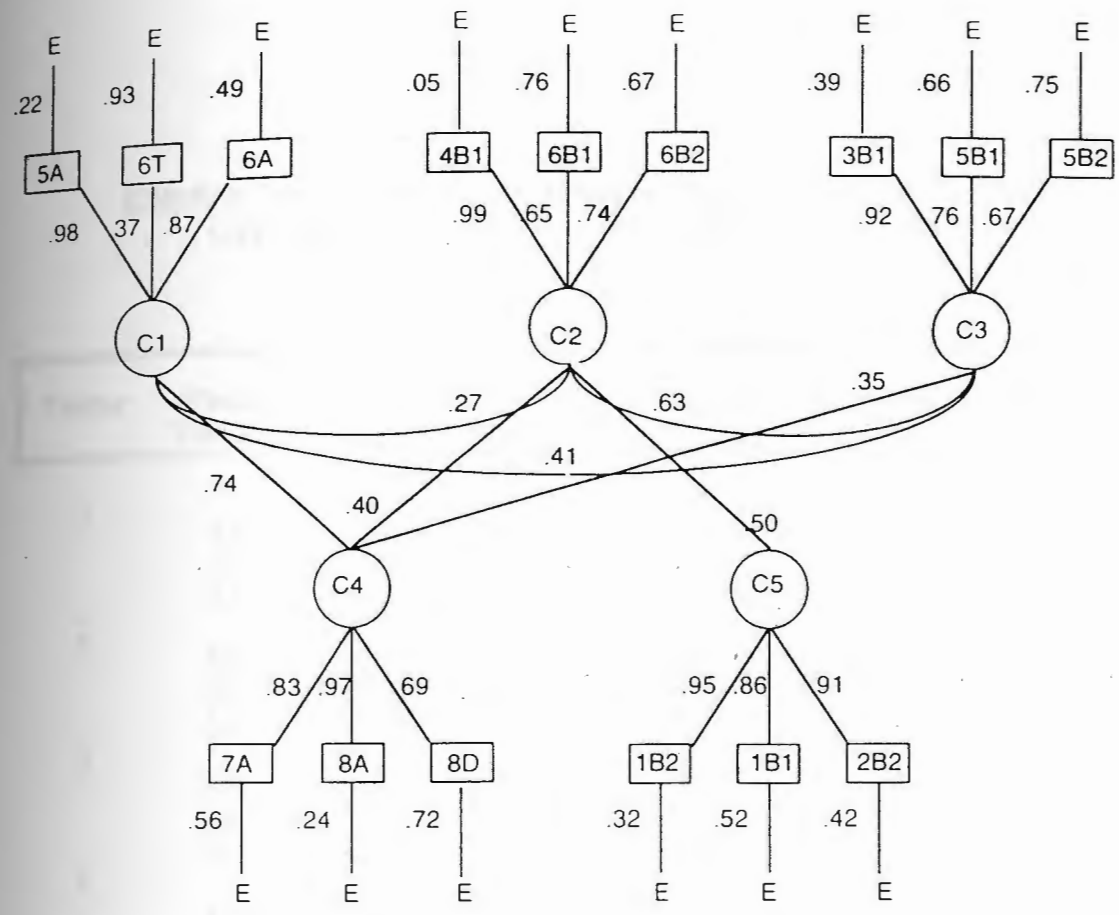
a. yes
b. no

20. Have you ever had an EEG before?

a. yes
b. no

Why was it ordered? _____

Appendix C



Path diagram of the oblique AP5 measurement model. C1: Posterior Slow 1; C2: RHAC; C3: Left Hemisphere Beta; C4: Posterior Slow 2; C5: Frontal Fast Beta

Table 1

Elliptical Reweighted Least Squares Factor Loadings for the Orthogonal, AP6 Measurement Model (N = 106)

Factor	Factor Variable	Factor Loading	Error Variance	Skewness	Kurtosis	Coefficient Alpha
1						0.77
	5A	0.86	0.52	2.61	7.47	
	6T	0.40	0.92	5.91	44.06	
	6A	0.99	0.13	2.73	8.26	
2						0.75
	4B1	0.97	0.24	2.03	5.14	
	6B1	0.67	0.74	2.35	7.40	
	6B2	0.76	0.65	2.53	7.62	
3						0.81
	3B1	1.00	0.08	1.93	5.14	
	5B1	0.70	0.72	2.42	10.77	
	5B2	0.64	0.77	1.50	2.13	
4						0.93
	1B2	0.95	0.32	4.07	17.53	
	1B1	0.85	0.52	3.09	14.66	
	2B2	0.91	0.41	4.63	24.74	
5						0.86
	7A	0.81	0.59	2.28	5.25	
	8A	1.00	0.00	1.63	2.03	
	8D	0.68	0.73	1.71	3.37	
6						0.82
	1A	0.75	0.66	2.44	8.11	
	2A	0.93	0.38	2.12	4.67	
	3A	0.67	0.75	3.07	15.26	

Note: All component loadings were statistically significant at $p < .001$.

Table 2

Elliptical Reweighted Least Squares Factor Loadings for the Oblique, AP5 Measurement Model (N = 106)

Factor	Factor Variable	Factor Loading	Error Variance	Skewness	Kurtosis	Coefficient Alpha
1						0.77
	5A	.976	.218	2.61	7.47	
	6T	.365	.931	5.91	44.06	
	6A	.871	.491	2.73	8.26	
2						0.75
	4B1	.999	.05	2.026	5.14	
	6B1	.652	.758	2.35	7.4	
	6B2	.738	.674	2.53	7.62	
3						0.81
	3B1	.923	.385	1.93	5.14	
	5B1	.755	.655	2.42	10.77	
	5B2	.667	.745	1.5	2.13	
4						0.86
	7A	.83	.558	2.28	5.25	
	8A	.97	.242	1.63	2.03	
	8D	.693	.721	1.71	3.37	
5						0.93
	1B2	.949	.315	4.07	17.53	
	1B1	.856	.517	3.09	14.66	
	2B2	.906	.424	4.63	24.74	

Note: All component loadings were statistically significant at $p < .001$.

Table 3

Pairwise Pearson Correlation Coefficients for the Oblique, AP5 Measurement Model

	C1	C2	C3	C4	C5
C1 Slow 1	----------	.35*	.41*	.63*	.16
C2 RHAC	----------	----------	.62*	.36*	.38*
C3 Left β	----------	----------	----------	.31*	.20
C4 Slow 2	----------	----------	----------	----------	.15
C5 Front β	----------	----------	----------	----------	----------

Note: *Statistically significant at $p < .005$, using a one-tailed test and a Bonferroni adjustment. Family-wise error rate was set to .035.

Table 4

A Comparison of the Fit of all Eight Measurement Models

[redacted]rement Model	N	χ^2	df	χ^2/df	CFI	RMR
Null	106	827.19	105	7.88	---	---
1 Factor	**106**	**408.94**	**94**	**4.35**	**.50**	**.150**
Orthogonal AP5 (Random)[cc]	**106**	**352.76**	**90**	**3.92**	**.59**	**.240**
Oblique AP5 (Random)	**106**	**314.55**	**80**	**3.93**	**.76**	**.140**
Orthogonal AP6[cc]	106	308.36	135	2.28	.79	.228
Orthogonal AP6[cc]	208	319.71	135	2.37	.80	.192
Orthogonal AP5[cc]	**106**	**207.93**	**90**	**2.31**	**.83**	**.200**
Oblique AP5	106	183.04	80	2.29	.92	.058

Note: [cc] = Condition Code.

Bold = The four additionall proposed measurement models.

Table 5

Means and Standard Deviations for all QEEG Component Scores and Performance Measures across TRIAL

	RESTING		CPT1		CPT2		CPT3		CPT4	
	M	SD	**M**	SD	**M**	SD	**M**	SD	**M**	SD
C1 Slow 1	**34.93**	37.40	**34.38**	38.29	**31.68**	36.15	**30.83**	35.81	**29.68**	35.35
C2 RHAC	**4.08**	3.41	**6.37**	4.72	**5.78**	4.63	**4.62**	3.60	**4.68**	4.15
C3 Left β	**4.50**	3.56	**5.51**	3.82	**4.82**	3.20	**4.53**	3.15	**4.36**	3.09
C4 Slow 2	**28.19**	23.29	**30.76**	27.03	**29.66**	26.33	**28.60**	25.53	**28.00**	27.05
C5 Front β	**2.49**	5.12	**2.34**	3.07	**2.22**	2.46	**2.42**	2.26	**2.43**	2.10
Hits	---	---	**.865**	.082	**.767**	.154	**.743**	.167	**.663**	.259
DL	---	---	**.678**	.093	**.744**	.088	**.747**	.014	**.769**	.117

Hits = frequency of hits/total target frequency

DL = The time in msec. that it takes for a participant to respond following the presentation of a target.

Table 6

Source Table for TRIAL: RHAC as the Dependent Measure*

Source	SS	df	MS	F	p<
TRIAL	165.50	4	41.38	8.79	0.01
T x Subjects	866.12	184	4.71		
Total	7256.55	234			

*The variability due to between subjects differences (Subjects), while not included in the table, were used in the calculations of SS_{total} and df_{total}.

Table 7

Pairwise Comparisons of the Five Levels of TRIAL, using Tukey's HSD Test:

Dependent Measure is the RHAC

Cells contain the Q Statistic

	RESTING	CPT3	CPT4	CPT2	CPT1
RESTING	---	---	---	---	---
CPT3	1.71	---	---	---	---
CPT4	1.90	0.19	---	---	---
CPT2	5.28*	3.57	3.38	---	---
CPT1	7.23*	5.53*	5.34*	1.86	---

*p < .01 level of significance.

$Q = x_i - x_j / \sqrt{MS_W/n_j}$

Table 8

Source Table for TRIAL x HEMISPHERE: QEEG Power as the Dependent Measure*

Source	SS	df	MS	F	p
TRIAL	175.27	4	43.82	7.98	0.00
T x S	1009.82	184	5.49		
Hemisphere	15.32	1	15.32	1.08	0.31
H x S	651.24	46	14.16		
T x H	30.26	4	7.56	4.04	.004
T x H x S	344.31	184	1.87		
Total	13624.88	469			

*The variability due to between subjects differences (Subjects), while not included in the table, were used in the calculations of SS_{total} and df_{total}.

Table 9

Correlation Matrix on the Proportion of Change from CPT1 to CPT2.

Criterion: Proportion of Hits Predictors: Component scores

	HITS	C3	C5	C1	C4	C2
HITS	1.00					
C3 Left β	.04	1.00				
C5 Front β	-.01	.37	1.00			
C1 Slow 1	.22	.04	-.22	1.00		
C4 Slow 2	.16	-.25	-.11	.70	1.00	
C2 RHAC	.09	.54	.40	.14	-.07	1.00

Hits = frequency of hits/total target frequency

Table 10

Heirarchical Multiple Regression on the Proportion of Change from CPT1 to CPT2.

Criterion: Proportion of Hits Predictors: Component scores

Component	R	RSQ	Change in RSQ	F to Enter
C3 Left β	.04	.0010	.0013	0.06
C5 Front β	.05	.0021	.0007	0.03
C1 Slow 1	.22	.0496	.0475	2.20
C4 Slow 2	.22	.0500	.0004	0.02
C2 RHAC	.23	.0528	.0028	0.12

Table 11

Standard Multiple Regression on the Proportion of Change from CPT1 to CPT2.

Criterion: Proportion of Hits Predictors: Component scores

Component	Coefficient	Standardized Coefficient	Squared Semi-Partial Correlation	T	P(2-tailed)
C3 Left β	.0012	.00	.00	.01	.99
C5 Front β	.0031	.00	.00	.03	.98
C1 Slow 1	.1374	.18	.01	.75	.46
C4 Slow 2	.0302	.04	.00	.17	.86
C2 RHAC	.0326	.07	.00	.35	.73

R	**RSQ**	**F**	P(2Tailed)
.23	.053	.468	.798

Table 12

Correlation Matrix on the Proportion of Change from CPT1 to CPT2.

Criterion: DL Predictors: Component scores

	DL	C3	C5	C1	C4	C2
DL	1.00					
C3 Left β	-.009	1.00				
C5 Front β	-.172	.370	1.00			
C1 Slow 1	.044	.039	-.217	1.00		
C4 Slow 2	.015	-.254	-.114	.700	1.00	
C2 RHAC	-.021	.537	.399	.139	-.070	1.00

DL = The time in msec. that it takes for a participant to respond following the presentation of a target.

Table 13

Heirarchical Multiple Regression on the Proportion of Change from CPT1 to CPT2.

Criterion: DL Predictors: Component scores

Component	R	RSQ	Change in RSQ	F to Enter
C3 Left β	.009	.000	.000	.00
C5 Front β	.182	.033	.033	1.54
C1 Slow 1	.182	.033	.000	.00
C4 Slow 2	.183	.033	.000	.01
C2 RHAC	.185	.034	.001	.04

Table 14

Standard Multiple Regression on the Proportion of Change from CPT1 to CPT2.

Criterion: DL Predictors: Component scores

Component	Coefficient	Standardized Coefficient	Squared Semi-Partial Correlation	T	P(2-tailed)
C3 Left β	.015	.06	.00	.29	.78
C5 Front β	-.059	-.21	.03	-1.15	.25
C1 Slow 1	-.010	-.03	.00	-.12	.90
C4 Slow 2	.010	.03	.00	.12	.91
C2 RHAC	.009	.04	.00	.20	.84

R	**RSQ**	**F**	P(2Tailed)
.185	.034	.298	.911

Table 15

Correlation Matrix on the Proportion of Change from CPT2 to CPT3.

Criterion: Proportion of Hits Predictors: Component scores

	HITS	C3	C5	C1	C4	C2
HITS	1.00					
C3 Left β	.05	1.00				
C5 Front β	-.04	-.04	1.00			
C1 Slow 1	.39	.29	.10	1.00		
C4 Slow 2	.44	.09	.12	.78	1.00	
C2 RHAC	-.05	.59	-.07	.37	.22	1.00

Hits = frequency of hits/total target frequency

Table 16

Heirarchical Multiple Regression on the Proportion of Change from CPT2 to CPT3.

Criterion: Proportion of Hits Predictors: Component scores

Component	R	RSQ	Change in RSQ	F to Enter
C3 Left β	.05	.00	.00	.13
C5 Front β	.06	.00	.00	.05
C1 Slow 1	.41	.17	.16	8.52
C4 Slow 2	.46	.21	.04	2.40
C2 RHAC	.51	.26	.05	2.82

Table 17

Standard Multiple Regression on the Proportion of Change from CPT2 to CPT3.

Criterion: Proportion of Hits Predictors: Component scores

Component	Coefficient	Standardized Coefficient	Squared Semi-Partial Correlation	T	P(2-tailed)
C3 Left β	.09	.13	.02	.77	.62
C5 Front β	-.07	-.11	.02	-.85	.97
C1 Slow 1	.16	.21	.03	.92	.34
C4 Slow 2	.24	.34	.08	1.59	.38
C2 RHAC	-.14	-.29	.09	-1.68	.60

R	**RSQ**	**F**	P(2Tailed)
.51	.26	2.94	.023

Table 18

Correlation Matrix on the Proportion of Change from CPT2 to CPT3.

Criterion: DL Predictors: Component scores

	DL	C3	C5	C1	C4	C2
DL	1.00					
C3 Left β	.03	1.00				
C5 Front β	.12	-.04	1.00			
C1 Slow 1	-.29	.29	.10	1.00		
C4 Slow 2	-.32	.09	.12	.78	1.00	
C2 RHAC	.00	.59	-.07	.37	.22	1.00

DL = The time in msec. that it takes for a participant to respond following the presentation of a target.

Table 19

Heirarchical Multiple Regression on the Proportion of Change from CPT2 to CPT3.

Criterion: DL Predictors: Component scores

Component	R	RSQ	Change in RSQ	F to Enter
C3 Left β	.03	.00	.00	.04
C5 Front β	.13	.02	.02	.70
C1 Slow 1	.35	.12	.10	5.21
C4 Slow 2	.37	.14	.02	.98
C2 RHAC	.38	.15	.01	.33

Table 20

Standard Multiple Regression on the Proportion of Change from CPT2 to CPT3.

Criterion: DL Predictors: Component scores

Component	Coefficient	Standardized Coefficient	Squared Semi-Partial Correlation	T	P(2-tailed)
C3 Left β	.01	.04	.00	.24	.81
C5 Front β	.04	.18	.04	1.23	.23
C1 Slow 1	-.06	-.18	.01	-.73	.47
C4 Slow 2	-.06	-.23	.03	-.99	.33
C2 RHAC	.02	.11	.01	.58	.57

R	**RSQ**	**F**	P(2Tailed)
.38	.15	1.45	.23

Table 21

Correlation Matrix on the Proportion of Change from CPT3 to CPT4.

Criterion: Proportion of Hits Predictors: Component scores

	HITS	C3	C5	C1	C4	C2
HITS	1.00					
C3 Left β	.35	1.00				
C5 Front β	.10	.28	1.00			
C1 Slow 1	.61	.55	-.06	1.00		
C4 Slow 2	.46	.27	-.16	.80	1.00	
C2 RHAC	.28	.70	.17	.40	.17	1.00

Hits = frequency of hits/total target frequency

Table 22

Heirarchical Multiple Regression on the Proportion of Change from CPT3 to CPT4.

Criterion: Proportion of Hits Predictors: Component scores

Component	R	RSQ	Change in RSQ	F to Enter
C3 Left β	.35	.12	.12	6.55
C5 Front β	.38	.14	.02	1.29
C1 Slow 1	.63	.40	.25	18.26
C4 Slow 2	.63	.40	.00	.19
C2 RHAC	.63	.40	.00	.05

Table 23

Standard Multiple Regression on the Proportion of Change from CPT3 to CPT4.

Criterion: Proportion of Hits Predictors: Component scores

Component	Coefficient	Standardized Coefficient	Squared Semi-Partial Correlation	T	P(2-tailed)
C3 Left β	-.13	-.09	.01	-.45	.65
C5 Front β	.20	.14	.05	1.09	.28
C1 Slow 1	1.07	.73	.33	2.90	.01
C4 Slow 2	-.14	-.09	.01	-.40	.69
C2 RHAC	.05	.04	.00	.23	.82

R	**RSQ**	**F**	P(2Tailed)
.63	.40	5.57	.001

Table 24

Correlation Matrix on the Proportion of Change from CPT3 to CPT4.

Criterion: DL Predictors: Component scores

	DL	C3	C5	C1	C4	C2
DL	1.00					
C3 Left β	-.22	1.00				
C5 Front β	-.07	.28	1.00			
C1 Slow 1	-.39	.55	-.06	1.00		
C4 Slow 2	-.34	.27	-.16	.80	1.00	
C2 RHAC	-.17	.70	.17	.40	.17	1.00

DL = The time in msec. that it takes for a participant to respond following the presentation of a target.

Table 25

Heirarchical Multiple Regression on the Proportion of Change from CPT3 to CPT4.

Criterion: DL Predictors: Component scores

Component	R	RSQ	Change in RSQ	F to Enter
C3 Left β	.22	.05	.05	2.33
C5 Front β	.24	.06	.01	.46
C1 Slow 1	.40	.16	.10	5.56
C4 Slow 2	.40	.16	.00	.17
C2 RHAC	.40	.16	.00	.01

Table 26

Standard Multiple Regression on the Proportion of Change from CPT3 to CPT4.

Criterion: DL Predictors: Component scores

Component	Coefficient	Standardized Coefficient	Squared Semi-Partial Correlation	T	P(2-tailed)
C3 Left β	.01	.03	.00	.12	.90
C5 Front β	-.03	-.11	.01	-.69	.49
C1 Slow 1	-.09	-.32	.03	-1.08	.28
C4 Slow 2	-.03	-.10	.00	-.41	.68
C2 RHAC	-.00	-.02	.00	-.11	.91

R	**RSQ**	**F**	P(2Tailed)
.41	.16	1.66	.17

Table 27

Source Table for TRIAL: Proportion of Hits as the Dependent Measure*

Source	SS	df	MS	F	p
TRIAL	.98	3	.33	22.79	0.00
T x Subjects	1.97	138	.01		
Total	111.34	187			

*The variability due to between subjects differences (Subjects), while not included in the table, were used in the calculations of SS_{total} and df_{total}.

Table 28

Pairwise Comparisons of the Four Levels of TRIAL, using Tukey's HSD Test:

Dependent Measure is the Proportion of Hits

Cells contain the Q Statistic

	CPT4	CPT3	CPT2	CPT1
CPT4	---	---	---	---
CPT3	4.60*	---	---	---
CPT2	6.01*	1.41	---	---
CPT1	11.6*	6.98*	5.57*	---

*p < .01 level of significance.

$Q = x_i - x_j / \sqrt{MS_W / n_j}$

Table 29

Source Table for TRIAL: DL as the Dependent Measure*

Source	SS	df	MS	F	p
TRIAL	.22	3	.07	22.74	0.00
T x Subjects	.36	138	.003		
Total	102.03	187			

*The variability due to between subjects differences (Subjects), while not included in the table, were used in the calculations of SS_{total} and df_{total}.

Table 30

Pairwise Comparisons of the Four Levels of TRIAL, using Tukey's HSD Test:

Dependent Measure is the DL

Cells contain the Q Statistic

	CPT1	CPT2	CPT3	CPT4
CPT1	---	---	---	---
CPT2	8.95*	---	---	---
CPT3	9.30*	.35	---	---
CPT4	12.30*	3.33	2.98	---

*p < .01 level of significance.

$Q = x_i - x_j / \sqrt{MS_W / n_j}$

Table 31

Pairwise Comparisons of the Five Levels of TRIAL, using Tukey's HSD Test:

Dependent Measure is the Left Hemisphere Beta Component

Cells contain the Q Statistic

	CPT4	RESTING	CPT3	CPT2	CPT1
CPT4	---	---	---	---	---
RESTING	.59	---	---	---	---
CPT3	.72	.13	---	---	---
CPT2	1.94	1.35	1.22	---	---
CPT1	4.84	4.25	4.13	2.91	---

*p < .01 level of significance.

$Q = x_i - x_j / \sqrt{MS_W / n_j}$

Table 32

Six, Twelve, and Eighteen Minute

Test-Restest Reliabilities

	C2 RHAC	C3 Left β	C5 Front β	C1 Slow 1	C4 Slow 2	Prop. of Hits	DL
6 Min.	.77	.85	.96	.97	.93	.56	.79
12 Min.	.76	.77	.87	.95	.89	.58	.70
18 Min.	.58	.66	.77	.88	.78	.50	.62

Table 33

Six, and Twelve Minute

Test-Restest Reliabilities for Change Scores

	C2 RHAC	C3 Left β	C5 Front β	C1 Slow 1	C4 Slow 2	Prop. of Hits	DL
6 Min.	-.43	.24	.06	-.04	.02	-.35	-.08
12 Min.	.14	.11	.04	-.10	-.05	.22	-.06

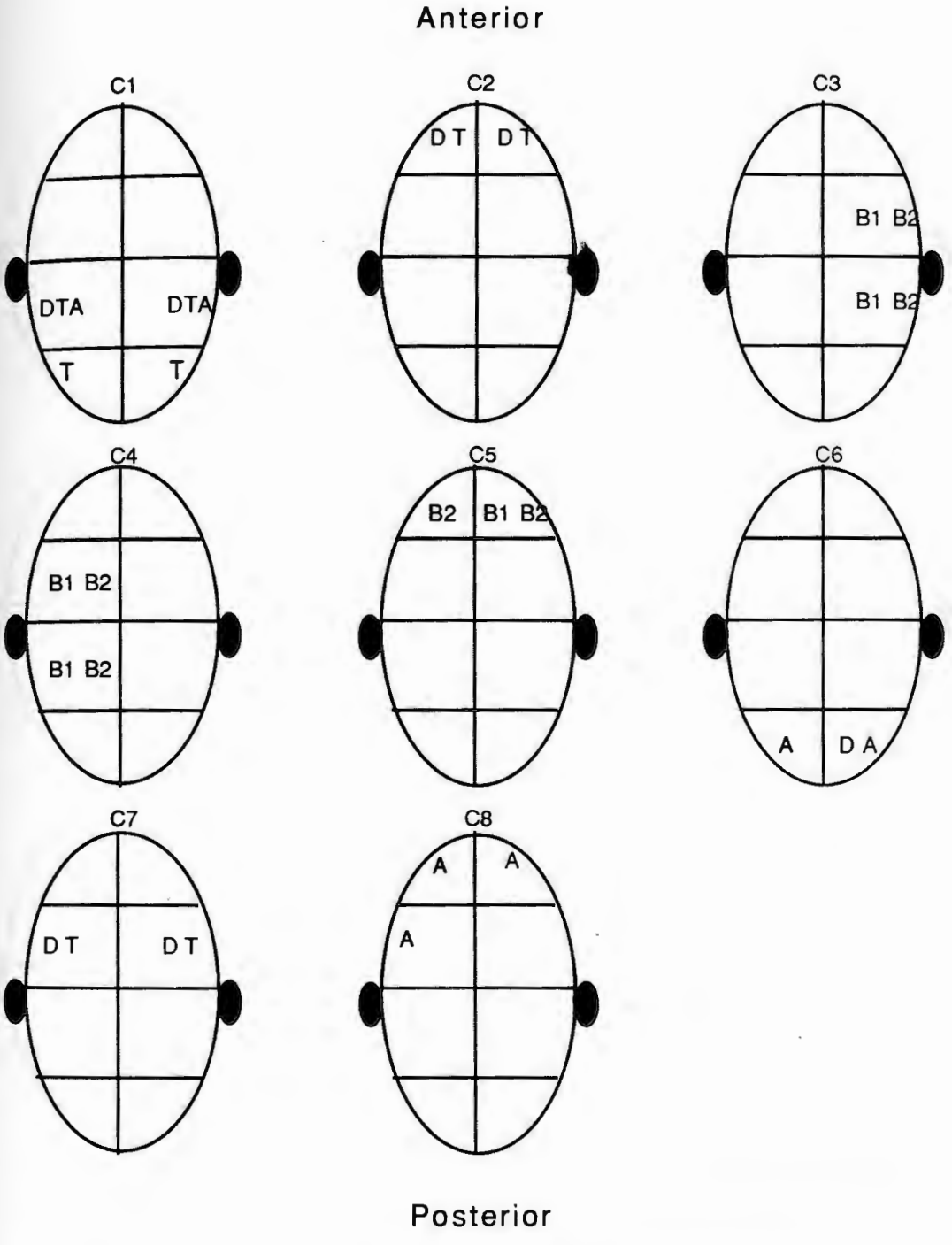
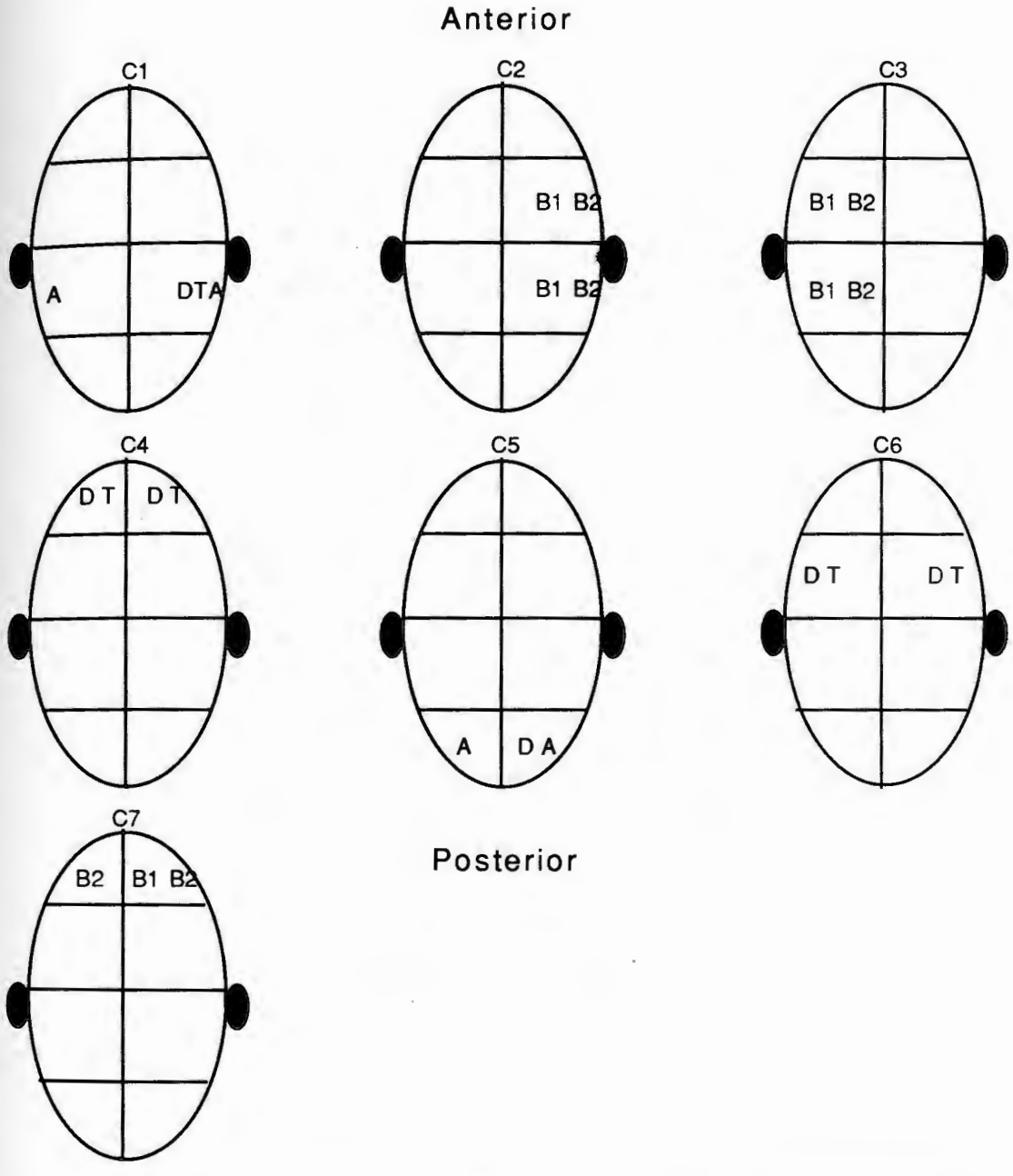


Figure 1. The orthogonal AP8 solution. D-Delta wave frequency band, 1-3.5Hz; T-Theta wave frequency band, 3.5-7.5Hz; A-Alpha wave frequency band, 7.5-12.5Hz; B1-Beta1 wave frequency band, 12.5-17.5Hz; B2-Beta2 wave frequency band.



The AP7 component solution with a reduced posterior slow wave component.

Figure 2. The oblique AP7 solution. D-Delta wave frequency band, 1-3.5Hz; T-Theta wave frequency band, 3.5-7.5Hz; A-Alpha wave frequency band, 7.5-12.5Hz; B1-Beta1 wave frequency band, 12.5-17.5Hz; B2-Beta2 wave frequency band.

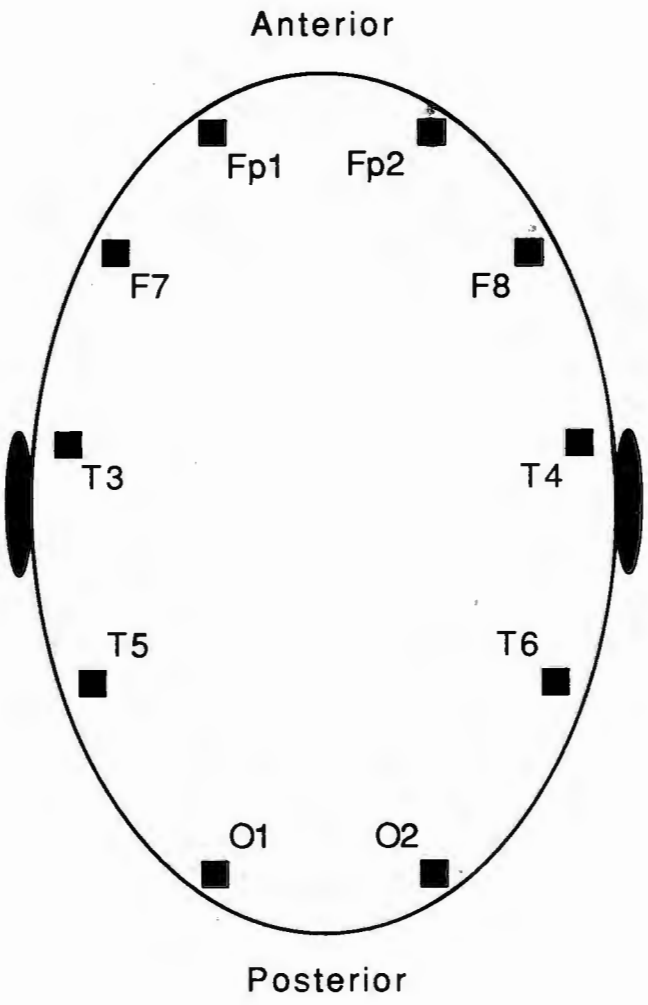


Figure 3. International 10-20 System of electrode placement. For the purposes of the proposed experiment only the lateral electrodes were used.

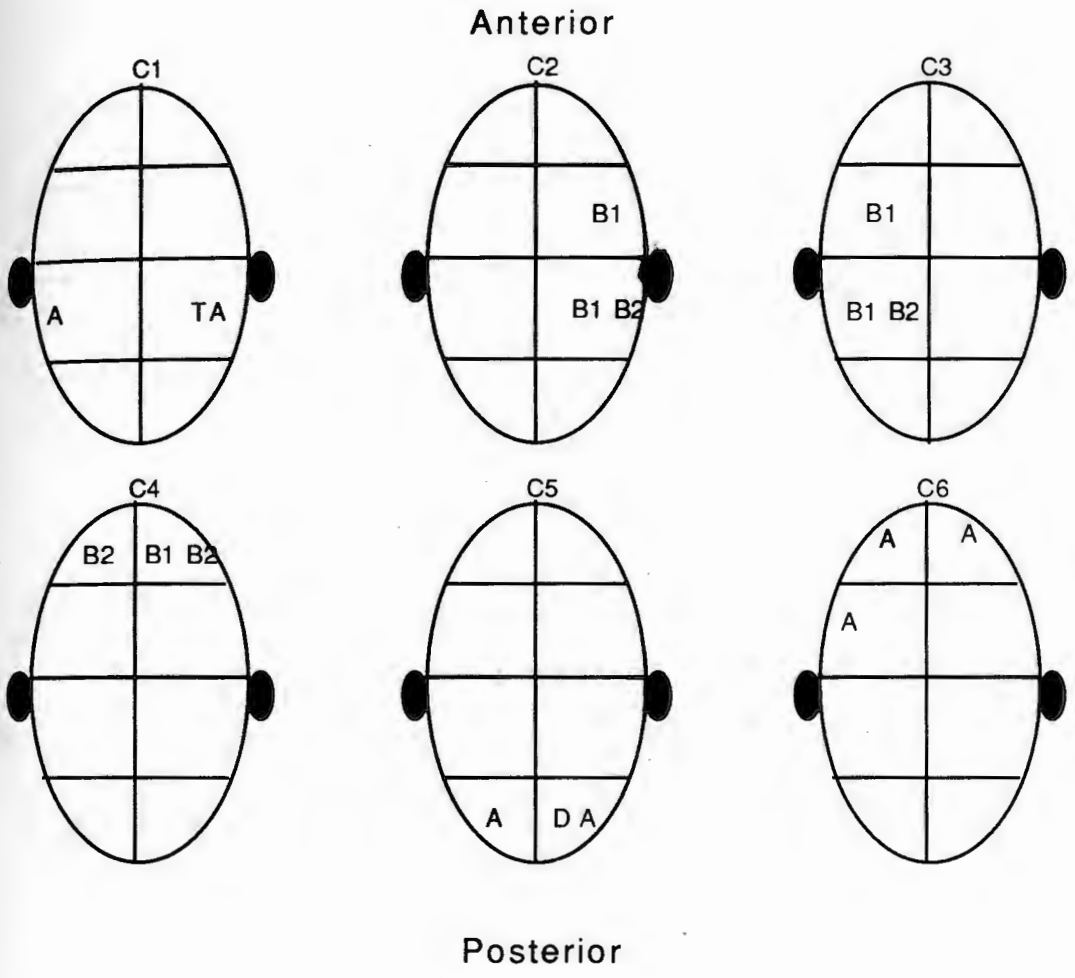


Figure 4. The reduced orthogonal AP6 measurement model.

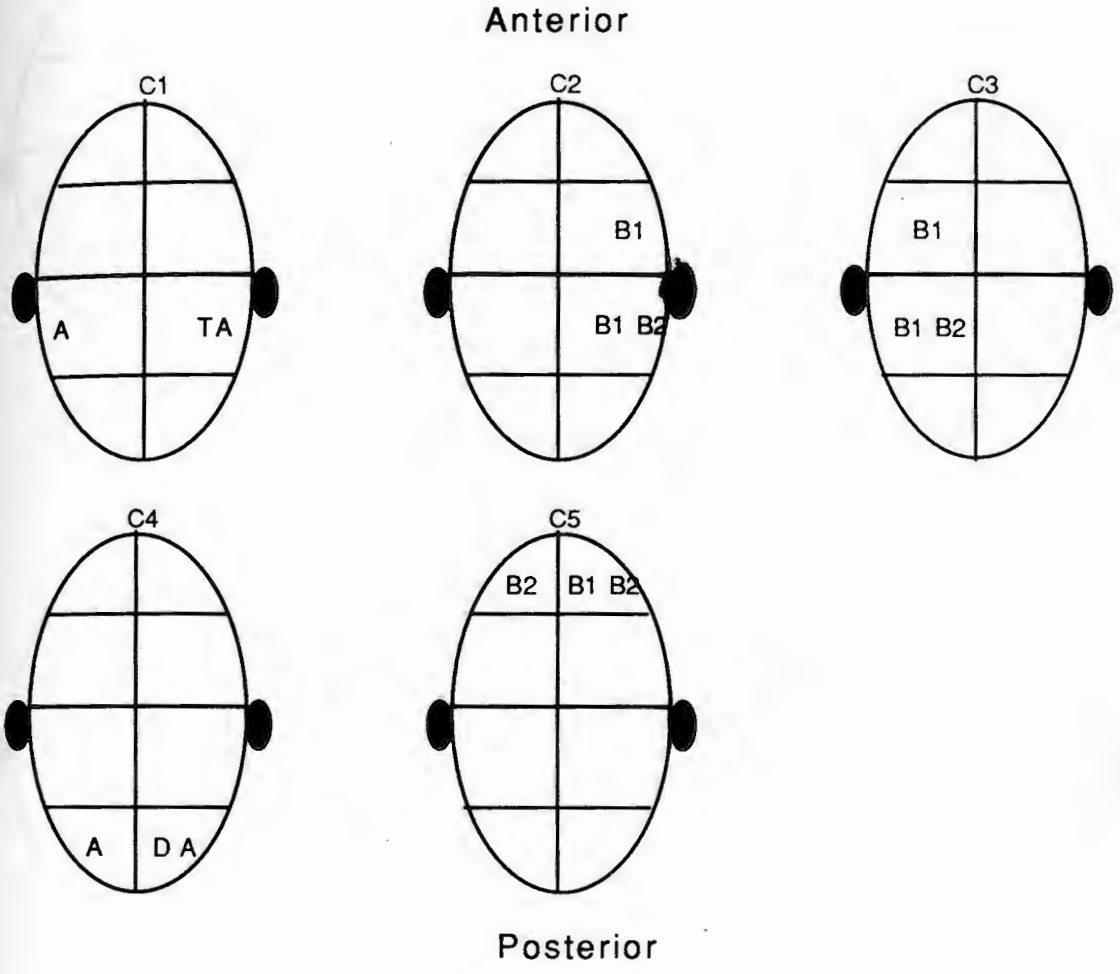


Figure 5. The reduced oblique AP5 measurement model.

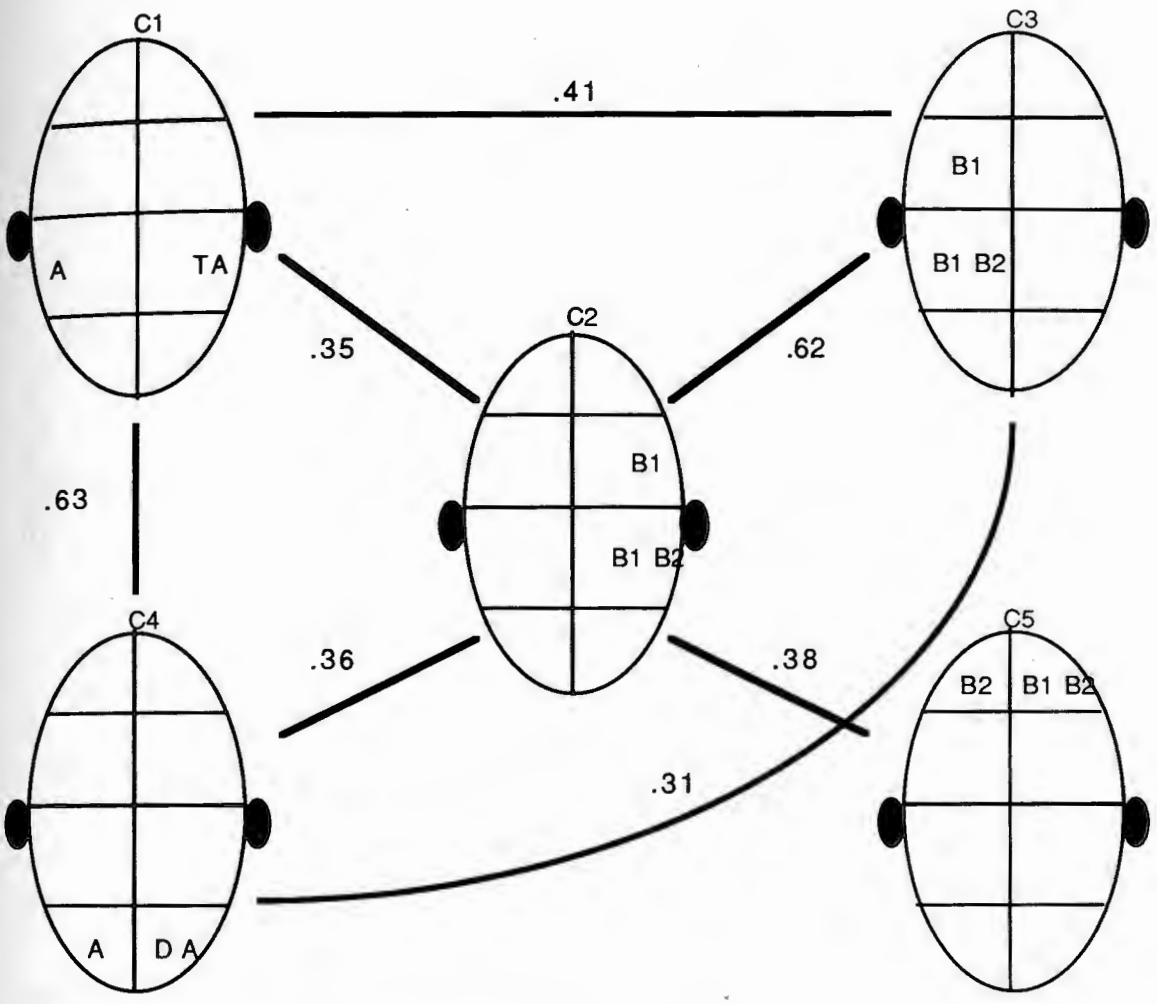


Figure 6. All seven correlations were statistically significant at $p < .005$, using a one-tailed test and a Bonferroni adjustment. Family-wise error rate was set to .035.

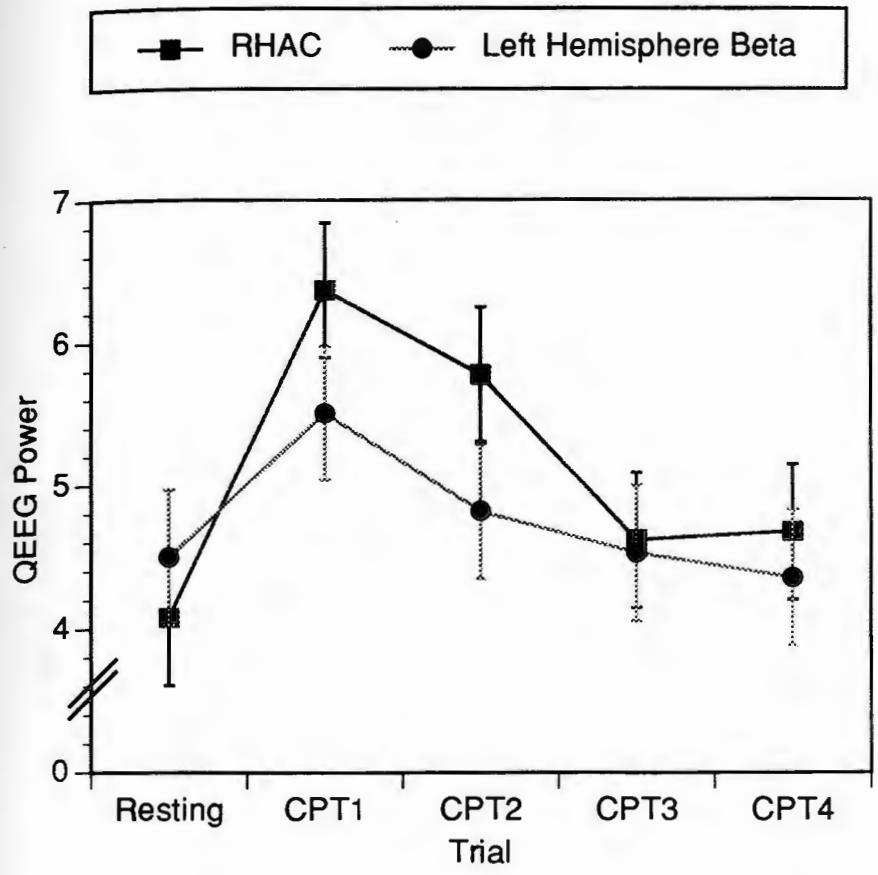


Figure 7. Trial (Resting, CPT1,CPT2, CPT3, CPT4) by HEMISPHERE (RHAC, Left Hemisphere Beta) interaction. Error bars represent the standard error.

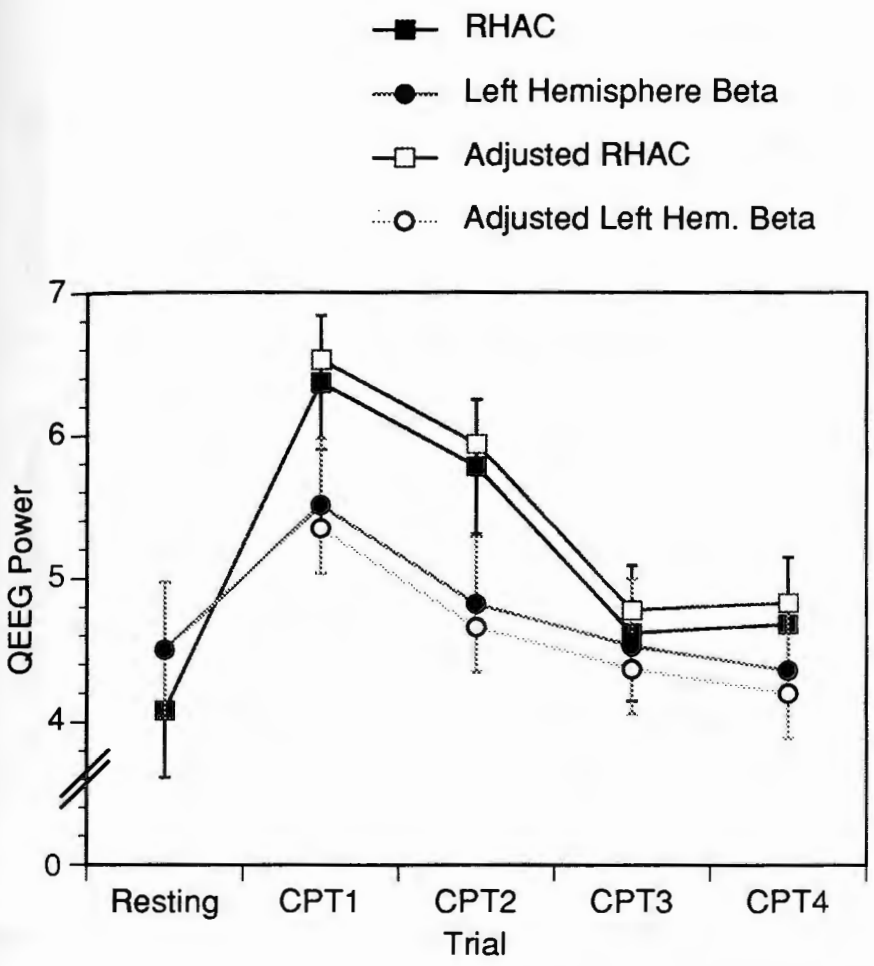


Figure 8. TRIAL (Resting, CPT1, CPT2, CPT3,CPT4) BY HEMISPHERE (RHAC, Left Hemisphere Beta) interaction using the adjusted means.

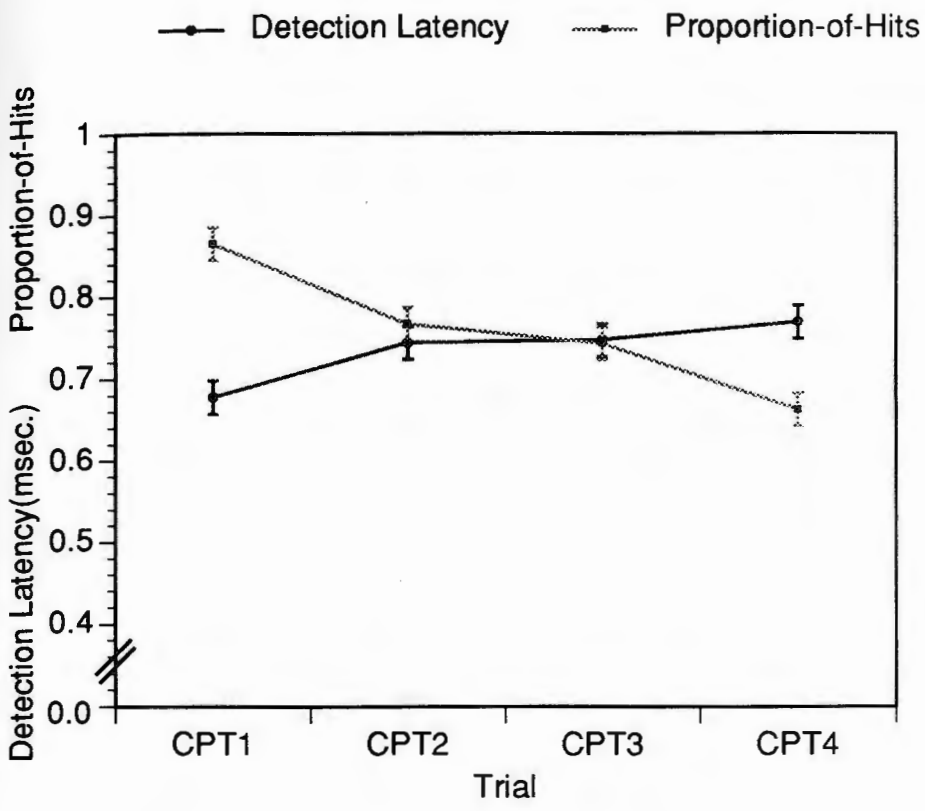


Figure 9. Main Effect for TRIAL (CPT1, CPT2, CPT3, CPT4) with the proportion-of-hits and DL as the two dependent measures. Error bars represent standard errors.

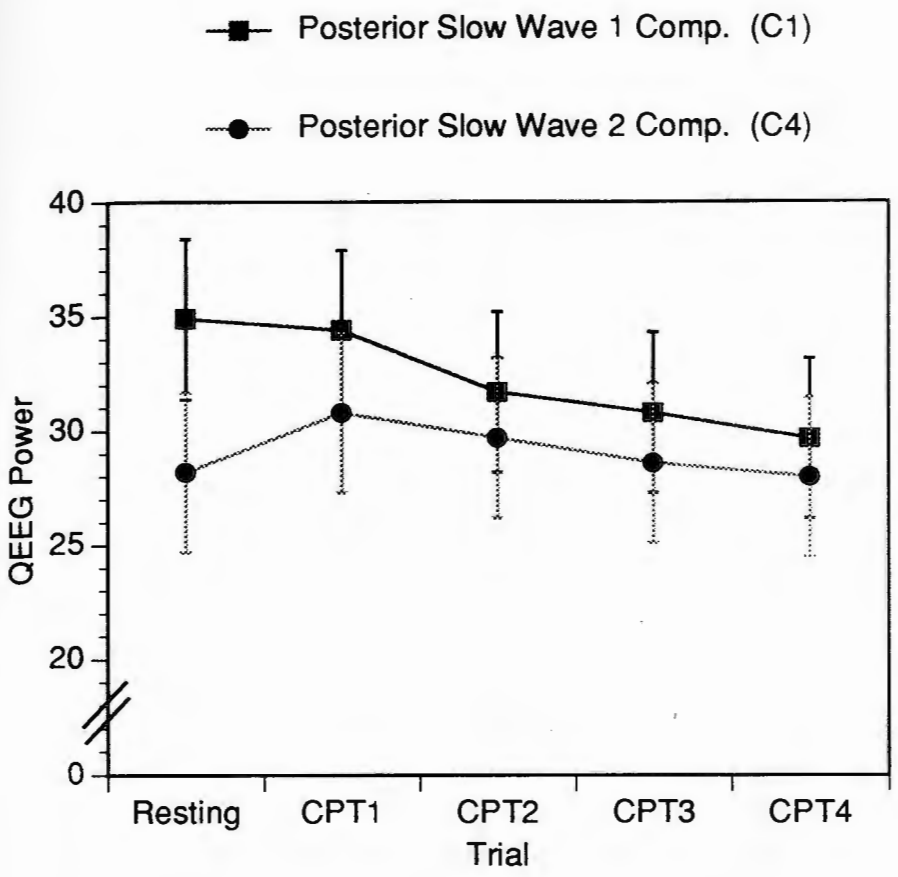


Figure 10. Main Effect for TRIAL (Resting, CPT1, CPT2, CPT3, CPT4) with C1 and C4 as the two dependent measures. Error bars represent standard errors.

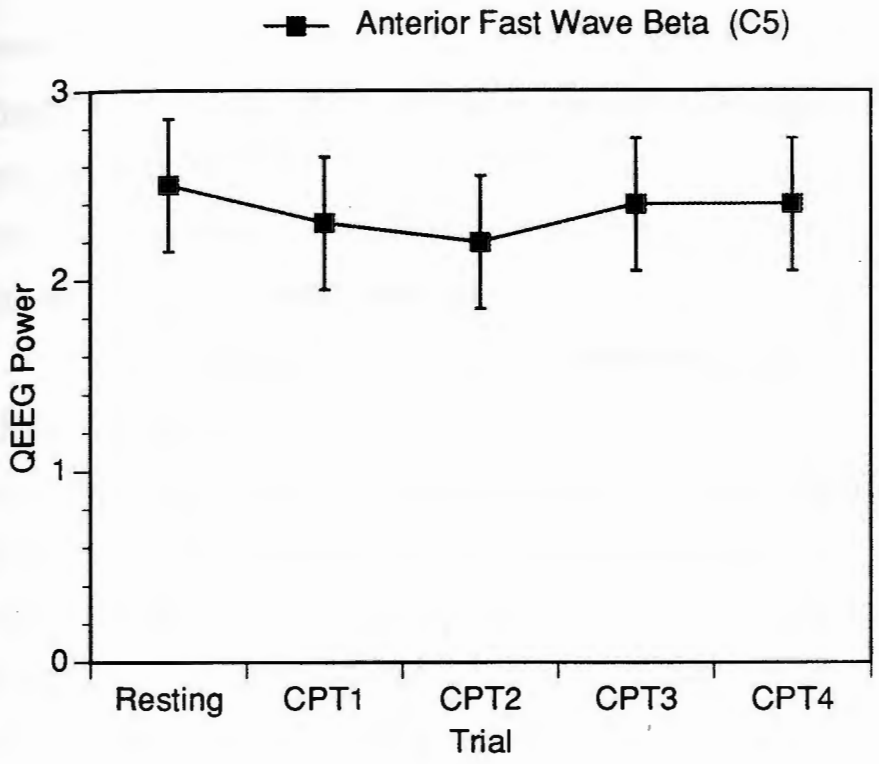


Figure 11. Main Effect for TRIAL (Resting, CPT1, CPT2, CPT3, CPT4) with C5 as the dependent measure. Error bars represent standard error.

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