

**Human-computer interfaces with regional lower and upper alpha frequencies
as on-line indexes of mental activity.**

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Abstract

The focus of this study involved the assessment of EEG signals to investigate mental activity associated with computer tasks when using two different interfaces. Eight subjects were used to contrast the mental activity associated with a visuo-spatial and a verbal task involving two human-computer interfaces: keyboard and mouse. To compare task difficulty, the mean lower alpha (8-10 Hz) and upper alpha (11-13 Hz) activities at the occipital, temporal, and frontal regions were used to analyze the data. Results revealed that there were differences in hemispheric activation in the lower and upper alpha wavebands. An interaction effect hemisphere by site was found at the temporal sites in the upper alpha band. Furthermore, an interaction effect task by computer interface was found at the temporal sites in the lower alpha waveband. Based on this study, lower and upper alpha activities appear to be valid measures to identify interfaces that are best matched to computer tasks. This type of research will allow the design of user-friendly human computer interfaces.

Keywords: computer, interfaces, EEG, alpha, mental, activity.

Human factors has been defined as the study of human capabilities and limitations that affect the design of human-machine systems (Wickens, 1992). Machines such as computers are becoming an essential tool at work and even in our private lives (e.g., e-mailing, database searching). Humans use interfaces such as the keyboard or mouse to interact with computers and a specific task may become more or less difficult depending on the computer interface that an individual is using. The measurement of mental activity with the appropriate technology provides us with the ability to objectively assess the match between an interface and a computer task so as to make such task user-friendly. The focus of this study was based on assessing mental activity associated with computer tasks when using different interfaces.

There are a number of non-invasive techniques that are being used to measure cognitive processing and mental activity in the field of human factors. These are Positron Emission Tomography (PET), Magnetic Resonance Imaging (MRI), Single-Photon Emission Computed Tomography (SPECT), and Electroencephalography (EEG). Research studies (Kerin and Aunon, 1990; Wilson and Fisher, 1995) have successfully determined that EEG recordings can be used to discriminate among the performance of a variety of tasks (e.g., spatial processing, memory search, visual monitoring).

In fact, the three subsystems comprised in The Model Human Processor that Card, Moran and Newell (1983) proposed as a simplified view of the human processing involved in interacting with computers, can be monitored through EEG. These subsystems are: the Perceptual System, which can be monitored by Auditory and Visual Evoked potentials (AEP and

VEP) in the EEG measured over the auditory and visual cortices (Spehlmann, 1985), the Motor System, which is expressed in the EEG as Readiness potentials (RP) over the motor cortex (Hiraiwa, Shimohara, and Tokunaga, 1999) and the Cognitive System, whose activity is manifested by a number of EEG features around the head.

In the last decade there has been a significant research effort to use EEG to monitor and assess the activity of the key intermediate Cognitive System in The Model Human Processor. The group led by Charles Anderson has been able to use autoregressive modeling of the EEG signals and artificial neural networks to achieve accuracies of up to 96% in identifying 5 different mental tasks (letter composition, math computations, visual counting and geometric figure rotation and Rest) from the variations in the EEG collected while the subjects were performing these tasks (Anderson, Duvelapalli, and Stoltz, 1995; Anderson, 1997; Anderson, Stoltz, and Shamsunder, 1998).

Simultaneously, Gevins and his colleagues (Gevins et al., 1998) have successfully utilized EEG signals to investigate mental activity in individuals performing computer tasks with different mental loads (i.e., difficulty), analyzing the dynamics of human working memory (Gevins and Cutillo, 1993), with the goal of assessing brain function in operational environments (Gevins et al., 1995). Hence, EEG recordings are a valid tool to determine the human capabilities and limitations when performing computer tasks with different interfaces.

In continuous EEG recordings, the alpha frequency band (8-13 Hz) of the EEG is generally associated with a relaxed state (Ray and Cole, 1985; Ray, 1990), and the reduction of

alpha activity (alpha blocking) indicates sensory stimulation or increased mental activity (Shaw, 1996). In studying the difficulty of a task, we can assess the level of alpha activity such that reduced levels indicate an increase in sensory stimulation or mental activity. Therefore, alpha activity is an appropriate measure to investigate differences in mental activity during task performance.

Alpha activity may be viewed in three distinct alpha frequency bands (8-13 Hz, 8-10 Hz, and 11-13 Hz). The most common alpha frequency band measured in previous research is the 8-13 Hz, which comprises the upper (11-13 Hz) and the lower (8-10 Hz) alpha bands. While the 8-13 Hz provides an accurate measurement of alpha activity, the upper alpha band (11-13 Hz) responds selectively to the encoding of the stimulus, whereas the lower alpha component (8-10 Hz) reflects processes related not only to cognitive processing but also to the mechanisms of mental effort (Klimesch, Pfurtscheller, and Schimke, 1992). Viewing the alpha frequency range from a split-band perspective further elucidates the mechanisms of alpha reactivity.

When studying brain wave activity by measuring alpha frequencies, the assessment of hemispheric differences allows for a contrast between psychological states associated with verbal-analytic and visuo-spatial processing (Hatfield and Hillman, 2001). This contrast reveals that the left-hemisphere is more involved in the processing of verbal/analytic material (e.g., mental arithmetic, word construction) while the right hemisphere is more involved in the processing of visuo-spatial/synthetic material (e.g., matching geometric figures, visualizing a task). Research using a variety of techniques including magnetoencephalography, functional magnetic resonance imaging, evoked potentials, as well as EEG, supports these interpretation of

hemispheric differences (Ackermann, Lutzenberger, and Hertrich, 1999; Canli, Desmond, Zhao, Glover, and Gabrieli, 1998; Petruzello, and Landers, 1994). Such interpretation is tenable in light of the functional differences in the right and left temporal areas (Lind, Flor-Henry, and Koles, 1999) and the cortical idling hypothesis (Pfurtscheller, Stancak, and Neuper, 1996).

This interpretation has further been tested using computer video games. In a study by Rebert, Low, and Larsen (1984), subjects performing a visuo-spatial task (i.e., Pong video game) revealed an engagement of their right hemisphere as reflected by a decreased alpha power in the right hemisphere compared to the left hemisphere. Therefore, it is important to contrast the involvement of the two hemispheres in the analysis of the computer task at hand as we would expect verbal tasks to require more mental activity in the left hemisphere while visual tasks would require more mental activity in the right hemisphere.

The purpose of this study was to investigate changes in lower (i.e., mental effort) and upper (i.e., stimulus encoding) alpha activities at selected sites associated with the execution of two basic tasks -- one verbal/analytic and one visuo-spatial/synthetic -- through two types of computer interfaces (i.e., keyboard and mouse). The objective was to determine differences in mental effort and stimulus encoding based on the type of interface used with the different tasks at each cerebral site (i.e., frontal, temporal and occipital). In addition, we wanted to assess the mental effort and stimulus encoding in each of the two cerebral hemispheres (left vs. right) with the different tasks. It was hypothesized that individuals would have greater lower and upper alpha activities in the left hemisphere when performing a visuo-spatial task. In contrast, we

hypothesized that individuals would have greater lower and upper alpha activities in the right hemisphere when performing a verbal task.

Methods

Subjects

Subjects were 8 college-aged students from Florida International University who had no prior experience on the tasks. To avoid gender differences in brain topography and handedness dominance among subjects, they were selected to be right-handed, right-eyed males. The Edinburgh Handedness Inventory (Oldfield, 1971) was used to confirm that subjects involved in this study were right-handed, right-eyed. The test-retest reliability for this inventory is .98 (Ransil and Schachter, 1994). Subjects were asked to sign the “Informed Consent Form,” which outlines the research purpose and testing procedure.

EEG recordings

The Electrical Signal Imaging with 256 electrodes (ESI-256) was utilized for data collection. EEG signals were collected with a 256-electrode cap built by Neuroscan, Inc. Impedance was homogeneously below 5,000 ohms. Eight high-gain amplifiers of NeuroScan amplified the electrical signals. The Acquire software sub-module was used to record continuous EEG data while testing each subject. The data was digitized through a signal processor (Scan 4.0 Interface) with a sampling rate of 1000 Hz and a gain of 40,000 was applied. Low-pass and high-pass filters were set at 35 and 1 Hz. respectively. Since filters do not eliminate all the unwanted frequencies, a 60 Hz. notch filter was employed.

EEG activity was recorded from electrodes that were positioned in the temporal, occipital and frontal sites in both right and left hemispheres. We followed the guidelines of the 10-5 system proposed by Oostenveld and Praamstra (2001). This system aims to accommodate the larger number of recording channels available in modern EEG systems such as the ESI-256. The proposed extension defines the position and nomenclature of 345 locations of the head, and it can accommodate a homogenous distribution of a subset of electrodes. We reduced the data to values that could be compared to the 10-20 system and measured the mean power average for each region across wavebands. This would allow researchers to compare studies using a smaller number of electrodes.

A vertical electro-oculogram (VEOG) and a horizontal electro-oculogram (HEOG) were taken to detect eye movement artifacts. VEOG and HEOG were obtained with four silver-silver chloride cup electrodes. Electrodes were positioned 1.5 cm. perpendicular and 1.5 cm. horizontal to the pupil of the right eye. Low-pass and high-pass filters were set at 40 and 1 Hz. respectively.

Procedures

Subjects were required not to exercise, consume caffeine, drugs, medication, or smoke 24 hours prior to testing. Subjects were seated in a comfortable chair and were entertained with a movie to reduce the fatigue factor. To prepare for EEG data acquisition, a 256-electrode cap was placed on the scalp and reference electrodes were placed on both earlobes. Each electrode in the cap was filled with conductive gel, and electrode impedances were kept below 5 kilo-ohms.

Subject preparation lasted approximately 1 hour with the help of 3 lab assistants. Every attempt was made so that the subject was as comfortable as possible. After cap placement, subjects reported to be alert and ready to play video games.

The tests consisted of two different computer tasks. In one task, subjects played a video game expected to exercise visuo-spatial skills (SP). The game chosen was 3DTetriMania, which consists of organizing figures according to their shapes. In the other task, subjects played a video game expected to exercise verbal skills (VE). The game chosen for this task was TrackWords, which consists of selecting letters from a given pool to create words of three letters or more. Each subject played both video games with each of two computer interfaces: the keyboard (K) and the mouse (M). The order of conditions of task and computer interface was randomly assigned (i.e., SP/K, SP/M, VE/K, and VE/M) for each subject. For each condition, the subjects played a 1-minute practice round to become familiar with the task. Then they played one timed round of the game for a total of 1 minute per game. To demonstrate equivalence with respect to task difficulty, ratings from subjects were collected following each 1-minute task period. To ensure the computer tasks were equivalent in difficulty subjects were asked to rate task difficulty using a Likert scale from 1 being the easiest to 7 being the most difficult. In addition, Subject's outcome performance was measured for each condition to ensure equivalence in ability across conditions.

Subjects were tested and four 60-second data files per subject were recorded. One file for each condition of task and computer interface (i.e., SP/K, SP/M, VE/K, and VE/M) was saved. The Edit sub-module of the Scan 4.0 Interface was used to perform the processing to the EEG

data recorded with the Acquire program. The continuous file was transformed into an epoch file, consisting of 60 1-second epochs. The data from the 20th second to the 40th second was analyzed which is the time when the subject should be most devoted to the given task. These selected 20 1-second epochs were analyzed one by one, and epochs showing artifact were rejected. There was an average of 15 accepted epochs per file. A software program computed the Power Spectrum by the use of Fast Fourier Transform. A Hamming window was applied to the data.

Design Analysis

To determine equivalence with respect to task difficulty, ratings from subjects on task difficulty were entered into a 2 x 2 (task x interface) repeated measures ANOVA. Further, to investigate equivalence in subject's ability, video game raw scores (i.e., outcome performance) were converted to t-scores and entered into a 2 x 2 repeated measures ANOVA.

The mean alpha power averages for each region of the brain in each of the hemispheres (left/right) was obtained. The absolute lower (8-10 Hz) and upper mean alpha (11-13 Hz) power values obtained for each subject from each region of the brain were used to analyze the data. These values were entered into a 2 x 3 x 2 x 2 repeated measures design (hemisphere x site x task x interface). A Huynh-Feldt adjustment was made to the degrees of freedom for all tests of within subjects in order to correct bias introduced by violation of the multisample sphericity assumption (Schutz and Gessaroli, 1987).

Results

Results revealed that there were no significant differences ($p > .05$) in subject's ratings of task difficulty. Further, results revealed that there were no significant differences ($p > .05$) in subject's outcome performance.

Interestingly, the main effect for hemisphere in lower ($F(1,7) = 17.81, p < 0.01$) and upper ($F(1,7) = 16.18, p < 0.01$) alpha activities was significant. The mean lower (8-10 Hz) and upper alpha (11-13 Hz) power values for the right and left hemispheres are presented in table 1. Mean lower and upper alpha power values were greater in the left hemisphere as opposed to the right hemisphere. Yet, there was not a significant interaction effect ($p > .05$) between hemisphere and task.

Insert Table 1 About Here

A significant interaction effect, hemisphere by site, was found in the upper (11-13) alpha waveband ($F(2,14) = 9.91, p < 0.01$). This interaction shows that individuals had greater upper alpha power at the temporal site in the left hemisphere. Figure 1 portrays this interaction effect in the upper alpha band (11-13 Hz).

Insert Figure 1 About Here

Finally, a significant main effect ($F(1,7) = 6.61, p < .05$) for task was found in the lower alpha band. Mean lower alpha power values were greater for Tetris ($M = 5.99, SD = 3.96$) as opposed to TrackWords ($M = 4.81, SD = 3.03$). Further, a significant interaction effect ($F(1.85, 13.01) = 6.54, p < .05$) site x task x interface was found in the lower (8-10 Hz) alpha band. Post hoc analysis assessing task x interface at each site revealed a significant interaction effect ($F(1,7) = 5.65, p < .05$) task x interface at the temporal sites. This interaction shows that individuals had greater lower alpha activity when playing Tetris with the mouse rather than the keyboard. Figure 2 illustrates this interaction effect in the lower alpha band at the temporal site.

Insert Figure 2 About Here

Discussion

In this study, lower alpha activity was measured as an indicator of mental effort and upper alpha as an indicator of stimulus encoding when using two computer interfaces with both a visuo-spatial and a verbal task. Neither task difficulty nor subject's outcome performance appeared to be confounding variables in our final results. Our results lead us to make three major

conclusions. First, the study showed that individuals had greater lower and upper alpha activities in the left hemisphere. Second, individuals showed greater upper alpha power at the temporal site in the left hemisphere. Finally, while the verbal task required more mental effort, individuals showed greater lower alpha power when playing the visuo-spatial task with the mouse when compared to playing the visuo-spatial task with the keyboard. We discuss theoretical and practical implications next.

Our first conclusion relates to hemispheric activation. This study reveals greater alpha activity in the left hemisphere as opposed to the right hemisphere. Differences in hemispheric activation were expected based on the specific task, hence, an interaction effect between hemisphere and task would have revealed such hemispheric lateralization. The main effect should be understood in light of the non-significant interaction. The lower levels of alpha activity in the right hemisphere suggest that both tasks required more activity on the right hemisphere, which is associated with tasks that are visuo-spatial in nature. One possible explanation for this finding is that while the TrackWords video game was intended to be a verbal task, subjects were involved in finding letters visually in the screen to write as many words as possible. The process of finding appropriate letters on the screen may have added an unexpected visuo-spatial component to the task. Thus, while our research findings appear to contradict the contrast of hemispheric differences based on the nature of the task (Hatfield and Hillman, 2001), we believe that the verbal task may have had an unintended visuo-spatial component. Future research should use eye-gaze tracking technology to measure visual involvement in the task, or alternatively, use other tasks that may be purely verbal to ensure that the tasks truly differ in intended ways.

Secondly, a significant interaction effect, hemisphere by site, was found in the upper alpha band. Upper alpha power was greater at the temporal sites in the left hemisphere when compared to occipital and frontal sites. Corroborating this finding, a study by Rebert, Low, and Larsen (1984) found that psychomotor performance of a visuo-spatial task (i.e, Pong video game) engaged the right hemisphere as reflected by a decreased alpha power in the right hemisphere compared to the left hemisphere. These hemispheric differences in alpha activity were most pronounced in the temporal region. The levels of upper alpha are an indicator of how humans selectively encode the stimulus. The temporal lobes are associated with audition, auditory, visual recognition, and perceptual aspects of language such as comprehension and syntax. This suggests that subjects in this study were not involved in an auditory task that entailed a verbal component (i.e., involvement of the left hemisphere) and therefore, individuals required less mental activity to encode the stimulus. In a different study, Molnar and Kletke (1996) found that a front-end voice interface hinders the user's computer performance resulting in individuals having less favorable attitudes towards the software tool than the menu interface users. Future research should include tasks that involve audio components in the design of computer interfaces. The performance on these tasks should be measured objectively with EEG recordings. This will help scientists understand the different task characteristics and the involvement of cerebral regions as humans attempt to accomplish a computer task.

Last, a significant main effect for task was found. The difference in means indicate that TrackWords required more effort than Tetris. Despite this finding, the difficulty of the task was moderated by the computer interface as shown by the significant three-way interaction effect,

task by computer interface by site in the lower alpha band. Post hoc analysis looking at the interaction between task and interface at each site revealed a significant interaction effect task by computer interface at the temporal sites. In this interaction, individuals showed greater alpha power when playing Tetris with the mouse. This suggests that Tetris (i.e., visuo-spatial task) became a less difficult task when played with the mouse than with the keyboard. Tetris involves matching a figure that may be moved around with the mouse as if the interface was the figure itself. In contrast, Tetris becomes a more difficult task with the keyboard since it may be cumbersome for subjects to use the directional arrows on the keyboard rather than moving the mouse. Such interplay in the bi-directional communication between user and interface through EEG activities is viewed as a potentially important contribution to the design of well-balanced human-computer interfaces. This type of research can be used to better improve the marketability of software programs as well as leading to a better understanding of appropriate interfaces for a diverse population including individuals with different disabilities. Given that EEG technology provides such an objective measure of mental activity, future research can use alpha activity to study and design user-friendly interfaces for specific software to be used by the blind.

A limitation of this study is the small sample size since EEG was collected from a total of eight subjects. However, past research (Collins, Powell and Davies, 1990; Hillman et al., 2002; Scott et al., 2001) has utilized a lesser amount of electrodes (i.e., 10-20 system) using an equal or smaller sample size. This demonstrates the validity and reliability of EEG as a powerful measure of human performance. Further, the ESI-256 allows for a higher resolution than conventional EEG equipments. The fact that we used a large array of electrodes increases the accuracy of EEG

measures and permits researchers to capture the activity of the brain in a more representative manner. Even though the average mean power value was taken from each region, this value represented the mental processes that occurred in each specific region. This allows researchers to compare studies using a smaller number of electrodes (e.g., 10-20 system).

In conclusion, based on the initial results obtained in this study, future research will prove useful if we can use lower and upper alpha activities to identify the interfaces that are best matched to basic tasks involved in the operation of computers towards the design of user-friendly human computer interfaces. The following points need to be considered for further research: (1) tasks under study should be more varied and difficult enough for all subjects; and (2) the verbal/analytic task should be selected such that the visuo-spatial components related to the task are reduced; and (3) lower and upper alpha activities should be viewed in context and in contrast to other wavebands such as Beta 1 and Beta 2 to constitute a behavior of inter and intra band interplays.

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Table 1 Mean lower (8-10 Hz) and upper (11-13 Hz) alpha power values in μV^2 for the right (RH) and left (LH) hemispheres.

Frequency	RH	LH	F-ratio
8-10 Hz	4.00 \pm 1.91	6.80 \pm 2.99	17.81*
11-13 Hz	2.43 \pm 1.56	4.09 \pm 2.02	16.18*

***p<.01**

Figure 1. Mean upper alpha power values (11-13 Hz) for the hemisphere by site interaction effect.

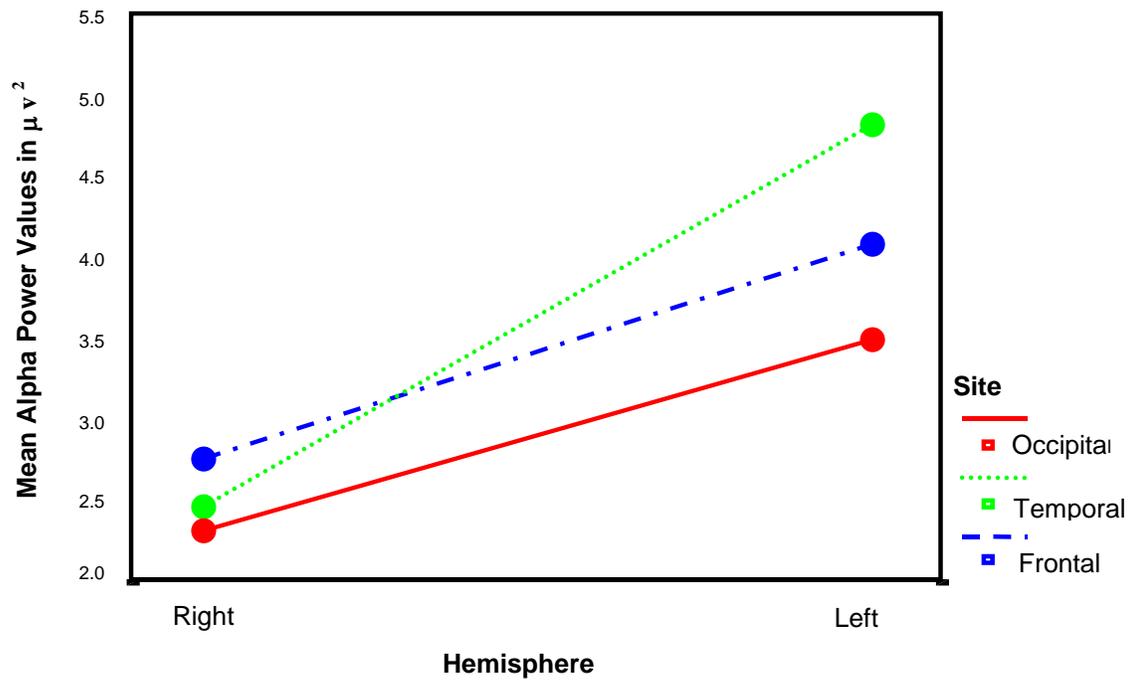


Figure 2. Mean lower alpha power values (8-10 Hz) for the task by computer interface interaction effect at the temporal site.

