The Effects of Human-Computer Interfaces in Mental Effort, as Measured by Alpha Activity

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Abstract

This is a case study involving empirical assessments of EEG signals collected using a Neuro Scan Electrical Signal Imaging brain recording system with 256 electrodes (ESI-256). Subjects were used in an effort to determine and contrast the mental efforts associated with given tasks involving different human-computer interfaces. This article demonstrates and confirms that indeed a particular frequency band between 8 and 13 Hz referred to as alpha activity can be used to characterize under different events or conditions the mental effort or activation associated with basic sensory experiences and mental tasks. The results obtained in this study support this assertion.

Key words: *EEG signals*, *alpha activity*, *mental effort*, *and human-computer interface*

Introduction

Humans use interfaces (e.g. keyboard, mouse) to interact with computers. A specific task may become more or less difficult depending on the computer interface that an individual is using. To compare task difficulty, researchers have investigated the levels of mental effort (Gevins, Smith, Leong, McEvoy, Whitfield, Du, & Rush, 1998). Gevins and his colleagues have successfully utilized current technology such as Electroencephalography (EEG) to investigate mental effort in individuals performing computer tasks with different mental loads.

The alpha frequency band (8-13 Hz) of the EEG is characterized by high amplitude (30 to 50 μV) waveforms. Alpha activity is associated with reduced levels of consciousness and awareness, and the reduction of alpha activity (alpha blocking) indicates sensory stimulation or increased mental activity (Shaw, 1992). This suggests that alpha activity is an appropriate measure to investigate differences in mental effort.

Mental effort as measured by alpha activity in specific sites of the human brain may depend on an event referred to as hemispheric lateralization. This event identifies specific involvement of each cerebral hemisphere, where the left hemisphere is more involved in the processing of verbal/analytic material, and the right hemisphere is more involved in the processing of visuospatial/synthetic material (Sperry, 1982). Furthermore, each lobe of the brain (e.g. temporal, occipital, parietal, etc.) is associated with a different role in human actions, such as speech, motion, and vision. Therefore, it is important to take into consideration the involvement of the two hemispheres as well as the involvement of each brain lobe, depending on the task at hand.

The purpose of this study is to investigate differences between the type of task (visuospatial/synthetic vs. verbal/analytic), the type of computer interface (keyboard vs. mouse), and the two cerebral hemispheres (left vs. right), as related to changes in alpha activity.

Data Acquisition Methods

Subjects tested were college-aged students from FIU. Figure 1 illustrates the experimental setup. To control gender differences in brain topography and handedness dominance among subjects, they were selected to be right-handed, right-eyed, and ipsilateral males. The Edinburgh Handedness Inventory (EHI) (Oldfield, 1971) was used to confirm the handedness dominance of all subjects prior to the testing. Subjects were asked to sign the “Informed Consent Form,” which outlines the research purpose and testing procedure. 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. This pre-testing process lasted about 2 hours per subject.

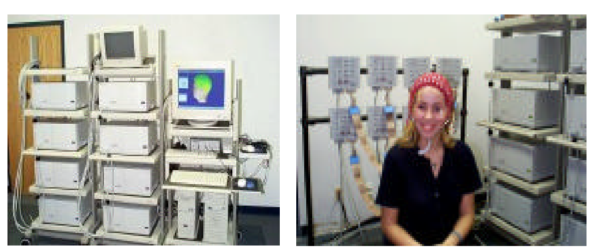

Figure 1: Experimental setup involving theESI-256 brain research machine.

The tests consisted of two different tasks. In one task, subjects played a video game that exercises visuospatial skills (SP). The game chosen was 3DTetriMania, which consists of organizing figures according to their shapes (see Figure 2). In the other task, subjects played a video game that exercises 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 (see Figure 3). Each subject played both video games with each of two computer interfaces: the keyboard (K) and the mouse (M). Subjects were randomly assigned to counterbalanced conditions of task and computer interface (i.e., SP/K, SP/M, VE/K, and VE/M). For each game, 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.

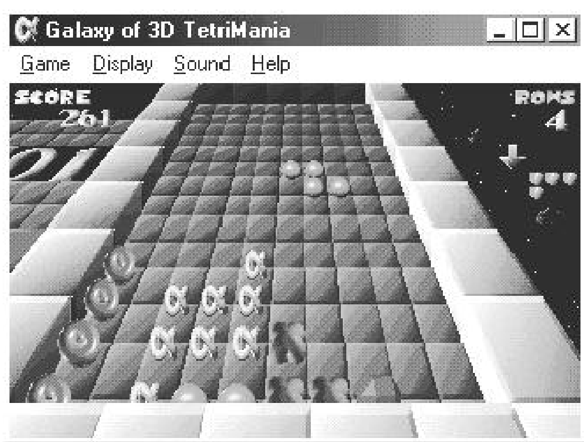

Figure 2. Visuospacial task: 3D Tetrimania

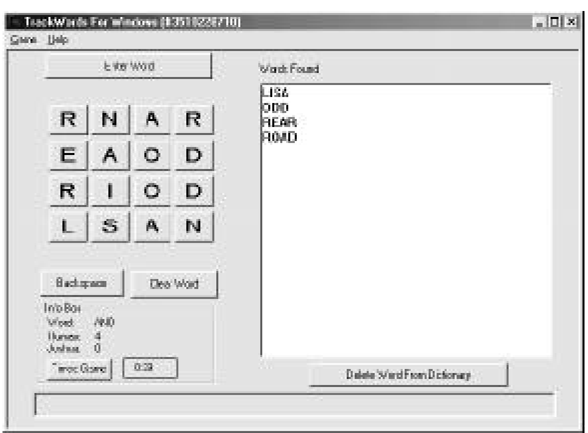

Figure 3. Verbal task: TrackWords.

EEG signals were collected with the Neuro Scan Electrical Signal Imaging System with 256 channels (ESI-256). The Acquire sub-module of the Scan 4.0 Interface was used to record continuous EEG data while testing each subject, at a sampling frequency of 1000 Hz, per channel. A total of 4 male subjects were tested. Four 60-second data files were obtained per subject. At the conclusion of the testing, each subject completed a questionnaire on their previous experience in using both games: all subjects had past experience with the games.

Data Analysis Methods

Digital Signal Processing

The Edit sub-module of the Scan 4.0 Interface was used to perform the first set of off-line processing to the EEG data recorded with the Acquire program. The process outlined below was followed for each file obtained from each subject.

The recorded continuous EEG data was first viewed in all 256 electrodes, in 1000 millisecond time sweeps (see Figure 4). By carefully analyzing the signal present at each electrode in the time sweep, noisy electrodes (those which oscillate or exhibit unexpected voltage spikes) were identified and rejected. This reduced the possibility of including noise in later calculations. Artifacts generated by eye blinking or movement of the subject were reduced by the ocular artifact reduction process, which identifies both the vertical electro-oculogram (VEOG) and horizontal electro-oculogram (HEOG).

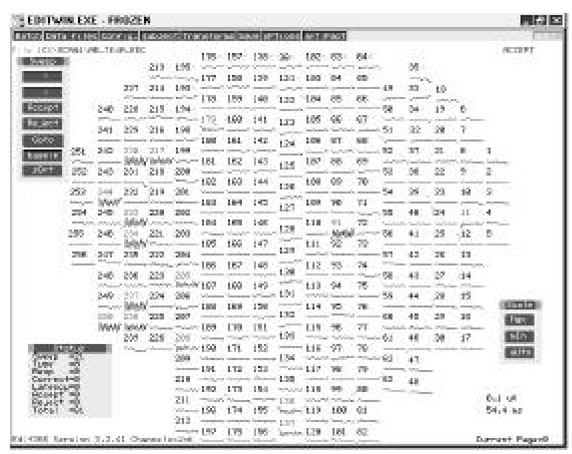

Figure 4. Recorded continuous EEG signals with ESI-256

The continuous file was transformed into an epoch file, consisting of 60 1-second epochs. In the epoch file, the first 20 epochs were rejected to account for the time required by each subject to become engaged in the task. The last 20 epochs were also rejected to consider that the subject is to finish the task within a few seconds. Therefore, only the data in the middle 20 epochs was accepted, which is the time when the subject should be most devoted to the given task. These remaining 20 epochs were analyzed one by one, and epochs showing a large percentage of noisy electrodes were also rejected. There was an average of 15 accepted epochs per file. To reduce unwanted noise added to the data by the external environment, the data was digitally filtered with a low pass filter set below 60 Hz. The last step before obtaining the Fast Fourier Transform (FFT) of the data, was to fit the data to 1024 points (power of 2 needed for the FFT) instead of the original 1000 points per epoch. An averaged FFT was obtained for all accepted epochs, which generated the power of each electrode at each frequency from 0 to 512 Hz (see Figure 5).

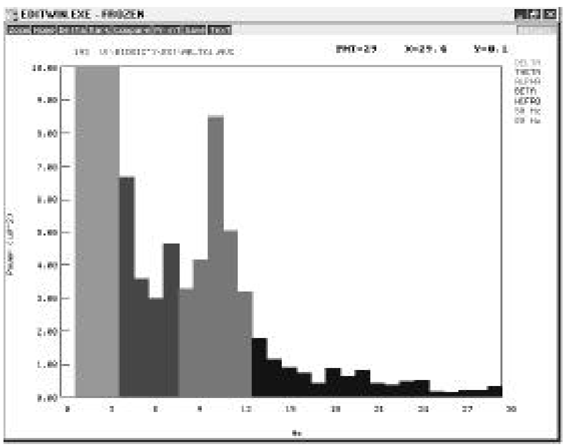

Figure 5. FFT for electrode in the left hemisphere: high alpha power from 8 to 13 Hz.

The frequency average file was saved in ASCII format with the Stats sub-module of the Scan 4.0 Interface. A program was written in C++ to perform the second set of off-line digital signal processing to the EEG data. The alpha power averages for each region of the brain in each of the hemispheres (left/right) was obtained with this program.

Statistical Analysis

The absolute mean alpha power values obtained for each subject from each region of the brain was used to analyze the EEG signals. These values were entered into Analysis of Variance (ANOVAs), each with a 2 x 2 x 2 repeated measures design (task x computer interface x hemisphere). Analyses were performed for each pair of active cerebral regions in the alpha frequency band. The dependent variable was the alpha power, and the independent variables were the task, the computer interface, and the hemisphere.

Results

Results reveal that there were significant differences in hemispheric activation at the occipital, parietal, temporal, and frontal sites ($p<0.05$). Mean alpha power values were greater in the left hemisphere as opposed to the right hemisphere (see Table 1). There were no significant differences in terms of hemispheric activation in the central regions ($p>0.05$). There were no apparent differences ($p>0.05$) in alpha activity when comparing the interfaces - mouse vs. keyboard. Furthermore, no significant differences ($p>0.05$) were found in alpha activity when comparing the Tetris vs. TrackWord tasks. However, a significant interaction effect task by computer interface was found at the temporal sites ($p<0.05$) (see Figure 6).

Table 1. Mean alpha power values for the right (RH) and left (LH) hemisphere at each cerebral region. * indicates p<0.05

Region	RH	LH	F-ratio
Occipital	4.19 ± 2.78	6.81 ± 2.57	6.52*
Parietal	4.06 ± 2.39	6.00 ± 2.90	3.59*
Temporal	3.68 ± 2.73	6.09 ± 1.89	8.54*
Frontal	2.99 ± 1.11	4.74 ± 1.09	18.51*
Central	3.00 ± 1.27	4.05 ± 2.10	2.40

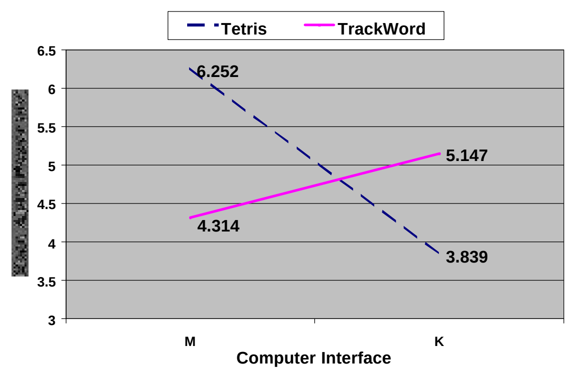

Figure 6. Mean alpha power values for the task by computer interface interaction at the temporal sites.

Discussion

In terms of hemispheric activation, this study reveals greater alpha activity in the left hemisphere as opposed to the right hemisphere. The lower levels of alpha activity in the right hemisphere suggest that both tasks were mainly visuospatial in nature. The TrackWord video game was intended to be a verbal task, but subjects were involved in finding letters in the screen to write as many words as possible. It appears that the process of finding appropriate letters on the screen added an unexpected visuospatial component to the task. There were no differences among hemispheres at the central lobes of the brain, perhaps because this region is activated by movement, and both tasks required the subjects to execute hand movements.

This finding supports the traditional view of hemispheric lateralization, where the left-hemisphere is more involved in the processing of verbal/analytic material, and the right hemisphere is more involved in the processing of visuospatial/synthetic material (Sperry, 1982; Bryden, 1982; and Springer & Deutsch, 1985). A significant interaction effect for task by computer interface at the temporal sites was revealed from the results. In this interaction, individuals showed greater alpha power when playing Tetris with the mouse, which suggests that Tetris became a less difficult task when played with the mouse.

This suggests that the integration of communication achieved from computer to user and user to computer by using the mouse as a human computer interface does facilitate the Tetris task, as characterized by the increased alpha power.

With regards to the two different computer interfaces, the results revealed that the subjects were involved in the same levels of mental effort when using either the keyboard or the mouse. This may be due to the level of difficulty of both tasks, which may have been too low for the subjects tested. Another possible reason may be that the number of subjects tested was too low.

Conclusion

The challenge of this case study was to identify through rather intricate empirical assessments those signals of the EEG that best characterize mental effort associated with the use of human computer interfaces. The objectives were (a) to investigate differences between tasks (visuospatial vs. verbal), (b) to contrast the use of different human computer interfaces (mouse vs. keyboard), and (c) to observe the different functions of the cerebral hemispheres (right vs. left). All of these objectives were weighed through the changes introduced in the alpha activity frequency band.

The EEG signals of each of the four subjects involved in performing the different tasks were recorded using the ESI-256 machine. Each subject played a Tetris game to test a visual task, and a TrackWord game to test a verbal task, each with the use of the keyboard and the mouse. The EEG signals collected were processed to obtain the absolute mean alpha power values. The statistical analysis of these values reveal that: (1) there were significant differences in alpha activity between the left and the right hemispheres, (2) there were no apparent differences in alpha activities between computer interfaces, and (3) there were no apparent differences in alpha activities between tasks.

Given the initial results obtained in this study, future research work will prove useful if we were to balance the mental effort associated with alpha activity with the design aspects of user-friendly human computer interfaces. We are conscientious of the practical implications of such a study, especially in view of the fact that our assessments are critically linked to the way our empirical data is collected. For this reason, and in order to make more stringent and discriminating decisions based on alpha activity, we need to consider the following points: (1) tasks under study should be more varied and difficult enough for all subjects; (2) the verbal/analytic task should be selected such that the visuospatial components related to the task are reduced; and (3) the results and the ensuing analysis would bear more credence with an increase in the number of subjects used in the study.

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