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Electroencephalographic activities during reading tasks in young adults : separate measures for localized and widespread brain functions

Efthymios Angelakis

To the Graduate Council:

I am submitting herewith a thesis written by Efthymios Angelakis entitled "Electroencephalographic activities during reading tasks in young adults : separate measures for localized and widespread brain functions." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Psychology.

Joel F. Lubar, Major Professor

We have read this thesis and recommend its acceptance:

Anne McIntyre, Eric D. Sundstrom

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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We have read this thesis and recommend its acceptance:

Anne McIntyre

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Accepted for the Council:

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Associate Vice Chancellor and Dean of the Graduate School

Electroencephalographic Activity During Reading Tasks in Young Adults: Separate Measures for Localized and Widespread Brain Functions

A Thesis Presented for the Master of Arts Degree

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Efthymios Angelakis

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Abstract

Although previous qEEG studies have observed differences in cortical activation between reading-disabled individuals and non-clinical controls during reading tasks, very little is reported about the qEEG effects of reading task conditions as compared to rest, within individuals. The present study explored the qEEG differences between resting and reading states in a group of 19 non-clinical college students to investigate the amplitude changes across seven frequency bands: 0.5-4, 4-8, 8-10, 10-12, 12-21, 21-32, and 38-42 Hertz. Nineteen channel EEG was recorded at 256 samples per second during an eyes-closed resting baseline, an eyes-open resting baseline, and five different reading tasks selectively engaging the visual, phonological, semantic, spelling and arithmetic reading modalities. ANOVA analyses comparing the five reading tasks with each other did not show significant intertask differences. ANOVA analyses comparing all reading conditions averaged to the eyes-open resting baseline revealed bilateral generalized significant amplitude increases during reading for the 0.5-4, 4-8, and 38-42 Hz bands; unilateral (left) amplitude increase for the 10-12 Hz band. No significant effect was found for the 8-10, 12-21, and 21-32 Hz bands. Post-hoc analyses revealed intertask differences only on the 4-8 Hz band and only for the right hemisphere. Results are interpreted as a manifestation of working memory and engrossment functions for the lower frequency bands, generalized arousal for the 8-10 Hz band, language specific processing for the 10-12 Hz band, and scanning and integration of information for the 38-42 frequency band. During reading tasks the brain may involve more widespread activity than localized to the language areas, as well as augment both very slow and very high frequency components. Implications for neurofeedback involve tentative models for cognitive and attentional processes.

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I. Introduction

The reading process involves several brain mechanisms which may be manifested in functional neuroimaging. For example, Positron Emission Tomography (PET) shows differential brain metabolism when participants look at false fonts, letter strings, pseudowords, or real words (Posner & Raichle, 1994).

Electroencephalographic (EEG) studies have also shown differentiation of cortical electrical activity between reading and other visual processing tasks using evoked response potentials (ERPs) or computer quantified EEG (qEEG) (Rumsey, Coppola, Denckla, Hamburger, & Kruesi, 1989; Galin, Raz, Fein, Johnstone, Herron & Yingling, 1992; Mattson & Sheer, 1992; Ackerman, Dykman, Oglesby, & Newton, 1994), as well as between different reading tasks (Ackerman, McPherson, Oglesby, & Dykman, 1998).

One reason why such neuroimaging techniques of the reading process are important is their potential contribution to the accuracy, specificity, and objectivity of diagnostic processes for various forms of reading difficulty (RD). Many studies based on childhood samples have shown distinct qEEG differences between reading disabled and non-disabled readers (Fein, Galin, Yingling, Johnstone, Davenport, & Herron, 1985; Rumsey et al., 1989; Marozi, Harmony, Sanchez, Becker, Bernal, Reyes, de Leon, Rodriguez & Fernandez, 1992; Ackerman et al., 1994; Harmony, Marozi, Becker, Rodriguez, Reyes, Fernandez, Silva, Bernal, 1995; Marozi, Harmony, Becker, Reyes, Bernal, Fernandez, Rodriguez, Silva, & Guerrero, 1995) as well as between participants with reading difficulties of different types (Duffy, Denckla, Bertels & Sandini, 1980; Flynn, Deering, &

Rahbar, 1992; Mattson & Sheer, 1992; Ackerman et al., 1998), mostly during active tasks including reading. Most of these studies have analyzed qEEG data by dividing the EEG spectrum into frequency bands of 0.5 - 3.5 Hz (delta), 3.5 - 7.5 Hz (theta), 7.5 - 12.5 Hz (alpha), 12.5 - 21 Hz (low beta) and 21 - 32 Hz (high beta), whereas other studies have focused only within the 35 - 45 Hz (gamma) band.

Another reason for the importance of such studies is their potential contribution to the development of neurofeedback (EEG biofeedback) protocols for the neurobehavioral treatment of reading difficulties. Lubar and colleagues have shown the effectiveness of neurofeedback for the treatment of learning disabilities associated with attention deficit disorders (Lubar & Lubar, 1984; Lubar, 1991; Lubar, Swartwood, Swartwood, & O'Donnell, 1995; Lubar & Lubar, 1999).

Most of the above studies have focused on children and adolescents from 6 to 16 years of age. However, very little research has been focused in the qEEG of the reading processes in adults. Moreover, very little is reported on the qEEG differences between resting and reading in non-clinical populations. The purpose of the current study was to explore the differential distribution of the qEEG under different reading tasks as compared to a resting baseline in a sample of college students without any reading difficulty. Furthermore, it was undertaken to establish a qEEG data set against which future data collected from students with reading difficulties could be compared, using the same procedures.

The existing literature on EEG measures comparing different cognitive tasks to rest has shown a number of phenomena. Gevins and colleagues found a frontal midline amplitude increase in the 4-8 Hz band during a visuospatial working memory task as compared with rest, in non-clinical adults. These investigators also found a parietal amplitude decrease of the 8-12 Hz and 12-32 Hz bands (Gevins, Smith, Leong, McEvoy, Whitfield, Du, & Rush, 1998).

Pfurtscheller has reported that during reading single words the 8-10 Hz band was inhibited mostly in response to arousal and attentional demands, whereas the 10-12 Hz band was inhibited in response to task-specific processing demands. The two frequencies showed differential timing and location for their Event-Related Desynchronization (ERD) (Pfurtscheller, 1989). Similar findings have been reported by Klimesch, who found that these two frequency bands were differentially distributed between good and bad memory performers. The good performers showed more of the higher component (10-12 Hz) whereas the bad performers showed more of the lower component (8-10 Hz). It was concluded that the lower component might reflect attentional functions whereas the higher component might reflect retrieval functions (Klimesch, 1997).

Another frequency related to cognitive operations is the 40 Hz (gamma). Some found this rhythm to increase in amplitude during scanning (Llinas & Ribary, 1992), whereas others have related to problem solving (Mattson & Sheer, 1992).

Many researchers have associated functions of language, including many kinds of reading, with the left hemisphere of the brain (e.g. Luria, 1973). It has also been shown that the left hemisphere is involved in the symbolic and analytic decoding of music symbols (Segalowitz, Bebout, & Lederman, 1979).

Based on these reports, we expected to find: 1) a frontal increase in 4 - 8 Hz amplitude during reading tasks as compared with a resting baseline, as affected by working memory mechanisms; 2) a bilateral decrease of 8 - 10 Hz (as compared with baseline) as affected by arousal and attentional processes; 3) a unilateral decrease of 10 - 12 Hz in the left hemisphere due to cognitive effort, as affected by the symbolic and analytic decoding nature of reading to which this latter band would selectively react; and 4) an increase of the 38-42 Hz activity, as affected by scanning and problem solving functions of reading. No prediction was made for the 0.5-4 Hz, 12-21 Hz, and 21-32 Hz bands.

II. Method

Participants

Twenty-two undergraduate (between 19 and 24 years of age) and one graduate (32 years old) psychology college students were recruited. All volunteered for extra credit. Among these, 14 were male and 9 female. During data analysis four participants (two male and two female) were eliminated from further analysis because they did not meet criteria for inclusion. Two of them showed increased alpha (7-13 Hz) activity in ten frontal locations from the Lifespan Normative Database; one scored lower than one standard deviation from the norms on six psychometric tests (IVA scores and five out of six Woodcock-Johnson scores), indicating a possible attention deficit with a reading difficulty; and one had excessive muscle artifact contamination of the EEG. The remaining number of participants analyzed was nineteen (12 male and 7 female).

Materials

A self-report form was administered to collect data on neurological and psychological history (see appendix).

Nine psychometric tests were administered in order to control for possible cognitive deviancies which would exclude participants from a non-clinical sample. These subtests included the Integrated Visual and Auditory Continuous Performance Test (IVA) that measures attention and hyperactivity; the Vocabulary and Block Design subtests of the Weschler Adult Intelligence Scale III (WAIS-III) that measure linguistic and visuospatial skills; and six subtests from the Woodcock-Johnson Achievement Battery Revised (WJ-R). These were the Letter-Word Identification subtest for the assessment of pronunciation and paralexic reading, the Passage Comprehension subtest for the assessment of reading comprehension skills, the Word Attack subtest for the assessment of phonic, structural and auditory processing skills, the Reading Vocabulary subtest for the assessment of word semantic/conceptual skills, the Calculation subtest for assessment of arithmetic operations skills, and the Quantitative Concepts subtest for the assessment of knowledge of mathematical concepts.

Reading materials for the five experimental tasks were developed in our laboratory (see appendix). Three pieces from Homer's *Odyssey* translated in English were used to selectively engage participants into visual, phonological, and semantic processing. Participants were asked to identify target words following different rules for each processing modality. Visual reading required the identification of four-letter words that include at least one "a" (e.g. *have*); phonological reading required the identification of words that included the sound "k" (as in *cross* or *peak*); and semantic reading required the identification of nouns that refer to a inanimate material object or entity (e.g. *table* or *ocean*). Texts were selected so that they were narrative, easy to read, and with a minimum number of names. Moreover, all three texts contained 20 (+/-1) target words for all three reading requirements.

A fourth task involved a list of words with 20 targets that had either a reversed "p" for a "q", or "b" for a "d", or vice-versa (e.g. *qarty*, or *ded*). The fifth task involved a list of number pairs with 20 target pairs in which one number was a multiple of the other (e.g. *8-2* or *10-20*). All target items were randomly distributed within the texts and lists.

Apparatus

EEG was recorded with a Lexicor Neurosearch 24 analog to digital system, and all data were stored and visually artifact rejected using a Pentium 120 MHz computer, and Lexicor's v41e software. Nineteen-channel electrode caps according to the 10/20 international electrode placement system by Electro Cap Inc. were used, with linked ear lobe references. The EEG data were collected with a band-pass filter set at 0.5-32 Hz for 128 samples per second recordings and at 0.5-64 Hz for 256 samples per second recordings. Digital EEG was processed by Fast-Fourier Transformation (FFT) with cosine tapering and a Hanning window.

Reading materials were presented with a Pentium computer with a 17" color screen.

In order to identify possible distinct EEG abnormalities, the Thatcher-Lifespan Normative Database (LND) was used to compare participants' eyes closed resting EEG recordings to a normative sample of non-clinical individuals of similar sex and age.

Procedure

All data were collected in a quiet windowless laboratory room with fluorescent lighting and no other persons present except for the participant and the experimenter. Participation was completed in two 2-hour sessions on different days. The first day, participants were asked to complete the self-report form concerning personal history on any psychological or neurological diagnoses (including reading difficulties), current prescription medication usage, head injuries, age, sex, and handedness (left or right). Then participants were fitted with the Electro Cap, and all impedances were measured to be below 5 kOhms.

Participants were seated in an armchair with their eyes toward a computer screen at a distance of 60 cm. Nineteen-channel EEG activity was recorded in the following order: first, during an eyes-closed resting condition; second, during an eyes-open resting condition, where participants were instructed to focus on the notepad window at the computer screen, while no text was running; then, the five reading tasks and a post-task resting condition (PTR) were recorded in a counterbalanced order between participants.

The three Odyssey texts were presented always in the same order, but for different reading requirements (i.e. visual, phonological, or semantic), according to the counterbalanced order. This varied presentation order was employed to avoid confounding of order effects and text related effects.

In order to minimize eye movements and control speed of stimulus presentation, reading materials were computerized and presented in a self running mode through a 1 x 5 cm Notepad window (Microsoft Windows 95), with the aid of Keyboard Express (Insight Software Solutions), which programmed the DELETE key of the computer to continuously strike every 100 milliseconds, "pulling" the text into the left side of the notepad window. This resulted in texts being presented at a pace of two words per second, the reversed-word list being presented at a pace of one word per second, and the number-pair list to be presented at a pace of 1.3 number-pairs per second. This presentation mode obliged participants to focus on a limited area to read, while the text was running through the window at a constant speed.

Each recording lasted 3.3 minutes, between which participants had the opportunity to rest, stretch, and relax for 1 minute. Before recording each reading task, a practice task was administered for 30 seconds. This enabled the participants to become familiar with the tasks. All reading was silent. While reading, participants were responding to target word identification by pressing a key on the computer keyboard with their right hand. This key put a marker on the EEG recording which was later compared (during data analysis) with a timed key of correct responses. This was done by visually inspecting the raw EEG files for markers at specific times according to the timed keys, with +/- 1 second allowance for differential reaction time and synchronization of the EEG and the Keyboard Express. The procedure was completed within 120 minutes. All seven eyes-open recordings were sampled at 256 samples per second, whereas the eyes-closed recording was sampled at 128 samples per second.

On a different day, within one week after the EEG recording, participants were measured with the psychometric tests.

III. Analysis

It was determined from the self-reports that no participant had any neurological or psychological history that would significantly affect the qEEG. To cross-validate this decision, relative power reports from the LND were inspected. The criterion for exclusion was set at more than four neighbouring locations deviating for any particular frequency band. Psychometric data were scored and evaluated for extreme deviancies. Criteria for exclusion were set at more than four (out of nine) psychometric measures to fall below one standard deviation from the norms.

Performance on all reading tasks was found to be above 50% correct for all participants (i.e. at least 10 out of 20 targets were identified).

Raw EEG data were visually inspected and all epochs including artifacts were removed from further analysis. It was noted that in many participants' recordings peripheral channels (FP1, FP2, F7, F8, T3, T4, O1, and O2) were frequently contaminated by muscle artifacts.

EEG data were reported in peak to peak microvolts (amplitude) averaged for each 3.3-minute recording. EEG amplitude was reported for frequency bands of 0.5-4, 4-8, 8-10, 10-12, 12-21, 21-32, and 38-42 Hz, separately for each recording and each scalp location. In order to avoid muscle artifacts possibly embedded in the high frequencies above 12 Hz, only the nine central locations (F3, C3, P3, FZ, CZ, PZ, F4, C4, P4) were analyzed further, whereas all nineteen locations for the frequency bands below 12 Hz were analyzed.

IV. Results

Results are shown in figure 1, each graph representing a single frequency band. Although all statistical tests were computed on the natural logarithm of the absolute power, task percent amplitude was graphed to illustrate the phenomena more clearly. The formula for computing task percent is

$$\text{task percent} = \frac{\text{each task uV}}{\text{all tasks uV}} * 100$$

where "each task uV" refers to the microvolts reported for the task for which the percent is calculated (for each location, frequency, and individual participant), and "all tasks uV" refers to the sum of microvolts for all tasks (for each location, frequency, and individual participant).

This transformation was employed instead of the traditional relative-to-total-EEG formula in order to exclude possible muscle contamination of the EEG from the frequencies above 12 Hz to the frequencies below 12 Hz, especially in the peripheral channels.

Since qEEG data do not usually fall under a normal distribution, a fact also confirmed by testing for normality on the present data, all values were squared and then transformed by their natural logarithm. This transformation yielded a significant normalization of the distribution of the data, as confirmed by less than 5% rejections of normality using both the Kolmogorov-Smirnov test and the Shapiro-Wilkinson test, independently. This transformation has universally been found to adequately normalize qEEG data (John, Ahn, Prichep, Treptin, Brown, & Kaye, 1980; Gasser, Bacher, & Mocks, 1982). Moreover, the Huynh-Feldt ANOVA test was used because the data did not meet the sphericity criterion.

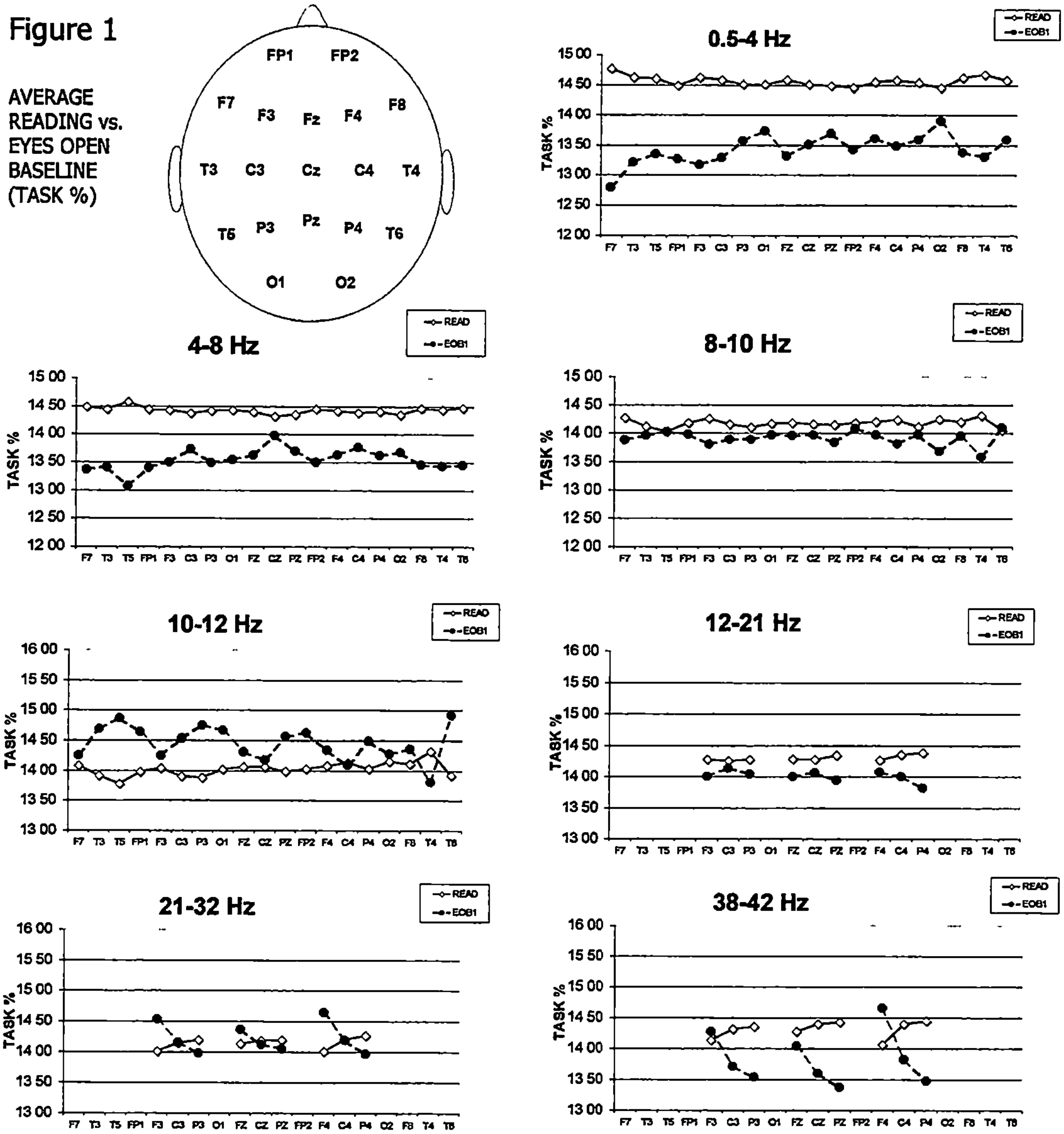
Repeated measures ANOVAs were computed first between the five reading tasks for each frequency and were found not to be significant. Hence, all five reading tasks were collapsed into one, by averaging their amplitude values for each individual, for each location, and for each frequency band. For the purposes of this report, the PTR condition was excluded from the analysis. This condition was not averaged with the initial resting baseline because it might show fatigue effects, a measure not related to this study. Hence, a two level comparison for the task variable was formed, namely resting baseline vs. reading, as shown in figure 1.

Figure 1.

Differences between reading (averaged for the five tasks) and eyes open baseline for all frequency bands (0.5-4, 4-8, 8-10, 10-12, 12-21, 21-32, 38-42 Hz). The vertical axis represents percent amplitude of average reading and baseline, and the horizontal axis represents cortical location. Frequency bands above 12 Hz do not include peripheral locations (FP1, FP2, F7, F8, T3, T4, T5, T6, O1, O2) due to muscle artifacts. The smooth appearance of reading across locations as compared to baseline is due to the averaging of all five reading tasks.

Figure 1

AVERAGE READING vs. EYES OPEN BASELINE (TASK %)



To test statistically for amplitude differences between these two levels, eight repeated measures ANOVAs were computed (task x location), one for each frequency band. For the 10-12 Hz band two ANOVAs were computed, one for the left and one for the right hemisphere.

ANOVAs revealed significant main effects for task, showing an increase in amplitude for the average reading scores as compared to resting baseline in the 0.5-4 Hz band ($F=61.46$, $p<0.001$), an increase in the 4-8 Hz band ($F=21.45$, $p<0.001$), a decrease in the 10-12 Hz band in the left hemisphere ($F=3.16$, $p<0.05$), and an increase in the 38-42 Hz band ($F=3.28$, $p<0.05$). No significant main effects for task were found for the 8-10 Hz, 12-21 Hz, and 21-32 Hz bands, or for the 10-12 Hz band in the right hemisphere. Although main effects for location showed significant differences in all ANOVAs, they are not reported because they are not relevant to the questions of this study. Finally, there were no significant interactions between task and location.

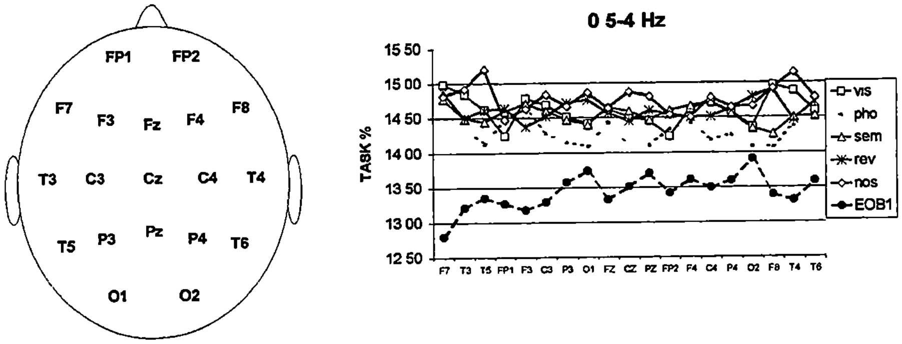
Figure 2 shows the differences between the initial eyes-open baseline (EOB1) and each reading task. Visual inspection of figure 2 shows some trends that may be considered to be tested with a larger sample. For example, one of these trends is the tendency of the arithmetic task to show the highest amplitude increases in the slow frequencies and the lowest increase in the gamma (38-42 Hz) frequency, whereas the phonological reading task showed a somewhat opposite effect. Another observation was that, for the 4-8 Hz, right hemisphere showed some inter-task differentiation, whereas the left hemisphere did not. Particularly, the arithmetic task exhibited the highest amplitude whereas the semantic and phonological tasks exhibited the lowest amplitude.

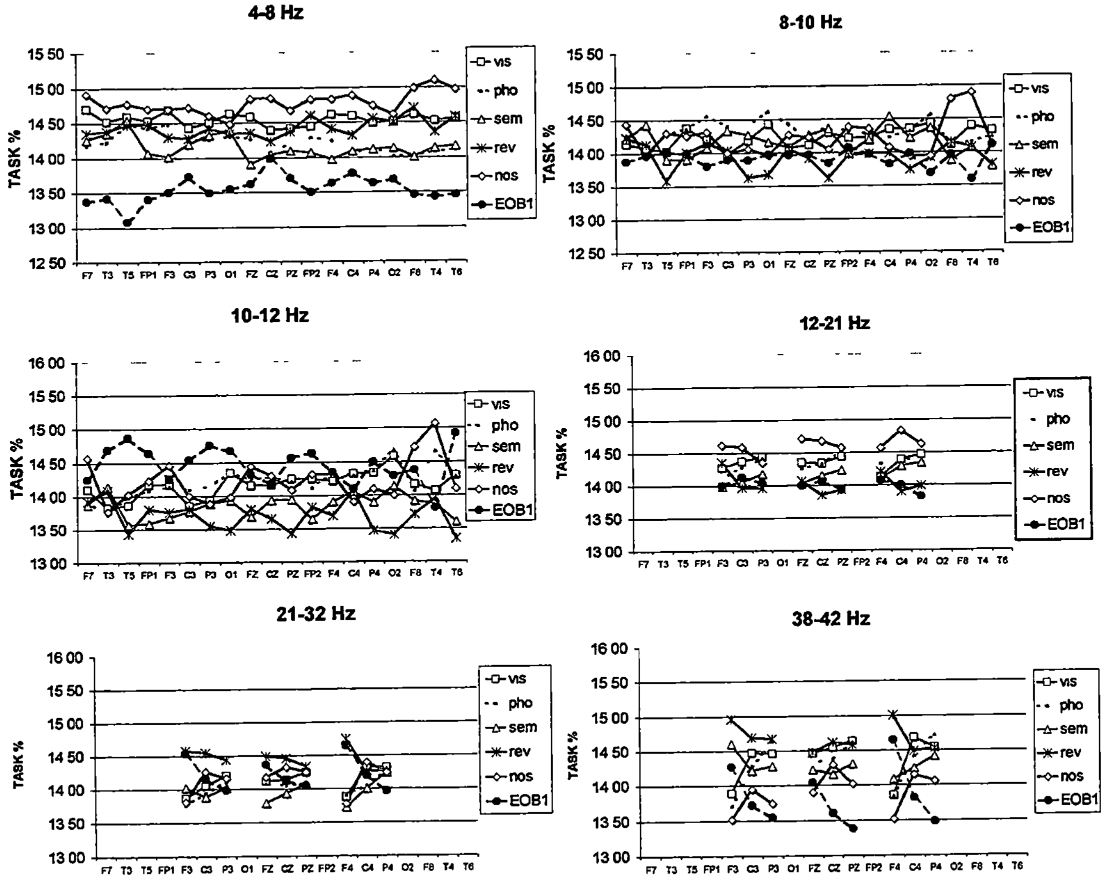
Figure 2

Differences between each reading task and eyes open baselıne for all frequency bands (0.5-4, 4-8, 8-10, 10-12, 12-21, 21-32, 38-42 Hz) The vertical axis represents percent amplitude of reading and baseline, and the horızontal axis represents cortical location Frequency bands above 12 Hz do not include peripheral locations (FP1, FP2, F7, F8, T3, T4, T5, T6, O1, O2) due to muscle artifacts.

Figure 2

READING vs
EYES OPEN
BASELINE
(TASK %)





In order to test further this latter observation, two post-hoc ANOVAs were computed comparing the five reading tasks (without baseline) separately for the right and left hemispheres, for the 4-8 Hz band. Results revealed no significant task effect for the left hemisphere, but a significant task effect for the right hemisphere ($F=3.65$, $p<0.05$). This latter test, however, did not show a significant effect when probability level for type I error was corrected for multiple comparisons (seven bands x two hemispheres).

V. Discussion

The prediction for amplitude increase in the 4-8 Hz band was supported by the data. However, this increase was distributed across on all locations rather than localized in the frontal midline area. If one interprets this distributed activity as underlying working memory, these results suggest that working memory functions are represented over the cortical surface rather than being localized to the prefrontal cortex. Lubar (1997) found a similar widespread significant increase in the 4-8 Hz band when participants reported being engrossed in listening to a story, as opposed to when they reported not being engrossed. It may be, then, that the present results in this frequency band represent not working memory, per se, but some form of engrossment in the material being read. Moreover, it seems that the lower frequency of 0.5-4 Hz may also be involved in this process, as it exhibited a very similar phenomenon. This latter effect appears to be real, rather than an artifact of eye movements, for several reasons. One is that the presentation of the reading materials minimized eye movements. Another reason is that all data containing eye movements were rejected by thorough visual inspection. Last, but not least, this phenomenon was found to be generalized over all locations, rather than on the frontal ones that would be expected for eye movements.

Some investigators have suggested that such widespread slow (2-6 Hz) oscillatory mechanisms connect the whole cortex with the hippocampus and may mediate memory retrieval and selective attention (Basar and Bullock, 1992). Other researchers agree with the hippocampo-cortical properties of this frequency which they found to be synchronized by episodic word-recognition tasks, as well as to correlate with the ability to encode new information (Klimesch, Schimke, & Schwaiger, 1994; Klimesch, 1998). Various neuroanatomical studies (e.g. Milner, 1970) have shown the relation of the hippocampus to intermediate-term memory. Damage to the hippocampus deprives the ability to retrieve memories formed during the last years (among other effects) before the damage, but leaves the ability to retrieve very long term memories intact. In the present context, it may be that the brain engaged into widespread cortico-hippocampal search and retrieval of information acquired during the last years in order to differentiate between targets and distracters. This post hoc hypothesis is also concordant with the finding that the arithmetic task showed more slow activity activation on the right hemisphere than the semantic and the phonological did. Since, however, this result did not show significance when corrected for multiple comparisons, further research is needed to validate it.

The prediction for amplitude decrease in the 8-10 Hz band was not supported by the data. One explanation may be that participants were already alert enough before getting engaged in the reading tasks so that no further suppression of this band could be manifested. Instead, the 10-12 Hz band activity was suppressed in the left hemisphere only, a finding that supports the hypothesis for task-specific attenuation of this band. Pfurtscheller and Klimesch have shown that Event-Related Desynchronization (ERD) of this narrow band shows very discrete task-dependent localization. They found for example that right finger tapping attenuated 10-12 Hz at bilateral central locations (C3, C4) whereas reading single words attenuated the same frequency at occipital areas and enhanced it at the central areas (1992). It is of interest that while single-word reading affected this frequency at both occipital areas (or in one experiment only the right), the tasks used in the present study showed a very unilateral effect on the left hemisphere. One possible explanation is that these differential phenomena may be due to the static versus serial processing nature of the two stimulus presentation modes.

The data also supported the prediction for amplitude increase in the 38-42 Hz band, which shows the importance of this frequency band in complex reading tasks. It is of interest that the 21-32 Hz band did not show any similar effect, thus minimizing the possibility for the 38-42 Hz band to show effects due to muscle artifacts, which would spread over to the 21-32 Hz band as well. This is also supported by the fact that the central locations analyzed are generally much less prone to be contaminated by muscle tension artifacts. Mattson and Sheer (1992) have suggested a relationship of the 40 Hz frequency with problem solving, and in the case of the tasks used employed here it seems that such a hypothesis may be true. Moreover, Llinas and Ribary (1992) interpret the synchronization of 40 Hz activity as a scanning mode associated with the formation of single percepts from multiple sensory components. Further experimentation manipulating those two functions may shed more light into the functional correlates of this high frequency activity.

Finally, the fact that the 12-21 Hz band did not show a significant effect although showing an increasing trend in the graph may be due to small sample size. However, it is of interest that this non-significant trend is in the opposite direction to the results of Gevins et al. (1998). These investigators found a decrease in 12-21 Hz activity during a visuospatial working memory task. One explanation is that this frequency band may react differently from a reading task to a visuospatial working memory task. An alternative explanation may be the fact that Gevins et al. had their participants thoroughly practice their tasks for days before recording the EEG, whereas in the present study participants were never before exposed to these specific tasks and procedures. If the latter case is true, it may be that this frequency band proves to be a sensitive indicator to differentiate naive from skilled performers.

A theoretical inference from these phenomena is that although the brain may involve localized mechanisms for different operations, as for example attenuation of the 10-12 Hz band at the left hemisphere shown here (a well known language-related area for serial processing of symbols), it also seems to employ co-operation of areas widespread over the cortical surface, something illustrated by the augmentation of slower (0.5-4 Hz and 4-8 Hz) as well as faster (38-42 Hz) electrical rhythms across most channels. These observations also show that during reading tasks the brain combines very slow with very fast components of the EEG, showing that the two ends of the cortical wave spectrum do not necessarily compete with each other.

A question that arises from the present findings as well as from other studies (e.g. Gevins et al., 1998) is why neurofeedback training to suppress amplitude of the slow frequencies (4-7 Hz) improves the attentional and cognitive abilities of children with attention deficit disorders when these frequencies seem mostly involved in different cognitive tasks in adults. One explanation may be that such slow activity (4-7 Hz) in children may be equivalent to higher rhythms, between 7 and 9 Hz in adults. It has been well documented, for example, that the posterior dominant frequency follows such a developmental pattern of frequency increase, starting from 6-9 Hz at preschool ages and reaching the adult level of 8-12 Hz around the age of 13 (Duffy, Iyer, & Surwillo, 1989; Niedermeyer & DaSilva, 1999). In this case, children with attentional deficit disorders may be developmentally delayed and what neurofeedback may suppress is their dominant oscillating rhythm. This model may be supported if future studies show that adults with attention deficit disorders exhibit this rhythm at much higher frequencies than children, and that they benefit from being trained to suppress it.

An alternative explanation would be that children with attention deficit disorders engage in some internal engrossment (that some may call it day dreaming), involving activation of cortico-hippocampal pathways that limits the ability to process external stimuli or events. It has been shown that engagement into working memory tasks impedes performance in concurrent attentional tasks (Posner & Raichle, 1994). In this case, by teaching children with attention deficit disorder to suppress their internal processes, more attentional resources may become available.

In conclusion, the 0.5-4 Hz, 4-8 Hz, and 38-42 Hz bands all showed bilateral widespread effects of cortical amplitude augmentation during reading as compared with a resting baseline, but only the 10-12 Hz band was sensitive particularly to the left hemispheric cortical involvement in reading. This implies that during reading tasks the brain may involve more generalized than localized activity.

The implications of these findings for neurofeedback involve some understanding of the reading process in young adults, and the role of different frequency bands in this process. Further implications will be more evident when these data will be compared to data collected from young adults with reading difficulties where it may be possible to differentiate which modality of reading (e.g. working memory, serial processing, etc.) is in dysfunction for each RD subtype. Since, however, the present study involved only a small number of participants as compared with the number of variables to be measured, further effects may be revealed by replication of this study with a substantially larger number of participants. It may be that different RD subtypes show different patterns of electrocortical deficiency, dependent upon EEG frequency and reading task and, in this case, appropriate neurofeedback protocols may be designed for each subtype.

References

Ackerman, P. T., Dykman, R. A., Oglesby, D. M., & Newton, J. E. O. (1994). EEG power spectra in children with dyslexia, slow learners, and normally reading children with ADD during verbal processing. *Journal of Learning Disabilities*, 27: 619-630.

Ackerman, P. T., McPherson, W. B., Oglesby, D. M., & Dykman, R. A. (1998). EEG power spectra of adolescent poor readers. *Journal of Learning Disabilities*, *31*: 83-90.

Basar, E. (1998). Brain Function and Oscillations, Vol. 2. Berlin; New York: Springer.

Duffy, F. H., Denckla, M. B., Bertels, P. H., & Sandini, G. (1980). Dyslexia: regional differences in brain electrical activity by topographic mapping. *Annals of Neurology*, *7*: 412-420.

Duffy, F. H., Iyer, V. G. & Surwillo, W. W. (1989). *Clinical Electroencephalography and Topographic Brain Mapping: Technology and Practice.* New York: Springer-Verlag.

Fein, G., Galin, D., Yingling, C. D., Johnstone, J., Davenport, L. & Herron, J. (1986). EEG spectra in dyslexic and control boys during resting conditions. *Electroencephalography and Clinical Neurophysiology*, *63*: 87-97.

Flynn, J. M., Deering, W., Goldstein, M., & Rahbar, M. H. (1992). Electrophysiological correlates of dyslexic subtypes. *Journal of Learning Disabilities, 25*: 133-141.

Galin, D., Raz, J., Fein, G., Johnstone, J., Herron, J., & Yingling, C. (1992). EEG spectra in dyslexic and normal readers during oral and silent reading. *Electroencephalography and Clinical Neurophysiology, 82*: 87-101.

Gasser, T., Bacher, P., & Mocks, J. (1982). Transformations towards the normal distribution of broad band spectral parameters of the EEG. *Electroencephalography and Clinical Neurophysiology, 53*: 119-124.

Gevins, A., Smith, M. E., Leong, H., McEvoy, L., Whitfield, S., Du, R. & Rush, G. (1998). Monitoring working memory load during computer-based tasks with EEG pattern recognition methods. *Human Factors, 40* : 79-91.

Harmony, T., Marozi, E., Becker, Rodriguez, M., J., Reyes, A., Fernandez, T. Silva, J. & Bernal, J. (1995). Longitudinal quantitative EEG study of children with different performances on a reading-writing test. *Electroencephalography and Clinical Neurophysiology, 95*: 426-433.

John, E. R., Ahn, H., Prichep, L., Treptin, M., Brown, D., & Kaye, H. (1980). Developmental equations for the electroencephalogram. *Science, 210*: 1255-1258.

Klimesch, W., Schimke, H., & Schwaiger, J. (1994). Episodic and Semantic Memory: an Analysis in the EEG Theta and Alpha Band. *Electroencephalography and Clinical Neurophysiology, 91*: 428-441.

Klimesch, W. (1997). EEG-alpha rhythms and memory processes. *International Journal of Psychophysiology, 26*: 319-340.

Klimesch, W. (1998). EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. *Brain Research Reviews, 29*: 169-195.

Lubar, J. O., & Lubar, J. F. (1984). Electroencephalographic biofeedback of SMR and beta for treatment of attention deficit disorders in a clinical setting. *Biofeedback and Self-Regulation, 9:* 1-23.

Lubar, J. F. (1991). Discourse on the development of EEG diagnostics and biofeedback for attention-deficit/hyperactivity disorders. *Biofeedback and Self-Regulation, 16* : 201-225.

Lubar, J. F., Swartwood, M. O., Swartwood, J. N., & O'Donnell, P. H. (1995). Evaluation of the effectiveness of EEG neurofeedback training for ADHD in a clinical setting as measured by changes in T.O.V.A. scores, behavioral ratings, and WISC-R performance. *Biofeedback and Self-Regulation, 20*: 83-99.

Lubar, F. J. (1997). Neocortical dynamics: implications for understanding the role of neurofeedback and related techniques for the enhancement of attention. *Applied Psychophysiology and Biofeedback, 22*: 107-122.

Lubar, J. F. & Lubar, J. O. (1999). Neurofeedback assessments and treatment for attention deficit/ hyperactivity disorders. In J. R. Evans and A. Abarbanel (Eds.) *Introduction to Quantitative EEG and Neurofeedback.* San Diego: Academic Press.

Luria (1973). *The Working Brain.* New York: Basic Books.

Marozi, E., Harmony, T., Sanchez, L., Becker, J., Bernal, J., Reyes, A., de Leon A. E. D., Rodriguez, M., & Fernandez, T. (1992). Maturation of the coherence of EEG activity in normal and learning-disabled children. *Electroencephalography and Clinical Neurophysiology, 83*: 350-357.

Marozi, E., Harmony, T., Becker, J., Reyes, A., Bernal, J., Fernandez, T., Rodriguez, M., Silva, J., & Guerrero, V. (1995). Electroencephalographic coherences discriminate children with different pedagogical evaluation. *International Journal of Psychophysiology, 19*: 23-32.

Mattson, A. J., & Sheer, D. E. (1992). Electrophysiological evidence of lateralized disturbances in children with learning disabilities. *Journal of Clinical and Experimental Neuropsychology, 14*: 707-716.

Milner, B. (1970). Memory and the temporal regions of the brain. In K. H. Pribram and D. E. Bradbent (Eds.) *Biology of Memory*. New York: Academic Press.

Niedermeyer, E., & DaSilva, E. L. (1999). *Electroencephalography. Basic Principles, Chemical Applications, and Related Fields (4^{th} ed.)*. Baltimore: Williams & Wilkins.

Pfurtscheller, G. (1989). Spatiotemporal analysis of alpha frequency components with the ERD technique. *Brain Topography, 2*: 3-8.

Pfurtscheller, G. and Klimesch, W. (1992). Event-related synchronization and desynchronization of alpha and beta waves in a cognitive task. In E. Basar, & T. H. Bullock, (Eds.) *Induced Rhythms in the Brain*. Boston: Birkhauser.

Posner, M. I., & Raichle, M. E. (1994). *Images of Mind.* New York: Scientific American Library.

Rumsey, J. M., Coppola, R., Denckla, M. B., Hamburger, S. D., & Kruesi, M. J. P. (1989). EEG spectra in severely dyslexic men: rest and word and design recognition. *Electroencephalography and Clinical Neurophysiology, 73*: 30-40.

Segalowitz, S. J., Bebout, L. J., & Lederman, S. J. (1979). Lateralization for reading musical chords: disentangling symbolic, analytic, and phonological aspects of reading. *Brain and Language, 8*: 315-323.

Appendix

READING MATERIALS

"Nine days and nine nights did we sail, and on the tenth day our native land showed on the horizon. We got so close in that we could see the stubble fires burning, and I, being then dead beat, fell into a light sleep, for I had never let the rudder out of my own hands, that we might get home the faster. On this the men fell to talking among themselves, and said I was bringing back gold and silver in the sack that Aeolus had given me. 'Bless my heart,' would one turn to his neighbor, saying, 'how this man gets honored and makes friends to whatever city or country he may go. See what fine prizes he is taking home from Troy, while we, who have traveled just as far as he has, come back with hands as empty as we set out with- and now Aeolus has given him ever so much more. Quick- let us see what it all is, and how much gold and silver there is in the sack he gave him.' "Thus they talked and evil counsels prevailed. They loosed the sack, whereupon the wind flew howling forth and raised a storm that carried us weeping out to sea and away from our own country. Then I awoke, and knew not whether to throw myself into the sea or to live on and make the best of it; but I bore it, covered myself up, and lay down in the ship, while the men lamented bitterly as the fierce winds bore our fleet back to the Aeolian island. "When we reached it we went ashore to take in water, and dined hard by the ships. Immediately after dinner I took a herald and one of my men and went straight to the house of Aeolus, where I found him feasting with his wife and family;

By and by morning came and woke Nausica, who began wondering about her dream; she therefore went to the other end of the house to tell her father and mother all about it, and found them in their own room. Her mother was sitting by the fireside spinning her purple yarn with her maids around her, and she happened to catch her father just as he was going out to attend a meeting of the town council, which the Phaeacian aldermen had convened. She stopped him and said: "Papa dear, could you manage to let me have a good big waggon? I want to take all our dirty clothes to the river and wash them. You are the chief man here, so it is only right that you should have a clean shirt when you attend meetings of the council. Moreover, you have five sons at home, two of them married, while the other three are good-looking bachelors; you know they always like to have clean linen when they go to a dance, and I have been thinking about all this." She did not say a word about her own wedding, for she did not like to, but her father knew and said, "You shall have the mules, my love, and whatever else you have a mind for. Be off with you, and the men shall get you a good strong waggon with a body to it that will hold all your clothes." On this he gave his orders to the servants, who got the waggon out, harnessed the mules, and put them to, while the girl brought the clothes down from the linen room and placed them on the waggon. Her mother prepared her a basket of provisions with all sorts of good things, and a goat skin full of wine;

Men-servants and pages were bustling about to wait upon them, some mixing wine with water in the mixing-bowls, some cleaning down the tables with wet sponges and laying them out again, and some cutting up great quantities of meat. Telemachus saw her long before any one else did. He was sitting moodily among the suitors thinking about his brave father, and how he would send them flying out of the house, if he were to come to his own again and be honored as in days gone by. Thus brooding as he sat among them, he caught sight of Minerva and went straight to the gate, for he was vexed that a stranger should be kept waiting for admittance. He took her right hand in his own, and bade her give him her spear. "Welcome," said he, "to our house, and when you have partaken of food you shall tell us what you have come for." He led the way as he spoke, and Minerva followed him. When they were within he took her spear and set it in the spear-stand against a strong bearing-post along with the many other spears of his unhappy father, and he conducted her to a richly decorated seat under which he threw a cloth of damask. There was a footstool also for her feet, and he set another seat near her for himself, away from the suitors, that she might not be annoyed while eating by their noise and insolence, and that he might ask her more freely about his father. A maid servant then brought them water in a beautiful golden ewer and poured it into a silver basin for them to wash their hands, and she drew a clean table beside them.

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QUESTIONAIRE FOR PARTICIPATION IN THE STUDY:

"EEG DIFFERENCES BETWEEN VISUAL, PHONOLOGICAL, AND SEMANTIC READING, IN COLLEGE STUDENTS"

Principal investigator: Efthymios Angelakis, B.A.
Co-principal investigator: Joel F Lubar, PhD.

I am going to ask you some personal information needed for this study. The use of this information is strictly limited to the purposes of this study and it will be available only to the above investigators. This information is confidential, if however you feel not comfortable to answer any of the following questions, ask for the next question.

1. Which hand do you write with? Right ___ Left ___ Both ___
2. Have you ever been diagnosed as learning disabled? ___ Dyslexic? ___
   If yes, give more specific details ________________________________.
   I no, have you ever experienced difficulties with reading? (e.g. too slow reading, too tiring, too many misperceived words, etc.) ____________________.
3. Have you ever been diagnosed with an attention deficit disorder (ADD/ADHD)?
   ______________ If no, have you ever experienced systematic difficulties to concentrate and/or focus attention on a task? ____________________.
4. Have you ever had any head injury? ____________________________.
   Surgical operation on the head? ________________________________.
   Lost consciousness for more than one minute? ____________________.
5. Have you ever had epileptic seizures? __________________________.
6. Have you ever had any neurological diagnosis? ____________________.
7. Do you need correcting lenses for vision ? (specify) ________________.
8. Are you currently using any prescription medication? _______________.
9. What is your gender? Male ___ Female ___
10. What is your date of birth? (MM/DD/YY) _________________________.

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I.V.A. scores ____.
WAIS Voc. score ________ W-J scores 22 _____ 23 _____ 31 _____ 32 _____.
Notepad scores ____.
Name ______________________________ Date __________ Time __________.
Participant No. ___________ Counterbalancing order ___________________.
Task scores: T-visual ________ T-phonological________ T-semantic ________.
Words: ____.

Vita

Efthymios Angelakis was born in 1965, in Athens, Greece. He graduated from high school in 1982, in Athens, and started working as a commercial agent assistant for three years. In 1986, Mr. Angelakis got his license as a commercial agent and worked since then as an independent commercial agent for ten years. In 1991, Mr. Angelakis received his diploma in Cinema Directing, after three years of attendance in the Private School of Cinema Studies, Athens. In 1998, Mr. Angelakis received his Bachelor of Arts degree from the American College of Greece, Athens, as well as his Diploma in Byzantine Music from the Music Conservatory Nikos Skalkotas, Athens.

Since 1998, Mr. Angelakis has been enrolled as a graduate student in the department of Psychology, Experimental Program, in the University of Tennessee, Knoxville, where he has been conducting research on electroencephalographic manifestations of the reading process in young adults, under the supervision of Dr. Joel F. Lubar. Mr. Angelakis has presented data from his research in the annual meeting of the Society for Neuronal Regulation (SNR) in Myrtle Beach, S.C., in September 1999, as well as in the annual meeting of the Association for Applied Psychophysiology and Biofeedback (AAPB), in Denver, CO., in April 2000, and he was awarded by both SNR and AAPB for these presentations.

Currently, Mr. Angelakis is enrolled in the doctoral experimental program of the Psychology department in the University of Tennessee, Knoxville.