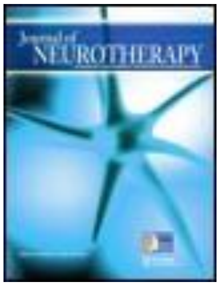

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Quantitative Electroencephalographic Amplitude Measures in Young Adults During Reading Tasks and Rest

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Quantitative Electroencephalographic Amplitude Measures in Young Adults During Reading Tasks and Rest

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ABSTRACT. *Background.* Previous studies have observed differences in the quantitative electroencephalogram (qEEG) between individuals

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with reading difficulties and non-clinical controls during reading tasks. However, little has been reported about the qEEG of reading tasks compared to qEEG at rest across a wide range of EEG frequencies. The present study explored the qEEG differences between resting and reading states in a group of 19 non-clinical college students. The purpose was to investigate the amplitude changes across five frequency bands: 8 to 10, 10 to 12, 12 to 21, 21 to 32, and 38 to 42 Hz.

Methods. Nineteen channels of EEG were recorded at 256 samples per second during an initial resting baseline, during five different reading tasks while selectively engaging the visual, phonetic, and semantic modalities, and during a second resting baseline. Absolute EEG amplitude was measured as the dependent variable. Ninety ANOVAs (task × channel) were computed, comparing each reading task to each baseline, for each frequency band, for each of three cortical areas, frontal, centro-coronal, and posterior. Single-channel t-tests were computed for significant ANOVAs.

Results. ANOVA analyses revealed significantly less amplitude for the 10 to 12 Hz band during all three reading tasks as compared to the second baseline. Single-channel t-tests showed this phenomenon to be lateralized towards the left hemisphere.

Conclusions. Results are interpreted as a manifestation of language specific processing for the 10 to 12 Hz band. The absence of amplitude changes in the 12 to 21 Hz band was interpreted as motor inhibition. It is suggested that future studies employ a post-task baseline when studying cognitive tasks.

KEYWORDS. EEG, reading, adults, delta, theta, alpha, beta, gamma

INTRODUCTION

Due to the obvious interest in the assessment of clinical groups as compared to non-clinical ones, little has been reported on the qEEG differences between resting and reading states in non-clinical adult populations. It may be, however, essential to establish EEG changes between reading and resting within groups of non-clinical individuals before inter-group hypotheses are formed. In this way, hypotheses for the latter may be limited to fewer factors derived from the within-group results, and thus allow between-group analyses to gain statistical power. Moreover, most studies investigating differences between groups of normally reading and reading disabled individuals do not report effects on the broad EEG spectrum, but usually limit their analyses to frequency bands within the range of 4 to 32 Hz (e.g., Fein et al., 1986; Rumsey, Coppola, Denckla, Hamburger, & Kruesi, 1989; Ackerman, Dykman, Oglesby, & Newton, 1994). In addition, many studies report only relative power EEG data, making it difficult to draw conclusions about the activity of different frequency bands, independent from each other. This may sometimes lead to misinterpretation of the results, since relative power increases in some frequencies may be the result of decreases in some of the rest frequencies (Fein et al. 1986).

The purpose of the current study was to explore the EEG differences between resting and reading conditions within individuals, covering a wide range of the EEG spectrum, between 8 Hz and 42 Hz, in a sample of young adults without reading difficulty. The goal was to attempt to break down the reading process into more specific brain functions. Despite the nature of this study being more exploratory than confirmatory, some expectations were formed, taking into consideration the existing literature on EEG correlates of cognitive tasks.

Since the slow frequencies between 1 to 8 Hz have been a subject covered extensively by a previous report (Angelakis, Lubar, Frederick, & Stathopoulou, 2001), this article will focus on the EEG frequencies above 8 Hz. In regard to the 8 to 12 Hz band, Gevins and associates found a parietal amplitude decrease during tasks involving short-term retention of visual stimuli (Gevins et al., 1998). This frequency band, although regarded as homogeneous by many, seems to have quite distinct subcomponents. Pfurtscheller has reported that during reading single words the 8 to 10 Hz band was inhibited mostly in response to arousal and attentional demands, whereas the 10 to 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 (1997), who found that these two frequency bands were differentially distributed between "good" and "bad" memory performers, using Individual Alpha Frequency (IAF) as a measure of spectral distribution of the alpha band. IAF is the center of gravity of the alpha band, showing the discrete frequency with the highest amplitude within the alpha range, and around which alpha amplitude is evenly distributed. The good performers showed a higher IAF than the bad performers. Good performers had their IAF within the 10 to 12 Hz range, whereas bad performers had their IAF within the 8 to 10 Hz range. It was concluded that the lower alpha frequency might reflect attentional functions whereas the higher might reflect retrieval functions.

EEG activity above 13 Hz (beta) is analyzed by many studies in two or sometimes three distinct sub-bands, 13 to 21 Hz, 21 to 32/35 Hz, and 35 to 45 Hz, the latter emphasizing the discrete frequency of 40 Hz. Amplitude of the 13 to 21 Hz band has been positively related to motor inhibition, including sustained immobility and muscle tone suppression (Sterman, 2000), as well as to states of focused attention (Lubar & Lubar, 1999). Steriade (1999) reports a series of animal and human studies involving tasks that require alertness that show increased amplitude of 20 to 40 Hz EEG. However, all of those tasks were employing motor inhibition, and so it is not clear whether it is alertness or motor inhibition that correlates most with this frequency band.

Reporting on the wide beta range (13 to 30 Hz), Gevins and colleagues found a decrease in amplitude with increasing load during a visuospatial working memory task in a group of non-clinical adults (Gevins et al., 1998). These authors interpreted this phenomenon as an extension of alpha attenuation into the beta frequency.

Reports on the acute effects of drugs have shown non-specific results on the "beta" rhythms. For example, neuroleptics, stimulants, anxiolytics, hypnotics, and nootropics all show amplitude increases on the 13 to 35 Hz band (Wauquier, 1999). Given the very different (or even opposite) behavioral effects of these drugs, especially in regard to alertness, the issue becomes more complicated than originally thought. In general, the literature on the "beta" spectrum is not consistently conclusive on any particular brain state to be correlated with it, suggesting that researchers and clinicians lack a clear interpretation of its manifestations.

Another frequency related to cognitive operations is around 40 Hz, also referred to as "gamma." Some reports relate amplitude increases in this rhythm to scanning processing (Llinas & Ribary, 1992), whereas others have related it to focused arousal at modality specific cortical areas, being mostly prominent in the left hemisphere during a sentence repetition task, and on the right hemisphere during a face recognition task (Mattson & Sheer, 1992). However, this frequency is also related to initiation of voluntary movements, as shown by amplitude increases over the primary motor strip (Pfurtscheller, Flotzinger, & Neuper, 1994).

Based on these reports, we expected to find the following phenomena on EEG amplitude during reading, as compared to a resting baseline:

- Decrease in 8 to 10 Hz as a result of arousal and attentional processes.
- Unilateral decrease in 10 to 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. 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).
- For the 13 to 21 and 21 to 32 Hz bands, given the controversy of the literature, we tested three alternative hypotheses. An increase would support the attention/alertness hypothesis; no increase would support the motor inhibition, since both baseline and reading tasks involved almost equal amount of sustained immobility; and a decrease would support the alpha-like attenuation hypothesis.
- Finally, a left hemisphere increase in 38 to 42 Hz activity was expected, as affected by scanning and verbal processing of reading.

METHODS

Participants. Nineteen psychology college students were included, 12 male and 7 female, all volunteering for extra credit. These were selected from an initial sample of 23 (14 male, 9 female) from which four participants (two male and two female) were eliminated from further analysis. Two of them showed increased alpha (7 to 13 Hz) activity in ten frontal locations from the Lifespan Normative Database; one scored lower to 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. Therefore, because of deviations from normative data, these four students were excluded from the study.

Materials. A self-report form was administered to collect data on neurological and psychological history, including prior diagnosis of learning disabilities, AD/HD, brain injury, seizures, and current drug use. Nine psychometric tests were administered in order to identify possible cognitive deviancies, which would necessitate excluding participants from a non-clinical sample. These subtests included the Integrated Visual and Auditory Continuous Performance Test (IVA) which measures attention and hyperactivity; the Vocabulary and Block Design subtests of the Wechsler Adult Intelligence Scale III (WAIS-III) which measure linguistic and visuospatial skills; six subtests from the Woodcock-Johnson Achievement Battery Revised (WJ-R), specifically 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.

Apparatus. The 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 using 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 to 32 Hz for 128 samples per second recordings and at 1 to 64 Hz for 256 samples per second recordings. A 60 Hz notch filter was used. Digital EEG was processed by Fast-Fourier Transformation (FFT) with cosine tapering (Hanning window).

Reading materials for the five experimental tasks were developed in our laboratory. Three pieces from Homer's *Odyssey* translated to English were used to selectively engage participants in 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 an 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 (plus or minus one) 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.

Reading materials were presented with a Pentium computer with a 17-inch color screen. In order to identify possible distinct EEG abnormalities, the Thatcher-Lifespan Normative Database (LND, Thatcher, Walker, Gerson, & Geisler, 1989) was used to compare participant's 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 were present except for the participant and the experimenter. Participation was completed in two 2-hour sessions on different days. During the first session, the self-report form was administered and all EEG recordings were completed. During the second session, within one week after the first, participants were given the psychometric tests.

During the first session, participants were asked to complete a self-report form concerning personal history on any psychological or neurological diagnosis (including reading difficulties), current prescription medication usage, head injuries, age, sex, and handedness. Then participants were fitted with the Electro Cap, and impedance at all channels was 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 with no text; third, the five reading tasks and a second eyes-open baseline 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 1×5 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 200 seconds. Between recordings participants had the opportunity to rest for one 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 plus or minus one-second allowance for differential reaction time and synchronization of the EEG recording with 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.

During the second session of participation, 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) which measures attention and hyperactivity; the Vocabulary and Block Design subtests of the Wechsler Adult Intelligence Scale III (WAIS-III) which measure linguistic and visuospatial skills, respectively; 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.

Analysis. It was determined from the self-reports that no participant had any neurological or psychological history that would significantly affect the qEEG. A participant would be excluded if he or she had a prior diagnosis of a condition already known to alter EEG, including (but not limited to) learning disabilities, AD/HD, seizures, brain injury, depression, schizophrenia, substance abuse, or if the participant was under the effects of any substance that is known to significantly alter EEG (e.g., amphetamines, antidepressives, marijuana, sedatives, anticonvulsants, etc.). To cross-validate this decision, relative power reports from the LND were inspected. The criterion for exclusion was set at more than four neighboring 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 falling below the norms by at least one standard deviation. This was a decision made more on quantitative rather than qualitative criteria. In other words, participants were not differentially diagnosed for any form of learning disability, but were included if their psychometric scores followed approximately a normal distribution.

EEG data were reported in peak-to-peak microvolts (amplitude) averaged for all included epochs (regardless of whether they contained marked responses or not) of each 200 seconds recording. EEG amplitude (uV) was reported for frequency bands of 8 to 10, 10 to 12, 12 to 21, 21 to 32, and 38 to 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.

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 to 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 tests, independently (Shapiro, Wilkinson, & Chen, 1968). This transformation has universally been found to adequately normalize qEEG data (John et al., 1980; Gasser, Bacher, & Mocks, 1982). Moreover, the Huynh-Feldt ANOVA for repeated measures was used because the data did not meet the sphericity criterion.

From the five reading tasks only three had their EEGs analyzed: the visual, phonetic, and semantic reading tasks. Each one of these three recordings was compared to each one of the two eyes-open resting baselines (pre and between tasks). To test statistically for amplitude differences between reading and resting conditions, ninety repeated measures ANOVAs (task $\times$ location) were computed totally, for the frequency bands of 8 to 10 Hz, 10 to 12 Hz, 12 to 21 Hz, 21 to 32 Hz, and 38 to 42 Hz, separately for frontal (F-channels), centro-coronal (T3, T4, and

C-channels), and posterior areas (T5, T6, P- and O-channels) (5 frequencies, 3 reading tasks, 2 resting baselines, 3 cortical areas). Frequency bands of 1 to 4 Hz and 4 to 8 Hz have already been reported in a separate article (Angelakis et al., 2001). The frequency band of 32 to 38 Hz was omitted, because it was not of particular interest to the present study. Then, for the ANOVAs that showed either significant main effect on task or on the task × location interaction, repeated measures t-tests were computed one for each individual location.

Given the large number of ANOVAs, probability threshold for significance (a-level) was corrected for multiple comparisons using a sequential Bonferroni adjustment. This technique increases the power of the standard Bonferroni adjustment, reducing the probability of type-II error (Rice, 1988; Miller, 1981; Holm, 1979). For the ninety ANOVAs the alpha level 0.05 was divided by the total number of comparisons (0.05/90 = 0.00055). Then, all p-values were rank-ordered, and the smallest p-value was compared to the corrected a-level. If the p-value was smaller, it was considered significant. Then, the next smaller p-value was compared to an adjusted a-level for the remaining number of comparisons (0.05/89 = 0.00056, 0.05/88 = 0.00057, etc.) until the p-value became greater than the adjusted alpha level. For the t-tests, probability thresholds for significance (a-level) were set at 0.05 (0.025 for two-tailed hypotheses) if the ANOVA showed significant main effect for task, or corrected for multiple comparisons if the ANOVA showed significant interaction between task and location, dividing the a-level by the number of locations included in the particular ANOVA (0.05/7 = 0.007, 0.05/5 = 0.01, or 0.05/3 = 0.016). The sequential Bonferroni was applied here, too.

RESULTS

Table 1 shows participant's performance on reading tasks. This was considered to be an index of adequate engagement in each task according to its rule, since a random performance would have either much more omission or commission errors (200 seconds per reading task divided by 2 seconds allowance for each response makes 100 possible random key strikes) and for the purposes of the present analysis we considered this success rate as acceptable. However, significant differences were found in both omission (misses) and commission (false alarms) errors, when comparing the semantic task with any of the other two.

Visual and phonetic tasks did not differ significantly in either omission or commission errors.

Table 2 shows main effects for task and interactions (task × location). Reported F-values are significant after correction of a-level for multiple comparisons (see Analysis section for details). Significant main effects for task and significant interactions between task and location were found only for the 10 to 12 Hz band, for all three reading tasks as compared to the second resting baseline. Task main effects were found only for the frontal area (visual reading: F = 38.001 p < .0001, phonetic reading: F = 39.507 p < .0001, semantic reading: F = 52.737 p < .0001), whereas significant interactions between task and location were found for all three areas (frontal, centro-coronal, and posterior).

Table 3 shows significant differences between each reading task and the second resting baseline for each location, for the 10 to 12 Hz band.

TABLE 1. Means and their standard errors for omission (misses) and commission (false positives) errors during visual, phonetic, and semantic reading. Semantic reading produced significantly less omission and more commission errors compared with visual and phonetic reading. Visual and phonetic reading did not differ significantly in the amount of errors. (Bold typed numbers refer to significantly different means from the rest in their group.)

	OMISSIONS				COMMISSIONS		
ERRORS	VISUAL	PHONETIC	SEMANTIC		VISUAL	PHONETIC	SEMANTIC
MEAN	3.05	4.37	**1.89**		1.37	1.84	**8.37**
STD. ERR.	0.55	0.62	0.37		0.38	0.30	1.18

TABLE 2. Reading task minus second baseline for 10 to 12 Hz.

	Visual	Phonetic	Semantic
FRONTAL			
Main effect	38.001	39.507	52.737
Interaction	64.524	69.391	59.118
CENTRO-CORONAL			
Main effect	ns	ns	ns
Interaction	77.735	54.761	45.686
POSTERIOR			
Main effect	ns	ns	ns
Interaction	68.102	59.527	56.339

ANOVA F-values (1,18) for task main effects and interactions (task × location), comparing three reading tasks to the second baseline, at three cortical areas, for 10-12 Hz. All reported F-values have p-values < .0001 (ns = not significant).

TABLE 3. Reading task minus second baseline for 10 to 12 Hz.

	VISUAL		PHONETIC		SEMANTIC	
	t-value	*p-value*	*t-value*	*p-value*	*t-value*	*p-value*
F7	−2.23	**0.019**	−2.57	**0.010**	−2.01	**0.030**
T3	−2.77	**0.006**	−3.21	**0.002**	−2.47	**0.012**
T5	−3.40	**0.002**	−3.55	**0.001**	−3.86	**0.001**
FP1	−2.99	**0.004**	−3.21	**0.002**	−3.94	**0.000**
F3	−2.80	**0.006**	−2.96	**0.004**	−3.30	**0.002**
C3	−2.67	**0.008**	−2.83	**0.006**	−2.67	**0.008**
P3	−2.64	**0.008**	−2.76	**0.007**	−2.63	**0.008**
O1	−1.43	0.085	−1.46	0.081	−2.36	**0.015**
FZ	−2.85	**0.005**	−3.04	**0.004**	−3.51	**0.001**
CZ	−2.33	**0.016**	−2.90	**0.005**	−2.56	**0.010**
PZ	−1.77	0.047	−2.05	0.028	−2.26	**0.018**
FP2	−2.13	**0.024**	−2.94	**0.004**	−3.11	**0.003**
F4	−2.40	**0.014**	−2.31	**0.017**	−2.73	**0.007**
C4	−1.57	0.067	−1.88	0.038	−2.14	**0.023**
P4	−1.79	0.045	−2.07	0.026	−2.66	**0.008**
O2	−0.53	0.303	−0.33	0.371	−1.13	0.136
F8	−1.71	0.052	−2.31	0.016	−1.92	**0.035**
T4	−0.52	0.303	0.15	0.443	−0.69	0.250
T6	−1.82	0.042	−1.82	0.042	−3.25	**0.002**

T-test results for each of 19 locations, comparing three reading tasks to the second baseline, for 10-12 Hz. T-values being negative indicate reading showing a lower amplitude than the second baseline. Bold typed p-values are statistically significant. Those that were included in an ANOVA with no significant main effect for reading task, but with a significant interaction between task and location are compared to an a-level adjusted for multiple comparisons. P-values are for 1-tailed tests.

Although Tables 2 and 3 show the only significant results after correction of a-level for multiple comparisons, t-test results for the 21 to 32 Hz band are also reported in Table 4, because of the large proportion of p-values below 0.05. These values, however, are not significant after correction of a-level.

DISCUSSION

Overall, there were no significant changes of any frequency bands during reading when compared to the initial resting baseline. The only significant results involved a comparison of the reading tasks to the second resting baseline, for the 10 to 12 Hz band. This finding, evident mostly in left hemisphere locations as revealed by the individual t-tests, suggests that this frequency band reflects task specific processing rather than arousal, supporting our literature-based expectations. It is of interest that this phenomenon appears only when reading is compared to a

TABLE 4. Reading task minus second baseline for 21 to 32 Hz.

	VISUAL		PHONETIC		SEMANTIC	
	t-value	*p-value*	*t-value*	*p-value*	*t-value*	*p-value*
F3	−3.85	0.001	−3.52	0.002	−2.38	0.029
C3	−3.39	0.001	−3.10	0.006	−2.85	0.011
P3	−2.28	0.035	−2.05	0.056	−2.05	0.055
FZ	−2.19	0.042	−2.76	0.013	−3.12	0.006
CZ	−2.57	0.019	−2.89	0.010	−3.21	0.005
PZ	−1.98	0.063	−2.29	0.034	−2.28	0.035
F4	−2.34	0.031	−2.44	0.025	−2.23	0.039
C4	−1.15	0.266	−2.09	0.051	−2.17	0.044
P4	−0.92	0.370	−0.99	0.335	−1.08	0.296

T-test results for each of 9 central locations, comparing three reading tasks to the second baseline, for 21-32 Hz. T-values being negative indicate reading showing a lower amplitude than the second baseline. Since ANOVA results for this frequency band were not significant, the above p-values are not statistically significant when a-level is adjusted for multiple comparisons. P-values are for 2-tailed tests.

post-reading resting baseline, rather than to a pre-reading baseline. Therefore, it is suggested that future research on this phenomenon (and possibly on other cognitive tasks) should always include a post-task resting baseline.

The prediction for amplitude decrease in the 8 to 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. Our results showed no significant changes in the 12 to 21 Hz band, which supports the hypothesis that this frequency may reflect motor inhibition, rather than attention or alpha-like idling. This conclusion is derived from the fact that although our reading tasks obviously required higher attentional and processing resources than the baselines, they did not differ significantly in motor activity from the baselines. Moreover, it is derived from the observation that the adjacent frequency of alpha (10 to 12 Hz) *did* show significant amplitude increase during the second baseline. Although the 21 to 32 Hz band showed a trend of increased amplitude during the second resting baseline, this did not pass the corrected a-level criterion, so it is inconclusive. Future research may attempt a replication of this. An alternative explanation for the 21 to 32 Hz increase being due to muscle tension is not accepted for several reasons. First, if that were the case, muscle activity would be expected to increase during reading, not during rest. Second, muscle activity should spread over to the gamma (38 to 42 Hz) band, something that was not supported by our results. Third, we analyzed all frequencies above 12 Hz only for the central channels (F3, C3, P3, FZ, CZ, PZ, F4, C4, P4) which are not particularly prone to muscle artifact contamination. In order to test this further, we computed a post-hoc ANOVA for the peripheral channels of the 21 to 32 Hz band that were excluded from the first analysis (FP1, FP2, F7, F8, T3, T4, T5, T6, O1, and O2). Results showed no significant differences between the reading and resting averages for these channels, supporting further the conclusion that our findings for this band in the central locations reflected EEG activity rather than muscle tension.

The present study was exploratory in nature, and is not conclusive. However, the implications of these preliminary findings for neurofeedback involve some basic foundation of the differential EEG activity across the frequency spectrum during the reading process in young adults, directing future research to the study of the 10 to 12 Hz frequency band as it changes from a reading or other cognitive task to a post-task resting condition. When we understand how the brain's electrical activity changes from rest to reading and from reading to rest in *normal* readers, we may be better able to understand brain functions in those with reading difficulties. We can then base the design of our neurofeedback protocols accordingly.

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