NeuroRegulation

The Coordinated Allocation of Resource (CAR) Electrophysiological Patterns of Recalling Names of Faces in Children, Adolescents and Adults and the Central Processing Unit (CPU) of the Brain

Kirtley E. Thornton[1*], *Dennis P. Carmody*[2]

[1] The Neuroscience Center, Charlotte, NC, USA
[2] Rutgers University School of Nursing, Newark, NJ, USA

***Address correspondence to**: Kirtley E. Thornton, PhD, Neuroscience Center, 9635 Southern Pine Blvd. Ste. 105, Charlotte, NC, 28273-5558. Email: ket@chp-neurotherapy.com

Abstract

The quantitative EEG (QEEG) has proven to be an important methodology in the understanding of brain functioning. The Coordinated Allocation of Resource (CAR) model maintains that cognitive effectiveness depends on the employment of a specific set of resources for specific cognitive tasks, which overlap in some situations. The model employs the flashlight metaphor in understanding the coherence and phase relations between locations. The metaphor asserts that each location can function as a flashlight that sends out a “beam” to the other locations within a frequency. The “beam” can involve all the other locations or be a mini-flashlight that involves only selected locations. The task of recalling names of faces was examined in the context of the CAR model.

The developmental changes that occur during the encoding of names of faces include increases in diffusely located communication connections involving theta (4–8 Hz) and alpha (8–13 Hz), increases in the relative power values of the beta variables (13–64 Hz), peak frequency of beta1 (13–32 Hz) and alpha, decreases in communication patterns involving the beta2 (32–64 Hz) and delta (0–4 Hz) frequencies as well as decreasing values of variables involving the lower frequencies (delta, theta), relative power values of alpha and magnitudes of alpha, beta2 and peak amplitudes of beta2.

The face-name task is both a verbal and visual task as the participant is hearing the name while he looks at the photograph. Variables that relate to success during the encoding task involve diffuse increases in flashlight activity from F7 and T3 across all frequencies to and between central locations. The QEEG variables that relate to immediate and delayed recall success involve flashlights from T3 across 4 frequencies, F7 involving 3 frequencies and the appearance of a heuristic “central processing unit” involving frontal (F3, Fz, F4), central (C3, Cz, C4) and posterior (P3, Pz, P4) locations.

Key Words: quantitative EEG, memory, memory for names of faces, name memory, coordinated allocation of resource model (CAR), central processing unit (CPU), encoding

Introduction

Face-name recall represents a specific cognitive task for memory functioning. General memory functioning concepts such as working memory (WM) and episodic, semantic and declarative memory are relevant to the task. Previous functional Magnetic Resonance Imaging (fMRI), Positron Emission Tomography (PET) and electroencephalographic (EEG) research in these conceptual areas have focused on locations and frequencies.

Neuroanatomical issues have dominated a substantial portion of the research in this area. Location differences were reported for word recognition (posterior portion of the left middle and inferior temporal gyri) and face recognition (right lingual and fusiform gyri) in a PET study (Kim et al., 1999). The amygdala and insula have been studied for the role of emotion in the recognition of faces (Gobbini & Haxby, 2007). The fMRI response pattern for faces and objects involving “the ventral temporal cortex are widely distributed and overlapping” (Haxby et al., 2001). It has also been asserted that there is a hierarchical system that involves occipito-temporal regions in the extrastriate visual cortex that mediates the visual analysis of faces (Haxby, Hoffman, & Gobbini, 2000, 2002).

Other locations that have been implicated in fMRI studies of working memory include the left prefrontal cortex, left posterior parietal cortex and hippocampus (Oztekin, McElree, Staresina, & Davachi, 2009). Support for the role of the parietal lobe in episodic memory has been reported in fMRI studies (Wagner, Shannon, Kahn, & Buckner, 2005). Verbal and visual working memories have also been shown in clinical studies of brain lesions to involve the dorsolateral prefrontal cortex (Barbey, Koenigs, & Grafman, 2013). Based on neurophysiological and neuroimaging studies, the prefrontal cortex has been hypothesized to be involved with the recovery of information (Miller & Cohen, 2001; Petrides, 2005). Several researchers have emphasized the role of the medial temporal lobe in episodic memory retrieval based on anatomical (Squire, 1992) and neuroimaging studies (Andrews-Hanna, Saxe, & Yarkoni, 2014; Diana, Yonelinas, & Ranganath, 2007).

The hemispheric encoding / retrieval asymmetry (HERA) model (Tulving, Kapur, Craik, Moscovitch, & Houle, 1994) asserts that the right frontal cortex is involved in the retrieval of episodic (versus semantic) information more than the left PFC (Habib, Nyberg, & Tulving, 2003). The right prefrontal cortex role in episodic memory retrieval has received support from others (Henson, Shallice, & Dolan, 1999). Studies of episodic retrieval using lists of items consistently find activations in the prefrontal cortex (Gilboa, 2004). Other research has focused on the same age bias in face recognition (Anastasi & Rhodes, 2005; Rhodes & Anastasi, 2012; Rhodes, Castel, & Jacoby, 2008).

Electrophysiological studies offer a different functional viewpoint on the subject and have focused on arousal measures (frequency amplitudes), communication variables (phase, coherence) in addition to location information. For example, EEG differences in word and face recognition have been reported for the alpha and beta frequencies in temporoparietal locations (Burgess & Gruzelier, 1997). The theta and alpha frequencies have been shown to be critically involved in memory processes (Jacobs, Hwang, Curran, & Kahana, 2006; Klimesch, 1999). Invasive electrophysiological monitoring has indicated phase locking in the 3–4 Hz “theta” range between the retrosplenial cortex and the medial temporal lobe during autobiographical retrieval (Foster, Kaveh, Dastjerdi, Miller, & Parvizi, 2013). The phase locking was limited only to the theta frequency of the 0–20 Hz range studied, and there was no significant relation between theta amplitudes and phase locking. However, the 3–4 Hz frequency range is typically considered in the delta frequency.

Theta amplitudes and theta phase relations have been shown to be significantly involved in memory functioning (Klimesch, 1999; Mizuhara, Wang, Kobayashi, & Yamaguchi, 2004, 2005; Mizuhara & Yamaguchi, 2007; Sarnthein, Petsche, Rappelsberger, Shaw, & von Stein, 1998; Sauseng et al., 2002). Theta phase coding has also been shown to be relevant for long-term memory formation and working memory (Lee, Simpson, Logothetis, & Rainer, 2005; Siapas, Lubenov, & Wilson, 2005).

Phase alpha has been shown to be relevant to memory functioning (Klimesch, 1999) while phase beta has been demonstrated to be relevant to cognitive processing, memory processing and working memory (Gross et al., 2004; Tallon-Baudry, Bertrand, & Fischer, 2001; von Stein & Sarnthein, 2000). The traumatic brain injured participant has deficit coherence and phase beta2 (32–64 Hz) activity, which is related to impaired memory functioning (Thornton, 2003).

Theta-gamma (30–100 Hz) synchronization (phase and coherence) during declarative memory consolidation in the hippocampal and parahippocampal regions has been reported (Axmacher, Mormann, Fernandez, Elger, & Fell, 2006). The researchers assert that "synchronization in the gamma frequency range has to be accompanied by a stimulus-locked phase reset of ongoing theta oscillations." A literature review of the area reported that the "gamma frequency hypothesis" implies that synchronized activity in the gamma range induces memory processes more successfully than both slower (e.g., beta) and faster activity (e.g., ripple [~ 200 Hz]; Buzsaki, Leung, & Vanderwolf, 1983; Engel & Singer, 2001). Increases in the power of both gamma and theta activity in diffuse locations have been reported during successful memory encoding (Sederberg, Kahana, Howard, Donner, & Madsen, 2003) as well as during successful encoding and retrieval (Gruber, Tsivilis, Montaldi, & Muller, 2004). The role of the gamma frequency has also been studied in the recognition of familiar stimuli such as faces and buildings (Zion-Golumbic, Golan, Anaki, & Bentin, 2008). Other electrophysiological studies have used event related potentials to activation differences when discriminating faces (Zheng, Mondloch, Nishimura, Vida, & Segalowitz, 2011) and face versus non-face stimuli (Zheng, Mondloch, & Segalowitz, 2012).

The brief literature review demonstrates a diverse set of findings varying by task and implicating several frequency ranges and locations. The tasks employed are generally restricted in terms of locations studied, frequency ranges, time periods analyzed and specific tasks employed. An alternate method to the problem of recalling someone's name would be a task which requires spontaneous free recall of the person's name after a short exposure (face-name recognition and recall). This research was designed to address the issue of how does someone recall an individual's name after a short exposure to their face and name, a common situation in many social and business situations. The investigation is one of discovery and confirmation of the previous research.

Methods

The methodology in this research does not employ the typical baseline versus task analysis methodology (fMRI, PET studies, etc.), but rather a correlational analysis between performance and absolute values of the QEEG variables. The senior author considers this approach to be the preferred approach to understanding brain electrophysiology due to several problems with the baseline versus task approach.

The first problem of the methodology is the assumption of what the activation means. Implicity, it has been considered to relate to performance in some positive manner. However, it is possible that the activation has: (a) no relation; (b) a negative relation; or (c) a necessary component but unrelated to performance in addition to the possibility that (d) activation does relate to performance. Some researchers have addressed this issue and have successfully related the activation levels to performance. Thornton and Carmody (2009) demonstrated that the normal brain does not necessarily activate the appropriate QEEG resources (those related to success during the task) to be successful at the task, thus an “inefficient” brain. In one case of a brain injury, the participant activated frontal beta2 relative power more than the control group, and that increase was negatively related to memory performance (Thornton, 2014). Thus, it cannot be assumed that an activation pattern is inherently relevant to success at the task, despite its compelling appearance. In a group of participants with mild cognitive impairment (MCI), the QEEG absolute power measures were negatively related to Mini-Mental Status Exam (MMSE) scores and were significantly higher in the MCI group compared to the control group. The coherence values were higher in the MCI group during a working memory task (and not at rest), but these values were not related to the MMSE scores (Jiang, 2005).

The second problem is the implicit assumption that if the brain activates a connection, a higher activation of that connection between the two locations will relate to higher cognitive performance on the cognitive task. This would be true if the absolute value of the variable relates to success (examined in this research). The alternative interpretation would be that somehow the brain records the amount of change in a variable and that record and degree of change relates to performance. For example, would a change from 40 to 60 be more predictive than a change of 70 to 75 or a raw score of 80 during the actual task? The assertion that the change is more important for functioning would be arguing that a 60 value is preferred to the value of 75 or 80 for the coherence number, contrary to common sense. It is more logical and simpler (Occam’s razor) to assume that it is the raw value during the task that is critical rather than the change from a previous state. The statement assumes present cognitive functioning levels are determined not by present neurophysiological variables but by past levels, a very contra-intuitive statement.

Participants

Participants were recruited (*N* = 167) at a general mental health clinic in response to advertising or word-of-mouth recruiting efforts, and they received a financial incentive ($25) or intention to enter a treatment program. The mean age was 31.2 years and ranged from 7.75–72.4 years. There were 80 females and 87 males. The average education level was 12.6 years. There were 79 non-clinical individuals, 65 head-injured individuals and 23 other clinical individuals with no diagnosis in the sample.

Table 1

Participant Characteristics

Sample Size	Age Mean (Mos.) (*SD*) and Range	Male	Female
167	374.9 (211) / 31.2 Yrs. Range: 93–869 Mos. 7.75–72.4 years	87	80

Procedure

Cognitive evaluation / measures. Each participant received an activation QEEG evaluation, which was conducted by the senior author (Thornton, 2014b), during which they participated in 26 cognitive tasks. The name / face task was presented approximately 15 minutes into the evaluation. The participants were presented with a laminated sheet containing 10 pictures of the faces of individuals. The first and last names for each photograph were verbalized to the participants. The participants were allowed 15 seconds to study the picture and internally record the association. After the 15 seconds, the second face picture was named. The procedure continued until all 10 faces had been named. The participants closed their eyes for 60 seconds to memorize the association. They then opened their eyes and recalled the names of the 10 faces, which had been re-arranged on a different laminated sheet. After a delay period (during which other tasks were presented) the participants were asked to recall (to themselves) the names of the faces. They then opened their eyes and named the faces shown in random order. Participants were given a score of 1 for each first name and last name they recalled. The total maximum score was 40. Thus, the QEEG was recorded during the studying phase (150 seconds), and the immediate (60 seconds) and delayed (60 seconds) recall tasks.

Quantitative EEG (QEEG) measures. This research employs the following frequency definitions: Delta (0–4 Hz), Theta (4–8 Hz), Alpha (8–13 Hz), Beta1 (13–32 Hz), and Beta2 (32–64 Hz). The QEEG variables involve two sets of data. The first set concerns “activation / arousal” variables, which involve specific cortical locations and frequencies with reference to magnitude (M), relative power (RP), peak frequency (PF), and peak amplitude (PKA). The second set examines the amplitude correlation coefficients between locations with concepts of phase (P) and Spectral Correlation Coefficient (SCC; Lexicor Medical Technology). The QEEG data were examined for artifact (eye movements, muscle activity, etc.), and epochs that contained the artifacts were marked for deletion.

Activation / Arousal Measures.

RP: Relative Magnitude/Microvolt or Relative Power: The relative magnitude of a band defined as the absolute microvolt of the particular band divided by the total microvolt generated at a particular location across all bands.

M: Absolute Magnitude*:* The average absolute magnitude (as defined in microvolts) of a band over the entire epoch (one second).

PA: Peak Amplitude: The peak amplitude of a band during an epoch (defined in microvolts).

PF: Peak Frequency: The peak frequency of a band during an epoch (defined in frequency).

Connectivity Measures.

C: Coherence or Spectral Correlation Coefficients (SCC): The average similarity between the waveforms of a particular band in two locations over the epoch (one second). The SCC variable is conceptualized as the strength or number of connections between two locations and is a correlation of the magnitudes.

P: Phase: The time lag between two locations of a particular band as defined by how soon after the beginning of an epoch a particular waveform at location #1 is matched in location #2. References in the figures employ a combination of letters. For example, **CA** refers to coherence (SCC) alpha and **RPA** refers to relative power of alpha.

Results

Memory Scores

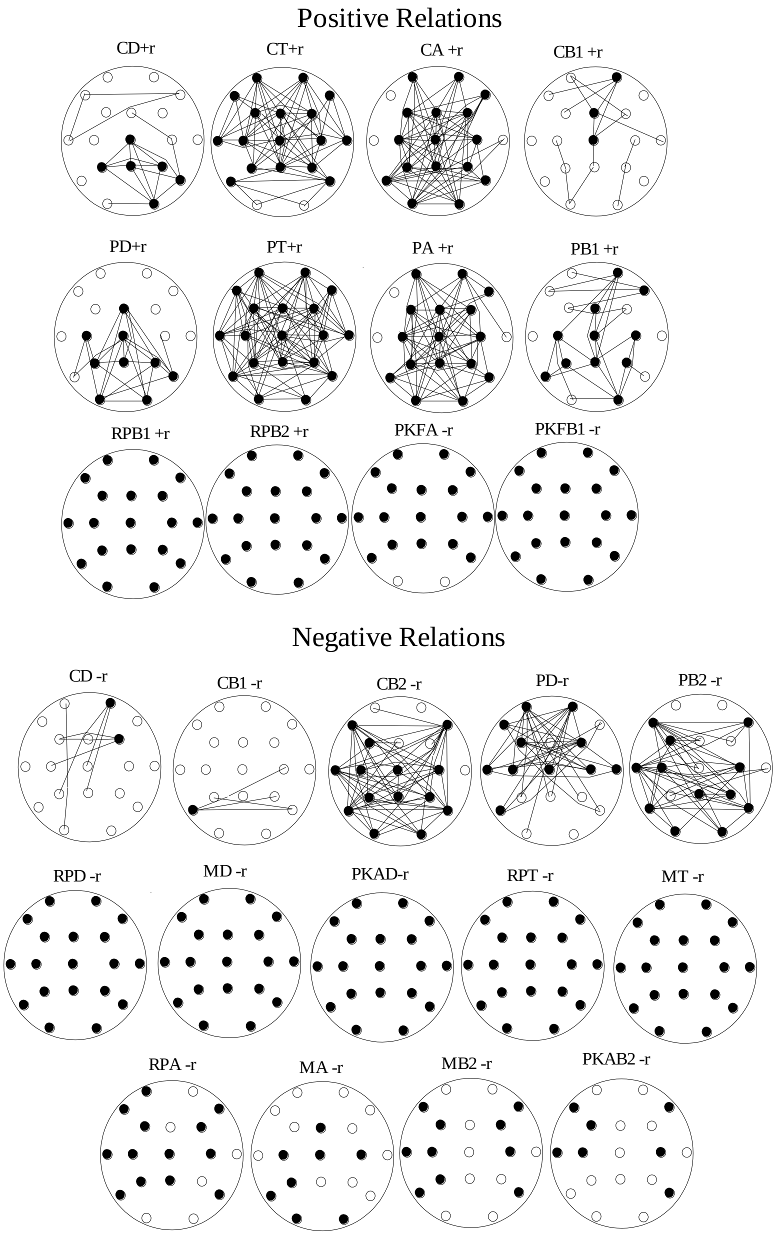
The memory scores ranged from 0 to 40 (*M* = 11.6, *SD* = 8.04). Given that the maximum potential score was 40 points (20 for immediate recall and 20 points for delayed recall) the task was very difficult for the participants. The correlations between age, education or sex and total memory score were non-significant.

Developmental Changes in QEEG Measures

Figure 1 presents the developmental patterns that were evident during the encoding task. All the lines were significant. The locations that involved 3 or more significant SCC or phase relations were indicated by a blackened circle to indicate a possible "source" of the signal and to provide greater clarity of the response patterns. Only frequencies that had at least one "source" were included in the figures. The "+" sign indicates a positive relation between the QEEG variable and the variable under investigation. The "–" sign indicates a negative relation. The individual significant groupings were arranged according to frequencies to provide a clearer presentation of the results. A specific blackened circle could be considered the source of the signal. However, there are overlapping connections, which renders it difficult, on occasion, to determine the source. A location with a greater number of significant connections might be considered a "source". For the purposes of the following discussion, a "source" will be assumed if it has a preponderance of significant connections.

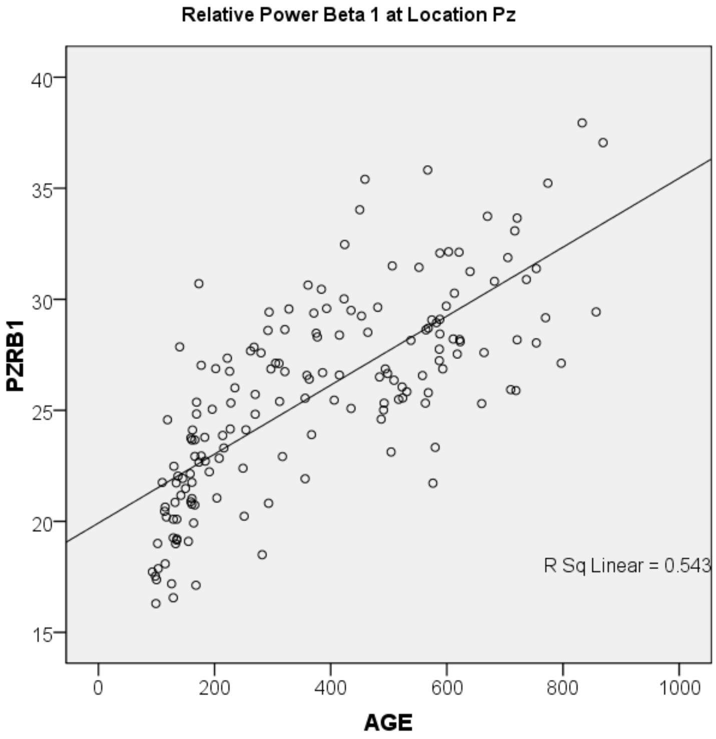
As Figure 1 indicates, the most significant connection pattern increases are in the alpha and theta frequency (SCC and phase), posterior CD and PD, and frontal CB1 and PB1. Notably absent are increases in F7 and T3 SCC and phase alpha, which are critical variables related to task performance. There are also broad increases in the beta variables (RPB1, RPB2, PKFB1) and alpha (PKFA). The negative developmental trends are decreases of SCC and phase (beta2) and decreases in frontal / central PD. Concomitant with these communication pattern decreases are diffusely located decreases in variables involving the lower frequencies (delta, theta), multiple locations for alpha variables (RP, MA) and diffuse locations for MB1, MB2, PKAB2 with a dominant focus on the left hemisphere (LH) locations. One possible interpretation of the patterns, albeit with some data inconsistencies, is that development results in a pruning of the brain into the more central frequencies—a "centralization" trend. This is evident in the decreases in the phase delta and phase and SCC beta2 values and corresponding decreases in the lower frequencies and decreases in magnitude values of the beta2 frequency. Alternatively, the decreases in the SCC and phase beta2 values may represent the electrophysiological underpinnings of the cognitive decline in the elderly.

Figure 1. Relations Between QEEG Variables and Development.



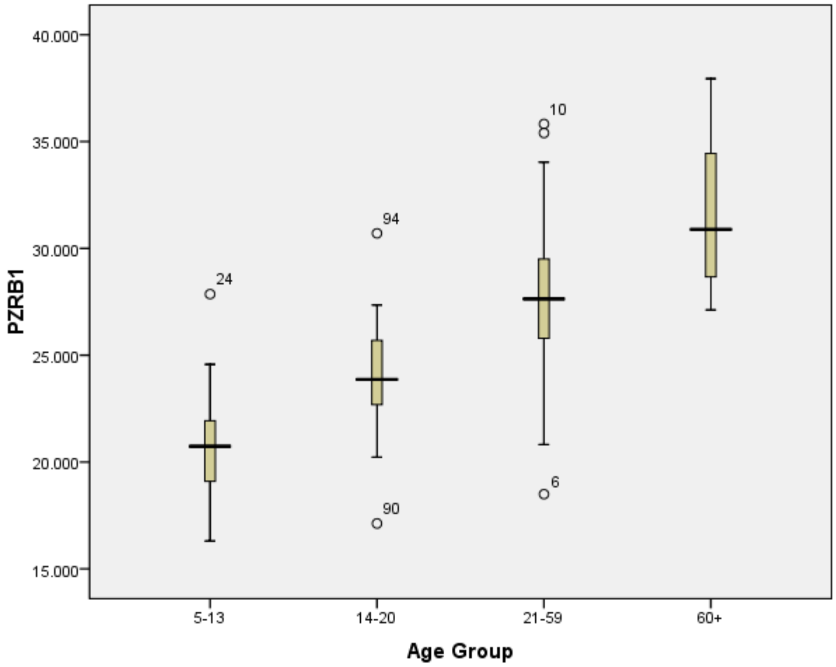
Note. CD = Coherence Delta; CT = Coherence Theta; CA = Coherence Alpha; CB1 = Coherence Beta1; CB2 = Coherence Beta2; PD = Phase Delta; PT = Phase Theta; PA = Phase Alpha; PB1 = Phase Beta1; PB2 = Phase Beta2; RPD = Relative Power Delta; RPT = Relative Power Theta; RPA = Relative Power Alpha; RPB1 = Relative Power Beta1; RPB2 = Relative Power Beta2; MD = Magnivolts Delta; MB1 = Magnivolts Beta1; MB2 = Magnivolts Beta2; PKFA = Peak Frequency Alpha; PKFB1 = Peak Frequency Beta1; PKAD = Peak Amplitude Delta; PKAB2 = Peak Amplitude Beta2

Figure 2. Scatterplot of Distribution of Pz Relative Power of Beta1 (13–32 Hz) and Age (Months)



There was a steady increase with age in the relative power of B1 at location PZ, with no evidence of a leveling with age and no decline in older years. While the linear fit was a significant model, the best regression model for the association of relative power and age was a logarithmic fit, *F*(1, 165) = 242.20, $p < .001$, adjusted $R^2 = .60$. Changes in RPB1 were examined by age groups: 7–13 years, 8–20, 21–59, and 60+ years. A one-way analysis of variance revealed a significant effect for age group, *F*(3, 163) = 61.15, $p < .001$. Post-hoc examinations using the Scheffe method showed significant (all $p < .005$) differences between all pairwise comparisons. Figure 3 shows the boxplots of RPB1 at Pz for the age groups.

Figure 3. Boxplot of Relative Power Beta1 at Location Pz by Age Group.

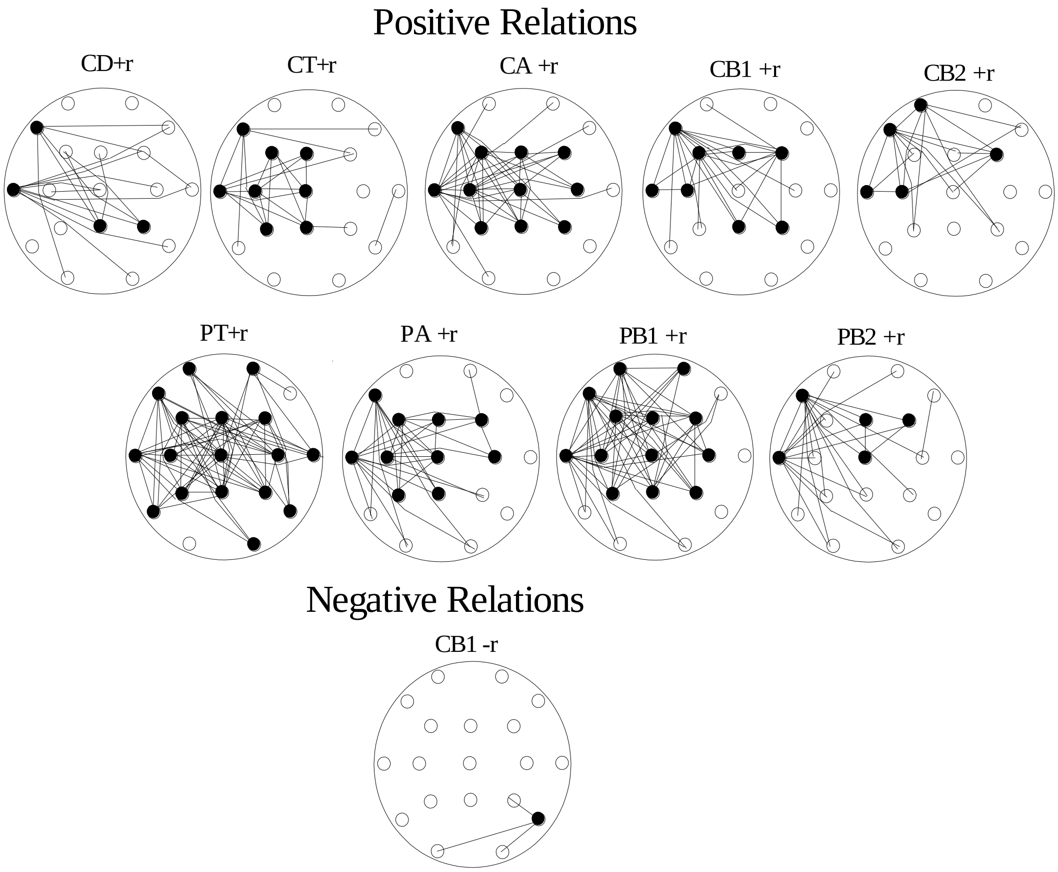


QEEG Measures Related to Memory Scores

Figure 4 shows the variables that are correlated with performance during the encoding names-faces task. The figure reflects significant involvement of the F7 and T3 SCC and phase flashlight activity from the delta to beta2 frequency, with the phase values dominant. There are also significant relations involving central and frontal locations (CA, CB1, CB2, PT, PA, PB1). The variables overlapping with development involve PT (temporal and central locations), PA (central locations), CA (central locations), and CD (posterior locations). Interestingly, PB2 (F7 and T3) decrease with age and yet are positively associated with performance.

There is an overall appearance of the left lateral locations (F7, T3, T5) sending signals to each other and into central locations (F3, Fz, F4; C3, Cz, C4; P3, Pz, P4). These central locations do not receive any direct sensory input during the cognitive task and yet are significantly involved in successful performance. These locations could be heuristically conceptualized as a Central Processing Unit (CPU).

Figure 4. QEEG Variables During Encoding Task Relations to Total Memory Score

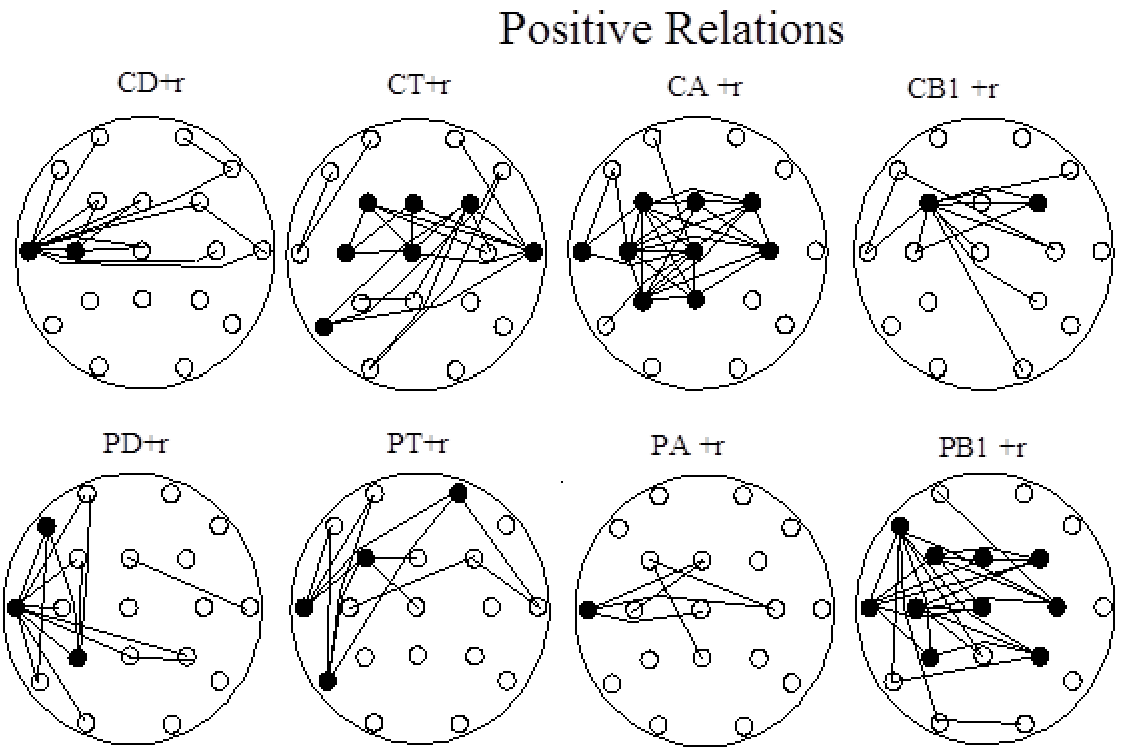


Note. CD = Coherence Delta; CT = Coherence Theta; CA = Coherence Alpha; CB1 = Coherence Beta1; CB2 = Coherence Beta2; PT = Phase Theta; PA = Phase Alpha; PB1 = Phase Beta1; PB2 = Phase Beta2

Figure 5 shows the variables associated with performance during the quiet recall task. The figure reflects the importance of the T3 flashlight (CD, CA, PD, PT, PA, PB1), which is evident during the encoding task. Many of the PB1 variables are involved in success during both the encoding and recall tasks. The dominant locations involve (F3, Fz, F4, C3, Cz, and C4) for CT, CA, and PB1. The posterior (O1, O2), frontal (Fp1, Fp2) and right hemisphere lateral locations (T6, P4, T4, F8) appear to be minimally involved. As in the encoding task, the lower frequencies (delta, theta) do not appear to negatively affect performance. The dominant frequencies involved in the CPU involve CT, CA, and PB1.

The difference between the input and immediate recall variables is a narrowing of the variables involved in successful performance, with the focus in CPU locations and CA and PB1. The right temporal (T4) projection activity involving CD and PT are implicated in both the input and immediate recall task.

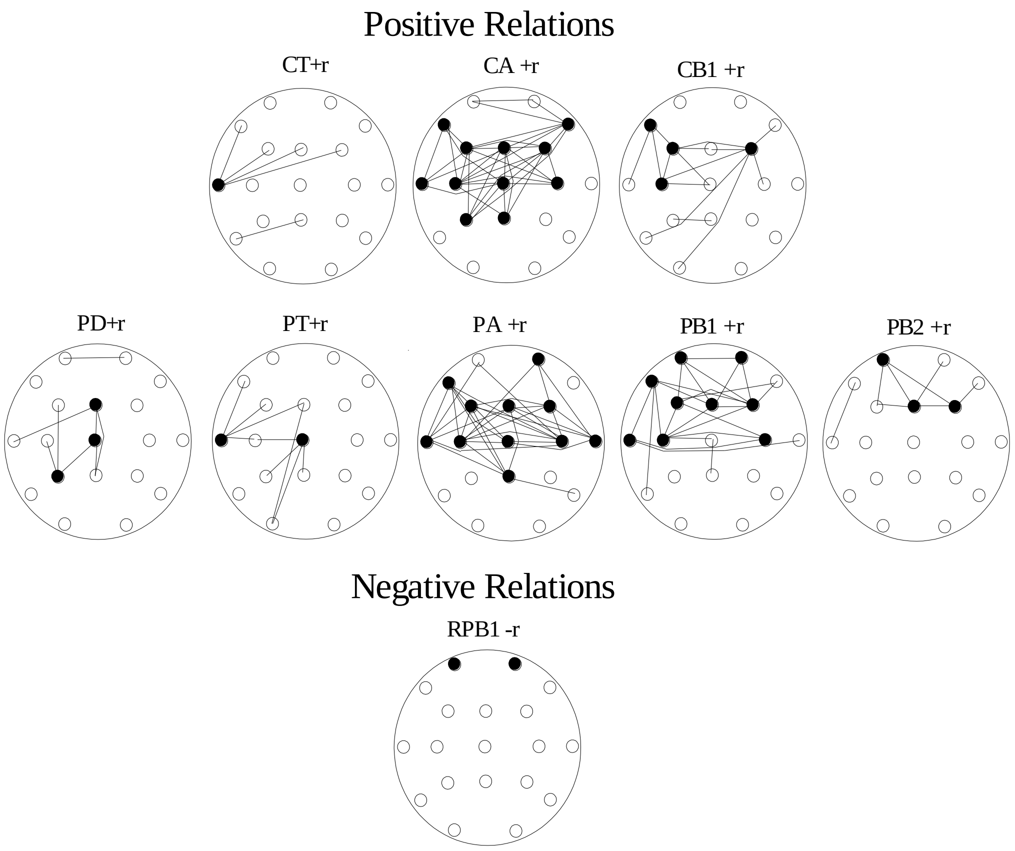
Figure 5. QEEG Variables During Silent Immediate Recall Task - Relations to Total Memory Score



Note. CD = Coherence Delta; CT = Coherence Theta; CA = Coherence Alpha; CB1 = Coherence Beta1; CB2 = Coherence Beta2; PD = Phase Delta; PT = Phase Theta; PA = Phase Alpha; PB1 = Phase Beta1; PB2 = Phase Beta2

Figure 6 shows the variables that are related to performance during the delayed recall task, which employs the delayed recall score (not the total memory score). The results point to the T3 location (CT, CA, PA, PB1). The variables that overlap across the input, immediate and delayed recall task and are involved in successful performance are T3 (CT, PT, CA, PA, PB1), and the CPU, which involves CA, PA, CB1 and PB1. The only negative effect involves Fp1 and Fp2 RPB1 values. The data suggests a further focusing of the variables in the CPU locations with CA and PA being the critical variables.

Figure 6. QEEG Variables During Silent Delayed Recall Task Relations to Delayed Recall Memory Score



Note. CT = Coherence Theta; CA = Coherence Alpha; CB1 = Coherence Beta1; CB2 = Coherence Beta2; PD = Phase Delta; PT = Phase Theta; PA = Phase Alpha; PB1 = Phase Beta1; PB2 = Phase Beta2; RPB1 = Relative Power Beta1

Discussion

This study investigates the associations of brain activation during encoding and recall of the names of novel faces. Developmental changes are addressed by examining QEEG measures as a function of age in the participants ranging from 8 to 72 years. Associations of QEEG measures and performance are also examined to identify the activation pattern associated with better memory for face names. Given that the photographs were of individuals in the age range of 20–40 years, we examined an age effect in brain activation. An example of this examination was the measure of relative power in the beta1 frequency band at location Pz during the encoding phase. The systematic changes in relative power with age were evident. The scatterplot of QEEG relative power and age did not suggest a potential effect age bias. The explanation for the increase in relative power may be found in the reduction of power in the delta and theta bands in childhood. However, the differences between adolescents, ages 13–20 years, and both younger and older adults, would not be explained by a reduction in theta and delta power in childhood. Therefore, the increase in RPB1 in adulthood may be an indication of the allocation of resources to the encoding task. However, the increase in relative power in encoding was not associated with better performance in recall.

The large developmental increases are most evident in the coherence and phase theta and alpha relations, relative power of beta values (13–64 Hz), and peak frequency values (alpha, beta1). There are decreases in the beta2 coherence and phase values and frontal / central phase delta values as well as decreases in variables related to delta, theta, alpha and beta2 values. The decreases in SCC and phase values associated with the highest and lowest frequencies might be conceptualized as a “centralization” trend of the brain. However, the decreases in coherence and phase beta2 values may also represent an important variable to investigate in terms of the cognitive decline in the elderly. The lack of increases in the alpha coherence and phase values from the T3 and F7 locations (critical variables in this task) presents a problematic finding that is difficult to understand.

The dominant pattern of successful performance on the names of faces tasks is flashlight activity from the F7 and T3 locations across all frequencies during the initial encoding task as well connection activity in the heuristic CPU. Neither the arousal levels involving the lower frequencies (delta, theta) nor the beta frequencies appear to be related to performance, contrary to most of the results for the other cognitive tasks (Thornton, unpublished). The negative relation of T6CB1 during the encoding task presents an interesting pattern, as previous research has focused on implicit positive activations. The presence of negative activation level patterns can’t be discerned from a methodology that does not examine the activation level patterns to performance (i.e., the general activation versus baseline methodology).

As noted previously, there is a pattern of left locations (F7, T3, T5) communicating with each other and sending signals into the central locations (F3-Fz-F4; C3-Cz-C4; P3-Pz-P4). The involvement of the central locations could be heuristically conceptualized as the central processing unit (CPU) of the brain. The specific function of the individual connections is beyond the scope of this research or the available data. In addition, the goal of identifying specific functions is reminiscent of localization theories in psychology, with all the limitations inherent in that approach. From the EEG biofeedback point of view, the specific function of a connection is not as relevant as the standard deviation difference from a normative reference group and the relation of that variable to performance. The CPU heuristic concept, however, could present a new model for effective intervention. The CPU appears to involve more left hemisphere (LH) locations than right hemisphere (RH) in the face-name task.

What is additionally important in this data is that the coherence and phase values for all the frequencies are involved in memory processing, contrary to previous research that has focused predominantly on theta phase relations (Mizuhara, Wang, Kobayashi, & Yamaguchia, 2005; Mizuhara, Wang, Kobayashi, & Yamaguchi, 2004; Sarnthein, Petsche, Rappelsberger, Shaw, & VonStein, 1998). The involvement of all the frequencies redefines how we think about the relation between cognition and the quantitative EEG. The role of left temporal (T3), left and right PFC and parietal locations in memory functioning was supported in the results in terms of connectivity. The occipital locations appear minimally related to successful performance.

The involvement of the CPU was also evident in the reading memory results (Thornton & Carmody, in press) and intermittently in results for other cognitive abilities (Thornton, unpublished data). The dominant recall flashlight location was T3 (across almost all frequencies). It is clear from the figures that successful completion of the task involves multiple connections across frontal and central locations.

This research presents an interesting understanding of how the brain functions in response to a very cognitively demanding task. It is clear from the results that the brain is a complex system that involves multiple locations and interrelationships between these locations. The CAR model and CPU concept appear to be useful concepts in describing how the brain functions in the name – face learning task. The results presented in this research may be of some benefit to the field of EEG biofeedback when addressing patients with a problem in face-name learning.

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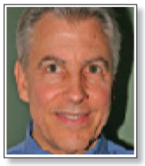
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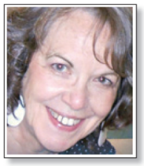
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