**This document provides a technical statement regarding the research employed at my center and some theoretical approaches to the problem of how to understand the qEEG.**

**Technical Foundations of the Activation Quantitative EEG Evaluation**

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The methodology employed in this research does not employ the typical baseline vs task analysis methodology, 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 vs task approach.

The first problem of the activation base methodology is the assumption of what the activation means, which is used in fMRI, PET and other technologies. Implicity, it has been considered to relate to performance in some positive manner. However, it is possible that the activation has 1) no relation; 2) a negative relation; or 3) a necessary component but unrelated to performance or 4) a positive relation. Thornton & Carmody (2009) demonstrated, in terms of QEEG variables, that the normal brain does not necessarily activate the appropriate resources (those related to success during the task) to be successful at the task, thus an “inefficient” brain.

In addition, we cannot necessarily rely solely upon the absolute value of a variable without understanding its relation to performance. 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](#_ENREF_20)). In the case of a brain injury the TBI participant has higher frontal beta2 relative power more than the control group and that value is negatively related to memory performance (Thornton, 2014b). Thus, it cannot be assumed that a higher value is inherently relevant to success at the task.

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 the true if the absolute value of the variable relates to success (examined in this research). The alternate assumption that the degree of activation from the baseline is related to success is not logical. This interpretation would argue 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 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 value of 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 change argument also assumes that the brain records the change somehow and ties memory performance to that change. The statement assumes present cognitive functioning levels is determined not by present neuropsychological variables but by past neurophysiological levels, a very contra-intuitive statement.

**The Coordinated Allocation of Resource (CAR) model**

Figure 1 presents the axial views of the standard 10-20 system of nomenclature and location.

Figure 1 – Standard location nomenclature in 10-20 system

Nose



Right Ear

Left Ear

The quantitative EEG (QEEG) has proven to be a useful technology in the understanding of brain functioning. The Coordinated Allocation of Resource (CAR) model (Thornton & Carmody, 2009) asserts that cognitive effectiveness is dependent upon the successful employment of specific set of network resources, albeit overlapping in some situations. Concomitant with this model is the use of the flashlight metaphor in understanding the coherence and phase relations between locations. The metaphor states that each location can function as a flashlight which sends out a “beam” to all the other locations within a frequency. The “beam” can involve all the other locations or be a mini-flashlight which will involve only selected locations. The metaphor is related to the generator concept employed in EEG research (Avitan et al., 2009) and is a method to reduce the number of variables available in QEEG research. The flashlight metaphor is similar to the network concept in neuroscience theory (Wig, Schlaggar, Petersen, 2011). The modern network viewpoint is that cognitive processes are a result of interactions between distributed information processing locations.

The CAR model takes the theory several steps forward as it asserts the concept of effective vs ineffective interactions, focuses on activity at locations and interactions (not just interactions), and moves towards specific definitions of frequencies and locations involved in specific network patterns for specific cognitive tasks. To address this difference the CAR model 1) employs a cognitive activation evaluation; 2) assesses the high gamma frequency (32-64 Hz); and 3) examines the relation between cognitive performance and the QEEG variables and 4) employs the flashlight metaphor in examining the coherence and phase relations.

The research presented in this report builds on previous research by the authors which have examined specific skills with reference to all locations and all frequencies across different input and recall conditions (Thornton, 2000, 2002; Thornton & Carroll, 2010; Thornton & Carmody, 2009, 2013). There are several conclusions which have been drawn from the previous research which are relevant to this study. Previous research (Thornton & Carmody, 2009) has established that the employment of eyes closed data is not relevant data in understanding how the human brain functions effectively under task conditions. For example, the relative power of theta in the eyes closed condition is positively correlated with subsequent recall under the paragraph listening condition, yet is negatively related to performance under the actual task condition. In addition, the variables which are activated as the task changes from the eyes closed condition to listening to paragraphs are not the variables, by and large, which are involved in successful recall. Thus, the hypothesis of an inefficient brain is proposed as an efficient brain would activate the relevant resources.

 The model which was employed, and is employed in this research, is the coordinated allocation of resource (CAR) model which asserts that cognitive effectiveness is determined by the brain’s use of the appropriate resources which are involved in effective functioning. An additional heuristic metaphor has recently been added to aid in understanding how the brain functions (Thornton & Carmody, 2014a). The heuristic metaphor is of a Central Processing Unit (CPU) which involves the following locations (F3-Fz-F4; C3-Cz-C4; P3-Pz-P4). The concept asserts that the lateral locations (Fp1, Fp2, F7, F8, T3, T4, T5, T6, O1, O2) send their signals into this CPU for processing. These locations do not receive any direct sensory input signals but are significantly involved in the success of the cognitive activity. Further elaboration on this metaphor is a Frontal Processing Unit (FPU) (Fp1, Fp2, F7, F8, F3, Fz, F4) and posterior processing unit (PPU) (T5, P3, Pz, P4, T6, O1, O2). The analysis of the developmental patterns across many of the studied tasks reveals a pattern, albeit not always, of the lateral locations sending their respective signals into these processing units. This approach has the added advantage of reducing the total number of variables under consideration from 2,090 to 140.

The data will be presented employing these metaphors when the results are applicable.

Research which will be published over the next several years will employ the CAR model and the flashlight and processing unit metaphors. The research will address the following groups: adolescents and adults (over the age of 14), children (between the ages of 6 and 14), combined group of children, adolescents and adults. The cognitive tasks to be reported include memory (auditory material, reading material, Korean figures, names of faces, where items were placed, a todo list, word lists), problem solving (Ravens matrices), spelling ability, math ability (multiplication tables, double digit spatial addition), pronunciation of nonsense words, and autobiographical memory.

**Quantitative EEG (QEEG) Measures**

Quantitative EEG research studies have employed varying definitions for the frequency ranges and have employed the cortical locations which have been defined by the 10-20 system (Jasper, 1958). The frequency definition ranges have typically been: delta: 0 to 4 Hertz; theta: 4 to 8 Hz; alpha: 8 to 13 Hz; beta: 13 to 25 Hz. The “gamma” frequency (above 32 Hertz) has been examined by different researchers (Thornton, 2000, 2002, 2007**;** von Stein et al., 2000). The cognitive activation research reports employed the following frequency definitions: Delta (0-4 Hz), Theta (4-8 Hz), Alpha (8-13 Hz), Beta1 (13-32 Hz), Beta2 (32-64 Hz).

Two types of data are available to QEEG analysis. The first type (arousal variables) involves the activity at a scalp location. The Lexicor manual defines the arousal variables as follows:

Magnitude (**M**): total magnitude (peak-to-peak) within a band's frequency range expressed in uV.

Relative power (**RP**) or relative magnitude: magnitude parameter divided by the full frequency

 spectrum magnitude, expressed as %.

Peak frequency (**PF**): frequency at which the maximum spectral amplitude occurs within a

 band's frequency range, expressed as Hz.

Peak amplitude (**PKA**): maximum spectral amplitude within a band's frequency range, expressed

 as uV.

The second type quantifies the association between locations using phase (**P**) and Spectral Correlation Coefficient (**SCC**) variables. The Lexicor definitions are as follows:

**Spectral Correlation Coefficient (SCC)**: spectral morphology comparison correlation

between two channels using the formula (∑│X││Y│)2/(∑│X│2 ∑│Y│2) expressed in percent, where X and Y represent the Fourier series of the two channels and ∑ represents the summation within a band's frequency range.

**Phase:** peak amplitude phase difference between two channels using the formula 100(1-│θ1-θ2│/π). A value of 100 percent represents zero degrees out of phase and a value of zero percent represents 180 degrees out of phase.

This article employs bolded capitalized letters to represent the variables employed for this analysis, i.e**. RPA** = Relative Power (magnitude) of Alpha. The figures presented employ the Coordinated allocation of Resource Model (CAR) as well as the heuristic Central Processing Unit (CPU), Frontal Processing Unit (FPU) and Posterior Processing Unit (PCU). Lateral locations (Fp1, Fp2, F7, F8, T3, T4, T5, T6, O1, O2) which have significant flashlight effects are indicated in the figures with a star symbol. Frontal and central / posterior locations are constructed for the arousal variables and employed when there are significant results.

###  *EEG Recording*

Brain electrical activity was recorded using the Lexicor 19-channel QEEG hardware device (Lexicor Medical Technology, Inc.). The bandpass filters were set between 0.0 and 64 Hz (3 dB points). The signals were analyzed with a Fast Fourier Transform (FFT), which uses Cosine-tapered windows and provides spectral magnitude in microvolts as a function of frequency. To allow for examination of the 32-64 Hertz range the sampling rate was set to 256. The participant was fitted with an Electro-Cap. The electrodes were positioned at 19 scalp locations according to the standard 10–20 system (Jasper, 1958) with ear-linked references and the standard ground electrode in front of Fz. The scalp was prepped with rubbing alcohol and Nu-Prep and the 19 electrodes were filled with Electro-gel. The earlobes and forehead were prepped with rubbing alcohol and Nuprep. Impedances were maintained below 10 K Ohm at all locations. Gain was set to 32000 and the high pass filter was set to off.

 The measurements available through the software provided by Lexicor Medical provided the numeric values of the QEEG variables. The data were examined for artifact (eye movements and EMG activity) as well as other possible sources of contamination (Thornton, 1996) and marked for deletion in the analysis. The bandwidths were grouped according to the following divisions: Delta: .00–4 Hz, Theta: 4–8 Hz, Alpha: 8–13 Hz, Beta1: 13–32 Hz, Beta2: 32–64 Hz.

**The Interrelations between QEEG variables and Cognitive Performance**

 An alpha level of .05 was employed for the correlational analysis in order to discern trends in the data.

**Pribram’s Holographic model and the binding problem**

The results pose a different picture of brain functioning than presented by fMRI and other technologies. It appears from the data that broad synchrony measures (coherence and phase relations) of neuronal activity is substantially related to conscious awareness. This conclusion is based upon the findings across a number of cognitive tasks (unpublished) and evident in these findings. The QEEG correlations with autobiographical memory relate to increases in synchrony across different frequencies between diverse locations. These findings are relevant to two previous discussions in the field, the binding problem (Revonsuo, 1999) and Pribram’s holographic approach (Prideaux) in understanding brain functioning.

The binding problem has been described by Damasio (1989, p. 29) as follows: “The normal experience we have of entities and events is coherent and ‘‘in-register,’’ both spatially and temporally. Features are bound in entities, and entities are bound in events. How the brain achieves such a remarkable integration starting with the fragments that it has to work with is a critical question. I call it the binding problem.” The “binding problem” in neurophysiology concern how it is possible that separate neurophysiological events relate to consciousness. For example, separated neurons respond to the information square and red, yet the mind “binds them” and sees a red square. The assumption behind the statement of the problem is that neuronal firing is the only information the brain has to render the perception and conscious awareness.

If, however, conscious awareness is conceptualized as involving the interacting of the wave forms then we begin to have a tentative answer to the problem. If the conceptualization is valid then it becomes necessary to enlist the conceptual framework of a different discipline, optical holography, to quantify and operationalize this translation.

“Holography is concerned with much than pictorial three-dimensional imaging. A closer look at the method will reveal its potential role in information storage, interferometry, microscopy and data processing” (Collier, Burckhardt & Lin, 1971). Interferometry (in physics) refers to “any acoustic, optical, or microwave instrument that uses interference patterns or fringes to make accurate measurements of wavelength, wave velocity, distance, etc.” <http://dictionary.reference.com/browse/interferometry> “The method of holography applies to all waves: to electron waves, X rays, light waves, microwaves, acoustic waves and seismic waves, providing the waves are coherent enough to form the required interference patterns (pg. 3).” (Collier, Burckhardt & Lin, 1971). Thus, the language and concepts of holography overlaps considerably with the language of the quantitative EEG.

Pribram’s approach to the holographic theory of brain functioning was summarized by Prideaux who states the following in presenting Pribram’s hypothesis: “dendritic processes function to take a "spectral" transformation of the "episodes of perception"… This transformed "spectral" information is stored distributed over large numbers of neurons. When the [episode](http://www.acsa2000.net/bcngroup/jponkp/) is remembered, an inverse transformation occurs that is also a result of dendritic processes. It is the process of transformation that gives us conscious awareness….The idea is simply that each part contains some information of the whole. Or stated another way, the information (or features) are not localized, but distributed…The holonomic brain theory claims that the act of "re-membering" or thinking is concurrent with the taking of the inverse of something like the Fourier transform. The action of the inverse transform (like in the laser shining on the optical hologram) allows us to re-experience to some degree a previous perception. This is what constitutes a memory… Memory is a form of re-experiencing or re-constructing the initial sensory sensation.”

The results presented in this research provide an empirical basis for the Pribram model, as it is evident that the memory is a global processing event with each wave form contributing information. The data from other tasks (auditory memory for paragraphs, reading memory, etc.) (in preparation for peer review) provide more specific evidence of the involvement of specific processes during the input period which were matched (along with other unmatched processes) by the same processes during the immediate and delayed recall tasks, which gives credence to the argument that the brain is recreating the original experience via the recreation of the wave forms which were present during the original experience. Employing this logic, the conscious awareness of a perception or memory is represented physiologically by the specific wave form interactions. A different wave form interaction would, presumably, present a different memory.

The exact functions or contribution of the specific wave forms is beyond the scope or design of this research. The hypothesis represents a beginning of a reconceptualization of how we understand the relation between physiological and psychological functioning (the mind-body problem) and many more details (mathematical and conceptual) need to be researched to understand the phenomena.

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