Experimental

CARTOGRAPHY OF CONSCIOUSNESS: A FUNCTIONAL RE-EXAMINATION OF THETA, ALPHA, AND BETA

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ABSTRACT

Scalp surface field potential changes (EEG) have long been associated with activities of neuronal processes in the brain. In spite of much knowledge, success in identifying EEG signatures which represent specific brain activation states has been limited. Using on line fast-fourier transforms of brainwave signals and computer displays with one-second updates of 5, 7, 10, 12, 14, 16, 20 and 28 Hz (with 1 Hz bandwidth), specific brainwave signatures were identified for attentional, cognitive, imaginal, and somatosensory states. The data bring into question the functional utility ascribed to the commonly used brainwave frequency bands designated as Delta, Theta, Alpha, and Beta. The quest for the neuroanatomic substrate of conscious intention is addressed within the context of brain-based parking spots and how they pertain to the invisible and difficult to quantify thing called "mind."

KEYWORDS: EEG, cognitive states, consciousness, 14 Hz

INTRODUCTION

Electroencephalograph (EEG) records are traditionally viewed in the form of pen drawn waves and visually evaluated for the presence and/or absence of standardized wave entities. Traditionally, such visual scoring of the EEG is conducted in terms of noting the number of waves occurring per unit of time (frequency), in terms of wave energy (amplitude) or in terms of unique wave forms (*i.e.*, spikes, K-complex, spindles, etc.). These visually productive criteria led to the "traditional" quantification of the human EEG in broad aggregate bands of electrical activity (Delta, Theta, Alpha, and Beta). This led to broad behavioral and cognitive observations, which resulted in the clinical EEG record being broadly labeled as so lacking in specificity to be scientifically unreliable when dealing with the domain of cognition and mental states. Early investigators of states of consciousness and its EEG substrates focused on the EEG-mind-body characteristics of meditative disciplines.

In 1961, Anand, Chhina, and Singh[1] investigated electroencephalographically the *samadi* meditative technique. They reported that the yogis presented with "well modulated alpha activity" during their meditative practice and that "persistent alpha activity" accompanied the yogis' ability not to be distressed by painful stimuli (being touched with hot glass rods, subjected to bright lights, loud noises, and having their hands immersed in ice water at - 4°C). Five years later, Kasamatsu and Hirai,[2] investigated electroencephalographically the Zen meditative technique. They found dramatically increased amounts of Alpha activity recorded from the Zen practitioners across their meditative practices and no increases over time for their controls. Then, two years later, Kamiya[3] found that people could discriminate when they were in an "alpha" state (not-thinking, letting the mind wander, alert tranquility) or in a "non-alpha state" (seeing with the mind's eye, engaging in mental imagery). Those subjects who Kamiya found able to learn to discriminate between the two "states" were also found to be able to produce either intentionally.

Thus, in a matter of a few years, several reputed researchers published mutually supportive findings as to observed correlations between the Alpha brainwave rhythm and meditative disciplines. Practically no one questioned what "Alpha" really was—beyond the fact that it was an internationally recognized and commonly used designation for quantifying electroencephalographic data.

These wide-band windows (Delta, Theta, Alpha, and Beta) of aggregate electroencephalographic energies were uncritically accepted as defined, and thereafter applied as one would single energy entities.

Analyzing the functional referents of EEG through the definitional constraints of Delta, Theta, Alpha, and Beta—whether with bandpass filters or spectral analysis—continues to yield no repeatable and scientifically verifiable insights into how the brain enables conscious experience. The pursuit of broad band EEG analysis in the early EEG research was necessitated by the bandpass filtering technology extant at the time. The continuance of this practice in the era of the Fast Fourier analysis, only produces more exact measures of uncertain attributes. However, one hertz bandwidth spectral analysis yields a much more exact representation of the energy characteristics of the EEG record. It allows us to become precise in our investigation of the energy constituents of the EEG.

The brain sets the stage for behavior—micro-temporally. The requisite brain-biologic correlates for cognitive behavior are functionally matched and sorted according to an evolving cognitive-brain archetype—in fractions of a second. This archetype for neural net inclusion and resultant behavioral manifestation is constantly under the shaping influence of stimulus-response reinforcement. These micro-state neural nets, along with stimulus refinement and associative response, define and determine cognition. The reflections and correlates of "mind" are also to be found in the interleaved energies of the brain's orchestration of individual functional manifestation.

There is the ongoing question as to where to place one's active sensor to optimally monitor specific nets of cerebral activation enabling a variety of levels of brain activity related to volitional as well as reflexive behavior. Sensorimotor Rhythm (SMR) is a good example. SMR, originally defined as a brainwave band encompassing 12 Hz to 15 Hz[4] has been monitored for neurofeedback from over the Rolandic cortex of the right hemisphere,[4,5,6] and from both right and left hemispheres,[7,8] and from over CZ as a 1 Hz wide, 14 Hz brainwave band. This controversy as to electrode placement and the viewing of hyperactivity and learning disorders as primarily reflecting either: (1) Ongoing underactivation of a medial bilaterally organized premotor Supplementary Motor Area (SMA) system,[9-22] or (2) As a more generalized underactivation of the sensorimotor cortex[7,8] was settled via independent medical research.

In the *New England Journal of Medicine's* November 15, 1990 issue, evidence was presented regarding frontal hypometabolism in hyperactives with significant global and regional reductions of cerebral glucose metabolism; with the largest reductions in the pre-motor cortex and superior pre-frontal cortex.[23] As such, the Tansey Technique,[19] with its CZ active electrode placement and long held hypotheses as to hyperactivity and learning disorders reflecting ongoing underactivation of a medial bilaterally organized premotor system, found its functional validity strongly supported.

Central to the understanding of why the "nontraditional" CZ Supplementary Motor Area (SMA) electrode placement was used in pursuing a cartography of consciousness is the long list of disorders that were found to positively respond to EEG neurofeedback from that site. Over the last 12 years EEG neurofeedback with the active sensor placed over CZ has resulted in effective treatment of asthma,[9] large populations of learning disabled youngsters with diagnoses of Neurologically Impaired (NI), Perceptually Impaired (PI), and learning disabled with Borderline , Average, and Superior FSIQ levels,[10-19] Petit Mal Epilepsy;[13] Giles de la Tourette's Syndrome,[14] Migraine,[18] the syndrome of asthmatic extrathoracic upper airway obstruction: Laryngeal Dyskinesis[22] and Chronic Fatigue Syndrome[20] wherein there is concurrent loss of volitional efficacy in both cognitive and perceptual-motor function. The positive impact/normalization of such a wide variety of brain-based disorders by EEG neurofeedback of a 1 Hz wide, 14 Hz brainwave band required further investigation into the function of the SMA. That investigation was greatly helped by Goldberg's (1985) summation of over thirty years of multi-discipline research as to the SMA's attributes and function.[24]

Goldberg determined SMA to be a crucial part of a medial, bilaterally organized system which operates synergistically with other cortical and subcortical structures to enable "context sensitive selection, linkage, initiation, and anticipatory control of a set of 'precompiled' motor subroutines each of which corresponds to a particular component perceptual-motor strategy or schema of the complete action."[24 (p. 576)] Concurrently, the SMA orchestrates the rostral flow of sensory information contributing to attentional and perceptual processes, and enables volitional "intention-to-act" in its serving as a primary link between the medial limbic cortex and primary motor cortex, and between the cortical limbic outflow via anterior cingulate cortex, the context-sensitive, goal-setting functions of the prefrontal cortex (whose outputs along with those of many other associational areas of the cortex, are integrated and refocused on to the SMA via the basal ganglia reentrant circuit), the sensory analysis functions of the association cortex of the superior parietal lobule and the executive components of the motor system.[24 (p.577)] In sum, the SMA and CZ as a point of EEG monitoring seemed a prime combination for an empirical, scientific approach to the brain-mind interface.

Through work with over 500 subjects, M. A. Tansey had identified specific 1 Hz wide frequency bands as being indicative of certain attentional, cognitive, imaginal and somatosensory states. In testing Tansey's informal cartography of consciousness, Tansey, Tansey, & Tachiki[21] presented the first empirical evidence for distinct, particular, neurocortical (EEG) activation signatures to which specific cognitive states were seen to be functionally related. An electroencephalographic cartography of conscious states was described therein, but the ramifications for charting of the functional representations of EEG activation were incompletely examined.

This paper expands on the findings of Tansey, Tansey, & Tachiki[21] and presents new findings as to the electroencephalographic cartography of cognitive states and the proposition that an individual possesses brain based predispositions for cognitive and/or perceptual processing. It also offers confirmation of the cortical activation nets proposed by Goldberg (wherein the cortical areas underlying CZ SMA are seen as functional substrates for the microtemporal manifestation of object relations and volitional responsive behavior).[24]

METHOD

SUBJECTS

Subjects for this study are 17 individuals (7 females and 10 males) ranging in age from 9 to 60 years old. Intake interview revealed no evidence of medical or mental disorders nor presence of a family history of mental illness. All subjects signed informed consent for participation in the study. With each of the individuals, EEG activity was recorded during and following presentation of a standardized series of computer generated, voice commands employing a NeXT computer system. The voice commands were recorded in a 16 bit digital stereo sound file. Since the recording was performed by the chief author, in his own voice, there were varying amounts of pause between words and commands. Thus, following certain commands only 1 epoch of EEG was collectable, whereas as many as 7 epochs were collected following other commands.

TANSEY TECHNIQUE OF EEG RECORDING

Unless stated otherwise for the control, one method of EEG recording as described in detail elsewhere[19] was used for collection of data. Briefly, three saline sensors are used (impedance in saline of 1K ohm). The active sensor is placed so that its 6.5 cm x 1.3 cm contact surface lay lengthwise along the midline of the top of the skull (overlaying the cerebral longitudinal fissure), centering about CZ (10/20 system). Based on Goldberg's work on the brain substrate of intentionality,[24] CZ was chosen as site from which to attempt to quantify and chart conscious intention. The active sensor is held in place with two elasticized headbands with velcro on the ends. One band is placed about the head, parallel to the eyebrows, across the middle of the forehead. A second band goes across the top of the head and the active sensor, attaching at either end on the other headband, near each ear. In this position, the active sensor is kept in place over the Rolandic cortex (pre- and post-central gyri) of both the right and left cerebral hemispheres; extending anteriorly over the upper portions of the bilateral Supplementary Motor Area.[24] The reference and ground sensors are randomly placed on opposite ears via comfortable earclips (See Figure 1).

The raw EEG is sampled at a rate of 8 KHz and is amplified with an optically isolated pre-amplifier and then digitized through use of a NeXT computer with a built in digital signal processor for spectral analysis. Utilizing this procedure, Fast Fourier transforms (FFT) of all EEG data in the 0 to 90 Hz range are automatically performed prior to further data analysis. The data is displayed on a computer screen as eight expanding and contracting horizontal bars (*i.e.,* 5 Hz, 7 Hz, 10 Hz, 12 Hz, 14 Hz, 16 Hz, 20 Hz, and 28 Hz) along with digital Peak-to-Peak microvolt reading for each bar. The NeXT computer

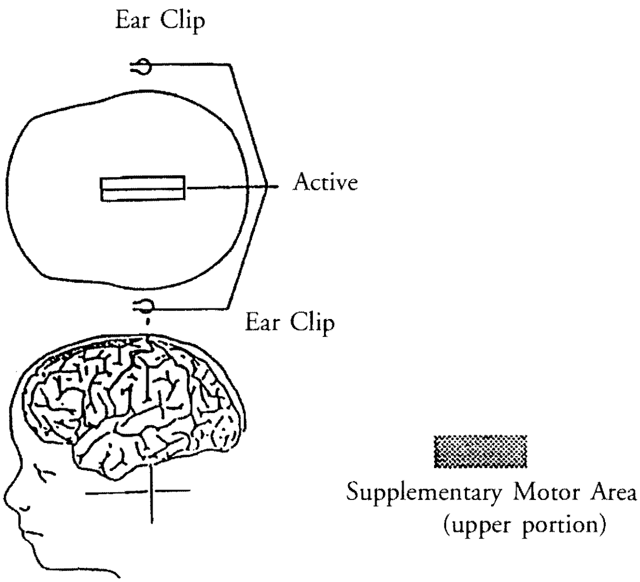

Figure 1. Diagram of EEG electrode placement (adapted from Goldberg[24]).

allowed for seamless incorporation of sound files within the EEG software,[25] permitting uniform presentation, and subsequent replay, of attentional voice commands while simultaneously recording brainwave activity, or replaying such recorded brainwave activity. All EEG data were collected under the same conditions—with the subject reclining comfortably in an arm chair in a quiet room with temperature control, and room light (incandescent only) of low intensity.

For the control subject, voice commands were presented by the operator through a speaker and EEG activity collected at 19 electrode sites using the standard international (10/20) pattern and linked ears as reference. Again, the data were analyzed in terms of the Tansey Technique (1 Hz wavebands sampled in 1 second epochs). For this subject, signal acquisition was achieved using 24 high performance differential amplifiers with less than 2 muVolts peak-to-peak noise, input impedance greater than 70 megohm differential, common

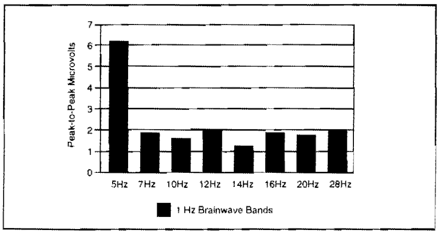

Figure 2. *8 Channel Brainwave Signature N=17. Brain Response to Voice Command "Just Let Be"*

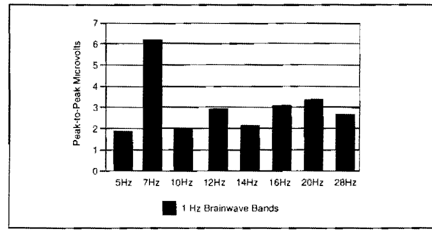

Figure 3. *8 Channel Brainwave Signature N=17. Brain Response to Voice Command "See a Yellow Ball"*

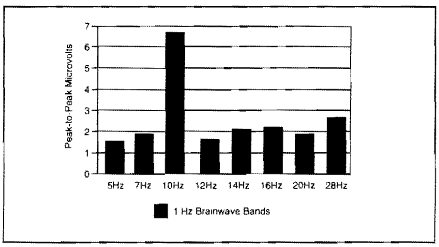

Figure 4. *8 Channel Brainwave Signature N=17. Brain Response to Voice Command "Add"*

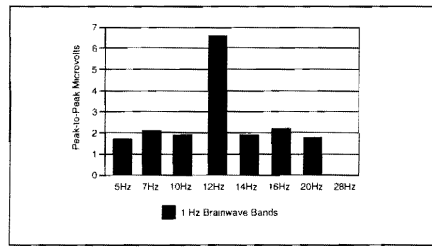

Figure 5. *8 Channel Brainwave Signature N=16. Brain Response to Voice Command "Be Aware"*

mode rejection of greater than 90 db at 60 Hz, high pass filter of 2 Hz, and low pass filter of 128 Hz. Analog to digital conversion of signal is achieved with a 12 bit A/D card that operates at 50 KHz.

RESULTS

Following each of the uniformly standardized computer presented voice commands, the frequency band with the highest activity was associated with the expected band. In each case where the collection of EEG following presentation of a voice command was longer than one second (*i.e.,* more than one epoch of EEG collected), the epoch with the highest amplitude for the frequency band in question was used for analysis. As Figures 2 through 9 show, conscious states and volitional attention were not reflected by changes in the wide band energy aggregates of Delta, Theta, Alpha, and Beta. Rather, they are specifically accompanied by changes in 1 Hz wide bands of EEG energy.

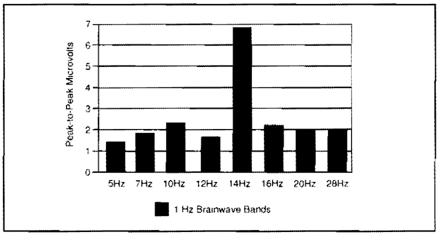

Figure 6. *8 Channel Brainwave Signature N=17. Brain Response to Voice Command "Be Aware of How Heavy Your Hands Feel"*

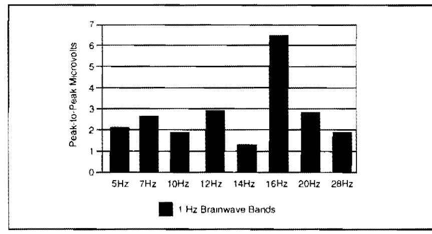

Figure 7. *8 Channel Brainwave Signature N=16. Brain Response to Voice Command "Feel"*

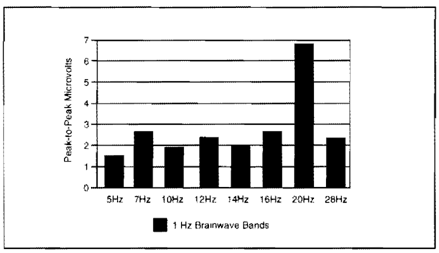

Figure 8. *8 Channel Brainwave Signature N=16. Brain Response to Voice Command "Be Aware of How Cool the Tops of Your Hands Feel"*

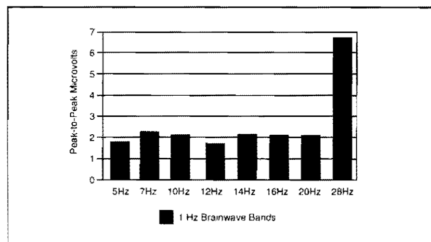

Figure 9. *8 Channel Brainwave Signature N=16. Brain Response to Voice Command "Be Aware of How Warm Your Hands Feel Against Your Thighs"*

Figure 10 gives a power distribution brain map of the 5 frequency bands being examined, for 19 electrode sites on the scalp surface (*i.e.*, 10/20 international system) for the control subject. Clearly, one would not expect the energy levels for any given frequency band to be uniform at all the electrode sites. Yet, 7 Hz as the predominant brainwave band at CZ for internally generated images was reflected in seven other electrode sites. In this state specific activation net, the 7 Hz dominant signature is uniquely elevated simultaneously at three electrode sites along the midline (CZ, F3 and PZ) with bilateral activation along the right (C4) and left (C3) Rolandic cortex, with temporal (T3) and left frontal (F3 and F7) involvement.

Figure 11 displays the first empirical evidence for specific repeated brain activation in service of specific cognition. The figure shows one subject's repeated alterations of the brain activation signatures with changes in the cognitive state. It goes significantly beyond depicting the cognitive state of "Just Let Be" as a 5 Hz dominant brainwave signature, or an internally generated mental image

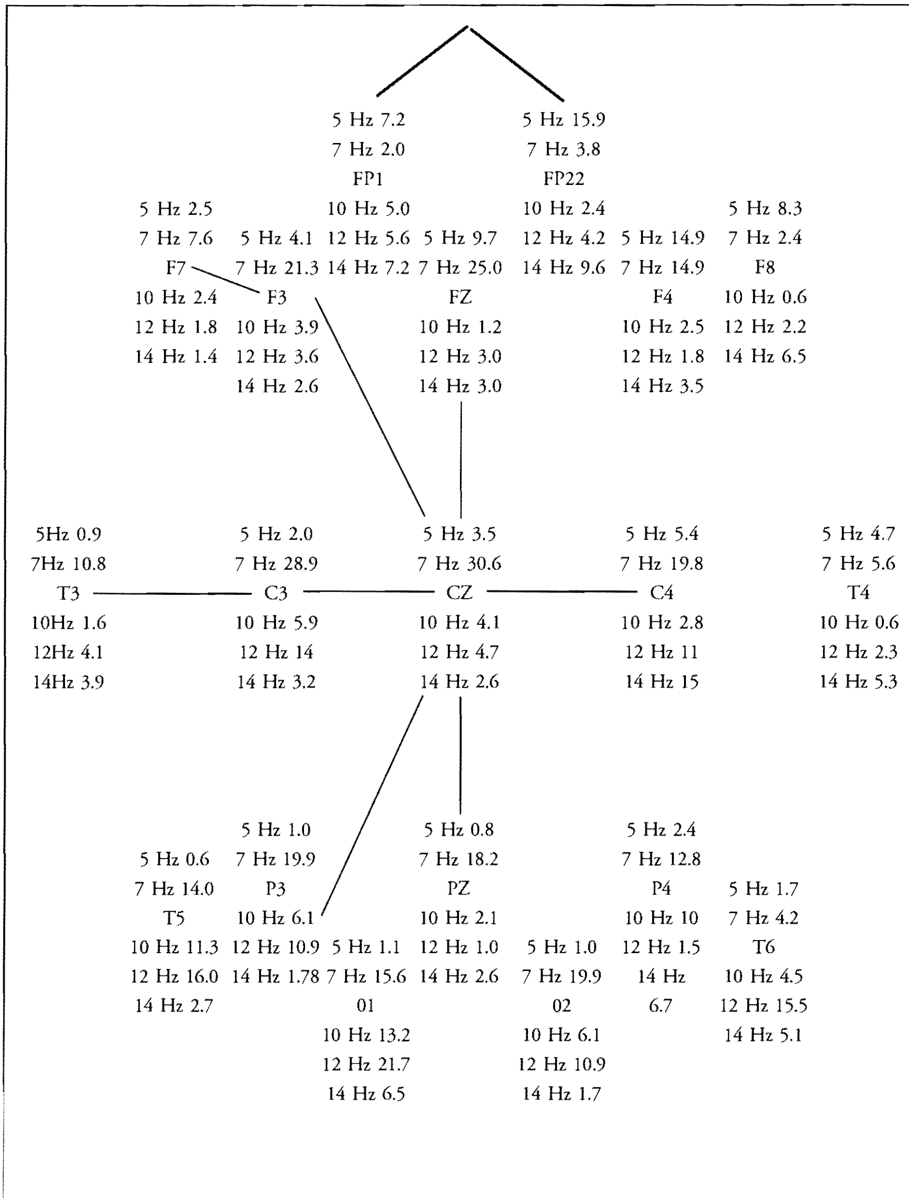

Figure 10. *"In Your Mind's Eye See a Pink Cow"*

1 Hz Window	5	7	10	12	14	16	20	28
Be Aware of Being Aware	0.52	3.43	1.27	*3.87*	2.26	0.21	0.33	0.10
And Let it all Go	3.14	2.84	1.71	*5.70*	1.41	0.16	2.84	4.01
And Just Let Be 1	*4.53*	0	1.63	2.00	2.11	1.85	1.12	0.16
In Your Mind's Eye								
See	1.63	**8.92**	3.28	0	3.57	4.53	4.82	0.90
A Yellow Ball	1.41	**4.82**	2.11	0.33	2.99	0.55	2.00	1.56
Let That Image Go	0.81	**7.75**	1.63	6.28	0.33	6.92	3.14	0.37
And Just Let Be	*5.70*	2.11	4.53	3.43	0.85	2.99	3.28	3.87
In Your Mind	0.10	0.05	3.28	*5.70*	2.26	1.78	3.14	0.37
Add	0.20	1.41	*5.70*	1.27	0.10	3.43	2.70	1.49
Six Plus Five	1.34	3.43	*5.99*	0.44	4.82	3.57	2.26	5.70
Let That Go	1.78	4.16	**5.41**	2.26	2.84	1.85	3.43	2.00
And Just Let Be 2	*4.53*	1.12	0.55	2.70	2.84	0.21	0.90	0.52
Be Aware	0.90	0.14	2.99	*4.31*	2.55	2.00	1.34	2.26
Of Watching Yourself Doing This	0.81	0.81	3.14	*4.53*	0.12	3.87	2.26	0.41
And Let That Go	3.14	3.72	0.90	*5.70*	3.72	3.43	0.63	4.16
And Just Let Be 1	*5.99*	3.72	2.55	0.77	3.57	2.84	5.41	3.14
Be Aware								
Of How Heavy You Can								
Allow Your Arms and								
Hands to Become	0.66	1.34	*5.70*	0.09	2.70	0.97	0.55	5.41
Feel	4.82	1.78	1.93	3.72	4.82	*6.58*	3.57	0.85
The Heavy	0.33	0.74	0.41	3.14	*4.16*	2.55	0.74	2.84
And Let it Go	2.40	2.16	1.12	5.70	*8.63*	0.12	0.44	1.05
And Just Let Be								
Feel	0.90	3.72	3.43	2.11	1.41	*5.70*	4.31	3.72
And Let Be 2	*5.99*	0.37	0.18	1.41	1.05	0.52	1.85	0.81
Become Aware								
Of How Warm your Palms Feel	2.11	4.01	4.31	0.70	0.20	0.05	0.18	*8.63*
Against your Thighs								
Feel the Warmth								
And Let It Go	5.70	2.99	0.55	4.82	1.05	0.37	4.16	*9.36*
And Just Let Be 3	*5.99*	3.72	0.30	1.85	0.74	2.40	1.05	1.85
Be Aware	0.90	4.53	0.03	*8.04*	4.82	0.30	6.58	5.99
Of How Cool the Tops of Your Hands Feel	1.19	2.70	3.87	0.70	4.82	2.40	*5.99*	0.97

Figure 11. *A Cartography of Cognitive States*

of "A Yellow Ball" as a 7 Hz dominant brainwave signature, or engaged thought as in doing mental math calculations as a 10 Hz dominant brainwave signature, or a non-critical self-awareness as a 12 Hz dominant brainwave signature, or a reduction of systemic musculoskeletal tension as a 14 Hz dominant brainwave signature, or a non-specific somatosensory awareness as a 16 Hz dominant signature, attentional focus on the skin surface or the space outside of the body as a 20 Hz dominant signature, and attentional focus on a sense of warmth (peripheral blood flow) in a body part.[21] Figure 11 clearly shows specific repeated cognitive states with strikingly similar brainwave band energy levels; *some with exactly the same Peak-to-Peak microvolt levels.*

DISCUSSION

A somewhat remarkable confirmation of the existence of functionally representative brainwave signatures arose from utilizing the chief feature of spectral analysis—an unbiased reliance on the pure frequencies made available by this investigative procedure. For the authors, the charting of EEG data in its functional manifestation has been found to be efficiently accomplished via vertically stacked 1 Hz wide windows reflecting one specific frequency per window. In this manner, the beginnings of an empirically accurate exploration of the cerebro-cognitive-somatic domain has been accomplished. This seminal initiative may very well open up to exploration the core issues underlying questions about how best to delineate treatment approaches for disorders of cognition, perception, intellectual manifestation, and dysfunctional neurophysiology.

Alterations of brain activation nets yield changes in the cognitive state and hence the state of mind of the individual. Our brains process much more than we are experientially aware of as we mentally track our conscious experience. M. A. Tansey references brain based cognitive predispositions as "parking spots."[21] Parking spots are pre-compiled brain-based cognitive activation nets which function like see through templates of up-to-date certitude as to self and world view. Figure 11 clearly provides support for the temporal stability and functional existence of brain based "parking spots." They are instantly, invisibly, and ubiquitously in the background filtering, quantifying, and ameliorating externally encountered experiential anomalies. They may be updated and refined, but must maintain temporal stability and functional representation in order to serve their purpose of maintaining a best-fit functional neurocognitive response net so that the individual is prepared optimally to meet the demands placed on the self by the environment.

M. A. Tansey also theorizes that individuals "park" their mental awareness in individually specific and experientially consistent parking spots—when not engaged in other mentally engaging activity. In addition, we postulate that mental events and/or memories are coherent totalities comprised of cerebro-neural predisposition and mental experience. This concept is also supported by the data. In this view, mental models become determinative due to their being based in temporally stable brain activation nets. Determinative mental models (personal schema which are coherently experienced via pre-compiled cognitive parking spots and synergistically activated neural nets) are what are used at a pre-conscious level to compare current experiential information against—and projectionally about—how one anticipates oneself carrying on in the future.

The charting of 1 Hz wide waveforms from a plurality of locations (See Figure 10) gives evidence of concurrent activation of several brain areas with virtually identical brainwave signature compositions. It gives evidence for synergistic concurrent activation in higher order processes. It gives credence to the observation that many cognitive functions seem to be related to activation of the frontal areas of the brain. It also gives credence to Goldberg's finding of the SMA as a critical aspect of a bilaterally interconnective "executive control center" whose cerebro-neural activation net spreads along the midline (CZ, F3 and PZ) with bilateral activation along the right (C4) and left (C3) Rolandic cortex, with temporal (T3) and left frontal (F3 and F7) involvement.[24] As such, CZ might be seen to be an optimal location for the monitoring of the brain substrates of intentionality and consciousness.

EEG activity is internationally referenced with respect to its composition insofar as the presence of Delta, Theta, Alpha, and Beta waves. The problem with experimental investigations dealing with functional and cognitive referents for the brainwave bands of Delta, Theta, Alpha, and Beta lay with the measures themselves. The problem with these cycles-per-second divisions for aggregate, broad band EEG activity was that no one at the time of their creation had any conception of the inherent broadness of their psychophysiologic responsivity. There is a sufficiency of incidence for general cognitive phenomena within the parameters of these wide bands of aggregate EEG activity, that many kinds of disparate cognitive activity resulted in increases in "alpha" production, "theta" production, "beta" production etc., with the upshot being that their operational utility remained unquestioned for decades. Broad visual observations (pen charts) led to the quantifying of the human EEG in broad bands (Delta, Theta, Alpha, and Beta. These broad behavioral and cognitive observations resulted in the clinical EEG record being broadly labeled as lacking in specificity and found to be an unreliable scientific tool when dealing with the domain of cognition.

The pursuit of broad band EEG analysis was necessitated by the early bandpass filtering technology. The espousing of the continuance of this practice within the advent of spectral analysis only produced more exact measures with uncertain attributes. As this work shows, the Theta, Alpha, and Beta bands each contain disparate cognitive states. The EEG neurofeedback practitioner utilizing these wide band aggregates of brainwave activity would have no inkling that he/she might be reinforcing a cognitive/attentional state that has nothing to do with what he wants to actually reinforce. Spectral analysis does, in fact, allow functionally exact, empirically repeatable, and reliable EEG indices for perceptual, cognitive, and intellectual functioning. To do this, one has to go beyond and within the broad band EEG definitions of Delta, Theta, Alpha, and Beta.

These findings provide a coherent view of the brain-mind-body synergy. It may be that not every brain uses the exact same neural nets to actualize desired outcomes, it appears that each brain may, in fact, utilize the same neural nets to actualize intentional outcomes. Brain, consciousness and "mind" are no longer indivisible and imponderable. As our work demonstrates, measures of the underlying cortical environment subsuming cognition and intentionality are beginning to manifest predictive validity. EEG measures are shown to have the ability to be more than a series of gross markers for ambiguous states of being in an inexact continuum of mental attention.

The human EEG, when properly quantified, can yield a cartography of consciousness, a functional representation of brain-behavior synergy, a charting of the meshing of intentionality and the brain's ability to manifest same, and the basis for more effective treatment of a wide variety of developmental, neurologic and addictive disorders.

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25. Some of the findings of this paper are reported in Tansey, Tansey and Tachiki (reference 21).

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