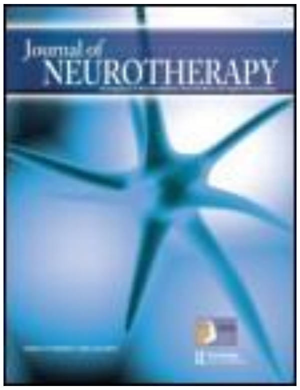

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Mathematically Derived Frequency Correlates in Cerebral Function:

Marvin W. Sams ThD, R.EEG T., QEEGT, L.Ac. [a]
[a] Technical Editor, Dallas, TX 75240
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Mathematically Derived Frequency Correlates in Cerebral Function: Theoretical and Clinical Implications for Neurofeedback Training

Marvin W. Sams, Th.D., R. EEG T., QEEGT., L.Ac.
Technical Editor

Many cortical and subcortical areas of the brain have spontaneously occurring 36-44 Hz ("40-Hz") activity. Across the scalp, the EEG peak frequency of 40 Hz is ≈ 39.5 Hz. A theory is proposed in which the brain has certain resident resonant frequencies that are subharmonics of 40-Hz activity. Some of these EEG frequencies are commonly trained in neurotherapy. Two examples are 12-15 Hz and 7-8 Hz activity, which are third and fifth subharmonics. Other frequencies with known cognitive and mental processing relationships and mathematical associations to 40 Hz include "Frontal mid Theta" at 6.5 Hz (sixth subharmonic) and Theta at 4 Hz (tenth subharmonic). Exploring 40 Hz and its subharmonics may provide further insight into the mechanics of the neurofeedback process and lead to more effective and efficient training. It is also anticipated that if the concept of 40-Hz / subharmonics is explored, the mechanisms of cerebral function might be better understood.

Introduction

Prior to the availability of the Quantitative (computerized) EEG, the recording of high frequency (over 30 Hz) electroencephalographic (EEG) frequencies could only be done with oscilloscopes or with special EEG amplifiers (often non-commercial) and fast paper speed. Oscilloscopes do not lend themselves to the permanent and reproducible recording requirements of researchers; recording the EEG with fast paper speed requires a major financial expenditure for chart paper and record storage. The Quantitative EEG (QEEG) does allow the recording of high frequency EEG data and the ability to maintain retrievable recordings. However, most EEG clinicians and researchers use a sampling rate of 128 Hz (cycles per second), restricting the high frequency response to 32 Hz. Also, if higher sampling rates are used, very slow (Delta) EEG frequencies are not recorded. As a result, pathology might be missed clinically, and traditionally reported EEG data are not available for scientific evaluation and publication. As a result of these technical limitations, frequencies above 30 Hz have received little attention in either clinical or research EEG.

Nobel Laureate Francis Crick, codiscoverer of the structure of DNA, has recently turned his attention to the brain. In a video recorded interview (*The Brain: Our Universe Within*), Professor Crick states that he believes that 40-Hz pulses control visual mechanisms in the brain. When we focus, certain neurons fire in a particular pattern (40 Hz) that create a phase lock with neurons in other areas of the cortex. He amplifies his speculations in his recent book, *The Astonishing Hypothesis: The Scientific Search for the Soul* (Crick, 1994).

Upon hearing Crick's comments, I remembered reading or hearing about 40-Hz EEG biofeedback several years ago. Rummaging through my library, I finally found a reference under "Beta-Wave Training" in *The Future of the Body* by Michael Murphy (Tarcher, 1992). Running the references, I was amazed to find a large volume of scientific data regarding 40-Hz

EEG and 40-Hz EEG biofeedback.

40-Hz Activity

In his book, Crick erroneously credits German researchers for the work behind 40-Hz activity and even makes it seem as if 40-Hz is a new idea. While the Germans have made important contributions, the early research, theory, and biofeedback work on 40 Hz was done by Americans in work dating back 30 years.

In strikingly meticulous research, psychophysiologist Daniel Sheer and a variety of associates have studied a narrow EEG frequency band that centers near 40 Hz (Sheer, 1967, 1970, 1972, 1973, 1974; Sheer & Grandstaff, 1970; Sheer, Grandstaff, & Benignus, 1966; Sheer & Hix, 1971). Sheer's research found frequencies in the range of 40 Hz (36-44 Hz) in various zones of the rhinencephalon, specifically the olfactory bulb, prepiriform cortex, and amygdala. Rowland (1968) found 40-Hz activity with conditioned stimulus in the ectosylvian and lateral cortex, medial geniculate, reticular formation, center median thalamus, and hippocampus. More recently, these oscillations were found to be present in the motor and visual cortex (DeFrance & Sheer, 1988).

According to Sheer, 40-Hz activity reflects a focused arousal associated with memory and learning processes. In his words: "...40-Hz reflects repetitive stimulation at a constant frequency for a limited time over a limited circuitry. The circuitry is defined behaviorally by the spatial-temporal patterning of sensory inputs, motor inputs, and reinforcement contingencies. It is 'optimal' for consolidation because repetitive synchronous excitation of cells maximizes the efficiency of synaptic transmission over the limited circuitry." (Sheer, 1975, p. 356) He bases his conclusions on studies in which he found 40-Hz activity during visual acquisition of a visual discrimination in cats (Sheer, 1970), in children mastering tasks involving short-term learning (Sheer, 1974), and visual problem solving in adults (DeFrance & Sheer, 1988). Sheer (1976) also found a deficit of 40-Hz in children with learning disabilities. For an excellent summary of Sheer's work, see the Theory section of Biofeedback Training of 40-Hz EEG and Behavior (Sheer, 1975).

German researchers have confirmed that the average local electrical activity (the field potential) in the vicinity of increased neural activity often shows 40-Hz oscillations (Gray & Singer, 1989; Gray, Konig, Engel, & Singer, 1989; Gray, Engel, Konig, & Singer, 1992). Some local neurons put out spikes, not at random moments, but "on the beat" of other local oscillations. These 40-Hz neurons may fire a short burst of two or three spikes that are in close synchrony with fellow neurons. Accordingly, the pulses "consolidate" (Sheer, 1970) or "bind" (Crick, 1994) the various areas of the cortex needed to process incoming sensory and motor information. Field potentials under certain visual conditions may be seen to oscillate in the same phase at two areas of the cortex, even if the electrodes are as much as 7 mm apart.

Confirming Sheer et al.'s work, Giannitrapani (1969) compared the EEG of middle- and high-I.Q. subjects during mental multiplication activity. A 40-Hz rhythm occurred just prior to the subject's answering the question. Forty-Hz pulses are thought to lead to synchronization and coordination of neurons assigned to the processing of incoming sensory stimulation. Put in "computerese," 40 Hz may be the brain's "operating system" frequency.

40-Hz EEG Biofeedback

An EEG biofeedback study by B. L. Bird and associates (Bird, Newton, Sheer, & Ford, 1978a, 1978b) evaluated three groups of subjects: one to increase 40 Hz only, another to bidirectionally increase and decrease 40-Hz activity, and a control group. The increase 40-Hz group achieved criteria in six sessions and the bidirectional group fared less well, but still achieved training. In follow-up studies, Ford, Bird, Newton, and Sheer (1980) showed that one to three years later, the previously trained subjects had retained their ability. Most still produced 40-Hz activity under task, without having benefit of EEG biofeedback. The EEG biofeedback research strongly suggests that 40-Hz biofeedback training helps to improve focused arousal and memory "consolidation," thereby potentially relieving certain learning disabilities.

Comment on 40-Hz Research

A striking aspect of 40-Hz research is its vision and depth. There are animal studies, human studies in both normal people and the learning disabled (LD), biofeedback studies showing easily trained ability to increase and decrease 40 Hz, and long-term follow-up studies. Furthermore, there is matching and correlated scientific theory on every aspect. While some may argue, there appears to be as much, if not more, science behind 40-Hz activity as with SMR, and certainly there is more than that found with Beta (15-18 and 16-20 Hz) EEG biofeedback.

Frontal Midline Theta Activity ("Theta2")

For the past several months, I have been clinically exploring "Frontal mid Theta activity," a rhythmic frontal Theta activity that is reported to occur during the performance of a mental task. While the original reports go back to the 1940s (Kennedy, Gottsdanker, Armington, & Gray, 1948, 1949; Arellano & Schwab, 1950; Brazier & Casby, 1952; Mundy-Castle, 1951), all the recent research is reported by the Japanese (Inouye, Ishihara, & Shinosaki, 1984, 1985; Inouye, Ishihara, Shinosaki, & Toi, 1985; Ishihara & Izumi, 1975, 1976; Ishihara & Yoshii, 1972; Mizuki, Tanaka, Osohaki, Nishijima, & Inanaga, 1976, 1980; Mizuki, 1987; Yamaguchi & Niwa, 1974; Yamaguchi, 1983). As "Frontal Mid Theta Activity" seems clumsy, I refer to this rhythm as "Theta2."

Theta2 consists of trains (long runs) of rhythmic frontal activity centering at 6.5 Hz with amplitudes reaching the 50-100 μV (microvolt) range. The maximum amplitude is just anterior to the Fz electrode and a few millimeters to the left of midline. The field spreads anteriorly to an area near the Fpz electrode site and posteriorly to the Cz, C3, and C4 electrodes.

Theta2 is induced in some people by the performance of a mental task such as mental arithmetic, tracing a maze, counting the number of cubes piled in a three-dimensional representation, and imaging a scene. Because Theta2 is associated with mental tasks and its influence is seen in evoked potential latencies, Mizuki (1987) believes that the appearance of Theta2 closely relates to mechanisms of attention or arousal. The incidence of Theta2, if measured during a mental task, is 32-73% of the normal population (Yamaguchi, 1983).

Theta2 is more common in extroverts with low traits of neurosis and anxiety. For this reason, Mizuki (1987) studied centrally acting drugs on college students to determine if differences in anxiety levels and performance existed between Theta2 producers and non-producers. Diazepam, amobarbital, methylphenidate, and a placebo were evaluated. The State Anxiety Scale of Speilberger's State Trait Anxiety Inventory (STAI) was used to measure anxiety. The mental task was arithmetic addition.

Beta power increased and Theta power decreased after administration of all drugs, though not with the placebo. In the Theta2 group, the placebo increased the appearance time of Theta2, decreased anxiety scores, and increased task performance. Diazepam increased Theta2 and decreased anxiety, but did not influence task performance. Amobarbital did not change the appearance of Theta2 or anxiety, but decreased task performance slightly. Methylphenidate failed to influence the appearance of Theta2, but did increase anxiety slightly and markedly increased task performance. In the non-Theta2 producers, Theta2 appeared with drug administration even though these subjects had not previously shown Theta2 over three days of testing. The appearance time of Theta2 increased in the following order:

diazepam > amobarbital > placebo > methylphenidate. Anxiety scores decreased in the same order. Task performance increased with methylphenidate and the placebo, but decreased with amobarbital and diazepam. The Mizuki study suggests that Theta2 is related to task performance and that decreased anxiety might occur with the appearance of Theta2.

40 Hz + Theta2 = Revelation

As I began trying to understand how rhythmic frontal Theta and poorly regulated, low amplitude posterior 40-Hz activity might be related, a fascinating thought came to me: maybe there is a mathematical association. Dividing 39.5 by 6.5, I discovered that Theta2 is a sixth subharmonic of 40-Hz activity! As I did more calculations, I found a fascinating relationship.

SMR (12-15 Hz) 13 Hz x 3 = ≈ 40 Hz
Alpha rhythm 9.5-10 Hz x 4 = ≈ 40 Hz
Alpha/Theta "border" 7.5-8 Hz x 5 = ≈ 40 Hz
Theta2 at 6.5 Hz x 6 = ≈ 40 Hz
Theta at 4 Hz x 10 = ≈ 40 Hz
Delta 1.3 Hz x 30 = ≈ 40 Hz

To appreciate the 40-Hz mathematical correlation, it is important to know that "40-Hz" activity is not precisely 40 Hz in frequency. Tracking (averaging) peak frequency on the Lexicor NeuroSearch™ system reveals that 40-Hz activity varies from 38.8 to 40.1, regardless of the electrode site. The average frequency is in the ≈ 39.5 range. Rarely, peak frequency is precisely 40 Hz, and even more rarely an average of 40.1 Hz is observed during a baseline (monitoring) period. When training begins, however, and the trainee is given audio feedback regarding 40 Hz, the peak frequency quickly drops to below 40 Hz.

Following are some considerations regarding 40-Hz mathematical relationships:

12-14 Hz/SMR

Much of the research and clinical attention in neurofeedback training has focused on SMR, a 12-15 Hz rhythm found in the sensory motor region of cats sitting quietly (Roth, Sterman, & Clemente, 1967; Howe & Sterman, 1972). While to my knowledge no one has identified an SMR rhythm in humans, it is common to train humans with a 12-15 Hz frequency band and call it SMR training.

Giannitrapani (1985) extensively studied the EEG of normal children under a large variety of mental tasks. (See also *The EEG of Mental Activities*, edited by Giannitrapani & Murri, 1988.) Using 16 2-Hz filter bands ranging from 0 to 32 Hz, measurements were made at 16 electrode sites (the vertex electrode sites were not included). Direct correlation was made of the EEG frequencies and the Weschler Intelligence Scale for Children (WISC).

As one would expect, the study found that EEG frequencies associated with various mental tasks are found in a number of frequency bands and electrode sites. Unexpected, at least to me, was the finding that the primary EEG power correlated with most mental tasks is in a 12-14 Hz frequency band. The power is maximal at the central electrode sites. Of interest to some neurotherapists, the 14-16 Hz band shows little or no association with intelligence and mental activity. The next highest band for most tasks is the 10-12 Hz band.

The Giannitrapani EEG results suggest that so-called SMR training may be widely effective, not because of the existence of a sensory-motor rhythm, but because of resonance. It may be the brain's affinity for a resonant frequency close to 13 Hz, which is captured by the 12-15 Hz frequency band. Should this challenging thought be true, so-called SMR training should be renamed, for example, "13-Hz training."

An implication for neurotherapy is that if increased intelligence and mental efficiency is the objective, then a frequency band with a 13-Hz center should be used. A more desirable frequency band than 12-15 Hz is 11.5-14.5 Hz. The Giannitrapani study agrees with the sensory/motor electrode sites (C3, C4) proposed by Lubar (1991), Tansey (1993), Sterman (1972), and others. EEG activity at the Cz electrode was not studied, so its association is not known.

Alpha

The peak frequency of Alpha in most people is in the 9.5- to 10-Hz range, a fourth subharmonic of 40 Hz. Starting in 1938 with Berger (Gloor, 1969), a number of studies have been published concerning the Alpha rhythm. See, for example, Andersen and Andersson (1968, 1974).

As neurons firing with 100-ms pulses (10 Hz) are common and Alpha is the largest rhythm in the ink-written EEG, it has been theorized that Alpha is the primary rhythm of the brain. Therefore, almost all of the early work around attention and consciousness is based on the Alpha rhythm. The association of Beta and attention is a relatively new idea (Mundy-Castle, 1951).

Eccles and Walter (1950) both agree that Alpha is the brain's scanning mechanism. In light of logic and current neurophysiological information, this makes sense. For example, when the eyes are closed and the visual centers in the occipital and parietal regions are deprived of visual stimuli, Alpha amplitude in the posterior head regions usually increases dramatically. Furthermore, Galin and Ornstein (1972) found Alpha magnitude decreases over the hemisphere of the brain that is under task.

Alpha rhythm, then, appears to be only indirectly involved in the brain's attentional mechanism. Alpha is the brain's scanning (idling) frequency, denoting a brain "standing by," waiting to give way to Beta should attention be required, or to be the bridge, the gate, to Theta and Delta for drowsiness, sleep, and certain cognitive challenges. Alpha is therefore an important cerebral rhythm, perhaps being mathematically a resonant piece of the 40-Hz Grand Conductor's ensemble of frequencies.

Alpha/Theta "Border"

A fascinating possibility is the harmonic association of 40-Hz activity and the Alpha/Theta Neurofeedback training for addictions. If the 40-Hz/subharmonics theory is correct, the objective in addictive work is to teach the brain to open the fifth subharmonic "gate" of 40 Hz (7-8 Hz).

Alpha/Theta may be the frequency correlate of Kenneth Blum's theory of the Cascade Theory of Reward (1990), which leads to the Reward Deficiency Syndrome. In Blum's theory, because of genetic anomalies, the neurochemistry in some people is satisfied with a drink (or bite) or two while the neurochemistry of the addicted person drives him or her into an unrelenting spiral of craving. Tying the 40-Hz theory with Blum's theory, it appears that those with genetic anomalies (addictive tendencies) can be "locked out" of certain EEG frequencies, and thus certain neurochemistry (or vice versa). As a result, those with addictive craving are not able to feel rewarded (satisfied) while non-addictive people are.

While there are exceptions in EEG patterning, the alcoholic's EEG while sober often demonstrates a low voltage Beta pattern mixed with low amplitude Theta and Delta activity. It is the type of low-voltage fast, "non-Alpha" EEG that is commonly associated with anxiety. If the alcoholic takes a relatively small amount of alcohol, he or she may quickly slip into a relaxed physiologic state and exhibit a relatively high amplitude, well-modulated Alpha rhythm. With that first drink, however, the brain of the alcoholic demands more alcohol. Instead of mellowing into an Alpha/Theta state as "normal" people do, additional amounts of alcohol cause a rapid descent into higher and higher amplitude Theta and Delta activity. The Alpha/Theta border of 7-8 Hz is seemingly "passed by."

It may be that the addicted person can open 40-Hz's fourth Harmonic gate (Alpha) with the alcohol or drugs. But, whether it is an anomalous gene, aberrant EEG frequencies, inappropriate neurochemistry, a neurochemical "lock out," or some other reason, the alcoholic is not able to open the fifth subharmonic 7-8 Hz gate. Instead of entering the Alpha/Theta state, the person sinks into the high-amplitude slow waves of profoundly lowered arousal (unconsciousness).

Alpha/Theta Neurofeedback results in some 80% of those addicts properly trained becoming non-craving, having a mellow personality and significantly adjusted neurochemistry (Peninston & Kulkosky, 1990). Alpha/Theta training may be a process by which the previously closed fifth subharmonic gate (40-Hz divided by 5) can be opened and certain critical neurochemistry accessed.

Beta

For Beta to fit the 40-Hz/Subharmonics theory, the frequency would have to be ≈ 19.6 (≈ 39.5 divided by 2). Peak frequency evaluations of the 18-22 Hz Beta band in a small number of subjects show that ≈ 19.6 Hz is close to the band's frequency peak.

If the 40-Hz/subharmonics theory and early results are correct, Beta should be trained, not at the 15-18 Hz frequency band as suggested by Othmer (1991) or the 16-20 Hz range as proposed by Lubar (1991), but at 18-22 Hz. Lubar's 16-20 Hz band seems close to the theoretical Beta frequency band, but his 16-20 Hz band is marginal. The ≈ 19.5 frequency center is to the far limits of the filter, probably restricting full access to the desired frequency.

Theta2

According to Inouye, Ishihara, Shinosaki, and Toi (1988), Theta2 has a prominent spectral peak at 6.5 Hz with smaller peaks at 3.2 and 13 Hz. The figure shown in their article (Figure 3), however, shows the lower spectral peak to be approximately 2 Hz (a twentieth subharmonic of 40 Hz) instead of 3.2 Hz as stated in the text. The 13-Hz finding is a second harmonic of Theta2, a third subharmonic of 40 Hz, and the primary frequency that Giannitrapani (1969) found with most mental functioning.

Theta at 4 Hz

According to Cavanagh (1972), Theta at 4 Hz corresponds to a full memory search. Theta, then, like Alpha, is a scanning frequency. Cavanagh began by compiling a number of studies dealing with different classes of stimuli (digits, colors, letters, words, geometrical shapes, random forms, and nonsense symbols). Each class of stimuli was found to have a characteristic reaction time. However, he found a constant of 243.2 ms when multiplying the reaction time for a single item by the maximum number of items in a given class. This indicated to Cavanagh that each item class was scanned at a different speed, but that scanning of the full memory is always executed at a speed of 4 Hz.

Giannitrapani (1985) states that according to the Cavanagh (1972) research, the brain has different scanning frequencies available for items of different degrees of complexity. I assume, based on the comments, that these scanning frequencies are all in the Theta range. The Giannitrapani study also shows a positive relationship between the level of performance for certain verbal subtests (WISC Information, Comprehension, Vocabulary, Block Design, and Verbal IQ) and 3-7 Hz Theta activity.

A conclusion one could make from these data are that the brain uses Theta band frequencies for important scanning and memory functions. Therefore, inhibiting Theta during neurofeedback training could conceivably be detrimental to memory storage and cognition.

Delta

In recent months, I have monitored the Peak Frequency of 0-32 Hz activity on every neurofeedback session. I have found that peak frequency at a variety of electrode sites may be as low as .9 and as high as 4.2 Hz. The average peak frequency in the vast majority of patients is, however, in the 1.2-1.4 range, averages that are in mathematical alignment with the 40-Hz theory. Delta also has mental/EEG associations: WISC Information (right fronto-central), Comprehension (left central), Vocabulary (right temporal), Digit Span (right occipital), Verbal I.Q. (bicentral).

Notes on Decrease Theta and Decrease Delta Training

For the past two years or so, I have been doing Decrease Delta training on children and adults with attention problems. I have found that if the training objective is to increase SMR or Beta, teaching Delta to downtrend at Cz or Pz will generally be more effective than attempting to reward the increase of SMR or Beta.

I am discussing Decrease Delta and Theta training at this time and in the context of this theoretical paper due to my personal communication with others regarding this training. It seems important to clarify my training protocol, in case of second-hand misinformation, especially in light of the information presented.

When I first started doing Decrease training, I began with Decrease Theta at 4-8 Hz. Results were admittedly quite good, at least in regard to increasing SMR and Beta. When I read about Theta2, however, I realized that there could possibly be some interference with cognitive processing by decreasing Theta above 5.5 Hz. As a result, I changed my primary Theta band to 3-6 Hz, calling it Theta1, and created a new secondary frequency band of 5.5-8 Hz, which became Theta2.

In time, I decided that any Decrease Theta training might be counterproductive to certain cognitive tasks, memory in particular (Cavanagh, 1972). The Delta frequency band, which I had changed to 0-3 Hz, then became my preferred band for the downtrending of slow wave activity.

It is not known how many children in the Giannitrapani (1985) study would be diagnosed with attention deficit disorder. Considering the sampling (general population), however, some probably were. In any case, Giannitrapani found that both Theta and Delta frequency bands have associations with mental processing. For example, Delta is seen in the EEG during the administration of the WISC comprehension test.

My training objective then is not to decrease Delta or Theta per se. The objective is to teach Delta *to downtrend under a performance challenge* such as the Game Boy™ strategy game Tetris™. Once the "decrease under task" goal is achieved, Decrease training is considered complete. The next training as specified in my clinical strategy protocol is then begun.

The interesting thing about teaching Delta to downtrend under task is that the resting Delta magnitude may actually increase as a result of the training. Higher amplitude Delta (implying more Delta is available) that decreases under task as SMR or Beta increases suggest that mental and attentional flexibility is improved. It appears that by doing Decrease training, Delta and certain fast frequencies are "unstuck." This flexibility is in alignment with the Giannitrapani study (1985) which shows that specific frequencies need to be available for certain mental tasks, Delta included. In the case of increased magnitude or percent power of Delta or Theta activity on a reference database, the clinical neurofeedback objective, of course, is to reduce the abnormal slow waves to normal magnitude levels.

20 Hz/40 Hz Notes

Another interesting mathematical correlation with 40 Hz is the EEG during meditation. Banquet (1973) found 20- and 40-Hz EEG changes in advanced Transcendental Meditators during the third stage of meditation (considered to be deep meditation or "transcendence"). The EEG was characterized by a dominant Beta rhythm at 20 Hz.

On the ink written record, Beta periods appeared at both 20 and 40 Hz. The amplitude of the background activity reached a surprisingly high voltage of 30-60 μV. Beta was mainly in the anterior head regions, but was sometimes present diffusely.

In the compressed spectral arrays

(CSA), the 20-Hz Beta power peaks seem to lie on an unvarying straight line with high amplitude, suggesting unusually regular frequency and amplitude. Forty-Hz activity, in comparison, is of significantly lower amplitude and of less steady regularity. The CSA shown in Banquet's article (1973) fits Crick's description of 40 Hz (1994), which he says is "more like a freehand drawing of a wave than a very regular mathematical wave of constant frequency." The spectral array also demonstrated a marked amplitude increase in the Delta range. Unfortunately, the peak frequency of the slow waves is not stated in the study.

Das and Gastaut (1955), recording from seven trained Yogis, reported high amplitude levels of 40-Hz activity during the Samadi state, which is the final, most intense concentration state in this form of meditation. Pollini and Peper (1976) reported Beta activity at 18-20 Hz in subjects during meditation.

In summary, when the body is profoundly relaxed and the mind is in a state of high focus and concentration, 20- and 40-Hz brain activity can be seen in the raw and quantitative EEG of some subjects. It is possible that 18-22 Hz Beta and possibly 40-Hz neurofeedback training may help create a "relaxed body/focused mind" state of consciousness.

40-Hz versus 12-15 Hz, 15-18 and 16-20 Hz training

It is not yet known whether 40 Hz, a subharmonic of 40 Hz, or harmonically unrelated other frequencies are the most efficient training for the remediation of cerebral dysfunction (learning disabilities) and attentional problems (Attention Deficit Disorder). As pointed out by Sheer et al. (1966), memory consolidation and learning impairments have not been adequately addressed in EEG biofeedback. Most of the research has been directed toward attempting to quiet the child's motor activity, that is, hyperactivity, rather than dealing with the learning problems and attentional flexibility. Subsequently, Increase SMR/Decrease Theta has historically been the most popular neurofeedback training. As 40 Hz specifically addresses the area of learning disabilities and memory consolidation ("focused arousal"), the training of 40 Hz may have a place in neurotherapy.

A strong consideration in any discussion of 40-Hz biofeedback training is the difficulty of training such a fast frequency. Significant electromyographic (EMG) contamination can naturally infringe and contaminate the training band. Sheer (1976), with further sophistication by Bird et al. (1978a), worked to overcome the EMG contamination problem by devising biofeedback equipment with a special "comparator" circuit. If EMG (at 72-78 Hz) occurs concurrently with 40-Hz activity (35-45 Hz), the "comparator" circuit discontinues EEG biofeedback until the EMG subsides.

To my knowledge, "comparator" circuits are not available on any commercially available EEG biofeedback equipment. The Lexicor NeuroSearch™ (and probably others) allows the silencing of the audio feedback should the magnitude of the frequency bands selected (EMG included) exceed the threshold set by the therapist. This filtering arrangement, while helpful, is probably not adequate to allow training of 40 Hz in tense and restless subjects.

Experiences with 40-Hz Biofeedback Training

1. Forty-Hz is thought to be either "off" or "on." For this reason, the neurofeedback objective may be to increase the amount of time that 40 Hz is on, rather than to attempt to increase its amplitude. The audio reward tone is therefore adjusted for a "flat" tone response rather than a "sliding" tone that becomes higher-pitched with increasing amplitude.

2. It seems important to train 40 Hz in brain areas that are associated with known sensory and motor processing, that is, the central and posteriorly placed electrodes (C3, C4, Cz, T5, T6, P3, P4, Pz, O1, and O2). It is important to avoid the midtemporal

electrode sites because of the temporalis muscle.

3. The Lexicor NeuroSearch™ requires a sampling rate of 256 to record 40-Hz activity.

4. The EMG file in Bands was changed to 48-52 Hz. If EMG is excessive, it is inhibited at the 20% level. A marked increase in EMG with a concomitant increase in 40 Hz suggests that the 40-Hz frequency band is being contaminated with EMG artifact. Forty-Hz magnitude increases should be discounted in these cases and in intersession training session comparisons.

5. While doing 40-Hz training, the client/patient should be continuously engaged in a cognitive task such as Tetris™. Non-verbal tasks and tasks with low potential for EMG contamination are preferred.

Some Clinical Notes on Theta2 Training

That Theta2 (Frontal mid Theta in the literature) is by definition rhythmical may present a technical problem. To my knowledge, no EEG biofeedback equipment has a "rhythmicity filter," which would allow the recording of rhythmic activity to the exclusion of non-rhythmic activity. In spite of this, I decided to trust the innate wisdom of the brain and attempt the training of Theta2.

Parents of children and adult trainees alike report improved behavior and performance after Theta2 training. However, neither have been measured with standard instruments. To complicate matters further, I have not done Theta2 training exclusively on any patient; it has always been done in combination with Increase SMR (12-15 Hz) or Beta (15-18 Hz), Decrease Delta and/or Theta, and a variety of Coherence, Phase and Symmetry training.

That said, a notable positive experience that seems directly attributable to Theta2 training is that of a 10-year old boy, heavy into knives under the mattress and the drawing of violent war scenes of robot warriors. This boy quickly mellowed with Theta2 training, much as is reported with Alpha/Theta training. All signs of violent behavior stopped. The robot cartoons continued to be drawn, but were essentially noncombative. My clinical experience with this boy is in alignment with Mizuki's (1987) drug studies showing less anxiety and neurotic behavior in those with Theta2.

My clinical experience with Theta2 thus far suggests the following:

1. My present training objective with Theta2 training is to make Theta1 (3-5.5 Hz) and Theta2 (5.5-8.0) autonomous. That is, while the trainee is under cognitive challenge, Theta1 should independently decrease over the session as Theta2 increases. When Theta2 stabilizes (remains the same over a session or two) as Theta1 decreases, I consider Theta2 training to be complete.

2. Theta2 training session time may be shorter than my usual training session time of 20 to 25 minutes. At the first clear indication of Theta2 downtrending (two quick decreases in the Theta2 magnitude averages while the trainee is under continuous cognitive challenge), stop the session. If the session is continued, Theta2 averages tend to downtrend and advances quickly decay. The Theta2 downturn can occur as early as 10 minutes into the session so the clinician should constantly monitor the magnitude average.

3. Only a few sessions are indicated for Theta2 training. Sessions should only continue until Theta2 increases and Theta1 downtrends while the trainee is doing a cognitive task. If sessions are continued after this point, the trainee seems to rapidly lose Theta2 magnitude gains. Only around five or seven sessions have been required in those trained to date.

4. While doing Theta2 training, the client/patient should be continuously engaged in a cognitive task such as Tetris™. Non-verbal tasks and tasks with low potential for EMG contamination are preferred.

The training protocol is based on my current electrophysiological perceptions. Much research and experience are needed to determine the proper protocol for Theta2. What is even more important is that it must be clinically determined whether increasing the magnitude or percentage time of Theta2 will yield such anticipated benefits as increased mental performance, improvement in anxiety states, and improved socialization in those with antisocial or unsocial behavior.

Theory

Two theories regarding 40 Hz are proposed:

"Gate" Theory

Commonly known clinical EEG frequencies, especially those shown to remediate attention problems and quiet hyperactivity (12-15 Hz), alcohol and drug addictions (Alpha/Theta at 7.5-8 Hz), and mental processing (Theta2 at 6.5 Hz and Theta at 4 Hz) mathematically relate to 40 Hz, an EEG frequency band centering at ≈ 39.5 Hz. It is proposed that those with attention problems, addictions, and mental processing problems (such as learning disabilities) may have restricted, limited, or no access to critical areas of cognitive and neurological functioning. Neurofeedback aids in the opening of certain critical, frequency-related "gates" in cerebral function to which the trainee previously had restricted, limited, or no access.

"Chord" Theory

Forty-Hz activity represents a chord—a computation—composed of several resident key brain frequencies. If these resonant frequencies are fully and dynamically present, maximum cerebral potential (volitional accessibility to specific neuronal functions, multiple states and levels of consciousness, and attentional flexibility) is available. Dissonance, deficiency, or excess in one or more key frequencies leads to discordance of 40-Hz activity, which in turn leads to hampered ability (a deficit) of some specific operation in cerebral functioning. Neurofeedback aids in the restoration of specific key resonant frequencies, thereby restoring full clarity to the 40 Hz.

Discussion

For readers with an interest or background in physics, it will be clear that 40 Hz itself may be a subharmonic of a still higher cerebral frequency. EEG frequencies over 40 Hz have been reported and I have recorded what appears to be true EEG activity at frequencies up to 128 Hz.

It is anticipated that the 40-Hz/Subharmonic theory will be met with both intrigue and skepticism. The contribution is presented to stimulate dialogue in anticipation that in doing so, the process of what we call neurofeedback will be better understood. Comments and questions are welcome.

No recommendations or claims are made regarding the efficiency, efficacy, or safety of a specific frequency or type of neurofeedback (EEG biofeedback) training. The reader, whether researcher or clinician, is solely responsible for the outcome of any training done on the basis of the information and theory presented.

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Key articles on 40 Hz •

Key summary article on 40-Hz ••

Key articles on Theta2 †

Key summary article on Theta2 ††

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