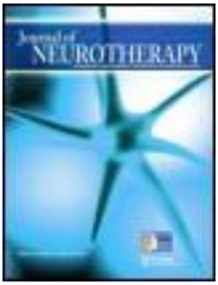

Journal of Neurotherapy: Investigations in Neuromodulation, Neurofeedback and Applied Neuroscience

What Do We Know About 40 Hz Activity and the Function It Serves?

D. Corydon Hammond PhD [a]

[a] Physical Medicine & Rehabilitation , University of Utah School of Medicine , Salt Lake City, Utah, 84132, USA

Published online: 17 Oct 2008.

To cite this article: D. Corydon Hammond PhD (2000) What Do We Know About 40 Hz Activity and the Function It Serves?, Journal of Neurotherapy: Investigations in Neuromodulation, Neurofeedback and Applied Neuroscience, 4:2, 95-104

To link to this article: http://dx.doi.org/10.1300/J184v04n02_10

CLINICAL CORNER

D. Corydon Hammond, PhD, Editor

This section is intended to be clinically focused. Therefore, contributions are often more informal and do not always include references. Our clinical work is guided by science whenever possible, but limitations in knowledge require practitioners to be guided often by clinical experience, no matter what their specialty. In other words, clinical work involves art as well as science. Thus, contributions to this section will refer both to science and to "clinical wisdom." Readers may send questions to: D. Corydon Hammond, PhD, University Medical Center, PM&R, Salt Lake City, UT 84132 (E-mail address: D.C.Hammond@m.cc.utah.edu).

THE ROLE OF 40 HZ ACTIVITY AND TRAINING

QUESTION 1: What do we know about 40 Hz activity and the function it serves?

RESPONSE: D. Corydon Hammond, PhD, Professor, Physical Medicine & Rehabilitation, University of Utah School of Medicine, Salt Lake City, Utah 84132.

The 40 Hz rhythm in animals has been found to be associated with the acquisition of learning. Basar-Eroglu, Struber, Schurmann, Stadler, and Basar (1996a) indicated that the 40 Hz rhythm exists spontaneously, can be evoked, and that it may have multiple functions in sensory and cognitive processing.

They believe there may exist a "distributed gamma system in the brain" (p. 101), and recently, Buchner, Gobbele, Waberski, Wagner, and Fuchs (1999) identified two source regions for 40 Hz activity: "one in the depth of the brain, suggested to reflect near thalamic activity, and a second at the visual cortex" (p. 59), with the deep source rhythm at 40 Hz and the cortical source operating at 37 Hz.

In humans, synchronous activity around 40 Hz seems associated with pre-attentive binding operations and mediating the binding of disparate perceived stimuli into coherent wholes so that information is processed simultaneously from different cortical areas (Engel, Konig, & Singer, 1991a). It thus appears to mediate the coupling of different areas of the brain that are involved in processing sensory input, binding various sensory inputs into a unitary sensation that is perceived (Jeffreys, Traub & Whittington, 1996; Krause, Korpilahti, Porn, Jantti, & Lang, 1998). Forty hertz activity during visual object perception seems to increase the efficiency of perceptual organization (Elliott & Muller, 1998), and Crick (1994) believed that 40 Hz bursts controlled visual brain mechanisms. In contrast with event-related desynchronization that occurs to the alpha rhythm with mental engagement, 40 Hz activity appears to represent event-related synchronization, is associated with active attention (Tiitinen, May, & Naatanen, 1997), and seems to occur in parallel with event-related desynchronization in the alpha band (Crone, Miglioretti, Gordon, & Lesser, 1998). Thus, Steriade, Amzica, and Contrera (1996) stressed "the conventional notion of a totally desynchronized cortical activity upon arousal should be revised as fast rhythms are enhanced and synchronized within intracortical networks during brain activation" (p. 392).

Sheer (1975) believed 40 Hz was "'optimal' for consolidation because repetitive synchronous excitation of cells maximizes the efficiency of synaptic transmission over the limited circuitry," and that it has an effect behaviorally "in sharpening of attention to relevant stimuli" (p. 356). This rhythm occurs in connection with cognitive activity such as selective attention, stimulus perception, and consciousness (Tiitinen, Sinkkonen, Reinikainen, Alho, Lavikainen, & Naatanen, 1993). An incredibly robust correlation has been found between peak gamma latency and reaction time (P = 0.000001) in the 37 to 41 Hz range, which was not due to EMG contamination, suggesting that 40 Hz seems to have functional significance in relation to stimulus processing (Haig, DePascalis, & Gordon, 1999).

Activation of this gamma rhythm will not occur with meaningless words, but does occur in response to meaningful stimuli (Lutzenberger, Pulvermuller, & Birbaumer, 1994), even when not attended to (Krause et al., 1998). Pantev, Makeig, Hoke, Galambos, Hampson, & Gallen (1991) believed that auditory (or other sensory modality) perception-induced gamma might function to synchronize and bind different regions of the auditory cortex together so as to combine different auditory features into a single auditory perception.

Rather than this rhythm carrying information itself, it has been suggested that it provides a temporal structure, correlating neurons that encode information (Engel et al., 1991a; Krause et al., 1998). Working with moderate to high IQ subjects, Giannitrapani (1966, 1969) found that increases of 35-45 Hz occurred immediately prior to answering in tasks such as multiplication questions, and 40 Hz activity seems to synchronize and coordinate neurons that process incoming sensory stimuli. Forty Hz activity has also been found during problem solving in children (Sheer, 1974) and adults (DeFrance & Sheer, 1988), but a deficit in 40 Hz activity was found in children with learning disabilities (Sheer, 1976). More recently, Kwon et al. (1999) discovered that schizophrenic patients showed reduced EEG power in response to 40 Hz auditory stimulation (but not at lower frequencies of stimulation) and delayed onset of phase synchronization compared to normals. Miltner, Braun, Arnold, Witte, and Taub (1999) has also found that increased gamma band activity is involved in associative learning. In addition, gamma-band coherence increases between areas of the brain that receive the two classes of stimuli involved in an associative-learning procedure. They found that "not only did gamma-band [37-43 Hz] abundance increase in regions of the brain that received the two classes of stimuli involved in the training procedure, but gamma-band coherence also increased between them. Coherence or in-phase synchronicity is, in conceptual terms, the simplest and most straightforward process that could provide the basis for the formation of hebbian cell assemblies" (p. 435). Thus, in-phase synchrony in the 40 Hz band literally seems to bind together parts of the brain that must communicate with each other for associative learning to take place.

In his review, De Pascalis (1999) stated: "Common to these studies is the view that 40-Hz EEG activity serves as an operator on attentional sensory and motor functions to allow single elements in the central nervous system to be linked or bound into functional states that represent and integrate external stimuli and motor sets into a unified whole" (p. 120). He conceptualized 40 Hz as focused arousal, much like Sheer and Grandstaff (1970) and Sheer's (1976, 1984) perception. This rhythm has been found to occur at high amplitude levels in the occipital area in highly trained yogis while in the samadhi, the final, intense state of concentration in one form of meditation (Das & Gastaut, 1955). In the third deep stage of transcendental meditation, Banquet (1973) also observed 40 Hz activity in left occipital and frontal sites. Sams (1995) has hypothesized this to be the brain's "operating system frequency." This fast, 40 Hz activity also seems capable of being dissociated from slower frequency beta activity and can be enhanced through neurofeedback (Bird, Newton, Sheer, & Ford, 1978; Ford, Bird, Newton, & Sheer, 1980; Sheer, 1977, 1984). Gamma level activity has also been shown to be capable of being induced by photic and visual stimulation, auditory stimuli, and motor behavior.

REFERENCES

Banquet, J. P. (1973). Spectral analysis of the EEG in meditation. *Electroencephalography & Clinical Neurophysiology*, *35*, 143.

Basar-Eroglu, C., Struber, D., Schurmann, M., Stadler, M., & Basar, E. (1996a). Gamma-band responses in the brain: A short review of psychophysiological correlates and functional significance. *International Journal of Psychophysiology*, *24(1-2)*, 101-112.

Bird, B. L., Newton, F. A., Sheer, D. E., & Ford, M. R. (1978). Biofeedback training of 40 Hz EEG in humans. *Biofeedback & Self-Regulation*, *3(1)*, 1-12.

Buchner, H., Gobbele, R., Waberski, T. D., Wagner, M., & Fuchs, M. (1999). Evidence for independent thalamic and cortical sources involved in the generation of the visual 40 Hz response in humans. *Neuroscience Letters*, *269(2)*, 59-62.

Crick, F. (1994). *The Astonishing Hypothesis*: *The Scientific Search for the Soul*. New York: Macmillan.

Crone, N. E., Miglioretti, D. L., Gordon, B., & Lesser, R. P. (1998). Functional mapping of human sensorimotor cortex with electrocorticographic spectral analysis. II. Event-related synchronization in the gamma band. *Brain*, *121(Pt 12)*, 2301-2315.

Das, N. N., & Gastaut, H. (1955). Variations de l'activite electrique du cerveau, du coeur et des muscles squellettiques au cours de la meditation et de l'extase yogique. *Electroencephalography & Clinical Neurophysiology*, *Suppl. 6*, 211.

DeFrance, J., & Sheer, D. E. (1988). Focused arousal, 40-Hz EEG, and motor programming. Chapter in D. Giannitrapani & L. Murri (Eds.), *The EEG of Mental Activities*. Basel: Karger.

De Pascalis, V. (1999). Psychophysiological correlates of hypnosis and hypnotic susceptibility. *International Journal of Clinical & Experimental Hypnosis*, *47(2)*, 117-143.

Elliott, M. A., & Muller, H. J. (1998). Synchronous information presented in 40-Hz flicker enhances visual feature binding. *Psychological Science*, *9(4)*, 277-283.

Engel, A. K., Konig, P., & Singer, W. (1991a). Direct physiological evidence for scene segmentation by temporal coding. *Proceedings of the National Academy of Science*, *88*, 9136-9140.

Ford, M., Bird, B. L., Newton, F. A., & Sheer, D. (1980). Maintenance and generalization of 40-Hz EEG biofeedback effects. *Biofeedback & Self-Regulation*, *5(2)*, 193-205.

Giannitrapani, D. (1966). Electroencephalographic differences between resting and mental multiplication. *Perceptual & Motor Skills*, *22*, 399-405.

Giannitrapani, D. (1969). EEG average frequency and intelligence. *Electroencephalography & Clinical Neurophysiology*, *27*, 480-486.

Haig, A. R., De Pascalis, V., & Gordon, E. (1999). Peak gamma latency correlated with reaction time in a conventional oddball paradigm. *Clinical Neurophysiology, 110(1)*, 158-165.

Jeffreys, J. G. R., Traub, R. D., & Whittington, M. A. (1996). Neuronal networks for induced '40 Hz' rhythms. *Trends in Neuroscience*, *19*, 202-208.

Krause, C. M., Korpilahti, P., Porn, B., Jantti, J., & Lang, H. A. (1998). Automatic auditory word perception as measured by 40 Hz EEG responses. *Electroencephalography & Clinical Neurophysiology, 107(2)*, 84-87.

Kwon, J. S., O'Donnell, B. F., Wallenstein, G. V., Greene, R. W., Hirayasu, Y., Nestor, P. G., Hasselmo, M. E., Potts, G. F., Shenton, M. E., & McCarley, R. W. (1999). Gamma frequency-range abnormalities to auditory stimulation in schizophrenia. *Archives of General Psychiatry, 56(11)*, 1001-1005.

Lutzenberger, F., Pulvermuller, F., & Birbaumer, N. (1994). Words and pseudowords elicit distinct patterns of 30-Hz EEG responses in humans. *Neuroscience Letters*, *176*, 115-118.

Miltner, W. H. R., Braun, C., Arnold, M., Witte, H., & Taub, E. (1999). Coherence of gamma-band EEG activity as a basis for associative learning. *Nature*, *397*, 434-436.

Pantev, C., Makeig, S., Hoke, M., Galambos, R., Hampson, S. A., & Gallen, C. C. (1991). Human auditory evoked gamma-band magnetic fields. *Proceedings of the National Academy of Sciences*, *88*, 8996-9000.

Sams, M. W. (1995). Mathematically derived frequency correlates in cerebral function: Theoretical and clinical implications for neurofeedback training. *Journal of Neurotherapy*, *1(1)*, 1-14.

Sheer, D. E. (1970). Electrophysiological correlates of memory consolidation. Chapter in A. Ungar (Ed.), *Molecular Mechanisms in Memory & Learning*. New York: Plenum.

Sheer, D. E. (1974). Electroencephalographic studies in learning disabilities. Chapter in H. Eichenwald & A. Talbot (Eds.), *The Learning Disabled Child*. Austin: University of Texas Press.

Sheer, D. E. (1975). Biofeedback training of 40-hz EEG and behavior. Chapter in N. Burch & H. I. Altshuler (Eds.), *Behavior and Brain Electrical Activity*. New York: Plenum.

Sheer, D. E. (1976). Focused arousal and 40 Hz EEG. Chapter in R. M. Knights & D. J. Bakker (Eds.), *The Neurophysiology of Learning Disorders*. Baltimore: University Park Press.

Sheer, D. E. (1977). Biofeedback training of 40-Hz EEG and behavior. Chapter in J. Kamiya et al., *Biofeedback and Self-Control 1976/1977. An Annual Review.* Chicago: Aldine.

Sheer, D. E. (1984). Focused arousal, 40-Hz EEG, and dysfunction. Chapter in J. Elbert et al., *Self-Regulation of the Brain and Behavior.* Berlin: Springer.

Sheer, D. C. & Grandstaff, N. W. (1970). Computer-analysis of electrical activity in the brain and its relation to behavior. Chapter in H. T. Wycis (Ed.), *Current Research in Neurosciences*, *Vol. 10*, *Topical Problems in Psychiatry and Neurology.* New York: Karger.

Steriade, M., Amzica, F., & Contreras, D. (1996). Synchronization of fast (30-40 Hz) spontaneous cortical rhythms during brain activation. *Journal of Neuroscience, 16(1)*, 392-417.

Tiitinen, H., Sinkkonen, J., Reinikainen, K., Alho, K., Lavikainen, J., & Naatanen, R. (1993). Selective attention enhances the auditory 40-Hz transient response in humans. *Nature*, *364*, 59-60.

Tiitinen, H., May, P., & Naatanen, R. (1997). The transient 40-Hz response, mismatch negativity, and attentional processes in humans. *Progress in Neuropsychopharmacology & Biological Psychiatry, 21(5)*, 751-771.

QUESTION 2: How can we do 40 Hz training without just increasing EMG? What electrode sites would you recommend for doing 40 Hz training, and when would you introduce this training in your overall scheme of neurotherapy?

RESPONSE 1: *Valdeane W. Brown, PhD and Susan Brown, PhD, Zengar Institute, 121 Prospect Street, Port Jefferson, NY 11777. E-mail address: weare@zengar.com*

While we routinely and regularly conduct neurofeedback using beta (15-18) and SMR (13-15) frequencies, we have found some additional frequencies to be even more interesting and powerful to work with. One of those is 40 Hz. Forty Hz training has non-routinely been used as part of a package for peak performance training. It creates a subjective feeling of enhanced awareness of both an open and a narrow focus simultaneously, with occasional patients reporting spontaneous integrative insight into personal issues. Forty Hz training also subjectively feels like an effortless, enhanced beta, which is energizing, but without the muscle tension that can frequently result from beta training. This can easily be verified both by collateral EMG placements, as well as by joint-time frequency analysis of the EEG signal. EMG activity has a time-frequency signature that is distinct from 40 Hz EEG, and this is especially apparent when clients provide phenomenological reports of feeling energized, connected, creative, peaceful and even blissful after 40 Hz training.

But these subjective experiences are not the only reason why we train at 40 Hz. We have found that 40 Hz training has an effect on the whole FFT; that is, 40 Hz training affects every frequency we are currently interested in–1 to 42 Hz. If we look at the whole FFT as we train with 40 Hz, we generally notice an increasing cohesion and "tightness" in the frequency mirror. Amplitudes tend to be reduced and variability decreases as next nearest neighbor frequencies re-normalize. This is extremely useful in working with individuals who have high amplitude eyes-open alpha, or high surging at 3-5 Hz activity which we place a high emphasis on reducing. We find that training with 40 Hz eyes open seems far more effective than simple suppression of alpha eyes open. We sometimes see eyes open alpha drop dramatically with 40 Hz training, even without active suppression of the 8-13 Hz itself. However, in about one-fifth of individuals, we see an opposite effect, in which 40 Hz will increase amplitudes and variability throughout the FFT. This can make it useful in assisting those individuals to "let go." Regardless of which of these effects it has, we always counterbalance 40 Hz training with training at 21 Hz. Direct observation of the emergent "real-time" FFT is the only way that we have found, however, to know which effect will occur with each of these targets as we begin to train a particular individual.

For our 40 Hz training, we generally combine it with 21 Hz training, and we almost always conclude our sessions with 40 Hz training. We use two channels of EEG with actives at C3 and C4 and ear clips for references and grounds, using a bandwidth of 38-42 Hz on our system. Even as little as five minutes will leave you or your client feeling alert, refreshed, energized, and ready for the day.

RESPONSE 2: Marvin W. Sams, ND, 1909 Central Drive, Suite 101, Bedford, TX 76021. E-mail address: drmsams@aol.com

When I first "discovered" the 40 Hz EEG and biofeedback literature (Sams, 1995), I was stunned by the quantity and depth of the available research. Why, I asked myself, was 40 Hz training not being commonly used in neurofeedback circles? Why has the exquisite work of Daniel Sheer and his associates been ignored? Why have these researchers not been recognized and honored for their contributions to electrophysiology and neurofeedback?

As I reviewed this treasure chest of information, I found research papers on 40 Hz's formational correlation with percepts and memory consolidation, linguistic processing, and associative learning. There were 40 Hz correlations with such diverse behavioral and perceptual functions as the sleep dream state, deep meditation, visual problem solving in normal adults, and task requiring mental activity. Especially relevant to neurofeedback, Sheer found clear brain wave differences in normal children versus those with learning disabilities: Forty Hz increases when normal subjects perform a task, but not in those with known learning difficulties. Sheer's elegant research papers presented highly detailed technical information about the specialized EEG biofeedback equipment, the training techniques, and the ease by which subjects were able to learn to produce 40 Hz activity under task (implying 40 Hz is a natural brain rhythm). There is even a follow-up report that five of six of the original research subjects could still produce 40 Hz activity under task when tested several years later.

"How do we do 40 Hz training without just increasing EMG?" Sheer and his associates describe custom-made, technically sophisticated biofeedback instrumentation. Special "comparator circuits" analyzed and compared electrical activity from neck and temporal region electrodes to those arriving from the scalp electrodes. For 40 Hz activity to be considered of cerebral origin and appropriate for training, the equipment required neck and temporal electrodes to show reduced or absent 40 Hz and 70 Hz EMG activity at the time of a 40 Hz signal. These studies demonstrated that 40 Hz is easily trained and that the training did not increase EMG activity. Indeed, EMG activity decreased over training sessions. We can anticipate, therefore, that 40 Hz is very trainable, EMG activity does not increase as a result of 40 Hz training, and a favorable physiological relaxation effect occurs as a result.

Technically, two potential ways for EMG to interfere with 40 Hz neurofeedback training come to mind: When the trainee swallows during the session, the temporalis muscle is briefly contracted and a flurry of EMG fast activity occurs. The training signal is no doubt affected. However, this is brief, lasting only a second or two, and would not be expected to adversely affect training any more than an occasional movement of the body does. Those under constant physiological tension, such as occurs with TMJ problems, have relatively constant muscle activity due to contracture of the temporalis muscle. While the resultant EMG activity is of considerably higher voltage than the 40 Hz activity, muscle cells fire rather continuously with a relatively repetitive voltage. It, therefore, is likely to have a minimal affect on the computer's analysis of the dynamical EEG signal within the narrow band of analysis. In my practice, this postulated non-interference of EMG activity on 40 Hz activity has been shown to be true. I routinely train with muscle tension being intermittently or continuously present in the EEG. Favorable changes always occur in the nine frequency bands being analyzed pre- and post-training, with most or all the five electrode sites being monitored (Cz, F3, F4, P3, P4) showing dynamical differences.

"What electrode sites would you recommend for doing 40 Hz training?" The early Sheer studies used the P3-01 electrode sites, but they subsequently changed to 01 or 02-Cz. The reason offered for the change was to "study larger brain areas in the association cortex." Sheer did not state why he chose the parieto-occipital electrode sites for the initial studies. However, as an EEG researcher during the time of this research (1970's and early 1980's), I know that electrode site decisions were strongly influenced by the high cost and technical limitations of the available recording equipment. If you have a single channel system, you chose two electrodes–somewhere–and that, for better or worse, became the source of your data. In those days, the parieto-occipital region was especially popular because eye blinks and eye movement do not affect the data, and temporalis muscle activity is eliminated or sharply

reduced. If this research project were done today, it would no doubt be done differently. Technology is now cheap and engineering possibilities are limited only by the imagination. Commercially available multi-channel EEG equipment easily reveal physiological changes occurring at many brain sites, and a variety of quantitative EEG displays (topographic, CSA, etc.) are readily available.

This historical information offered as a backdrop, when I began doing 40 Hz training with referential-style (scalp to joined ears) recording as is common in the SMR tradition, I did not notice changes in either the resulting EEG magnitudes or in behavior. Before abandoning the project, however, I decided to try the Lexicor LCC montages. These montages join multiple electrode sites into a single training channel to allow increased or decreased magnitude, coherence, phase, or synchrony training over wide brain areas. Since that time, some five years now, these special LCC montages have provided excellent training results, showing strong ability to reduce delta and theta activity, while increasing 13 Hz and beta. To improve training efficiency, I developed several custom LCC montages, and routinely use increase magnitude and increase synchrony (50% coherence/50% phase) for training. Forty Hz coherence and phase training have been disappointing.

Knowing that the brain uses 40 Hz pulses to process information by phase-locking multiple cortical and subcortical areas strongly suggests that training multiple electrode sites with the LCC montages will provide optimal results. That said, I circled back recently to see if I could develop an effective 40 Hz referential-type training. I found that reasonably good 40 Hz training can be done with favorable EEG movement (decreased delta and theta, increased 13 Hz and beta) with the following three-frequency technique: 13 Hz (11.5-14.5 Hz); beta 2 (20-26 Hz) (central or frontal vertex) or Beta 1 (15-20 Hz) (parietal vertex); and 40 Hz (37-43 Hz). Training is at a vertex electrode. Each frequency band is trained for 5 minutes, resulting in a 15 minute training time. A two-minute no-audio baseline is done under task to reveal pre- and post-changes. With all types of training, the y-axis is used to adjust the audio tone for high pitch with a 99-100% audio reward time (the tone is continuous with slight dips in pitch every 3 to 5 seconds).

"When would you introduce this training in your overall scheme of neurotherapy?" I use a number of different frequencies, electrode sites/combinations, and training types on each client. For example, increase fast, decrease slow, and increase synchrony LCC and referential protocols are routinely used. Forty Hz training is done routinely, being part of the training "mix."

Sheer spent his life studying 40 Hz's ability to increase "focused arousal," and discovered the brain requires 40 Hz activity to learn. Furthermore, Sheer and his associates, along with researchers in this country and in Germany, have done or are doing research showing that 40 Hz is the only brain frequency present throughout both cortical and subcortical structures. It is how the brain consolidates or binds different areas to perform many of its vital tasks. Just recently, for a dramatically striking example, E. Roy John, reporting at the 1999 Society of Neuronal Regulation meeting, stated that 40 Hz is responsible for consciousness (making 40 Hz the answer to the ancient question). Are we ignoring a remarkable training? Are we neurotherapists doing our job as well as we could?

A detailed reference list may be found in Sams (1995), which is posted on the SNR web site (222.snr-jnt.net) and on my web site (http://www.greatbrain.com/mathematics.html).