

REVIEW ARTICLE

A COMPREHENSIVE REVIEW OF THE PSYCHOLOGICAL EFFECTS OF BRAINWAVE ENTRAINMENT

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Objective • Brainwave entrainment (BWE), which uses rhythmic stimuli to alter brainwave frequency and thus brain states, has been investigated and used since the late 1800s, yet many clinicians and scientists are unaware of its existence. We aim to raise awareness and discuss its potential by presenting a systematic review of the literature from peer-reviewed journals on the psychological effects of BWE.

Data Sources • Terms used to describe BWE and psychological outcomes were used to search English language studies from OVID Medline (1950-2007), PsychInfo (1806-2007), and Scopus.

Study Selection • Twenty studies selected satisfied the following criterion: studies needed to use rhythmic stimuli with the aim of affecting psychological outcomes. Peer-reviewed experimental and quasi-experimental studies were accepted. Case studies and review articles were excluded. Psychological outcomes were measured using standard assessment methods or as deemed appropriate by peer review.

Data Extraction • Other clinical measurements, including electroencephalogram response, galvanic skin response, and neurotransmitter levels were not included.

Data Synthesis • Psychological outcomes addressed cognition, stress and anxiety, pain relief, headaches or migraines, mood, behavior, and premenstrual syndrome (PMS). Protocols included the use of single, alternating, ascending, or descending frequencies or were determined by the subject, using auditory and/or photic stimulation. Studies examined single session effects and/or longer-term multiple session effects.

Conclusions • Findings to date suggest that BWE is an effective therapeutic tool. People suffering from cognitive functioning deficits, stress, pain, headache/migraines, PMS, and behavioral problems benefited from BWE. However, more controlled trials are needed to test additional protocols with outcomes. (*Altern Ther Health Med.* 2008;14(5):38-50.)

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DISCLOSURE

Tina L. Huang, PhD, is an employee of Transparent Corporation (a brainwave entrainment software corporation) in Columbus, Ohio. Transparent Corporation has allowed Dr Huang complete independence in the design, interpretation, and completion of this paper.

Standard treatments for mental or cognitive disorders do not work for everyone or have undesirable side effects. In fact, there are few or no satisfying solutions for many, including the 7% of children with learning disabilities.¹ Brainwave entrainment (BWE) has the potential to safely and effectively fill this gap, yet few clinicians have heard of it. We aim to introduce the reader to BWE and review the scientific literature on its effectiveness to improve cognitive functioning, mood, stress/anxiety, pain relief, headaches/migraines, behavior, and premenstrual syndrome (PMS). Then

we will briefly examine the effects of various stimulation frequencies on psychological outcomes and conclude with recommendations for future research.

DEFINITION

The term *brainwave entrainment* refers to the use of rhythmic stimuli with the intention of producing a frequency-following response of brainwaves to match the frequency of the stimuli. The stimulus is usually either visual (flashing lights) or auditory (pulsating tones). By those in the industry, it is also commonly called "brain entrainment," "audiovisual entrainment (AVE)," "audiovisual stimulation (AVS)," "auditory entrainment," or "photic stimulation."

GENERAL USE OF BRAINWAVE ENTRAINMENT

BWE is provided to the user in the form of a device that often includes goggles with light-emitting diodes (LEDs) and/or a CD, usually requiring the use of headphones. It also comes in the form of software, which allows the user more flexibility in adjusting individual sessions to his/her needs. Sessions most commonly last from 20 to 60 minutes, during which a user sits either with his or her eyes closed in a quiet setting or, depending on the goals of the user and session used, with eyes open while

working. Those with a history of epilepsy are advised against use of photic stimulation.

The most commonly used methods of BWE are to stimulate the brain at the desired frequency via auditory tones, flashing lights, or a combination of both. The 3 most common forms of auditory stimulation use isochronic, monaural, or binaural beats. Isochronic tones are evenly spaced tones that simply turn on and off. Monaural and binaural beats are presented as 2 tones with very similar frequencies, and the brain perceives a beat that is the difference between the 2 pitches. The pitches are presented together with monaural beats but fed separately to each ear with binaural beats. For photic stimulation, most devices use goggles with lights or a flashing screen, and most instructions suggest that the user's eyes remained closed. Pulses of light can be presented as different waveforms or colors. Photic stimulation also can be presented independently to each eye or each visual field in order to more effectively target stimulation to the right or left hemisphere.

HISTORY

The first known clinical application of BWE was discovered by a French psychologist, Pierre Janet, in the late 1800s. Janet noted that his patients appeared calmer after being exposed to a rotating strobe wheel that was illuminated by a lantern, and thus he used this method therapeutically as needed.² After Berger showed that electrical activity could be recorded from the human brain in 1929,³ Adrian and Mathews (1934) showed that the Berger rhythm (alpha) could be further amplified by photic stimulation at the same frequency.⁴ In 1942, Dempsey and Morison found that BWE could also be induced by a tactile stimulus,⁵ and Chaitran reported entrainment effects with an auditory stimulus in 1959.⁶ Psychological effects of BWE were further explored in 1946 when flickering light produced frequency-dependent sensations of "pattern, movement and color."⁷ In 1959, BWE was found to reduce the need for anesthesia during surgery,⁸ and in 1975, it was found to enhance meditation.⁹ The development of BWE tools proliferated after Oster's 1973 article on the properties of the binaural beat.¹⁰ Research on the effects of BWE on pain, headaches, migraines, anxiety, and stress followed in the 1980s and expanded in the 1990s to include learning and memory, ADHD, learning disabilities, behavioral problems, and PMS.

CURRENT THEORIES ON BRAINWAVE ENTRAINMENT MECHANISMS

Placement of sensors on the scalp allows the measurement of brainwave patterns that reflect the current state of an individual. The best studied brainwave frequencies range from the slower delta frequencies (1-4 Hz), which are associated with deep sleep; to theta frequencies (4-8 Hz), which are associated with light sleep, creativity, and insight; to alpha frequencies (8-12 Hz), which reflect a calm and peaceful yet alert state; to beta frequencies (13-21 Hz), which are associated with a thinking, focusing state; to high beta frequencies (20-32 Hz), which are associated with intensity or anxiety.¹¹ Research shows that presentation of a consistent rhythmic stimulus (usually either a pulsating light or a

tone) within 8 to 10 Hz causes brainwaves in the occipital lobe, parietal lobe, or temporal cortex to exhibit a frequency-following response that either resonates with the presenting stimulus or shows a frequency harmonic or a sub-harmonic of a stimulus.^{7,12-16} Although many believe that the same mechanism applies to other frequencies, this has been harder to substantiate. Recent research suggests that baseline electroencephalogram (EEG)¹⁷ or emotional lability¹⁸ may influence post-stimulus EEG changes. Most researchers agree that emotional or cognitive changes do correlate with changes in the EEG but how or whether the EEG changes is likely to be dependent on the individual's current state.

METHODS

Search Strategy

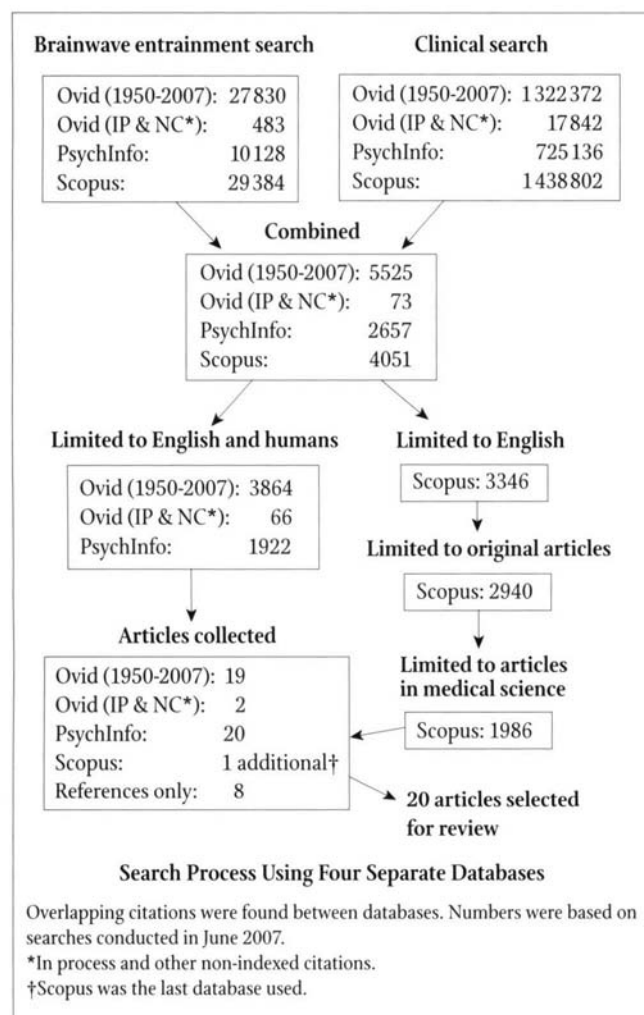
Ovid Medline databases (Ovid Medline [1950-2007], in process, and other non-indexed citations), PsychInfo (1806-2007), and Scopus (1900-2007) were used. All papers containing any of the following terms were selected: *visual entrainment, auditory evoked potentials, auditory entrainment, brain entrainment, brainwave entrainment, brain stimulation, brainwave stimulation, frequency following response, photic stimulation, photo stimulation, photic driving, audio-visual entrainment, AVE, sonic entrainment, evoked potentials, flicker, brain AND entrainment, cortical evoked response, visual evoked response, afferent sensory stimulation, variable frequency photo-stimulation, repetitive sensory response, brain wave synchronizers, brainwave synchronizers, audiovisual stimulation, AVS, auditory stimulation, binaural beats, monaural beats, isochronic beats, or isochronic tones.*

To select psychological terms, we used information gathered from professional conferences, review articles, a review of websites of several of the most well-known BWE companies, and 2 unpublished manuscripts by Dave Siever (*The rediscovery of audio-visual entrainment technology* [2000] and *The physiology and applications of audio-visual entrainment technology* [2006]). Articles containing the following clinical terms were selected: *learning disorders, learning disabilities, dementia, cognitive decline, Alzheimer's, intelligence, IQ, mental disorders, behavioral disorders, attention deficit, verbal learning, memory, creativity, depression, anger, rage, migraine, headache, pain, anxiety, stress, premenstrual syndrome, or sleep.* We then combined the outcomes of the BWE and the psychological searches. For each relevant original and review article found, references were examined for additional papers.

Criteria for Article Selection

To be included in the review, articles had to examine the effects of BWE using auditory or visual stimulation on psychological outcomes. The stimuli had to be delivered using either pulses of lights or tones at frequencies hypothesized to have a beneficial effect or a protocol based on a systematic approach toward addressing clinical outcomes. Only original full-length journal articles in peer-reviewed journals in English were included. Case studies and review articles were excluded. Studies had to be of an experimental design using a comparison group or a pre-test post-test design. Clinical or psychological outcomes had to

be measured using reliable and appropriate test procedures as deemed by peer review. Selected studies were required to reveal statistical outcomes, such as descriptive statistics, analysis, and *P* values. The Figure shows the search strategy and number of articles retrieved for each step with each of the 4 databases.



RESULTS

Overview

Twenty articles met our criteria, and all examined 1 or more outcomes. We categorized psychological outcomes into the following categories: cognition (verbal outcomes [2], nonverbal/performance [2], attention [5], memory [3], and overall intelligence and achievement [2]), stress (short-term [5] and long-term stress/burnout [4]), pain (3), headaches/migraines (4), mood (3), behavioral problems (1), and PMS (1). These categories are divided into Tables 1-5.

Nine studies used healthy subjects, 4 used subjects with either learning disabilities or attention deficit hyperactivity disorder (ADHD), 3 examined subjects with migraines, 2 used stressed subjects, 1 examined subjects with anxiety symptoms, 3 examined subjects while experiencing day surgery, and 1 included subjects with bruxism or myofascial pain dysfunction syn-

drome. Fifteen studies were of adults, 3 of children, 1 of college students, and 1 of elderly subjects. Studies that used children, college students, and the elderly were primarily interested in cognitive functioning and academic outcomes. Nine of the studies used multiple sessions, ranging from approximately 7 to 100, and another 9 studies used single sessions. Two additional studies used multiple sessions but also measured changes before and after each session. Session lengths ranged from 0.5 seconds to 60 minutes. Frequency of sessions in long-term studies ranged from 1 session per week to 2 sessions per day. Two studies used a protocol with alternating frequencies, 11 used constant frequencies (3 that were selected by the patient), 2 used 0.5-second frequency bursts, 3 studies began with descending frequencies and then ended in a single frequency, 1 study alternated between ascending and descending frequencies, and 1 study used 3 different tapes of theta and delta but gave no further details. Among studies that used constant or alternating frequencies as specified by the investigators, frequencies ranged from low delta to high gamma. Nine studies used photic stimulation only, 6 used auditory stimulation, 4 used AVE, and 1 compared AVE to photic stimulation. The number of subjects in each study ranged from 4 to 108. Seven groups had fewer than 20 subjects, 10 groups had between 21 and 40, and 3 groups had more than 40. Thirteen studies had control groups.

Cognition

Within the 8 studies that addressed cognitive functioning, a large range of outcomes was examined, which we categorized into verbal skills, nonverbal skills, memory, attention, general intelligence, or success in school as measured by grade point average (GPA). Four of the 8 studies examined longer-term changes over weeks and multiple sessions, and 4 examined immediate effects of BWE.

One study that examined verbal abilities in school-aged children with ADHD used a protocol that alternated between alpha (10 Hz) and beta (15-18 Hz) AVE.¹⁹ A separate study used 4 healthy adult subjects and compared the effects of theta (7 Hz) auditory stimulation with rain sounds to rain sounds alone to examine the same outcome (Table 1).²⁰ The study that alternated between alpha and beta entrainment on children with ADHD found significant increases with a standardized reading test,¹⁹ but the study that used only a single theta stimulation with healthy adults saw no significant improvements.²⁰

Nonverbal skills (Table 1) were examined in 2 studies of children with LD or ADHD.^{21,22} There was no change with the Raven Progressive Matrices with 12 to 14 Hz photic stimulation.²¹ However, in a separate study, 30 children were alternately exposed to an excitatory program (starting at 14 Hz and increasing to 40 Hz) and an inhibitory program (which started at 40 Hz and decreased to 14 Hz) over 6 weeks.²² These children showed a significant improvement with arithmetic using WISC-III, suggesting that incorporation of gamma frequencies (38-42 Hz) should be examined further as a potential method to improve nonverbal skills such as math.

TABLE 1 Cognition*

Study and sample	n, description	Study design	Stimulation (photic/aud/AVE)	Hz	Duration of session	Length of treatment	Effect	Proportion of significant positive outcomes
Verbal Skills								
Carter & Russell, 1993 Group 1	14 children with LD	Pre vs post	AVE, BB	2 min 10 Hz/1 min 0 Hz/2 min 18 Hz	25 min	80 sessions over 8 wks	Improvement with Auditory Sequential Memory, WRAT-reading, WRAT-spelling, $P < .01$ No improvement with Peabody Picture Vocabulary Test	3/4
Carter & Russell, 1993 Group 2	12 children with LD	Pre vs post	AVE, BB	2 min 10 Hz/ 1 min 0 Hz/ 2 min 18 Hz	25 min	18 sessions over 6 wks	Improvement with WRAT-spelling, WISC-R Verbal IQ, $P < .05$ No improvement with WRAT-reading	2/3
Joyce & Siever, 2000	E: 8 C: 12 children with ADHD	E vs C	AVE, IT vs environmental music	1st 8 sessions: 7-9 Hz Remaining: L & R Visual field separately- L: 10/16-18 Hz, R: 10/15 Hz; 170 Hz isochronic tones	1st 8 sessions: 20 min, Remaining: 25 min	Mean 31 sessions over 7 wks	STAR standardized reading test (Grade equiv): E: increased by 0.6 grades C: decreased by 0.2 grades	
Wahbeh, 2007b	4 healthy adults	Randomized double-blind cross over; E vs C	BB	E: 7 Hz with sound of rain C: sound of rain only	30 min	Single session	No difference with verbal fluency using COWAT	0/1
Nonverbal/Performance Skills								
Carter & Russell, 1993 Group 1	14 LD children	Pre vs post	AVE, BB	2 min 10 Hz/1 min 0 Hz/2 min 18 Hz	25 min	80 sessions over 8 wks	Improvement with Raven Progressive Matrices No improvement with WRAT- arithmetic	1/2
Carter & Russell, 1993 Group 2	12 LD children	Pre vs post	AVE, BB	2 min 10 Hz/1 min 0 Hz/2 min 18 Hz	25 min	18 sessions over 6 wks	No improvement with WRAT- arithmetic or WISC-R Performance	0/2
Patrick, 1996	E: 21 C: 10 children with ADHD	Pre vs post for E vs C	Photic vs nothing	12-14 Hz	40-50 min with frequent rest	15 daily sessions, slowly withdrew stim as subjects produced more on their own	No improvement with Raven Progressive Matrices	0/1
Olmstead, 2005	30 children, ages 6-16 with LD/ADHD	Pre vs post	AVE	Alternating sessions of excitatory program (14 Hz increasing to 40 Hz), and inhibitory program (40 Hz decreasing to 14 Hz)	35 min	12 sessions over 6 wks	Improvement with WISC-III Arithmetic	1/1

TABLE 1 Cognition, cont*

Study and sample	n, description	Study design	Stimulation (photic/aud/AVE)	Hz	Duration of session	Length of treatment	Effect	Proportion of significant positive outcomes
Attention								
Patrick, 1996	E: 21 C: 10 children with ADHD	Pre vs post for E vs C	Photic vs nothing	12-14 Hz	40-50 min with frequent rest	15 daily sessions, slowly withdrew stim as subjects produced more on their own	Improvement with TOVA impulsivity, WISC-R processing speed, and WISC-R freedom from distractibility No improvement in TOVA inattention	3/4
Joyce & Siever, 2000 Total group (34)	34 children with ADHD	Pre vs post	AVE, IT vs Environmental music	1st 8 sessions: 7-9 Hz Remaining: L & R Visual field separately- L: 10/16-18 Hz, R: 10/15 Hz; 170 Hz isochronic tones	1st 8 sessions: 20 min; remaining: 25 min	Mean 31 sessions over 7 wks	Improvement with TOVA inattention, TOVA impulsivity No improvement with TOVA reaction time	2/3
Olmstead, 2005	30 children, ages 6-16 with LD/ADHD	Pre vs post	AVE	Alternating sessions of excitatory program (14 Hz increasing to 40 Hz), and inhibitory program (40 Hz decreasing to 14 Hz)	35 min	12 sessions over 6 wks	Improvement with WISC-III freedom from distractibility and processing speed	2/2
Lane, 1998	29 healthy adults	Double-blind crossover for E1 vs E2	Aud, BB	Pink noise with BB or simple tones in beta (16-24 Hz) or delta (1.5-4 Hz) through stereo headphones	30 min	Single session	Comparing beta to theta/delta: Improvement with CPT correct targets, CPT false alarms	2/2
Wahbeh, 2007b	4 healthy adults	Randomized double-blind crossover; E vs C	BB	E: 7 Hz with sound of rain C: sound of rain only	30 min	Single session	No difference using Stroop-Word or Stroop-Color tests	0/2
Memory								
Carter & Russell, 1993 Group 1	14 children with LD	Pre vs post	AVE, BB	2 min 10 Hz/1min 0 Hz/2 min 18 Hz	25 min	80 sessions over 8 wks	Improvement with auditory sequential memory	1/1
Williams, 2001	51 healthy adults	Compared effects at varying frequencies	Photic	Randomly stimulated with 0/8.7/10/11.7 Hz	0.5-1.5 sec	Single session	The most trigrams were recognized at 10Hz	1/1

TABLE 1 Cognition, cont*

Study and sample	n, description	Study design	Stimulation (photic/aud/AVE)	Hz	Duration of session	Length of treatment	Effect	Proportion of significant positive outcomes
Williams, 2006	30 cognitively healthy elderly	Compared effects at varying frequencies	Photic	Randomly stimulated with 9/9.5/10/10.2/10.5/11/11.5 Hz	1 sec	Single session	The most trigrams were recognized at 10.2Hz	1/1
Wahbeh, 2007b	4 healthy adults	Randomized double blind cross over; E vs C	BB	E: 7 Hz with sound of rain C: sound of rain only	30 min	Single session	Reduced immediate recall in experimental sessions compared to control using RAVLT	0/2
Overall Intelligence and Achievement								
Carter & Russell, 1993	12 children with LD	Pre vs post	AVE, BB	2 min 10 Hz/1 min 0 Hz/ 2 min 18 Hz	25 min	18 sessions over 6 wks	No improvement with WISC-R Full scale	0/1
Group 2								
Budzynski, Jordy et al, 1999	E: 8 C: 8 college students with academic difficulties	Pre vs post for E vs C	Photic & EDR vs nothing	Altered between 1 min 14 Hz, 1 min 22 Hz	15 min	30 sessions over 6 wks	Improvement in GPA	1/1
Patrick, 1996	E: 21 C: 10 children with ADHD	Pre vs post for E vs C	Photic vs nothing	12-14 Hz	40-50 min with frequent rest	15 daily sessions, that slowly withdrew stim as subjects produced more on their own	Improvement in WIAT	1/1

*Hz indicates hertz; E, experimental; C, control; M, mean; SD, standard deviation; NS, not significant; LD, learning disability; ADHD, attention deficit hyperactivity disorder; Aud, auditory; AVE, audiovisual entrainment; BB, binaural beats; IT, isochronic tones; L, left; R, right; WRAT, Revised Wide Range Achievement test; WISC-R, Wechsler Intelligence Scale for Children-revised; TOVA, Tests of Variable Attention; CPT, Continuous Performance Test; WIAT, Scholastic Achievement: Wechsler Individual Achievement Test; COWAT, Controlled Oral Word Association Test; RAVLT, Rey Auditory Verbal List Test; EDR, electrodermal stimulation.

Five studies used 3 different stimulation methods (photic, auditory with binaural beats, and AVE) to examine attention (Table 1). Three studies^{19,21,22} examined children with ADHD or learning disabilities over multiple sessions; 2 studies examined normal adults over a single session.^{20,24} Four studies that used a protocol that involved beta stimulation found significant improvements in attention using the Tests of Variable Attention (TOVA)^{20,21} or the WISC,^{21,22} but the study that used theta stimulation found no improvements.²⁰

Two studies that examined memory in different populations found significant effects, but 1 study found a negative effect (Table 1). Two single session studies examined the optimal photic frequency stimulation associated with trigram recognition in cognitively healthy middle-aged adults and seniors. Both studies concluded that the most trigrams were recognized with 10- or 10.2-Hz stimulation.^{16,24} In a separate study, a single 30-minute session of theta stimulation in healthy adults reduced immediate

recall using the Rey Auditory Verbal List Test compared to sessions with no BWE.²⁰

Two studies used photic stimulation with²⁵ or without electrodermal stimulation (EDR)²¹ at different frequencies to examine its effect on general intelligence or GPA (Table 1). The studies selected children with ADHD²¹ or college students with "academic challenges"²⁵ and found that stimulation of 14 Hz alternating with 22 Hz²⁵ or 12 to 14 Hz²¹ over multiple sessions resulted in significant improvements on GPA²⁵ or the Scholastic Achievement Wechsler Individual Achievement Test.²¹

Stress and Anxiety

Seven articles examined stress and anxiety, which we divided into short-term stress relief and long-term stress/burnout (Table 2). Of the 5 studies that examined short-term stress (Table 2), 3 used auditory stimulation,^{26,27} 1 study used AVE,²⁸ and a fifth compared

TABLE 2 Stress/Burnout*

Study	n	Study design	Stimulation (Photic/Aud/AVE)	Hz	Duration of session	Length of treatment	Effect	Proportion of significant positive outcomes
Short-term Stress								
Morse et al, 1993	E1 (Photic): 10 E2 (AVE): 10 C: 10 adults getting root canal	Pre vs post for E1 vs E2 vs C	Photic with sounds of waves vs AVE vs none	10 Hz (photic) vs 10 Hz (AVE) vs none	1 hr during dental procedure	Single session	Trend toward a difference between C group and each E group on dental fear questionnaire	0/1
Ossebaard, 2000	E1 (alpha): 13 vs E2 (beta) 12 employees of addiction care facility	Pre vs post for E1 vs E2	AVE	Alpha : 5 min 30 Hz, 35 min 10 Hz. Beta : 5 min 30 Hz, 5 min 25Hz, 30 min 16 Hz	40 min	Single session	Significant difference for both alpha and beta on STAI (state anxiety), but no significant difference between alpha & beta	1/1
Le Scouarnec et al, 2001	14 mildly anxious adults seeking treatment for anxiety	Pre vs post	Aud, BB	Choose between 3 tapes designed to reduce anxiety. All 3 have theta and delta	Mean: 30 min	Single session	All 3 tapes showed significant effect on Journal Anxiety Scale	1/1
Padnmanabhan et al, 2005	E: 36 C (music): 36 C (nothing): 36 undergoing day surgery	Randomized double-blind E: vs C1 vs C2	Aud, BB	Progressive slowing of BB, resulting in 10 min of delta	30 min	Single session	Experimental groups showed significant difference using STAI (state anxiety)	1/1
Wahbeh, 2007b	4 healthy adults	Randomized double-blind crossover; E vs C	BB	E: 7 Hz with sound of rain C: sound of rain only	30 min	Single session	No difference with STAI state or trait anxiety	0/2
Long-term Stress/Burnout								
Ossebaard, 2000	E1 (alpha): 13 vs E2 (beta) 12 employees of addiction care facility	Pre vs post for E vs C	AVE	Alpha : 5 min 30 Hz, 35 min 10 Hz. Beta : 5 min 30 Hz, 5 min 25 Hz, 30 min 16 Hz	40 min	2 sessions per wk for 8 wks	MBI-NL emotional exhaustion: significant effect with beta, but not alpha MBI-NL personal competence: significant effect with alpha, but not beta MBI-NL depersonalization: no effect	alpha: 1/3 beta: 1/3
Howard et al, 1986	E: 12 vs C: 11 dental students	Randomized Pre vs post for E vs C	AVE vs progressive relaxation	30 Hz ramped down till subject is relaxed for 15 min, then 8-14 Hz for 7 min	22 min	7 sessions for 7 wks	Both AVE and progressive relaxation showed improvement using POMS (fatigue and anxiety), STAI (state and trait anxiety), Thurstone temperament schedule, ORI by self, SSQ (no of days relaxed, the summary stress score and sleep) AVE had a positive effect on ORI by other. No effect on POMS (hostility), SSQ (number of minutes relaxed and coping devices) AVE had a slight negative effect on life satisfaction using the SSQ	For AVE: 12/16

TABLE 2 Stress/Burnout, cont*

Study	n	Study design	Stimulation (Photic/Aud/AVE)	Hz	Duration of session	Length of treatment	Effect	Proportion of significant positive outcomes
Le Scouarnec et al, 2001	14 mildly anxious adults seeking treatment for anxiety	Pre vs post	Aud, BB	Choose between 3 tapes with theta and delta designed to reduce anxiety	Mean: 30 min	1.4-2.4/wk for 4 wks	No effect with STAI (state and trait anxiety)	0/2
Wahbeh, 2007a	8 healthy adults	Pre vs post	Aud, BB with over-laying sounds of rain and bells	Starts at 10 Hz, decreases incrementally, staying at 2.5 Hz for 40 min	60 min	60 sessions over 60 days	No effect with STAI (state anxiety), and tension/anxiety using the POMS Decreased trait anxiety using STAI	1/3

*E indicates experimental; C, control; M, mean; SD, standard deviation; SEM, standard error of the mean; NS, not significant; L, left; R, right; Hz, hertz; Aud, auditory; AVE, audiovisual entrainment; BB, binaural beats; MBI, Maslach's Burnout Inventory; STAI, Spielberger's State-Trait Anxiety Inventory; POMS, Profile of Mood States; TTS, Thurstone temperament schedule; ORI Observer Rating Inventory; SSQ, Stanford stress questionnaire.

photic stimulation to AVE.²⁹ Two studies had subjects who were undergoing stressful medical procedures, 1 study had employees of an addiction care facility, another treated mildly anxious adults, and the fifth had healthy adults. Of the 2 groups that stimulated at alpha frequencies (10 Hz), 1 found a trend but not a significant difference between the experimental groups (photic stimulation and AVE) and the control group.²⁹ The other study, which compared alpha to beta stimulation, found a significant difference after stimulation but not between the 2 frequencies.²⁸ A study that used a combination of theta and delta frequencies and another study that used progressive slowing from alpha to 10 minutes of delta found significant reductions in anxiety.^{26,27} The smaller study that used just theta stimulation on healthy adults found no significant differences in effects between stimulation and control conditions.²⁹

Of the 4 studies that examined long-term stress, 2 used AVE, and 2 used auditory stimulation with binaural beats over 4 to 8 weeks of sessions (Table 2). Two studies treated people with stressful occupations, 1 treated mildly anxious adults, and another used healthy adults. One study found no effect on state or trait anxiety in the Spielberger's State-Trait Anxiety Inventory (STAI) with theta and delta,²⁶ and another found no effect with state anxiety with the STAI or tension/anxiety with the Profile of Mood States (POMS) but did find a difference with trait anxiety on the STAI with mostly delta stimulation.³⁰ A third study that compared alpha to beta stimulation found significant effects in personal competence with alpha and emotional exhaustion with beta but not other measurements using the Maslach's Burnout Inventory (MBI).²⁸ The study that had the most success began at 30 Hz and ramped the frequency down until the subject was relaxed for 15 minutes and then administered 8 to 14 Hz for 7 minutes and found beneficial effects with 75% of the outcomes (POMS, STAI, Observer Rating Inventory [ORI] and the Stanford Stress Questionnaire [SSQ]) used to measure long-term

stress.³¹ Among these studies, there was no benefit for subjects experiencing more stress or anxiety than for the healthy adults.

Pain

The 2 studies that examined the effects of either photic or auditory stimulation on pain showed beneficial effects with BWE (Table 3).^{32,33} In a study of 40 patients ready to undergo their second esophagogastroduodenoscopy, 20 patients who received 9 Hz of photic stimulation during surgery were compared to 20 patients whose goggles were turned off. The experimental group had lower pain scores than controls, and 18 out of 20 who received photic stimulation experienced considerably less pain in comparison to their previous esophagogastroduodenoscopy.³² Another study used subjects with bruxism and myofascial pain dysfunction syndrome who were given isochronic tones of constant frequency and duration that were adjusted and selected by the patient and electromyographic (EMG) feedback. Subjects experienced significantly less temporal mandibular joint pain and muscle spasms at the end of the 3-week period.³³

Headaches and Migraines

Of the 3 studies that examined the effects of entrainment on migraines or headaches, 1 tested the ability of photic stimulation to prevent migraines, and the other 2 used photic stimulation as a treatment (Table 4). In a study that treated subjects with frequent migraines at 30 Hz over 30 days, 44% of subjects and 53% of those who normally had preceding warning signs had a decreased frequency of migraines.³⁴ A separate study stimulated subjects with sinusitis or acute, chronic, or migraine headaches with 1 to 3 Hz of photic stimulation for 5 minutes. Most people with acute (14 out of 15) and chronic (5 out of 6) headaches experienced complete relief, but those with sinusitis and migraine headaches had no relief.³⁵ Closer testing of 4 patients with chronic muscle contraction

TABLE 3 Pain*

Study	n & previous symptoms	Study design	Stimulation (Photic/Aud/AVE)	Hz	Duration of session	Length of treatment	Effect	Proportion of significant positive outcomes
Nomura, 2006	40 adult patients getting a 2nd esophagogastroduodenoscopy E: 20, C: 20	Randomized; E vs C	Photic stim vs goggles with no light	9 Hz	10 min before endoscopy until a few min after ended	Single session	Experimental group had a significantly smaller amount of pain than controls. Number of subjects who experienced decreased pain compared to 1st esophagogastroduodenoscopy was significantly higher in experimental subjects than controls.	1/1
Manns, 1981	14 adult patients with <1 yr of bruxism and myofascial pain-dysfunction syndrome	Pre-post	Combined Aud, IT and EMG feedback	Constant freq selected by patient	3 stages: 15 min auditory stim, 15 min in 1 ear auditory stim, other ear EMG	Avg 14 sessions, 5/wk	Reduced TMJ pain, reduced muscle spasm in 5 measured areas in head and neck	12/12
Manns, 1981	19 adult patients with >1 yr of bruxism and myofascial pain-dysfunction syndrome	Pre-post	Combined Aud, IT and EMG feedback	Constant freq selected by patient	3 stages: 15 min auditory stim, 15 min in 1 ear auditory stim, other ear EMG	Avg 14 sessions, 5/wk	Reduced TMJ pain, reduced muscle spasm in 5 measured areas in head and neck, except for temporal muscle spasm on the left	11/12

*E indicates experimental; C, control; Aud, auditory; M, mean; SD, standard deviation; SEM, standard error of the mean; NS, not significant; L, left; R, right; Hz, hertz; IT, isochronic tones; TMJ, temporomandibular joint; EMG, electromyography.

headaches, using a variety of more stringent controls, confirmed these findings.⁴⁵ In a third study, 7 subjects with migraines were given red LED goggles and allowed to choose a frequency from 0.5 to 50 Hz, which they used for 5 to 60 minutes upon the occurrence of migraines. Forty-nine of 50 migraine headaches were relieved, 36 were completely stopped, and the median duration of migraines decreased from 6 hours to 35 minutes.³⁶

Mood

Three studies examined mood with auditory stimulation using binaural beats in healthy adults. One study compared beta to theta/delta stimulation over a single session and found that as measured by the POMS, confusion/bewilderment and fatigue/inertia increased and vigor/activity decreased with both session types, and depression/dejection increased with theta/delta but decreased with beta.²⁴ A second study used 1-hour sessions that began at 10 Hz and progressively dropped to 2.5 Hz for 60 days and found no effect with depression.³⁰ In a small double-blind cross-over study, 4 adults were stimulated at 7

Hz for a single session, and as measured by the POMS, total mood disturbance was not affected, but there was an increase in depression score.²⁰ None of the protocols used in these 3 studies was specifically designed or hypothesized to ameliorate depression.

Behavior

One study tested the ability of photic stimulation to positively influence behavior in school-aged children with ADHD over multiple sessions.²¹ It used the Achenbach Child Behavior Checklist to measure both the parental and child assessment of behavioral change before and after 15 sessions of photic stimulation at 12 to 14 Hz, which was gradually withdrawn in cases vs controls. Both the parental assessment and the child's self-assessment of the child's behavior improved by approximately 70%.²¹

Premenstrual Syndrome

One study found significant relief of PMS symptoms in women with severe and long-standing PMS with daily photic stimulation at

TABLE 4 Headaches/Migraines*

Study	n & previous symptoms	Study design	Stimulation (Photic/Aud/AVE)	Hz	Duration of session	Length of treatment	Effect	Positive finding? (Y or N)
Noton, 2000	55 adult subjects with migraines	Pre vs post	Photic	Photic stim: 30 Hz, with left eye illuminated, R eye in dark, and then reverse using monochromatic red light	15 min	Every day for 30 days	Frequency decreased for 44%, increased for 7% Frequency decreased for 53% of those with preceding warning signs (ie, auras)	Y for prevention
Solomon, 1985	28 adult subjects, 15 with acute, 6 with chronic muscle contraction headaches, 3 with sinusitis, 4 with migraine	Pre vs post	Photic	1-3 Hz, option to have eyes open or closed	5 min	Single session	14/15 subjects experienced complete relief with acute muscle contraction headaches, 5/6 with chronic muscle contraction headaches, and 0/3 had relief with headaches associated with sinusitis, and 0/4 had relief with migraines	Acute & muscle: Y Chronic muscle: Y Sinusitis: N Migraine: N
Solomon, 1985	4 adult subjects with chronic muscle contraction headache Treated 2-3x	Pre vs post for E vs C	Photic vs ambient light on/off or glasses on/off	1-3 Hz, option to have eyes open or closed 1st time: with glasses on, ambient light off 2nd time: 2 subjects with glasses off, ambient light on 3rd time: All 4 subjects: glasses on, ambient light on	5 min	Single session	4/4 experienced relief for chronic muscle contraction headache, with entrainment; 0/6 controls experienced relief	Chronic muscle: Y
Anderson, 1997	7 adult patients, 50 migraines total	Pre vs post	Photic	Red LEDs in goggles, alternating L & R at 0.5-50 Hz (patients reported use in higher freqs), eyes closed Use upon symptoms, patients asked to adjust frequency and intensity for comfort	Median duration 30 min (range 5-60 min)	Single session	49/50 migraines were helped; 36/50 migraines were stopped: median duration of migraine changed from 6 hrs to 35 min	Y

*E indicates experimental; C, control; L, left; R, right; LED, light-emitting diode; Y, yes; N, no.

the flicker fusion point (the point at which flicker is no longer seen) for 3 menstrual cycles. A luteal score was calculated based on the addition of each subject's 6 most prominent symptoms and recorded each of the 6 days prior to menses. The median luteal score dropped 64% by the second cycle and 76% by completion. Each luteal symptom, including depression, anxiety, affective lability, irritability, difficulty concentrating, fatigue, change in appetite, breast tenderness, and bloating decreased, and there was a trend toward a reduction in social withdrawal. Only 1 person out of 50 did not show improvement.³⁷

Analysis by Brainwave Entrainment Frequency

To determine whether specific outcomes were associated with specific frequencies, we also grouped studies by frequency or pattern of frequency stimulation. Out of 4 outcomes that were exam-

ined with delta stimulation, only headaches/migraines³⁵ and short-term stress²⁷ improved but not long-term stress^{26,30} or mood.^{23,30} Theta was examined in conjunction with 2 outcome-study groups and yet showed no benefit for cognitive functioning,²⁰ mood,²⁰ or relieving stress.²⁶ A single session of alpha stimulation relieved stress for the employees of the addiction care facility²⁸ but not for subjects undergoing a root canal,²⁹ suggesting that the effectiveness of alpha could be based on the type of stress exposure. Alpha also appeared to relieve pain³² and improve personal competence using the MBI.²⁸ Trigram recognition was also most effective at alpha in 2 separate adult populations.^{16,24} Beta appeared to improve attention,^{21,23} overall intelligence,^{21,25} short-term stress,²⁸ headaches,³⁴ and behavioral problems²¹ and to relieve emotional exhaustion.²⁸ It had no effect on nonverbal intelligence²¹ and

TABLE 5 Mood*

Study	n & previous symptoms	Study design	Stimulation (Photic/Aud/AVE)	Hz	Duration of session	Length of treatment	Effect	Proportion of significant positive outcomes
Lane, 1998	29 healthy adults	Double-blind crossover; E1 vs E2	Aud, BB	Pink noise with BB or simple tones in beta (16-24 Hz) or theta/delta (1.5-4 Hz) through stereo headphones	30 min	Single session	Comparing theta/delta to beta: Using POMS, confusion/bewilderment increased, fatigue/inertia increased, depression/rejection increased.	0/6
Wahbeh, 2007a	8 healthy adults	Pre vs post	Aud, BB with overlaying sounds of rain and bells	Starts at 10 Hz, decreases incrementally, staying at 2.5 Hz for 40 min	60 min	60 sessions over 60 days	No effect with depression using BDI, total mood disturbance with POMS, or with depression using POMS	0/8
Wahbeh, 2007b	4 healthy adults	Randomized double-blind crossover; E vs C	BB	E: 7 Hz with sound of rain C: sound of rain only	30 min	Single session	No effect with total mood disturbance using POMS. Increase in depression in experimental condition using POMS	0/7

*POMS indicates Profile of Mood States; BDI, Beck Depression Inventory.

mood.²³ The alpha/beta protocol improved verbal skills and helped with attention,¹⁹ and in another study that used beta and gamma stimulation, it showed beneficial effects with arithmetic skills in children with learning disabilities and/or ADHD.²²

CONCLUSIONS

Seventeen of the studies were developed to confirm or challenge a hypothesis that a specific frequency or protocol would have a beneficial effect on a specific outcome. Two studies generally explored the response of subjects to stimulation at specific frequencies. Another study that compared the outcome of beta to theta stimulation hypothesized a beneficial effect of beta stimulation on vigilance, but no hypothesis was made with regard to mood.²³ Of the studies with specific hypotheses, there were positive findings in the 1 group that examined verbal skills, 4 out of 4 groups with attention, 2 out of 2 with memory, 2 out of 2 with overall intelligence and achievement, 3 out of 3 with pain, 3 out of 3 with migraines, 1 out of 1 with PMS, with the 1 study that examined behavioral problems, and the 2 studies that used theta/delta stimulation out of the 4 that examined short-term stress. Although beta stimulation was not effective for nonverbal skills, findings from 1 study suggest that the use of gamma alternating with beta may enhance nonverbal performance skills.²² Findings regarding long-term stress/burnout were more mixed, but a beneficial finding by Howard et al³¹ suggests that their protocol that began at 30 Hz and was lowered until the subject was relaxed for 15 minutes

and then used 8 to 14 Hz for 7 minutes might be worth further investigation. Specific protocols that used either delta and theta,²³ theta alone,²⁰ mostly delta,³⁰ or beta²³ were ineffective in elevating mood in healthy adults, but there may be other protocols that help relieve depression in subjects diagnosed with depression.

The immediate psychological effects of memory, attention, stress, pain, and headaches/migraines were shown to benefit from even a single session of BWE. Many practitioners and developers of BWE tools believe that repeated exposure to BWE will allow the user to enter the desired brain states unassisted. Indeed, the study by Patrick,²¹ which found improvements in overall intelligence and behavior, gradually withdrew the stimulus until users could produce the targeted brainwave frequencies on their own. Most studies that examined long-term effects did not withdraw stimulus over a specified time period before testing, so the duration of the effects are unclear. Nor are there studies that compare the effects of duration or frequency of stimulation, so it is not known whether there is a minimal length or frequency of entrainment required to achieve each positive outcome or if there is a limit to the intensity of symptom relief from BWE.

Most studies used photic stimulation. However, there need to be more studies to address the effectiveness of auditory stimulation, given that it is so widely used because of its convenience. Further studies are needed to compare the effects of auditory, photic, and AVE stimulation at the same frequencies for each outcome and to compare the clinical benefits of monaural, binaural,

TABLE 6 Behavior*

Study	n & previous symptoms	Study design	Stimulation (Photic/Aud/AVE)	Hz	Duration of session	Length of treatment	Effect	Proportion of significant positive outcomes
Carter & Russell, 1993 Group 1	14 LD children	Pre vs post	AVE, BB	2 min 10 Hz/1 min 0 Hz/2 min 18 Hz	25 min	80 sessions over 8 wks	Significant improvement from excessive anxiety, excessive dependency, poor ego strength, poor coordination, poor intellectuality, poor academics, poor attention, excessive suffering, poor anger control No improvement from excessive self-blame, excessive withdrawal, poor physical strength, poor impulse control, poor reality contact, poor sense of identity, excessive sense of persecution, excessive aggressiveness, excessive resistance, poor social conformity	9/19
Carter & Russell, 1993 Group 2	12 LD children	Pre vs post	AVE, BB	2 min 10 Hz/1 min 0 Hz/2 min 18 Hz	25 min	18 sessions over 6 wks	Significant improvement from excessive dependency, poor academics, poor attention, poor impulse control, excessive sense of persecution, excessive resistance No improvement from excessive self-blame, excessive anxiety, excessive withdrawal, poor ego strength, poor physical strength, poor coordination, poor intellectuality, poor reality contact, poor sense of identity, poor anger control, excessive aggressiveness, poor social conformity	6/19
Patrick, 1996	E: 21 C: 10 children with ADHD	Pre vs post for E vs C	Photic vs nothing	12-14 Hz	40-50 min with frequent rest	15 daily sessions, slowly withdrew stim as subjects produced more on their own	Significant improvement with CBCL-P	1/1

*E indicates experimental; C, control; Aud, auditory; AVE, audiovisual entrainment; BB, binaural beats; ADHD, attention deficit hyperactivity disorder; CBCL-P, Achenbach Child Behavior Checklist and Profiles.

and isochronic beats and the use of white noise vs music as a background. New and existing protocols based on common QEEG signatures for each disorder need to be developed and tested using standardized and validated psychological assessment methods. Since subjects' response can depend on baseline conditions,^{17,18} population characteristics, including mental health, psychological profile, QEEG, age, gender, and other baseline variables, should be specified clearly. Measurement of QEEG and relevant hormones pre- and post-stimulation would help substantiate clinical outcomes and improve our understanding of mechanism. Hormones

such as glucocorticoids and melatonin fluctuate during the day and affect arousal and thus the EEG, so time of day should be kept consistent and monitored closely. Protocols should be described more clearly so that they can be replicated. For example, when subjects are encouraged to find frequencies that make them comfortable, these specific frequencies should be reported. Studies that specifically examine the relationship between the frequency and/or length of sessions to outcomes should be conducted. And finally, larger randomized controlled trials are needed to substantiate previous studies through clinical research.

In conclusion, preliminary evidence suggests that BWE is effective in several cognitive domains and can relieve acute and long-term stress, reduce pain, headaches, migraines, and PMS and improve behavior. Research has yet to prove BWE's effectiveness for mood. Inconsistent protocols between studies were used to test each outcome. Preliminary evidence suggests that alpha stimulation was preferable for trigram recognition, short-term stress, and pain relief, whereas beta was used to enhance attention, increase overall intelligence, relieve short-term stress, and improve behavior. The alternating alpha and beta protocol was used successfully to improve behavior, verbal skills, and attention. A protocol that alternatively ascended and descended from beta to gamma enhanced arithmetic skills and attention. A protocol that alternated between 14 and 22 Hz increased overall intelligence. Several protocols, including a combination of theta and delta and a progressive slowing over 30 minutes to delta, were effective in relieving short-term stress. Migraines were prevented with a 30-Hz stimulus that alternated between left and right hemispheres, and a few studies that allowed the subject to choose the frequency of stimulation were successful in alleviating long-term stress, pain, and migraines. It is clear that more research needs to be conducted to confirm the effectiveness of specific protocols to each outcome, but given the evidence so far, we conclude that BWE is worthy of further consideration by clinicians and researchers as a therapeutic tool.

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