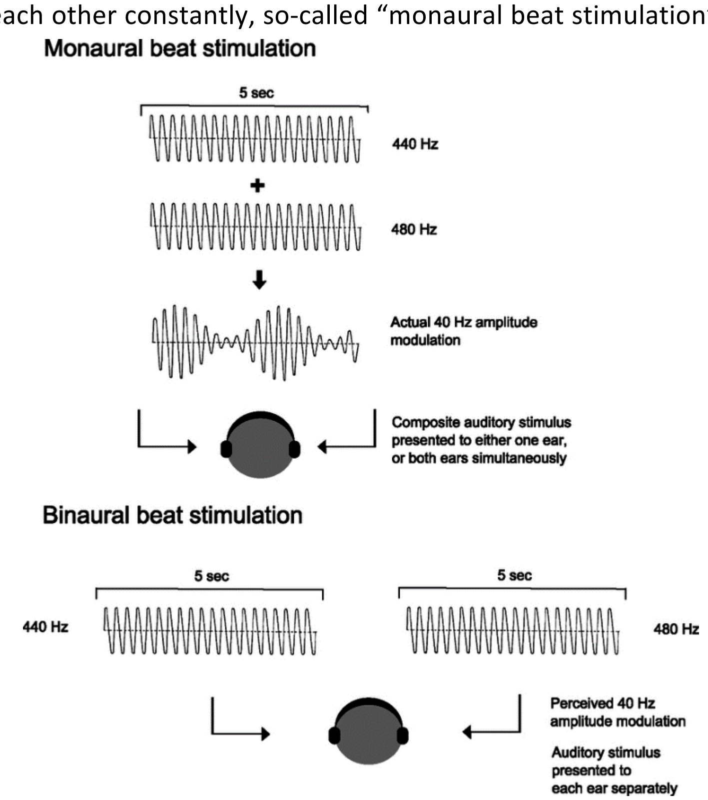
A Primer on Binaural Beats

Somadome Research Advisory Board

Introduction

Binaural beats are believed to affect the brain for purposes of modified human performance in areas of mood, attention, and perception of sensory information (including pain). Although binaural beats have been tested for decades, it can be very difficult to identify evidence-based claims among anecdotal case reports, uncited studies, and marketing materials that come up in most searches. A small number of scientific studies have been performed, including some Class I evidence with randomized clinical trials, with evidence building towards specific indications for their use. This White Paper will describe the process of brain entrainment, review evidence on binaural beats from scientific or psychological studies, discuss the limitations of existing findings and suggest questions for further research.**Binaural Beats Explained**

For you to perceive sound, waves must conduct through your inner ear (cochlea), enter your nervous system, and be received by your brain. When sound enters your body, it is transformed into electrical impulses along nerves between your ears (cochlea) and your brain. It istransmitted to your central nervous system first in your brainstem, at an area called the superior olivary complex [SOC]. It is through a complex series of interactions that begin here in the SOC that sound is "localized," allowing you to identify whether sound originates from the right side or left side of your head, based on volume differences and delay in arrival time. Competing sounds interfere with each other constantly, so-called "monaural beat stimulation" refers to the However, if you isolate each ear using headphones, and your ears are simultaneously exposed to tones at different frequencies, these tones can ceate an interference pattern that is a new frequency. Depending on the interaction, they may combine into a new sound that exists only in the convergence within the nervous system. In the original 1973 paper on binaural beats by Dr. Gerald Oster, he described a 440Hz tone in the left ear, mixed with a 434Hz tone in the right ear, yielding the detection of a 6Hz tone in the listener. This new 6Hz tone is a binaural beat (Oster 1973). A representation of this description is included below, using the combination of a 440Hz and 480Hz signals, offset to produce a 40Hz binaural beat (cited from Becher 2011):



Brainwave Basics

You may have heard the term "brainwaves" used to describe brain activity. Brainwaves are a representation of the electrical activity of the brain produced by electroencephalography (EEG). In EEG, leads are attached to the scalp that amplify the electrical impulses of neurons as sensed at the surface. The EEG generates a wave pattern that represents the summed average wave lengths of tens to hundreds of thousands of neurons (depending on the number of leads attached and the length of time data are gathered).

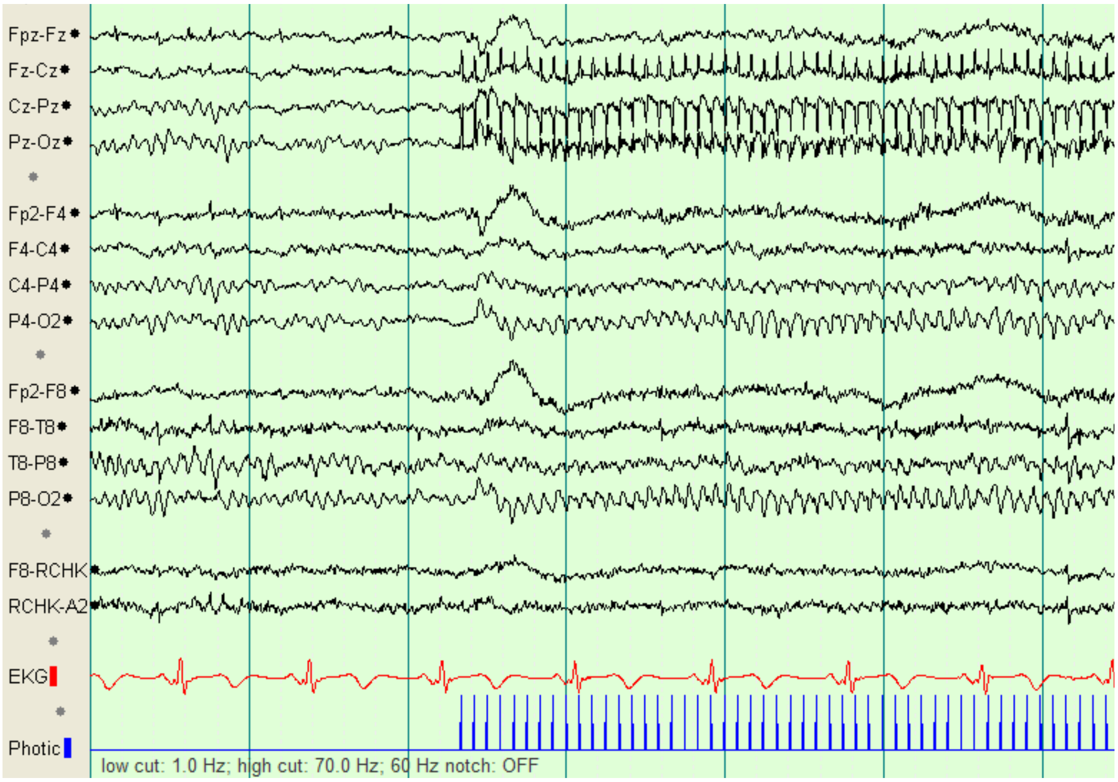
Over time, doctors have learned to associate certain brainwave frequencies with "states of mind," that is to associate measured rates with cognitive states, including attention, drowsiness, dreaming, concentration, and relaxation, as examples. There is a range of what is considered "normal brainwave function," because there is such a range of what is considered normal across the population. We call the brainwave present at rest in a person who is lying still with their eyes closed their *background,* also known as their *posterior dominant rhythm* (PDR). There is some disagreement on the fine details. However, generally speaking, when the PDR is approximately 8-12Hz, it is called *alpha* frequency range, and this range is considered a normal background in adults. Frequencies were named in the order of their discovery, rather than the order of their frequency range, so they are listed as follows:

Delta (δ) <4Hz <-- Commonly seen in slow, non-REM sleep, has a role in declarative memory
Theta (θ) = 4-7.9Hz <-- Reported in meditative states, also seen in REM sleep, euphoric states
Alpha (α) = 8-12.4Hz <-- Baseline relaxed state, also seen in REM sleep, attentive states
Beta (β) = 12.5-24.9Hz <-- Baseline waking state, also seen under the influence of anti-anxiety drugs
Gamma (γ) >25Hz <-- Bursts with site-specific utility

Entrainment: Synchronizing Brainwaves with Sensory Information

Many factors contribute to a person's brainwave state. For example, cognitive control allows an otherwise relaxed person to "think" themselves into being anxious - through the active process of memory recall, the person recruits feelings that activate a stressful response. Or, if if someone has an overactive amygdala, even at rest the person may be bombarded with feelings of fear or anger that prevent relaxation (LeDoux 2003). Sensory information from the body can also overwhelm the brain – pain is the simplest example of this.

An easy way to change brain state is to simply close your eyes; many people will switch from beta (attentive) to alpha (relaxed) with just this exercise. Your brain is powerfully affected by what you see, and brainwaves can be overpowered with a visual signal as demonstrated in the figure below. An EEG recording of an awake person is shown. Normal resting pattern is on the left, and when a bright pulse of light is shown at 13Hz (Photic: pulses at the bottom), the subject's brainwaves match the pulsing of the light. This process is known as *entrainment*, and the brainwave result is known as *photic driving*.



Research showing the effect of sound on brainwave entrainment of EEG is more difficult to reproduce than studies in the visual system for photic driving. However, reliable scientific studies have shown the effect of binaural beats in alpha, beta, and gamma ranges using scalp electrodes (Vernon 2014, Pastor 2002, Schwarz 2005). Recordings were recently published using very high-fidelity electrodes in patients with implants deep inside the brain, undergoing evaluation for epilepsy surgery (Becher 2015). This data is particularly compelling because the number and clarity of electrode recording sites is far superior in surgical studies when compared to scalp recordings, which have significant interference that may prevent studies from finding an effect.

Binaural Beats and Effect on Brain State

There is still much research to be done before we fully understand the connection between sound and brain state entrainment. However, psychological and clinical studies have shown that binaural beat exposures can affect the brain states of mood, attention, and perception of pain (Huang 2007, Chajeb 2015). In two interesting studies involving the same commercial product, binaural beat exposure was found to reduce peri-operative and post-operative pain medication, post-operative pain scores, and earlier discharge times (Dabu-Bondoc 2003, 2010). Binaural beats have been shown to reduce scores on a standardized test for anxiety, the State-Trait Anxiety Inventory (STA-I) questionnaire, in a randomized study which compared a delta-range exposure to a white-noise control under similar conditions. Those who received the delta-range binaural beat session showed a reduction in anxiety score over twice as improved compared to the placebo group (Padmanabhan 2005). Studies in anxiety have been reproduced; an

Australian hospital randomized patients in their emergency room to receive a 20-minute binaural beats track, an indistinguishable sham track, or calming white noises such as rainfall. The binaural beats track was shown to significantly reduce anxiety over both the sham track, and the white noise track (Weiland 2011). One of the more cited studies compared binaural beat exposures in beta and theta on a performance attention task for vigilance, and found that even though they had been blinded to the presence of a binaural beat exposure, people who were exposed to beta-frequency entrainment (16/24Hz) had significantly more correct target detections, and less negative mood compared to people who did the same tasks with white noise, or with theta/delta range frequencies (1.5/4Hz) (Lane 1998).

Discussion

Any discussion of the few articles presented here, and of the many others available for review online and in the lay or academic press, must conclude that binaural beats represent a reproducible interface technology with potentially important effects on the human nervous system and behavior. It is also important to discuss the limitations of studies on this technology, and consider such limitations when describing how this technology will be used.

First, there are general limitations regarding claims of EEG association with mood states – reporting of both of these measures has a degree of subjectivity, in that mood is reported by survey and thus suffers immediately from recall and observation bias. So associating even a known EEG finding with mood to establish a baseline to test the binaural beat technology against is problematic. Likewise, EEG findings are not necessarily known for reliability – for example there is often considerable inter-rater reliability for clinical diagnoses (Benbadis 2009). Thus, results that find effects on comparatively more difficult states of attention or relaxation, often used as outcomes in neuropsychological studies, must be taken with some caution. In the case of studies discussed here, some care was taken to refer to work using generalizable metrics such as standardized surveys used in the FDA approval for anxiety medication (STA-I), or using randomized placebo-controlled design.

Next, there are limitations to generalizing binaural beats across the range – just because the 9Hz binaural beat generator used for 20minutes yielded a reproducible entrainment to alpha in study subjects, does not mean that the 9Hz binaural beat generator you have downloaded will produce the same result in you. Test conditions vary, as do tone used, volume, degree of noise cancellation and sensory isolation. Most importantly, the training used to prime expectations in study subjects can have a strong impact on outcomes. Any of these factors may modify the experience, and the extent to which they affect efficacy of brain entrainment is not known. For these reasons and others, an isolated and comfortable environment with limited distractions is an important component to creating a predictable binaural beat exposure process and results.

Finally, and perhaps most importantly, binaural beats suffer from many of the same limitations as other treatments that are not yet FDA-approved, namely lack of indications for their use, and lack of a dose-response curve for efficacy. Since these do not exist, caution should be taken while interpreting any claims made regarding a specific symptom that will be treated through a binaural beats exposure. However, a sufficient amount of evidence appears to justify the claim that binaural beat exposures of approximately 20 minutes can be effective at assisting transition to states of reduced anxiety and increased attention, and may even have utility for reducing the perception of pain – it would be useful to see studies that reproduced the findings cited here. There are other, less well described but significant areas of exciting research ongoing for use of binaural beats to assist in reducing insomnia, for improving performance in cognitive behavioral therapy sessions when used as an adjuvant to traditional psychotherapy.

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