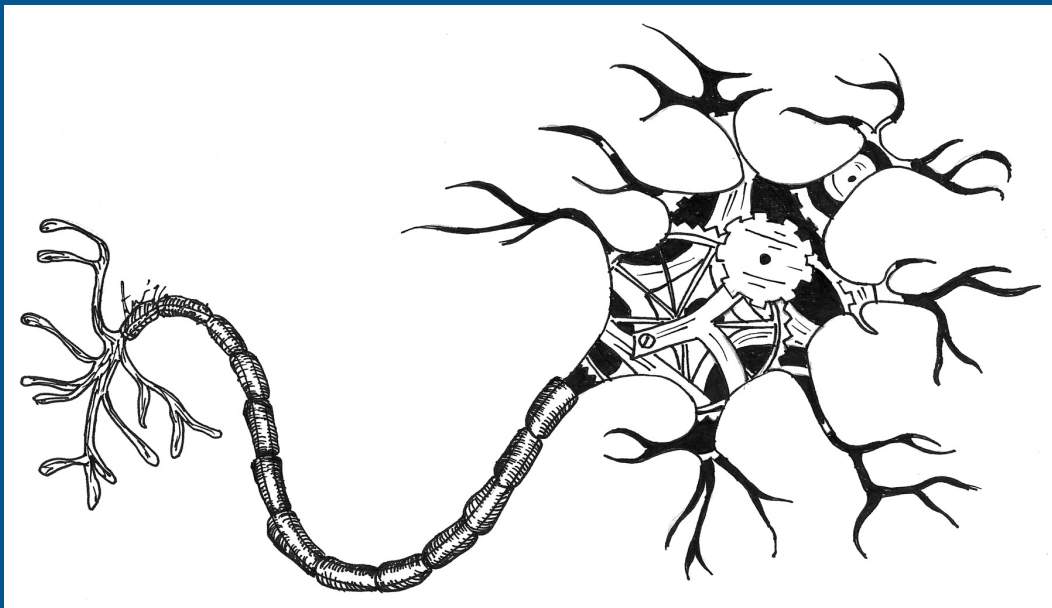


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therapy and cognitive enhancement

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Introduction to Sound and Beat Frequencies

By its simplest definition, sound waves are waves of molecule vibration that pass through matter. As sound waves with identical displacement converge, they create constructive interference, therefore doubling the amplitude of displacement (see figure 1). Conversely, when two waves with opposite displacement converge, they create destructive interference, canceling the displacement of each wave and reducing their amplitude to near zero (Kinsler, Frey, 1999). When two pure tones of different frequencies continuously converge, pulses are created over the original tones that sound like beats to the auditory system (figure 1). These perceived beats are called monaural beats because they occur before reaching the auditory system and may be perceived by one ear (Schwarz, et al., 2005). Very specific monaural beat frequencies can be created depending on the difference in frequency between each tone. For example, a pure tone of 454 hertz played simultaneously with a pure tone of 461 hertz will produce beats with a frequency of seven hertz (Oster, 1973).

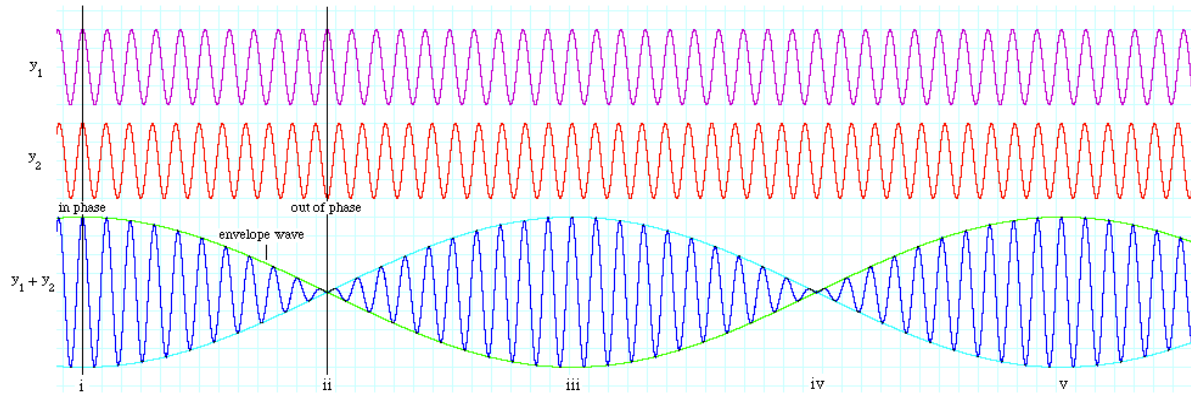


Figure 1. A sin wave (the bottom wave) resulting from the top two sin waves converging. At point *i* the top and bottom waves are in phase causing their amplitudes to sum and therefore double. The top wave has a higher frequency causing them to move out of phase over time. Point *ii* shows the result of the two waves interfering when in completely opposite phase and canceling each other out. The in phase portions of the resulting sin wave, seen at points *i*, *iii*, and *v*, create the beat that auditory system perceives. The out of phase portions of the sin wave, seen at point *ii* and *iv*, are the lack of sound between the beats. Figure 1 from (UNSW School of Physics, 2016).

Introduction to Binaural Auditory Beats

In 1839, German experimenter, H.W. Dove discovered that a person could detect beats when each ear was presented with a different tone simultaneously (Oster, 1973). More recently, it has been demonstrated that these beats are created by the olivary nucleus in the brain stem, which perceives the difference between the two tones and creates the beat frequency that people can hear. This phenomenon is known as binaural auditory beats (BAB) and is unique from monaural beats because the beat frequency is manifested within the brain as opposed to manifested in the air by physical interference of sound waves (Lane, et al., 1998). For many years, the discovery of BABs went unnoticed until the entraining frequency following response was discovered. By using specific frequencies in each ear, presented through headphones, the resulting beat frequency was found to influence the electrical signaling in the brain and induce difference levels of consciousness depending on the frequency (Foster, et al., 1990).

Introduction to States of Consciousness

Specific states of consciousness are shown to correlate with specific electrical signaling patterns in the cortex (McMurray, 2004). One who is focused and alert will often exhibit frequencies between 12 and 24 Hz, known as beta waves (Kennerly, n.d.). One who is relaxed and receptive to information exhibits frequencies between 7 and 11 Hz, known as alpha waves. One who is in a meditative state or on the cusp of falling asleep, will exhibit frequencies between 4 and 6 Hz called theta waves. One who is sleeping will exhibit very low waves, less than 4 Hz, called delta waves (McMurray, 2004) and (Klimesch, et al., 1994). These waves are evident when recording brain electrical activity with an electroencephalogram (EEG). They have been documented in people with normal cognitive function, but are not evident in people with cognitive disability (El-Sayed, et al., 2002). Some studies suggest that people diagnosed with attention deficit disorder (ADHD) experience electrical signals with lower frequency in the frontal lobe mostly falling in the theta band. This has been hypothesized as contributing to the common symptom of inattention in people with ADHD (El-Sayed, et al., 2002).

Binaural Auditory Beat Hybrid System for Therapy

Many treatments have been developed to alleviate the symptoms of ADHD, including Ritalin and Adderall. However, the side effects of such drugs are often undesirable and parents are often concerned about the long-term effects of continuous medication (Schonwald, et al., 2006). The discovery of the entraining frequency following response has led to the initial stages of BAB testing, as BAB would hopefully serve as an alternative method for alleviating symptoms of inattention. Multiple studies have suggested a correlation between exposure to BAB with beta wave frequency and mood elevation (McMurray, 2004). One study measured the

effects of beta wave BABs on activity in the frontal cortex and on the ability to focus in people diagnosed with ADHD using EEG recording. In addition, researchers measured attention through multiple Continuous Performance Tests. Each participant went through five different phases of testing, including the performance of focusing tasks without any music, with music, and with BAB hidden underneath music (McMurray, 2004). The researchers found significant results that people with ADHD show improved ability concentrate after listening to beta-frequency BABs (McMurray, 2004).

Binaural Auditory Beats as a Cognitive Enhancement

As academic competition and expectation levels rise in most western countries, many high school and college students who have not been diagnosed with ADHD are inclined to use drugs such as Ritalin and Adderall to enhance their cognitive ability (DeSantis & Webb, 2008). This is dangerous considering that research of the effects of these drugs on individuals without ADHD has not been conducted and therefore, the negative and long-term effects are unknown (DeSantis & Webb, 2008). BABs are also being used as a cognitive enhancement to induce desired states of consciousness in people with normal cognitive ability and have become more popular in students wanting improved ability to focus (DesMarais, 2013).

Independent research has been done on using BABs as a cognitive enhancement. One study focused on the effect of alpha waves on working memory capacity (Kraus, 2015). The study used 40 college students and compared a control versus an experimental group on an operation span task, which required participants to remember series of letters while doing simple math problems. The study found significant improvement of working memory capacity for participants listening to the BABs (Kraus, 2015). Another study measured the difference in

attention and mood when people were listening to beta versus theta/delta frequencies. Results showed a significantly enhanced attention in participants listening to beta frequencies than theta frequencies as well as a reduction in negative mood associated with beta frequencies (Lane, et al., 1998).

The results from Lane et al, (1998) and Kraus (2015) studies promise the possibility of using BABs as an alternative therapy for people with ADHD and as a cognitive enhancement. Using BABs as a therapy or as an enhancement is far less expensive than most medications (ConsumerReportsHealth, 2012) and (Brain Sync, 2016). In addition, it is generally more comfortable for people who can avoid the negative side effects of most medication (ConsumerReportsHealth, 2012). Finally, although BABs may have their own dangers, they sidestep the unknown dangers of taking medication without a prescription (Brain Sync Faq, 2016). The downside of BABs is that they require the full use of both ears, which interferes with one's ability to hear other sounds in their environment (Oster, 1973). One other potential negative effect, which I have experienced from my own use of BABs but has no scientific supporting evidence, could be a learned dependency to BABs, causing difficulty in individuals who must focus without BAB. Future research should aim to determine whether or not this is a serious issue.

Future Directions

Future directions could lead to an irreversible hybrid technology that consists of BAB and bone conduction technology. Bone conduction headphones would be permanently attached to skull, thus allowing individuals to have the benefits of different induced states of consciousness without interfering with their ability to hear and communicate with others (Oster,

1973). If BABs does become an irreversible hybrid system, people will have the capacity to control their states of consciousness at anytime. This would enable BABs to be used a cognitive enhancement and as a therapy for many cognitive disorders. Articles and websites postulate that binaural beats could greatly contribute to the future of medicine as a therapy for depression, insomnia, attention disorders and more (Rice, 2016), (McMurray, 2004) and (Kennel, et al., 2008).

I have abided by the Wheaton College Honor Code in this work.

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