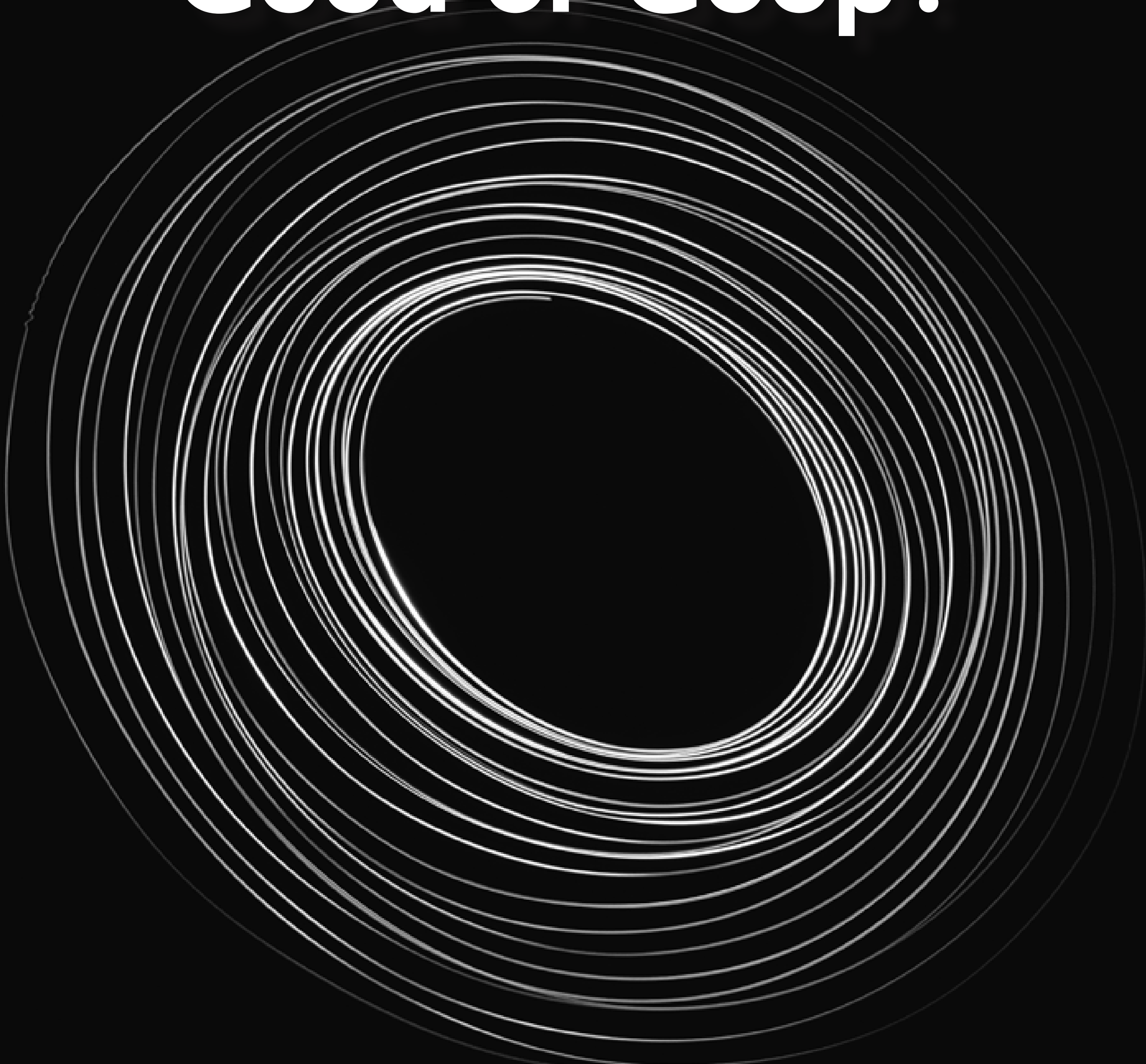
Binaural Beats: Good or Goop?



By Sari Wagner

"A circular shape created using light painting" by Subhrajyoti07. Image from Wikimedia Commons (CC BY 4.0).

Have you ever been tempted to buy adaptogen-spiked sparkling sodas? Gummies that promise to make period pain go away? Even supposedly-aphrodisiac candles? I have (and honestly, the period gummies are life-changing)! We live in an age of product saturation of every kind. You can have your pick of items that promise to heal you in every imaginable way, such as those made famous courtesy of Gwyneth Paltrow and her mega-brand Goop. Snake oil salesmen have been around since the dawn of capitalism, and today they take a new yoga-doing, coffee-enema getting, incense-burning,form. The monetization of the health industry and health products means we all are constantly toggling between roles as consumers and patients, and we're treated as both by companies that simultaneously promise to help us and sell us something.

No sector of the American health, wellness, and medical industries escapes this problem. Classical western medicine is often expensive, tends to treat symptoms as opposed to root cause, and has a documented history of discrimination against various marginalized groups. Alternative medicine is incredibly broad, often not as rigorously supported as western medicine, and can also be expensive. The wellness industries tend to capitalize on perfectionist tendencies by encouraging us to become ever more "healthy" by dubious, and once again expensive, means. Today, American patients are forced to choose between various imperfect and expensive options, leaving us all with a difficult, complicated decision. But some remedies escape this predicament. Enter: binaural beats.

A Free and Effective Therapuetic Tool?

Binaural beats are a unique auditory illusion created by playing two different sound frequencies in each ear. Instead of perceiving both sounds simultaneously, the brain combines the two sounds to create a third, illusory pitch, which is the sound we perceive when we listen to binaural beats [1],[2]. The frequency of the illusory pitch is the difference between the two tones played in each ear. For example, if your left ear received a 130 Hz pitch and your right ear received a 150 Hz pitch, you would perceive a 20 Hz pitch. These frequencies must differ between 1 and about 30 Hz in order for the illusion to work, and are most effective when the frequencies themselves are below 1000 Hz– especially between 450 and 500 Hz. We also perceive this pitch to waver in volume, increasing and decreasing at a constant rate, creating a "beating" effect [3],[4],[5],[6].

Really, the best way to understand binaural beats is to listen to them, which you can easily do by typing "binaural beats" into YouTube. There, you'll find hundreds of examples of binaural beats recordings, all accessible for free, often with overlaid pink noise or meditative music to keep the persistent buzz of the beat itself from becoming annoying. But what makes binaural beats so special?

It has been suggested that the illusory waves we perceive when we listen to binaural beats can actually have an effect on brain waves. The illusory wave that we perceive when we listen to binaural beats might have the power to synchronize the frequency of your own brain waves to its frequency. This is especially true when the beats are played for at least 8 minutes straight [7],[8]. But the vital detail here is that the frequencies of these brain waves aren't arbitrary: it's been known for a while that certain brainwave frequencies are associated with certain cognitive states. So, by influencing the predominance of a particular category of wave, binaural beats might be able to also induce a certain cognitive state. But what are these categories of

Figure 1. *Created using Biorender. Listening to two similar frequencies, one in each ear can create an illusion called a binaural beat. This beat can influence your own brain waves, "syncing" them to the frequency of the beat.*

waves, and what do they do?

Brainwaves and Cognitive States: Measuring Levels of Consciousness

Just as the visual color spectrum categorizes color by wavelength – with, say, 380-430 nm representing the color violet—the frequency of electrical brain waves can also be measured. Brain waves are measurements of the electric impulses that allow neurons to communicate with each other. They are generally organized by frequency into five categories: delta, theta, alpha, beta, and gamma waves, and each of these wave types is associated with a specific cognitive state[9].

First, there's Delta, which refers to waves with a frequency between 0.1-4 Hz, and is considered indicative of the most relaxed state. Researchers often refer to this wave type when discussing sleep: a predominance of delta waves is common during the deepest sleep phase (non-REM stage 3, if you're curious!). They are the dominant brain waves in infants and, when seen in awake adults, can indicate a head trauma.

Next, there are Theta waves, which are second to delta in terms of reflecting a relaxed state. They are waves with a frequency between 4-8 Hz, and they typically indicate a state of deep relaxation or drowsiness. They are also common during meditation. Theta waves are also indicative of light sleep (that of non-rem stages 1 and 2), as opposed to the deep sleep of delta waves. Theta is also sometimes associated with creativity, as it tends to suggest a disengaged, daydreamy cognitive state, in which a variety of ideas can flow without critique. The last breakthrough you had in the shower might be associated with this kind of theta-creativity!

In the middle of the arousal spectrum are alpha waves: representing frequencies between 8-13 Hz, these waves are associated with a relaxed, almost hypnotic focus. This state is not quite as unregulated as that associated with theta waves, and not quite as conscious as that associated with beta waves (the next-highest state of arousal). Although alpha waves do appear to be involved in cognition and focus, they are also associated with a calmer, restful mental state. It's even been found that increased alpha wave activity decreases symptoms of depression.

In contrast to alpha waves, beta waves reflect a more aroused, conscious state. Beta waves have a frequency between 13-30 Hz, and are associated with active problem solving and directed focus. Beta waves appear to be involved in facilitating working memory and are associated with conscious cognitive work. Interestingly, they are also present specifically during REM sleep, which is characterized by brainwaves similar to those that occur in the waking brain.

Finally, the most aroused state of brain activation is typically indicated by Gamma waves. Representing any frequencies higher than 30 Hz, Gamma waves are associated with peak concentration and high level cognitive functioning and information processing. Gamma waves are also associated with various memory processes, including working memory retrieval, and short and long term memory retrieval. They also seem to play a vital role in the binding of sensory information to create a unified conscious experience. An abundance of Gamma waves can be associated with anxiety and stress, while a lack of Gamma waves can be associated with ADHD and depression.

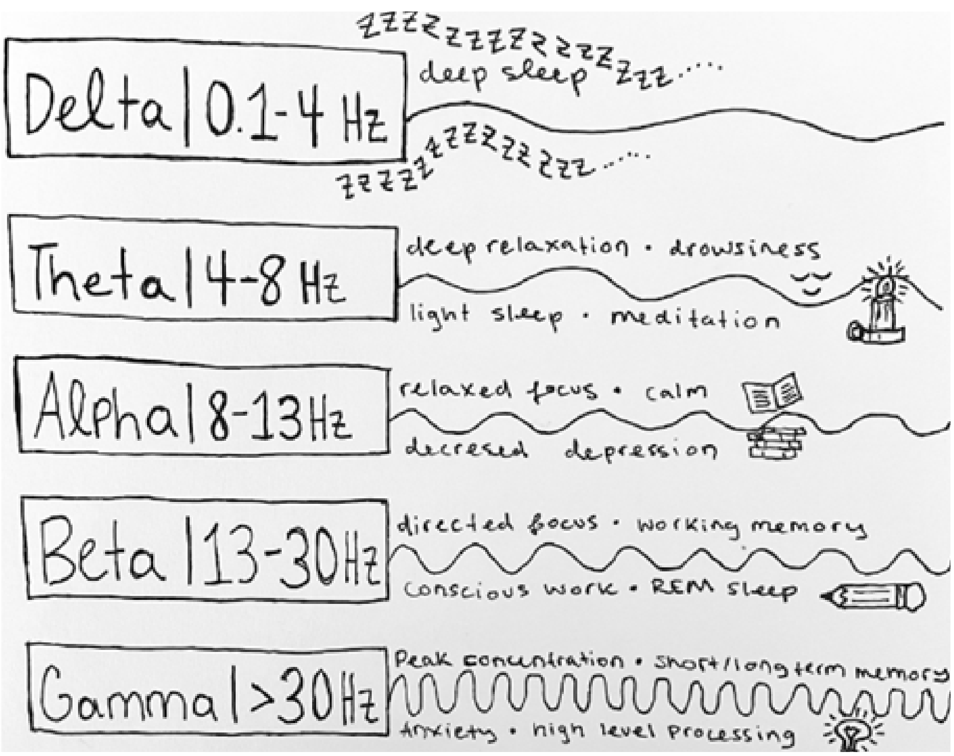


Figure 2. *Different brain frequencies are associated with different cognitive states.*

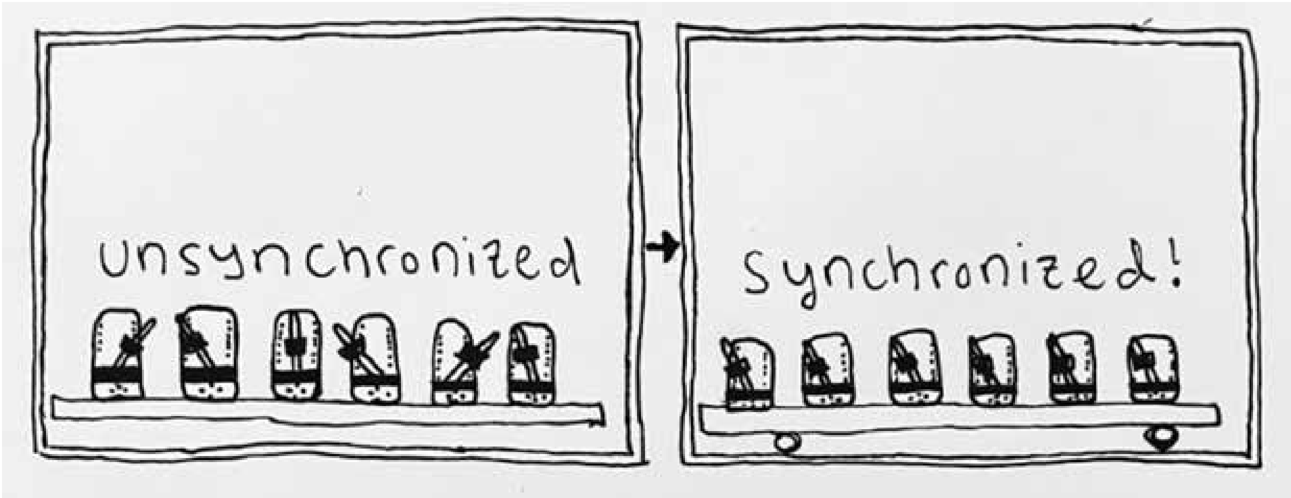


Figure 3. *When weakly coupled, an group of ossiclating units (like metronomes!) will slowly begin to sync to the same oscillation frequencies.*

Theoretically, by syncing your brainwaves to a specific binaural beat corresponding with one of these wave bands, you could induce the state associated with that wave. But how does this "syncing" actually work, and why are binaural beats uniquely able to do this?

Brain as a Metronome: How do Binaural Beats Work

Binaural beat frequency syncing is thought to occur through the power of spontaneous synchronization: a physics concept describing a phenomenon in which a population of oscillating units, moving at a variety of frequencies and in weak interaction with each other, will eventually all adopt the same oscillation frequency. So, for example, if you placed several metronomes on a shared surface, and set them so each was moving at a different frequency, eventually, all of the metronomes would sync to move at the same rhythm. The same thing is thought to happen with binaural beats: when the two frequencies are played simultaneously and separately in each ear, they are first processed monaurally (meaning, the sound information from each individual ear is processed separately) through the usual sound processing pathways. In the same way that each of our eyes takes in and processes its own information, only for that information to be combined– this combination is what gives us depth perception– our ears perform a similar process. Each ear processes sound individually (monaurally!) but the signals from each brain eventually meet at a structure called the superior olivary nucleus, deep in the midbrain. The signals from each ear meet here, and become a (bi)naural signal. But something else happens once those monaural signals are finally integrated in the superior olivary nucleus: something called a frequency-following response begins to occur [10],[16].

It's worth noting that the binaural signals typically processed by the superior olivary nucleus are used by the brain to locate a sound in space. In everyday life, you encounter binaural sounds all the time: when a siren sounds from your left, your left ear is going to hear a slightly different version of that sound than your right ear, due to your ears being located at different distances from the sound and one ear being obstructed by your head. Your brain uses the difference between the sounds received by each ear to "calculate" the location of the sound– and, because it does this using information from both ears, this is called a binaural cue. Binaural information is always processed first in the superior olivary nucleus, and is then sent on to the inferior colliculus and thalamus, where the information is further processed and made sense of. However, compared to the kinds of binaural cues our brains are used to, binaural beats are unique: they aren't fleeting, and they aren't quickly changing sounds indicating a sound moving around us. Instead, they are constant, unmoving binaural stimuli– not a stimuli the brain necessarily evolved to deal with. And so, when introduced to the brain, it's perhaps not that surprising that it responds to these "unexpected"

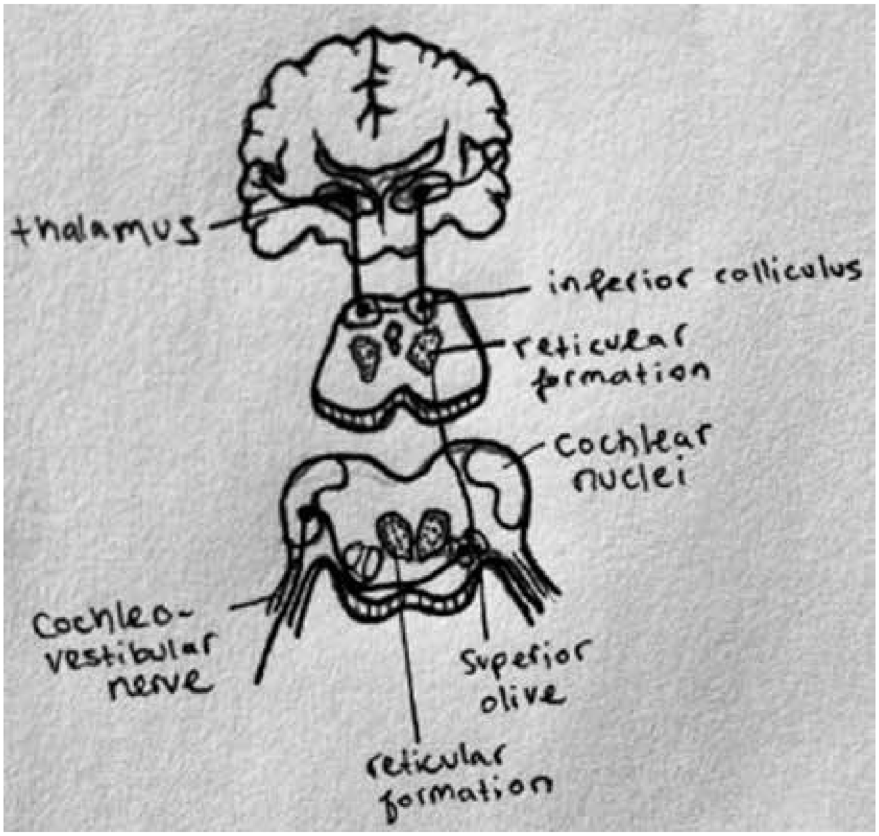


Figure 4. *The primary-sound processing pathway.*

stimuli in unexpected ways[12].

The current theory on the mechanism of binaural beats is that, once the monaural cues reach the superior olivary nucleus and are processed binaurally as an illusory wave, that wave initiates a "frequency-following response" in the reticular formation. This response can be measured by EEG, although the signal created by this response is likely not strong enough to account for the cognitive changes attributed to binaural beats. These cognitive changes are most likely caused by the beats' activation of the nearby reticular formation, which projects throughout the brain to play a vital role in stimulating/dampening arousal in the brain. It is thought that lower-frequency binaural beats propagating to the reticular formation might thus induce lower-arousal states, like those usually associated with delta and theta waves, while higher-frequency beats might induce higher-arousal states like those associated with alpha, beta, and gamma waves, via the reticular formation. Thus, by propagating to the reticular formation, binaural beats of various neurologically important frequencies might be able to induce a specific state of arousal [6],[17].

Tubes and Tuning Forks: H.W. Dove, Robert Monroe & Sound as Therapy

The idea that a simple buzzing sound could have an effect on the way you think– maybe even your behavior– seems so far-fetched that it's hard to imagine how this illusion and its effects could possibly have been discovered. Maybe it makes sense, then, that the history of research on binaural beats is almost as crazy as the beats themselves. Binaural beats were first discovered by a German scientist named Heinrich Wilhelm Dove in 1839, long before the invention of headphones or earbuds. How is this possible?

Instead of using headphones, Dove used tubes: he'd set a subject up in a room, with one tube attached to their left ear, and another attached to their right, and then play a tuning fork into the end of each tube.The forks would play slightly different sounds, and Dove found that his subjects did not report hearing both pitches—instead, they heard one slow-wave, low pitch. This was the first time a binaural beat had ever been reported, and Dove's discovery would be contested by others who claimed that the tuning forks' sound wasn't being fully monaurally administered. A century later, however, the invention of headphones confirmed Dove's illusion [12],[18].

In the 1970s, not long after the popularization of headphones for music, binaural beats began to be examined anew. This also isn't so surprising: I'm not sure you could have paid me to use tuning fork-tube-binaural beats, even if they were proven to be good for me. Imagine walking around with that contraption strapped to your head! Thankfully, by the 70s, tubes and tuning forks were no longer necessary. Two researchers pioneered this new age of research: the first was Gerald Oster, a physicist who published his investigation of binaural beats in Scientific American in 1973. The second was Robert Monroe, a former Ohio state pre-med grad and hobo (yes, hobo: he hitchhiked on cargo trains for a year after college) turned radio broadcaster who became fascinated by the science of sound, also in the 70s. Monroe used his resources as the founder of the Jefferson cable corporation to create a research and development arm of his radio company, composed of a group of hired scientists from various fields. Especially important was F. Holmes Atwater, a former army scientist who published much of the group's early work.

Both Oster and Monroe outlined theories and made several discoveries that continue to be referred to and investigated in the research on binaural beats today. Oster, working in the early 70s, actually never investigated binaural beats' brainwave-syncing power, and instead wrote about the auditory illusion itself, and how perception of it can actually vary from person to person. One particularly interesting finding was that people with certain neurological conditions, or women either at the beginning of menstruation or at ovulation, vary in their ability to perceive and respond to binaural beats. There is also an overall gender difference in the ability to process the beats. Oster suggested that estrogen levels may actually modulate binaural beat perception, such that low estrogen levels would decrease the likelihood of beat perception. This is now consistent with more recent research finding that estrogen does play a role in hearing, and, in general, high levels are protective against hearing loss. Given that binaural beats are such low frequencies, and, in most research, are played almost undetectably amidst carrier music (this allows a control condition to be indistinguishable), it makes sense that subtle variations in hearing ability would be significant [12].

One of Monroe and Atwater's most important contributions was their theory about how binaural beats create their effects. In 1997, Atwater published a paper summarizing his group's findings, and suggested for the first time that binaural beats might create their effects through interaction with the extended reticular-thalamic activating system (ERTAS), as I described above [17]. Until that point, almost no one had attempted to articulate the mechanism underlying binaural beats, and this theory persists today as the prevailing theory.

Of course, today's research looks a lot different from that conducted by Oster and Monroe in the 70s, 80s, and 90s, not least because our headphones today are more sophisticated. As binaural beats become more popular among the public, researchers have caught up by conducting a variety of studies investigating the various purported benefits of binaural beats.

One particularly interesting recent study, published in 2013 in the journal, Frontiers of Human Neuroscience, investigated binaural beats' effect on various measures of creativity [19]. They measured the effects of alpha and gamma binaural beats on participants, and also used eye-blink-rates as a proxy for levels of dopamine– a neurotransmitter associated with creativity. They found that, in those with low eye-blink rates (indicating low dopamine), the alpha binaural beats significantly increased measures of creativity, while in those with high eye-blink rates (indicating already high dopamine), the binaural beats did not make a significant difference. This affirms the idea, first put forward by Atwater, that binaural beats may have a varied effect on individuals depending on a variety of factors.

Another review study from 2019 looked collectively at the effects of binaural beats on memory, attention, anxiety, and pain perception [20]. They found binaural beats to have a significant effect on all of these variables, increasing measures of memory and attention and decreasing measures of anxiety and pain perception. The authors also listed several other variables that seemed to have an effect on the strength of results. First, masking binaural beats with white or pink noise did not have an effect on the strength of results. Second, beats exposure before or before and during a task made a bigger difference than exposure only during the task. And third, a longer period of exposure to the beats seemed to create a stronger effect than shorter periods of exposure. Overall, the authors concluded that binaural beats can have a significant effect on several aspects of cognition, including attention and memory.

What Don't We Know About Binural Beats?

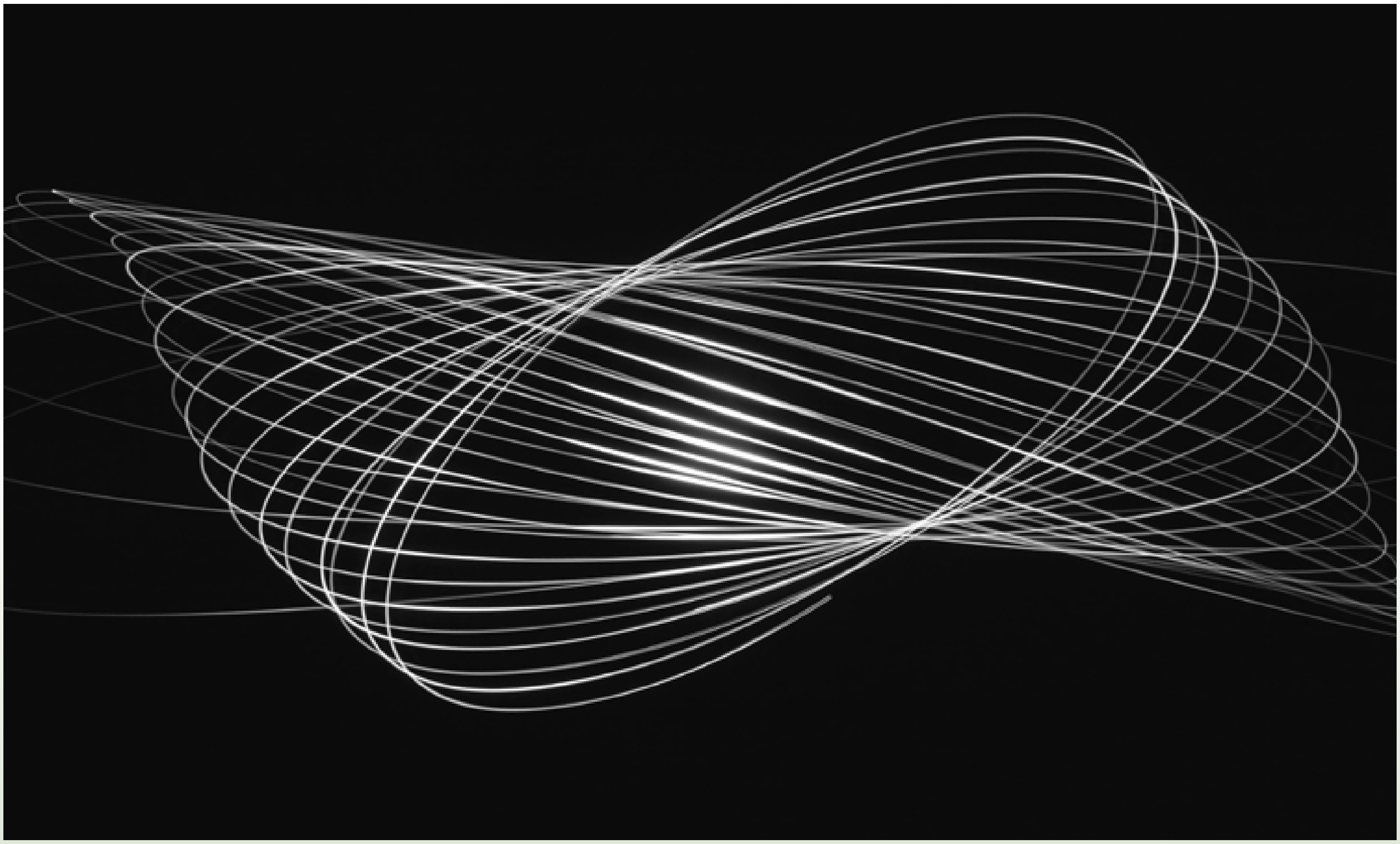
Despite this research, there is still so much that isn't known about binaural beats and how they work. Arguably, there is more that we don't know about binaural beats than we do. For one thing, the current theory on the mechanism through which binaural beats create cognitive effects is just that: a theory. It is only proposed, and only a few studies have attempted to confirm it. Currently, most studies of binaural beats have exclusively looked at the behavioral effects of the beats, not the mechanisms creating those effects.

But even these behavioral studies are methodologically in-consistent: some set binaural beats against "carrier" music (like pink noise or nature sounds), some only play the beats for short periods and others play them for longer periods, and finally, the idea that binaural beats might affect different people differently has rarely been taken into account in studies of binaural beats. Despite this inconsistency, a significant number of these studies have found binaural beats to create real cognitive and behavioral effects, suggesting that further research is needed.

In general, a more consistent methodology across binaural beat behavioral studies, and more studies using this methodology, is strongly needed. And, more research investigating the proposed mechanism/pathway through which binaural beats create their cognitive and behavioral effects will also be a vital part of uncovering the fascinating and important effects of these unique sounds.

While it is true that research isn't yet totally clear on binaural beats, that doesn't mean they're not worth studying. Even if BBs are not necessarily effective for the purposes many youtube videos suggest–"align your chakras" "serotonin release" "inner peace" are some frequent title buzzwords--they are a complicated phenomenon that have the potential to reveal important information about our auditory system. In his 1973 Scientific American paper, Gerald Oster actually proposes binaural beats as a tool for researching the auditory system: the enhancement of the beats by noise is a model of the mechanism by which auditory messages are sorted from a noisy background. That sub - threshold sounds are effectively rendered audible by binaural beats suggests that there may be other stimuli processed by the brain of which we are not aware. Finally, it is possible that hormonally induced physiological or behavioral changes too subtle to detect by ordinary means may be made apparent by measuring the binaural beat spectrum"[12].

Besides these potential uses in research, current studies have suggested that binaural beats can be effective for cognitive enhancement. If the parameters of this effectiveness were more rigorously defined– that is, if it was better understood how BBs are best used, by who, and how/whether each of the wave types create different cognitive effects–these beats could represent a free and effective intervention available to anyone with internet connection, a phone, and earbuds. In a world where profit rules just about everything, from western pharmaceutical medicine to the wellness world, binaural beats are priceless (literally).



"A shape created using light painting" by Subhrajyoti07. Image from Wikimedia Commons (CC BY 4.0).

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