Health Implications of Binaural Auditory Beat (BAB): Its Perils and Applications

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Abstract

Binaural Auditory Beat (BAB) is known to induce frequency-specific health effects. Theta frequency BAB, for instance, triggers a meditative state whereas alpha frequency BAB may function as an anxiolytic. Findings upon BAB exposure demonstrate mixed results and thus require further academic investigation, for the beneficial effect of a BAB in question may become detrimental if applied inappropriately. There are, unfortunately, hundreds of publicly available commercial BABs (C-BABs) today that are neither scientifically verified nor clinically safe. Virtually anyone can construct/distribute any kinds of BAB mixes at any given time via freely available BAB generators. This means customers may be exposed to unknown or even prematurely released C-BAB, not to mention that its neurophysiological mechanism is not yet fully understood. Considering a dearth of research and a pile of anecdotal reports on its side effects, C-BAB customers are exposing themselves to medically unrecognized health risks. The health effects of C-BABs will be reviewed and the perils of its clinical implementation and recreational applications will be discussed.

Keywords: Binaural Auditory Beat, Brain entrainment, I-doser, Auditory medication

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The simultaneous presentation of two pure sinusoidal tones with slightly different frequencies, f_1 and f_2 , causes the perception of a third tone with a midpoint frequency between f_1 and f_2 . This perceptual phenomenon is called Binaural Auditory Beat (BAB). The frequency of BAB is identical to the frequency difference of two pure tones. Thus, if 495Hz tone is present in the left ear and 505Hz tone present in the right ear concurrently, the perceiver will hear 500Hz tone with the amplitude oscillating in a frequency of 10Hz. Although the 10Hz tone itself is beyond the human hearing range, amplitude modulation of 10Hz is audible in the form of BAB (Moore, 2012). This is known as an illusory tone, as there is no external stimulus corresponding to the perceived frequency, f_3 . The perception of f_3 is rather a product of neural processing of two different dichotic tones.

Studies have shown that the frequency difference of pure tones f_1 and f_2 must be lower than 35Hz for the BAB phenomenon to occur (Perrott & Nelson, 1969) and the optimal frequency for f_1 and f_2 is around 400~500Hz (Oster, 1973), although BAB phenomena can occur at any given audible frequency. Theoretically, this means we can construct a customized BAB with amplitude modulation of anywhere between 0 and 35Hz. As it turns out, exposure to a specific BAB induces corresponding health outcomes. Beta-frequency BAB (13~32Hz), for example, is related to less negative mood, enhanced attention and vigilance performance (Lane et al., 1998), as well as long-term memory (Garcia-Argibay et al., 2017). Studies have also shown that the BAB exposure reduces anxiety levels and the perception of pain (Garcia-Argibay et al., 2019), and theta-frequency BAB (4~8Hz) induces a meditative state (Jirakittayakorn & Wongsawat, 2017).

Given these established findings on the effects of BAB, it is odd to notice that the commercial use of BAB has been criticized for its baseless or rather pseudo-scientific premise that it is possible to induce a certain mental state by the systematic arrangement of BAB sequences (Wahbeh et al., 2007). I-Doser is both an application and the name of a company that distributes a set of purchasable BABs, some of them named after recreational drugs. Let us call these commercial binaural beats as C-BABs, to distinguish them from noncommercial binaural beats, BABs. One of the key differences between them is that a single C-BAB audio file usually contains multiple BABs present either simultaneously or successively in a pre-sequenced manner. For instance, BAB used in the study conducted by Jirakittayakorn & Wongsawat (2017) was 6Hz BAB on a 250Hz carrier tone. Participants were exposed to this single BAB for 30 minutes. A typical C-BAB, by contrast, may (1) start from 24Hz (beta-frequency) binaural beat on 400Hz carrier tone, (2) slow down to 2Hz (delta-frequency) binaural beat on 200Hz carrier tone, (3) end with 10Hz (alpha-frequency) binaural beat on 1300Hz carrier tone. Hence C-BABs are both *structurally* and *audiographically* more complex than a single BAB.

Unfortunately, research on commercially available BAB is extremely scarce; perhaps this is why the scientific community tends to be skeptical about its health impact. However, as we will see, there is plenty of experimental research on the effects of BAB. Therefore, if BAB can be used to improve psychophysical health in experimental settings, *and* if C-BAB is simply a compiled version of multiple BABs, it does not make sense that C-BAB all of sudden loses its efficacy. Rather this claim *itself* is the object of investigation. The only reason C-BAB is not scientifically well-grounded is that this topic has not been scientifically investigated yet. In this research review paper, the mechanism and health impacts of BAB will be discussed. Then we will shift our attention to C-BABs and their potential applications as well as their perils. Based

on previous findings, this review paper will discuss both the clinical implementation of BABs and the necessity of further academic investigation upon the safety of recreational usage of C-BABs.

Preliminary discussion: Mechanism of BAB and Brain Entrainment Theory

A binaural beat is composed of two pure tones, f_1 and f_2 , with slightly different frequencies. Both f_1 and f_2 undergo constructive and destructive interference processes to produce a third, illusory tone. The resulting frequency, f_3 , is equal to $(f_1+f_2)/2\text{Hz}$ with an amplitude modulation of $|f_1-f_2|\text{Hz}$. The BAB phenomenon occurs in the inferior colliculus and the superior olivary complex (Draganova et al., 2008) in which the sensory integration of dichotic auditory stimuli takes place. The perception of f_3 itself is both acoustically and audio-physiologically not abnormal given that this is a result of audio interference. The next question is: How does it *affect* the brain?

Prolonged exposure to BAB induces a neurophysiological phenomenon called the brainwave entrainment. According to the Brainwave Entrainment Theory (BET), the mammalian brain has a natural capacity to synchronize its brainwave to the rhythm of external stimuli (Llinas, 2014). Neural oscillation is the result of electromagnetic fluctuation originated by hundreds of synchronous neural firings. When this neural oscillation is visualized via electroencephalographic representation, we call it *the brainwave*. A typical brainwave is composed of frequency, amplitude, and phase. Modern electroencephalographic studies have, moreover, shown that a specific brainwave is linked to a specific activity and/or levels of consciousness. For example, delta waves (0.1~3.99Hz) are associated with stage 3 of NREM sleep (Iber et al., 2007), theta waves (4~7.99Hz) with hippocampal memory formation (Lega et

al., 2012), alpha waves (8-12.99Hz) with relaxation and beta waves (13~32Hz) with alertness and arousal (Padmanabhan et al., 2005).

If the brainwave is the effect, neurochemical activities are the cause. But is this causality reversible? According to BET, neural oscillation is not fixed. Rather, it can synchronize to the rhythm of periodic external stimulus (Will & Berg, 2007). This means the “frequency of the binaural beat can thus be selected to produce particular EEG-associated states.” (Padmanabhan et al., 2005, p. 874) Such synchronization has been confirmed by a number of studies including Huang & Charyton (2008) and Karino et al. (2004). Given that the mechanism of BAB is explicable via the BET, we can conclude that C-BAB is also based on the brain entrainment phenomenon that has been scientifically confirmed.

Health Implications of BAB in experimental settings

The induction of neural synchronization via BAB has a number of health implications. Padmanabhan et al. (2005) has shown, for instance, that preoperative anxiety can be significantly reduced by exposing patients to binaural beats. In this study, participants were randomly divided into three groups: (1) the Binaural group received audio embedded with BAB in amplitude modulation of 10Hz, (2) the Audio group received audio without any BAB and (3) control group with no intervention. Given that alpha brainwave corresponds to relaxation, researchers applied alpha frequency BAB upon the binaural group. The measured State-Trait Anxiety Inventory (STAI) score revealed that the binaural group experienced the least preoperative anxiety, suggesting that clinical brain entrainment via BAB application may function as anxiolytic (Padmanabhan et al., 2005).

Research has discovered that theta-frequency BAB can be used to induce a meditative state and improve sleep quality. Jirakittayakorn & Wongsawat (2017) for example observed that

exposing subjects to 10 min. of 6Hz BAB on a 250Hz carrier tone can induce a meditative state, enhancing theta waves in the frontal and parietal-central region similar to a meditative state. The induction of theta-frequency synchronization via BAB can thereby produce meditation-related health effects including stress reduction and relaxation. BAB, likewise, can be used to induce sleep (Lee et al., 2019). Based on the assumption that 6Hz theta-frequency corresponds to the brainwave of the stage 1 NREM sleep, Lee et al. (2019) applied 6Hz BAB to participants. The obtained EEG data along with self-reported emotions demonstrated that the application of 6Hz BAB *reduces* beta activity and thereby reduces the arousal level. They also concluded that, although BAB alone can lead to negative emotions, mixing BAB sequences with autonomous sensory meridian response (ASMR) audio may help promote psychological stability.

Negative emotions associated with BAB mentioned in Lee et al. (2019) may be a frequency-specific phenomenon. Although some participants reported negative emotions upon the presentation of theta wave BAB, a study conducted by Lane et al. (1998) suggests that the application of BAB in the beta-frequency range can enhance psychomotor performance and improves mood. In fact, this study demonstrates that both *the suppression of theta EEG activity* and *the promotion of beta EEG activity* leads to improved mood and vigilance performance. This implies that a desired emotional state may be inducible by applying the BAB with an appropriate amplitude modulation frequency. Thus, both studies by Lee et al. (2019) and Lane et al. (1998) are compatible in that BABs with different EEG frequencies may result in different emotional states. Therefore, a type of mood inducible by a specific BAB may be determined by the type of frequency the binaural beat in question has.

Discussion on C-BAB: Its perils and a dearth of research

A few studies demonstrate the positive efficacy of C-BAB concerning psychophysical health. Le Scouarnec et al. (2001) used a commercial version of BAB in the delta/theta range to examine its anxiolytic efficacy. Patients with mild anxiety disorders were exposed to this 30 min. long C-BAB for one month. The consequential STAI score indicates that appropriate use of C-BAB can significantly reduce anxiety (Le Scouarnec et al., 2001). Padmanabhan et al. (2005) mention as well about how the application of C-BAB can be more effective in controlling preoperative anxiety compared to the experimental BAB used in the research. Given that a typical C-BAB is constructed via a set of independent BABs, the observation that C-BAB seems to display similar health effects as BABs is not only possible but also reasonable.

The only problem is that (1) there are thousands of C-BABs available worldwide, and that (2) there is not a single C-BAB that has been thoroughly investigated within a scientific community. Not surprisingly, this is a serious issue. As we have seen, while some BABs do have positive health effects, some BABs may have side effects. In fact, the same positive health effects may at the same time be negative health effects if used inappropriately.

Suppose beta-frequency BAB increases arousal. Suppose further that there is a C-BAB called “Narcotic” which claims to help the user to fall asleep. When C-BAB is purchased, what the user receives is a single wave file with a set of pre-sequenced BABs. Oftentimes users do not fully know whether that particular C-BAB will induce what it claims to induce—not to mention that most users are not knowledgeable about BABs in question. If, for instance,

there is a beta-frequency BAB contained in the purchased C-BAB instead of delta-frequency BAB, it will increase arousal and therefore worsen the sleep quality.

Current research on BABs is not enough to provide conclusive answer on the health impact of C-BABs. This is because each BAB sequence seems to be associated with a specific mental state. The outcome of each BAB is, in other words, unique and unpredictable unless its effect is experimentally known. Clarifying and examining the efficacy of C-BAB is a difficult task since there are a number of variables to consider. Some of these are (1) Carrier tone frequency, (2) carrier tone amplitude, (3) BAB frequency, (4) exposure duration, (5) exposure frequency, (6) exposure time of the day, (7) presence of distraction, (8) prior experience of BAB exposure, (9) presence of a non-BAB audio sample (ex. river sound) over a particular BAB in question, (10) the order/type of BABs which the user is exposed to, et cetera. Here (1)~(9) apply both to BAB and C-BAB, whereas (10) is exclusively applied to C-BAB. The difficulty of C-BAB research lies specifically upon this particular variable. Because C-BAB is a mixture of multiple BABs, there are literally *infinite possible* combinations of variables that we can conceive of. For example, suppose that a particular C-BAB is composed of two independent BABs with the following characteristics:

BAB1: 500Hz carrier tone played for 10 minutes in 30dB with an amplitude modulation of 5Hz (theta-frequency).

BAB2: 1200Hz carrier tone played for 7 minutes in 10dB with an amplitude modulation of 10Hz (alpha-frequency).

The user of this C-BAB will first listen to BAB1 for 10 minutes and BAB2 for 7 minutes. A typical C-BAB can have a customized transition time starting from 1 second. Supposing that

each element of a set $P=\{\mathbf{n}, \mathbf{m}, \mathbf{p}, \mathbf{q}, \mathbf{r}, \mathbf{s}\}$ represents random positive integers, we can generalize that, for a random binaural beat $BAB_{\mathbf{n}}$, it is defined as the following.

$BAB_{\mathbf{n}}$: $\mathbf{m}$ Hz carrier tone (where $20000 > \mathbf{m} > 20$) played for $\mathbf{p}$ minutes in $\mathbf{q}$ dB with amplitude modulation of $\mathbf{r}$ Hz with $\mathbf{s}$ seconds of transition to $BAB_{\mathbf{n}+1}$.

There is a multitude of variables even in a single BAB. Because customized C-BAB can sometimes have more than 50 BABs present in a single wave file, the controlled experiment of C-BAB is expected to be difficult. Indeed, we do not yet fully understand the health impact of any given BAB combination. There are infinite kinds of constructible BAB sequences. If, however, only a few BAB combinations can be studied one at a time, the cost-efficiency of BAB research is fundamentally questionable. This leads to the issue that we are dealing with today: There are hundreds of scientifically unverified C-BABs sold to customers that may have unknown health effects. Although there is accumulated research on BABs, this is insufficient to confirm the safety of a given C-BAB. There are, for example, numerous anecdotal reports on side effects of premium C-BABs where symptoms range from vomit, nausea, hallucination all the way to hearing impairment and psychomotor dysfunction (Musiek et al., 2012). Hence, while BABs in experimental settings can be relatively safe, the health effect of C-BAB is not well-understood.

Future research on BAB and C-BAB: Its necessity and direction

Currently, open-source BAB generators are freely available. C-BAB can be constructed via a GPL-licensed BAB generator called SBaGen. This means, with SBaGen, virtually anyone can produce any BABs similar to C-BAB as long as the corresponding recipe of the target C-BAB is provided. Although a detailed exposition of C-BAB construction is beyond the scope of this paper, this point implies that both the distribution of unknown C-BAB and BAB misuse

can lead to irreversible health consequences. Since many customers are exposed to scientifically and medically unexamined C-BAB, relevant research is urgently required.

Meta-analysis has illustrated that the magnitude of a given BAB effect is largely dependent upon the BAB frequency and exposure time (Garcia-Argibay et al., 2019). As Le Scouarnec et al. (2001) has demonstrated, the efficacy of BAB seems to be enhanced with frequent exposure over an extended period of time. This explains the experimental result of Crespo et al. (2013) in which C-BAB is used as a target stimulus. While these researchers concluded that a specific C-BAB believed to improve concentration is not as effective as hypothesized, it must be pointed out that the efficacy of both BAB and C-BAB are determined by the frequency of BAB exposure. Because participants in this study were exposed to C-BAB only for 20 minutes, no significant improvements were observed in concentration ability. This result is therefore consistent with what the meta-analysis suggests because the study by Crespo et al. (2013) has not manipulated BAB exposure amount/duration that are as important as BAB exposure itself (Garcia-Argibay et al., 2019). Hence, future research on the efficacy of BAB must take account of all relevant variables that contribute to the brain entrainment phenomena.

Studying C-BAB is more challenging than studying a single BAB. A good starting point may be to select a C-BAB that is both (1) powerful enough to observe relevant effects and (2) widely known to be effective among users. The second point is extremely important because, as mentioned above, there is no single experimental research on C-BAB that conclusively demonstrates the health efficacy of a specific C-BAB. While there are numerous C-BAB customers worldwide, the relevant C-BAB research is scarce. This means researchers should rely upon anecdotal reviews and *thereupon* select appropriate C-BAB suitable for the purpose of a study.

For example, customers can purchase a premium C-BAB from the I-Doser application called “Gates of Hades/Premium (Unexplainable).” This notoriously painful 30 min. C-BAB is made up of four independent BABs of differing delta-frequency amplitude modulation and is widely known to cause intense feelings, hallucinations, and anxiety. There is one common claim about this C-BAB found in hundreds of reviewers: “Don’t do it” (Toaster032, 2010). Hence, instead of investigating C-BAB which targets mild health outcomes, C-BAB that aims to elicit intense emotional experience could be studied in priority, as it is more urgently required and, if lucky, may gain more academic attention.

Conclusion

Binaural auditory beat (BAB) is a consequence of the brain entrainment phenomenon which allows the brain to synchronize to the presented BAB frequency. Research has shown that BAB can be used as an anxiolytic (Padmanabhan et al., 2005), vigilance performance and memory enhancer (Lane et al., 1998; Garcia-Argibay et al., 2017), and even as an anti-insomnia stimulus (Lee et al., 2019) that can induce meditative states (Jirakittayakorn & Wongsawat, 2017). This opens up the possibility of BAB application in clinical settings. While there are studies indicating that BAB either could not achieve what it claims to achieve or failed to produce positive psychophysical effects (Crespo et al., 2013; Lee et al., 2019), these cases can be explained by (1) a failure to control relevant variables that contribute to the BAB efficacy, and (2) recognizing that the health effect of BAB is frequency-specific.

The BAB research is in its infancy. But there are commercially available BABs (C-BABs) already in the market. The problem is that most, if not all, C-BABs are scientifically unverified and thus users are exposed to unknown health risks. There are numerous anecdotal reports indicating that some C-BABs induce intense experiences and long-lasting side effects.

While the systematic C-BAB study is challenging due to the number of variables that can be controlled, it is necessary to investigate and confirm the psychophysical safety of specific C-BAB usage. For a conclusive answer, we need a set of thorough experimental research upon the health impact of C-BAB in a specific frequency range and thereupon build the “frequency map” as in DNA mapping of the Human Genome Project. Since each mixture of BAB sequences targets unique psychophysical outcomes, a frequency-specific C-BAB study will be quasiessential for the prospective BAB research.

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