Dosage and Lasting Effects of Binaural Beats on Working Memory and Attention.

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ABSTRACT

Binaural beats have been hypothesized as a potential tool for creating cognitive stimulation for over a hundred years (Peterson, J. 1916). When two slightly different tones are played simultaneously in each our brains synchronize the two into one tone. The resulting tone can stimulate certain brain areas and either increase or decrease their functioning. The objective of this research was to determine the overall efficacy, lasting effect, and dosage needed of binaural beats stimulation for the purposes of increasing focus and working memory. A systematic review was conducted using the PRISMA method, where 23 peer-reviewed studies were examined relating to binaural beats stimulation specifically for the purposes of assessing attention and memory networks. Forty Hertz binaural beats are the most effective for increasing focus and attention, however the methodology applied is significantly connected with results, where the minimum dosage needs to be at least nine minutes. Further, longer exposure correlates with an increased effect. Carrier tones should be played at a frequency that is comfortable and perceivable (90 and 440 Hz). Timing of binaural beats stimulation should be applied either before or before and during any proposed cognitive task. Playing binaural beats stimulation during the cognitive task alone may index their effect. Because this is a novel topic, deductive reasoning was applied to render results. Future studies should examine the topic of dosage and lasting effect concerning binaural beats stimulation to access the full breadth of their effectiveness on attention and working memory networks.

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CHAPTER ONE

OVERVIEW OF THE STUDY

Binaural Beats is a specific kind of sound that when listened to can enhance a person's creative ability, focus, memory, as well as mood (Reedijk, Bolders, & Hommel, 2013; Colzato, Barone, Sellaro, & Hommel, 2017, p. 275; Kraus & Porubanová, 2015, p. 142; Chaieb, Wilpert, Rever, & eFell, 2015, p. 5). Binaural Beats ("bi"-*two*, "aural"- *relating to the ear)*, are a combination of two closely related frequencies played in each ear. When the human brain receives input from both the frequencies, it synchronizes them through a process called entrainment. For example, when frequency (a) is played at 500 hertz in the left ear, and frequency (b) is played at 514 hertz in the right ear; the brain will synchronize the frequencies at 14 hertz, which is the difference between the two. The result of this process is the synchronization of multiple groups of neurons across different parts of the brain, resulting in brain waves (Reedijk, Bolders & Hommel, 2013). The brain emits waves when a large number of neurons fire together in a synchronized manner; these brain waves can be recorded as Delta (0.9–3.5 Hertz), Theta (3.5–7 Hertz), Alpha (7–14/15 Hertz), Beta (14/15–28 Hertz) and Gamma (28–56 Hertz)(Jaiswalet al., 2019); each of which has a particular frequency and function. For example, Alpha waves range between 7-14 or 15 hertz, and are emitted when we are in a restful and conscious state.

Researchers have attempted to determine the potential application of binaural beats stimulation, and have found many significant correlations of improvement related to attention/focus (Shekar, Suryavanshi, & Nayak, 2018), working memory (Kraus and Porubanová, 2015), alleviating anxiety, promoting a dreamless sleep, increases in alertness, orientation, increased mood (Chaieb, Wilpert, Rever, & eFell, 2015), increased vigilance (Citaldi, 2018), increased multitasking (Hommel et al., 2016), and decreased reaction time (Shekar, Suryavanshi, & Nayak, 2018).

There does seem to be promise regarding the potential benefits of binaural beats stimulation on these various areas, however there does not seem to be a consensus regarding the length (duration of exposure) needed to achieve these results, how long the effects of the binaural beats stimulation are expected to last, as well as which specific frequencies found to be the most effective for the desired effect. For example, it may be helpful for future research to have foundational conclusions to guide further research such as; *10 minutes of binaural beats exposure prior to testing using alpha waves (7 Hertz) and using a carrier tones of 400 Hz, followed by 10 minutes during testing, activates both the dorsal and ventral attentional networks for an average of 20 minutes.* Data such as this would be profoundly important because it could allow for cross comparisons between other studies revealing similar data, providing conclusions as to which frequency, duration of exposure, and carrier tones are needed to achieve maximum effectiveness.

In this literature review, relevant recent studies were analyzed to determine the range of cognitive benefits of various binaural beats, with a goal of determining, which frequency or frequencies are the most effective, as well as the length of effectiveness (dosage) and the duration (length) needed for beats to trigger particular brain waves related to working memory and attention. Until now, there has not been a literature review to assess the dosage and duration effect of binaural beats exclusively as it relates to the overall effectiveness of these methods.

Examination into these areas could unlock more information regarding the potential for binaural beats in various settings and applications.

Background of the Problem

In modern society, the cognitive load requirements on our focus and working memory are great (Maksimenko et al., 2018; White & Shah, 2019). We make thousands of decisions daily, and receive what some might say is a bombardment of information across a multitude of mediums. Recent studies have shown a decline in our attention span to less than that of a goldfish (Microsoft Corporation, 2015). Our focus has been turned to screens, such as tablets, smart watches, television sets, and smartphones, where recent data has concluded that the average adult spends approximately 11-hours a day (Zimmerle, 2019).

The nature and content on those devices are specifically aimed at grabbing our attention, and keeping it for as long as possible. This can put a strain on our cognitive load or the quantity of mental effort being exerted in our working memory at a given point in time. One research poll of 2,000 smartphone owners in the UK found users use their phones for tasks an average of 221 times per day, compared to an average of 140 times per day on a desktop or laptop (Tecmark, 2014).

A seminal study conducted in 1956 by George Miller at Princeton University found the average person can hold seven units of information at a time, with a normal range plus or minus two units (Miller, 1956). Research into areas of improving our ability to concentrate and focus is pivotal in preventing further cognitive decline in these areas. There are methods available to us that have been shown to increase our working memory and ability to remain focused, such as mindfulness meditation (Rahlet al., 2017), streamlined music (Mossbridge, 2016) and binaural beats stimulation. Of those methods mentioned, binaural beats will be the topic for this review because there is room for further research on how binaural beats affect attention and working memory, as well as the necessary frequency and dosage needed in order to obtain a lasting effect.

Multiple studies have supported the use of binaural beats stimulation for a multitude of reasons, ranging from post-workout recovery (Mcconnel et al., 2014) to a reduction of the negative effects associated with tinnitus (Munro & Searchfield, 2019). There currently exists room for exploration to access the dosage and lasting effects needed to achieve the various benefits of binaural beats stimulation. There are a multitude of studies related to the topic of binaural beats stimulation, which have varying results (Beauchene et al., 2016; Calomeni et al., 2017; Kalyan & Kaushal, 2016; Kraus & Porubanová, 2015; Shekar, Suryavanshi, & Nayak, 2018), leaving a void in consensus among the scientific community on which form of binaural beats (i.e. alpha waves, gamma waves) is best for maintaining or increasing concentration and working memory. Additionally, it remains unclear as to what dosage was used for those studies and any relevant measurements concerning the duration of effect post-stimulation.

Statement of the Problem

Multiple studies have demonstrated a positive correlation between binaural beat stimulation and increased working memory and focus while binaural beats are being played through headphones (Calomeni et al., 2017; Gálvez, Recuero, Canuet, & Del-Pozo, 2018; Kalyan & Kaushal, 2016; Kraus & Porubanová, 2015; Shekar, Suryavanshi, & Nayak, 2018). However, these studies have not shed light on the duration of overall effect on brainwave activity post binaural beats stimulation (Kirk, Wieghorst, Nielsen, & Staiano, 2019; Jirakittayakorn, & Wongsawat, 2017). Since there is a gap in research regarding the lasting effect of binaural beats stimulation, naturally there also exists a gap in research regarding the dosage (time of use) in which binaural beats were applied. Additionally, there exists a gap in two other areas; the timing of application and frequency of carrier tones. Timing of application is when binaural beats stimulation will be applied (i.e. before, before and during, or during testing only). Lastly, the frequency of carrier tones (the tones used to deliver the entertainment of BB) is often not included as a factor in the research methodology of much of the literature pertaining to binaural beats stimulation and attention and working memory. Although carrier tones and timing of application were not the main focus of this literature review, they are contributing factors that if present could help draw conclusions, therefore were explored.

The potential gap in research on dosage and duration of effect can have future implications if not adequately addressed. To add context to this concern, a comparison to medicine can be made. Medicine is defined as “any substance or substances used for treating disease of illness” (Medicine, n.d.) and can be applied in various forms, such as medications. Medications are prescribed in order for a recipient to receive some type of beneficial effect. If a physician prescribes medication without knowing the pharmacodynamic information concerning dosage and duration of the effects, they would be missing vital information, potentially resulting in ineffective treatment or an array of negative consequences.

Without data providing information on the dosage and duration of effect of binaural beats stimulation, future research is limited to learning only the potentialities of binaural beats while the brain is actively undergoing external stimulation. The psychological benefits of binaural beats stimulation will not be fully known and we will remain in the dark regarding the future potentialities related to which frequencies last the longest and what length of stimulation is needed to achieve the lasting effects; not to mention the spectrum of applications in which this information can be applied in the future. Furthermore, additional data concerning the carrier tones (tones used to deliver binaural beats stimulation), as well as when binaural beats stimulation are specifically applied (i.e. before testing, before and during testing, or during only) would be beneficial in order to make accurate cross-comparisons.

Lastly, there exists a gap in research concerning tailoring binaural beats stimulation specific to a person's individual frequency. Klimesh (2018), theorized there may be a binary neural oscillation hierarchy, which follows certain harmonic principles, where lower frequencies are harmonic multiples of higher frequencies. Future studies seeking to examine the most effective frequency of binaural beats stimulation and the limits to those effects may benefit from considering an individual approach, basing the desired binaural beats stimulation frequency off an existing individual frequency as a platform.

Purpose of the Study

The purpose of this study was to identify research regarding the effectiveness of binaural beats stimulation for the purposes of increasing attention and working memory. Additionally, the purpose of this study is to determine the necessary frequency and dosage needed to achieve the increase in focus and working memory and discover if an overall consensus can be found relating to the duration of cognitive stimulation (duration of effect) after the binaural beats stimulation exposure has been terminated. This systematic literature review was conducted using the Preferred Reporting Items for Systematic Reviews and Meta- Analyses (PRISMA) criteria (Moher, 2009). This method was used to answer the following research questions:

Research Question 1 (*RQ1*): What research is there supporting the effectiveness of binaural beats stimulation for the purposes of increasing attention and working memory in healthy participants?

Research Question 2 (*RQ2*): What frequency of binaural beats stimulation is best to achieve cognitive enhancing effects in areas of the brain associated with increased working memory and focus?

Research Question 3 (*RQ3*): What evidence is there regarding the dosage and lasting cognitive enhancing effect from binaural beats stimulation exposure, if so what are the boundaries of those effects.

In order to answer these questions, peer-reviewed research accessing the function and potentialities of binaural beats stimulation on humans, with an emphasis on enhancing physical, physiological, or psychological effects will be assessed. The intended goal is to identify the essential components of the journal articles related to duration, frequency, dosage, and provide conclusions to the above research questions. By highlighting areas of need for future research, the fields of neuropsychology, gerontology, neurology, audiology, psychiatry, psychology may add more focus to those areas; ultimately to serve those who struggle with maintaining focus and working-memory, such as with person's diagnosed with Attention Deficit Hyperactivity Disorder, Alzheimer's Disease, or Auditory Processing Disorder. Thereby providing them with additional resources to help them improve their quality of life.

Theoretical Framework

The theory of binaural stimulation was first proposed by Heinrich Wilhelm Dove, who discovered when two tuning forks of slightly different frequencies were sounded in each ear, a phenomenon occurred where the sounds could be perceived as one single sound (Dove, 1839). The potential benefits were further explored by Joseph Peterson in 1916, who sought to understand the nature and function of binaural beats stimulation (Peterson, 1916). From its first discovery in the 19th century, through today, binaural beats stimulation has demonstrated a multitude of applications.

The differing brain wave frequencies can be found to achieve varying results. Delta waves (0.9–3.5 Hertz), have been shown to alleviate anxiety and promote a deep dreamless sleep (Chaieb, Wilpert, Rever, & eFell, 2015; Bastek, 2018). Theta waves (3.5–7 Hertz), can increase alertness and orientation (Jirakittayakorn & Wongsawat, 2017). Alpha waves (7–14/15 Hertz) can create heightened focus and increase working memory (Shekar, Suryavanshi, & Nayak, 2018; Kraus and Porubanová, 2015). Beta waves (15–28 Hertz), have been shown to increase mood and vigilance (Chaieb, Wilpert, Rever, & eFell, 2015; Citaldi, 2018). Lastly, Gamma waves (28–56 Hertz) have shown to increase multitasking, moments of insight, and reaction time (Hommel et al., 2016; Shekar, Suryavanshi, & Nayak, 2018).

Dove's discovery of what would later be termed "entrainment" has been proven through the use of electroencephalograms, an apparatus that records brain electrical activity in the form of rhythmic oscillations which emit a frequency. These rhythms have been connected to a multitude of physiological functions (Shekar, Suryavanshi, & Nayak, 2018, p. 829).

The theoretical framework surrounding binaural beats effectiveness on various physiological functions allows for additional research to shore-up the credibility of existing research, such as effectiveness of the Mente Autism Device, which utilizes binaural beats stimulation and has been shown to aid with symptoms associated with Autism Spectrum Disorder (Carricket al., 2018). Additionally, the existing theoretical framework allows for application of existing methods using binaural beats stimulation in areas where no research exists (i.e. Alcohol Addiction), or areas of consensus are needed, such as with the dosage and lasting effects of binaural beats stimulation, which is the aim of this study.

Significance of the Study

The intent of this study is to discover a consensus that is not currently present regarding the topics of dosage and lasting effects from binaural beats stimulation, and what particular frequencies achieve the lasting effect as it relates to focus and working memory. If there is no consensus to be found among the existing research, the intent of the study is to highlight the need for future research to incorporate these topics into their areas of focus.

Current research covering the topic of binaural beat stimulation does show the various psychological and physiological benefits of binaural beats. However, incorporating the topics of dosage and lasting effect would fill a current void in research on binaural beats stimulation and act as a foundation for future research to build upon. In other words, it’s useful to know that putting gas in a car allows it to travel (proof of effect), however this knowledge is incomplete without knowing *X* amount of gas (dosage) allows you to travel *X* amount of distance (duration of effect).

Researchers who attempt to learn more about binaural beats would greatly benefit from this study because it allows them to redirect efforts into the existing research trends and incorporate factors of dosage and duration of effect into their research framework moving forward, thereby expanding upon the potential applications of their findings. If future research gave notice to these missing elements, a definitive consensus could be made regarding which frequencies provide the longest lasting effect, and the necessary dosages a person would need to be exposed to to promote a longer effect. In addition to researchers, this study can aid a multitude of people from various backgrounds who are seeking to improve their focus and working memory because it encapsulates key points from a wide body of literature on the topic of binaural beats stimulation, and provides clear applicable evidence-based methods to achieve measurable results in their daily lives.

Limitations and Delimitations of the Study

Because this was a literature review, the literature reviewed was not my own, therefore the conclusions gathered from the research reviewed was reliant upon others' methodology, data, interpretation, and results. One potential limitation was the broad spectrum of research covering binaural beats stimulation as it relates to cognitive and physiological changes, the demographics of those studies, and the methodologies used added to the difficulty in creating an overarching conclusion. Another area of limitation, was the volume of available literature covering the topics of binaural beats stimulation and focus and working memory was not robust, requiring an expansion of focus into other binaural beats stimulation research domains (i.e. Anxiety, Tinnitus, Physical Recover) in order to come to findings and conclusions. Lastly, the methods used for literature reviews, specifically qualitative systematic reviews, are still being developed; leaving room for debate about when particular methods or approaches are appropriate (Grant & Booth, 2009).

Another area of concern was the problems associated with working memory and attention, or lack thereof. The problems of working memory and focus were addressed to add context to the overall aim of this study, which was identification of potential gaps regarding dosage and lasting effects of binaural beats stimulation on attention and working memory tasks. Therefore, an exhaustive review of the various facets concerning the topic of attention and working memory was not fully explored.

The delimitations of this study were limited to the topic of binaural beat stimulation. Other methods have been shown to increase focus, such as mindfulness meditation, medications, and dietary supplements, however those topics will not be explored. Another area of delimitation the research explored was only related to the psychological and physiological benefits of binaural beats stimulation, which excluded the potential negative side effects of binaural beats stimulation.

Definitions and Key Terms

Binaural Beats. An auditory illusion that is considered a form of cognitive entrainment that operates through stimulating neural phase locking (Reedijk, Bolders, & Hommel, 2013).

Entrainment. An auditory illusion that occurs when two sinusoidal waves at slightly different frequencies are presented separately to each ear (Shekar, Suryavanshi, & Nayak, 2018).

Electroencephalogram (EEG). A neuro-metric method of recording electrical activity of the nervous system (Lubar, 1985).

Autism Mente Device. A device that reads signals from EEG, augmented in a real-time neurofeedback training in association with auditory therapy that is delivered through binaural beat sounds transmitted via earphones connected directly to the headband (Carrick et al., 2018).

Neuronal Oscillation (Brain Waves). Transient and rhythmic variations in neural activity; which are synchronized from a local neuronal population (Conolty & Knight, 2010).

Frequency (Band). Oscillations generated by active neuronal tissue often exhibit characteristic rhythms (Conolty & Knight, 2010, p. 7).

Amplitude (Envelope). The instantaneous magnitude of a complex-valued signal. Intuitively, a function that interpolates from peak to peak of an oscillatory waveform (Conolty & Knight, 2010, p. 7).

Cross Frequency Coupling (CFC). The synchronization of differing neural oscillation frequencies with a function of projecting and reflecting information across various areas of the brain (Salimpour & Anderson, 2019).

Phase Amplitude Coupling (PAC). A mechanism for information transfer through neural circuits (Poppelaars, Harrewijn, Westenberg, & Melle, 2018).

Phase. A measure of position within an entire cycle of a brainwave form (Conolty & Knight, 2010).

Organization

This project is organized into five chapters. Chapter one contains the following sections: A general overview of the function of binaural beats, it's applications for use, the current range of benefits, as well as a brief introduction of the potential gaps in research covering these applications. A section covering the background of the problem, which provides context into the environmental factors currently in place that make this study relevant, and how binaural beats stimulation can serve to improve the problems described in this section. A section discussing the statement of the problem, which addresses the potential benefits of binaural beats stimulation and highlights the current gap in research regarding dosage and lasting effects. The purpose of the study, which includes research questions and the method used to answer those questions. A section covering the theoretical framework which provides a brief historical background regarding the origins of binaural beats and the differences in brainwaves. A section regarding the significance of this study and who will be affected by the findings and conclusions therein. A section that includes the limitations and delimitations, covering the scope of this research to a particular portion of the topic of binaural beats stimulation, and information regarding what related areas to this study which will not be addressed and why. Next there is a key terminology and definitions section which serves to provide clarity to the reader for uncommon terms.

Chapter two is broken down into four sections. Section one contains an extensive review of the literature related to the overview of the study, and includes the history of the discoveries related to neural oscillations, brain wave stimulation, binaural beats, and the instrumentation used to record changes in brainwaves. Section two is a review of literature covering the topic of binaural beats stimulation for the purposes of increasing attention/focus and working memory, as well as the brain regions involved. Section three is a review of literature covering the dosage and duration of effect of binaural beats stimulation. Lastly, section four covers the theoretical framework involved in this chapter as well as a summary of the three previous sections in the chapter.

Chapter three covers the discussion on the methodology used in this research project, a section of why the PRISMA method is used for researching articles covering dosage and duration of effect for binaural beats stimulation, and why this method is appropriate compared to other methods. Chapter three also includes a section covering details of how information is gathered, what steps are taken, including the keywords and databases utilized.

Chapter four, addresses each research question in depth; covering the overall intent to discover if there is a consensus in the available literature regarding which particular dosage of binaural beats stimulation is necessary to achieve a lasting effect. Additionally, themes that present themselves during the course of this study are presented and discussed. Lastly, chapter four ends with a summary related to the answers presented to the research questions.

Chapter five covers the interpretation of the results from reviewing the various literature covering the topic of dosage and lasting effect of binaural beats stimulation. The results are then discussed, with the identification of a consensus amongst the available literature or lack thereof. After these results are analyzed, a section including the areas of potential impact this data may have in the field, and what recommendations are needed for future studies.

CHAPTER TWO

LITERATURE REVIEW

Binaural Beats Stimulation for the purposes of altering states of consciousness to achieve a desired effect has had some promising results. Several studies have demonstrated the positive effects of binaural beats stimulation and increased working memory and focus, during the course of exposure (Calomeni et al., 2017; Gálvez, Recuero, Canuet, & Del-Pozo, 2018; Kalyan & Kaushal, 2016; Kraus & Porubanová, 2015; Shekar, Suryavanshi, & Nayak, 2018). One area that needs further research is the dosage of exposure required to achieve a desired effect, as well as the duration of positive effects post-exposure. Additionally, a review of the available literature concerning binaural beats stimulation blended with music or other sounds was included to determine if there is a positive or negative impact compared to binaural beats stimulation stimulation alone.

This literature review covered research pertaining to Binaural Beats Stimulation and has been broken down into the following four categories. (1) Binaural Beats Stimulation; the origins of binaural beats stimulation, covering seminal research on brain wave manipulation and physiological changes, as well as methods of recording binaural beats stimulation in the brain. (2) Focus and Working Memory; the brain regions involved in focus and working memory, binaural beats frequencies for improving these areas, the problems associated with improper function in these areas, and commonly used test measures for those areas. (3) Literature covering the necessary dosage and duration of effect from binaural beats stimulation. (4) A summary reflecting the theoretical framework as it relates to current literature on this topic.

Binaural Beats Stimulation

In order to adequately address the literature regarding the dosage and lasting effect of binaural beats stimulation for the purposes of enhancing focus and working memory, it will first be necessary to provide context into the theory of binaural beats stimulation. This will be best done by providing some background regarding the nature of neural oscillations, the origins of binaural beats, as well as the origins and functions of the devices used to record brain waves.

The Nature of Neural Oscillations

Making sense of the theories related to neural oscillations is critical in determining their purpose and function. The brain experiences different forms of neural oscillations, and the prevailing theory is high-frequency oscillations in the brain represent local information processing, whereas low-frequency oscillations in the brain project information across larger areas of the brain by both external stimuli and internal cognitive events (Salimpour & Anderson, 2019; Canolty & Knight, 2010). These oscillations happen simultaneously, resulting in complex information transmission through the interactions between them, which is termed cross frequency coupling (Poppelaars, Harrewijn, Westenberg, & Melle, 2018; Salimpour & Anderson, 2019). Furthermore, the brain and the body both experience neural oscillations, which show identical coupling principals, which is dependent on the person's body mass, blood volume, network size in the brain, and amount of myelination, meaning each person has their own frequency structure (Klimesch, 2018).

The brain emits simultaneous oscillations from different frequency bands, these oscillations behave according to a set of biological and mathematical principles. First, differing brain waves will modulate in a particular way based-off the amplitude (envelope) between frequencies, where the slower frequency will regulate the faster frequency (Klimesch, 2018).

Second, the different frequencies will couple, where the faster frequency will be a harmonic multiple of the lower frequency (Klimesch, 2018).

Due to the nature of laws governing these oscillations, they can be arranged in what is called the *binary hierarchy brain body oscillation theory* (Klimesch, 2018). EEG frequency bands are harmonically arranged in the form of a binary hierarchy of differing frequencies, which are as follows: Delta waves are at 2.5 Hertz, Theta waves are 5 Hertz, Alpha waves are 10 Hertz, Beta waves are 20 Hertz, and Gamma waves are 40 Hertz (Rassi, Dorffner, Gruber, & Klimesch, 2018). Each frequency moving up the hierarchy is always twice as fast as its predecessor.

Before it was mentioned the brain and the body follow identical coupling principles. It is important to know the binary hierarchy also travels downwards at the same doubling measures as it does upwards. For example, the heart exhibits a slower frequency, which is half of delta (2.5Hertz) at 1.25Hertz (Rassi, Dorffner, Gruber, & Klimesch, 2018; Klimesch, 2020). Klimesch's (2018) binary hierarchy brain body oscillation theory has been confirmed by recent studies who identified that harmonic ratios of 2:1 can be found between alpha and theta during moments of peak concentration and diminished during moments of mind wandering, or thought clearing, as seen in mediation. Furthermore, new research has found neural oscillations of different types of frequency can synchronize fully only when their peak frequencies start to develop a harmonic relationship, meaning the harmonic cross-frequency relationship occurring during task related events underlie effective brain processing (Rodriquez-Larios & Alerts, 2019; Rodriquez-Larios et al., 2020).

Origins of Binaural Beats

Binaural beats stimulation traces its roots to Heinrich Wilhelm Dove, a Polish-born physics professor, who is mostly known as the father of meteorology (Dove, 1839, p. 387). Dove discovered when two tuning forks of slightly different frequencies were struck and placed next to each ear, the sound emitting from the two slightly different frequencies could be perceived as a single tone, which was perceived as the difference between the two tones (Chaieb, Wilpert, Reber, & Fell, 2015; Dove, 1839). This phenomenon was later termed as "entrainment," meaning the brain attempts to synchronize two closely related frequencies as one coherent sound.

The brain perceives binaural beats by processing two slightly different variations in frequency coming through each ear. The sounds are recorded in the cochlea, then in the cochlear nucleus, where the electrical signals from each cochlear nucleus cross into the opposing hemisphere's superior olivary complex (SOC). From the SOC, the signal transfers to the inferior colliculus (IC), which is the first integration center in the brain's auditory system (Ito, Bishop, & Oliver, 2016). The IC is able to contrast the two different frequencies, accessing the timbre and the time for both ears. The IC then computes the difference between contrasting sounds, and the BB travels to the auditory pathway into the primary auditory cortex (PAC), as shown in Figure 1.1 (Beauchene, 2018).

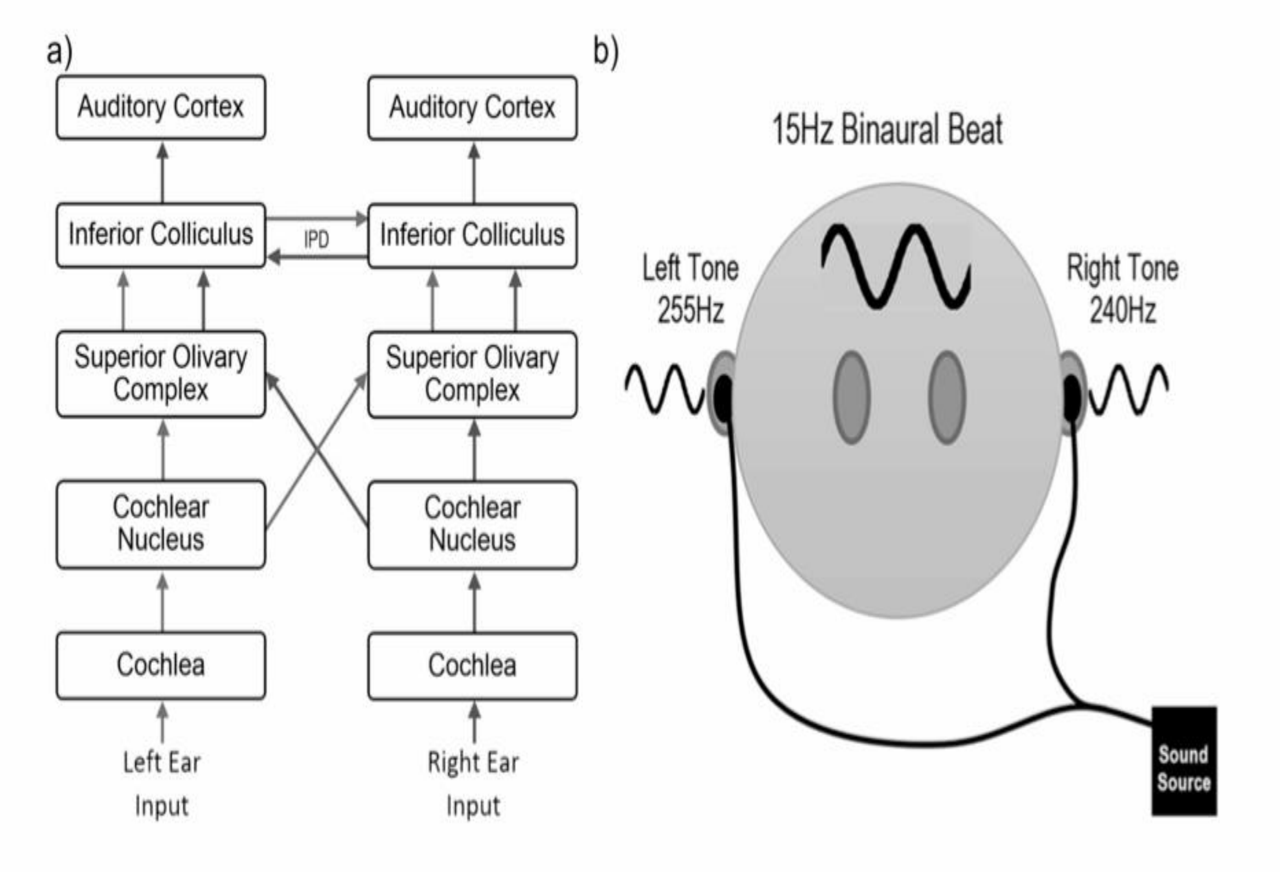


Figure 1.1: Binaural Beats Stimulation of Beta Frequency Range of 15Hertz (Source: Beauchene, 2018)

The Electroencephalogram

Once the discovery of binaural beat frequency was made by Dove (1839), it wasn't until the 1920's that a method was invented for recording brainwave frequencies. In 1924, German psychiatrist Hans Berger invented the electroencephalogram (EEG), which came from his observations of the electrocardiogram, which traces its roots to the telegraph instrumentation used to transfer electrical signals over long distances. Berger came to realize a modified version of the electrocardiogram could be used over the scalp. By placing electrodes over various areas of the scalp and using a conductive gel, the EEG device was able to collect postsynaptic data from cells in the areas where the electrode was placed, ranging from thousands to millions of neurons (Carlson & Birkett, 2017).

The data collected was less rhythmic like with a heartbeat, and appeared more like random and chaotic waves, similar to those emitted from a telegraph when communicating language, this later was found to represent the subject's conscious experiences in real-time (Holmes, 2014). Later Berger would go on to discover abnormalities in brain waves between those with healthy brains, and those with injuries to their prefrontal cortex region (Haas, 2003).

The Discovery of Manipulating Brain Waves

English electrophysiologist Edgar Adrian was credited with the discovery of manipulating brain waves, making two important revelations. Those include that: (1) Brain waves could be manipulated, and (2) there is electrical activity in nerve cells. By using the same style EEG invented by Berger, Adrian found that when the field of vision is exposed to flickers of light, brain waves can be manipulated or controlled (Alastair, 2010). The process was later called "intermittent photic stimulation." Building off this discovery, British neurophysiologist William Grey Walter upgraded Berger's original EEG, to allow for recording of additional brainwaves, such as Delta frequencies found when a person is sleeping. Walter later found photic stimulation could be used to elicit emotional and mental changes in his subjects (Walter & Walter, 1949).

These pioneering discoveries paved the way for mental state manipulation through binaural beats stimulation. Because the brain attempts to synchronize or "entrain" two closely related frequencies, and can create alpha, gamma, beta, delta, and theta waves, those frequencies can be played at particular times to create intentional neural oscillations, and thus creating a desired mental state.

Devices Used to Record Brain Activity

Several devices we used today have been game-changing in our ability to understand how the brain processes information. Today the EEG is still the most-used device for recording brain waves due to its efficiency, low-cost, ease of application, and real-time data. However, since the brain has several regions and layers, determining the depth of a region involved in activity can be difficult. Fortunately, other devices that provide Magnetic Resonance Imaging (MRI) and Functional Magnetic Resonance Imaging (fMRI) can be used to provide further information regarding brain activity. An MRI provides a three-dimensional map of the brain in a set moment in time or a static image which does not include activity. An fMRI measures blood flow changes to regions of the brain, these images are often shown over an MRI image (Hennig, Speck, Koch, & Weiller, 2003).

Another more recent and more accurate device than the EEG is called the electrocorticography (ECoG). This device is commonly used for patients suffering from epilepsy, and functions by placing electrodes directly on the brain's surface thereby minimizing distortions to the electrical signals from brain waves and greatly improves problems associated with spatial distortion (Makin, 2018). Lastly, microelectrodes can be used to record very specific groups of neurons over a period of time, this is often called single-unit recording. This process often involves implanting a fine tipped wire or electrode, which will record the electrical activity of particular neurons that researchers want to examine. More recently, this process has been refined to soft carbon nanotube fiber microelectrodes, which can help with stiffness issues and bending fatigue from more traditional microelectrode devices (Vitaleet al., 2015). The sensitive microelectrodes can report changes in the rhythm level of depolarization in both somatic and dendritic masses of neurons; thereby detecting changes in the local field potential.

Those changes are categorized as either high phase or low phase excitability, which are responsible for modulating the probability of firing or action potential of neurons (Klimesch, 2018). Together these methods can provide a comprehensive look into the brain regions involved when binaural beats are introduced.

Variations of Binaural Beats Stimulation

By having a clear understanding of the nature of brainwaves, and how the devices that are designed to record them function, the influence of binaural beats on brainwaves and the recordings emitted on the devices can be better understood. Originally, binaural beats were heard through tuning forks, now the application of binaural beats are mostly applied through headphones. From the literature gathered in this review, there are four common categories of binaural beats stimulation applications used in research; pure binaural beats stimulation (without additional sound), binaural beats stimulation blended with music (Beauchene, Abaid, Moran, Diana, & Leonessa, 2016; McConnell et al., 2014), binaural beats stimulation blended with nature sounds (Munro and Searchfield, 2019; McConnell et al., 2014), and binaural beats stimulation blended with white or pink noise (Garcia-Argibay, Santed, & Reales, 2017; Garcia-Argibay, Santed, & Reales, 2018; McConnell et al., 2014; Chaieb, Wilpert, Reber, & Fell, 2015). Understanding the impact of adding additional sounds to pure BB is essential in determining the overall effectiveness of binaural beats stimulation. Typically adding sound overlay with binaural beats stimulation is done in order to provide the listener with a more comfortable experience, or to mask the sounds of binaural beats stimulation during controlled conditions. In order to determine the effectiveness of binaural beats stimulation on focus and working memory, it's first important to know if adding sounds overlay negatively impacts the effectiveness. This is important because many studies covering binaural beats stimulation utilize various sounds with binaural beats stimulation.

Binaural Beats Stimulation with Nature or Natural Sounds

In a pilot study designed to investigate the potential for binaural beats stimulation to aid in the reduction of children and adolescents suffering from attention deficit hyperactivity disorder (predominantly inattentive type), researchers Kennel et al. required participants to either listen to BB embedded with natural sounds, or a sham recording of pink noise for 20 minutes, 3 times a week for three weeks. Using the test of variables of attention (TOVA), the researchers measured the changes in attention over time during the course of treatment. Kennel et al. found no significant correlation of the binaural beats stimulation impacting the participants' attention over time. An important drawback to this study is that the audio parameters of the beat stimulation were not reported. However, subjects did report less problems with attention during the course of the study period. (Kennel, Taylor, Lyon, & Bourguignon, 2010).

Another more recent study conducted by Munro and Searchfield (2019) aimed to explore the short-term effects of binaural beats stimulation on tinnitus. Twenty participants were selected and provided auditory stimuli containing ocean waves with and without binaural beats (8Hertz). Subject completed the Perceived Arousal Scale and Tinnitus Rating Scales before and after the sound stimuli period of two 10-minute audio recordings. The results showed marginal differences with or without ocean sounds for individuals completing tinnitus ratings scales (Munro & Searchfield, 2019).

Another study conducted by Kraus and Porubanova (2015) attempted to test the effects of BB on working memory capacity; using two groups of 20 participants, with the experimental group undergoing BB while listening to the sound of the ocean with binaural beats stimulation, while the control group listened to the sound of the ocean alone. Subjects were tested using the Operation Span Task Measure (OSPAN), which tests for working memory capacity. Subjects in both groups listened to sounds for a total of 12 minutes, while the control group listened to an added element of Alpha wave binaural beats stimulation at 9.55Hertz. Kraus and Porubanova's results showed a 7% increase in scores from the experimental group who listened to the ocean sounds with BB added compared to the control group, demonstrating a significant correlation. Concluding binaural beats stimulation in the frequency of 9.55 Hertz can improve working memory.

Binaural beats blended with nature sounds has been shown to increase attention in participants diagnosed with ADHD, utilizing TOVA, and with participants who experience tinnitus perception, when tested using the Perceived Arousal Scale and Tinnitus Rating Scales with 10-minutes of dosage at 8Hertz (Munro & Searchfield 2019). Lastly, BB with nature sounds has been shown to be effective in improving working memory capacity in participants tested using OSPAN, with a dosage of 12-minutes at 9.55Hertz.

Because these studies used different frequencies, apart from the Kennel et al. study, which include no data on frequency used, different testing measures, and different functional objectives (working memory and focus), there does seem to be support for the effectiveness of binaural beats stimulation blended with nature sounds. However, the range of effective frequencies, dosage, and duration of effect of binaural beats stimulation with nature sounds remains unclear

Binaural Beats with Blended with Music

To date, two studies have shown a positive correlation with binaural beats stimulation with music overlay. The first, a double-blind, randomized, repeated measure study designed to measure the effect of theta wave binaural beats stimulation on cardiovascular (CV) stress response for military service members with complaints of post-deployment stress. This study found a positive correlation between the effects of music with binaural beats stimulation, compared to the control group of music without binaural beats stimulation (Gantt, 2016).

The second study completed by Munro and Searchfield (2019) found a positive correlation between BB blended with music over music alone, or a control condition of no music at all, for decreasing operative anxiety in patients undergoing cataract surgery. The random controlled trial study accessed 44 patients using binaural beats blended with music at 20Hertz for 5 minutes, then gradually declined to 10Hertz for 50 minutes. Forty-four additional patients were provided music alone with no binaural beats stimulation. Lastly, 47 patients were placed in the control group and provided with headphones but with no sound. The patients were provided with a State-Trait Anxiety Inventory Questionnaire (STAI) prior to the commencement of the operation, and their blood pressure was monitored right before, 20 minutes into, and after the surgery. The study revealed music with both binaural beats stimulation and without lowered anxiety levels and systolic blood pressure. Additionally, patients who listened to BB with music showed additional decreases in heart rate (Munro & Searchfield, 2019).

The results of these studies are limited to cardiovascular changes in response to a specific surgical procedure and post-deployment stress in military members. These studies do seem to present a theme of the potential benefits of binaural beats stimulation blended with music in efforts to aid in cardiovascular stress related to anxiety and stress, however applying the benefits to binaural beats stimulation blended with music for the benefit of increasing working memory and focus remains unknown.

Binaural Beats with White or Pink Noise

Pink and white noise are considered a neutral sound and is often used with psychoacoustics (Gálvez, Recuero, Canuet, & Del-Pozo, 2018). Because binaural beats stimulation alone can be considered intense or uncomfortable to some, pink noise is sometimes used simultaneously with binaural beats stimulation to achieve a more comfortable listening experience (Lavallee, Koren, & Persinger, 2011). The efficacy of pink noise overlaid with binaural beats stimulation has been a topic of discussion. Researchers have sought to determine its effectiveness compared to binaural beats stimulation alone.

One of the first studies to assess binaural beats stimulation using pink noise was conducted by Lane (1998), who utilized pink noise alongside two different frequency bands, delta/theta ranges (1.5-4Hertz) and beta (16-24Hertz), as well as a control group listening to pink noise with simple tones. In the double-blind, crossover study, Lane found presentation of beta frequencies provided more correct target detections and fewer false alarms during a performance vigilance task than delta/theta ranges, as well as less negative mood (Lane, 1998).

Another study sought to determine whether binaural beats stimulation with pink noise would aid in reducing the falling asleep process. The experimenters used a combination of binaural beats stimulation with pink noise, a similar sound with monaural beats, and a similar sound without any beats. Researchers applied the conditions and measured the speed at which the onset of stage two sleep (sleep spindles) signs started to appear. The researchers concluded there was a decrease in sleep onset time for binaural beats stimulation with pink noise compared to the other conditions. However, it remained unclear whether the combination of binaural beats stimulation and pink noise, or one of the two was the primary reason responsible for the decrease in sleep onset time (Shumov, Arsen, Sveshnikov, & Dorokhov, 2017).

Lastly, one meta-analysis covering twenty-two relevant studies, seeking to determine the effectiveness of binaural beats stimulation on cognition, anxiety, and pain perception determined masking pink or white with binaural beats stimulation did not seem to reveal any significant differences in results compared to binaural beats stimulation alone, therefore binaural beats cannot be masked out by white or pink noise (Garcia, Miguel, & José, 2018).

binaural beats stimulation with pink or white noise has not been exhaustively studied, however the articles examined during this literature review appear to provide evidence that the choice in determining whether to use white or pink noise as a masking measure for comfort purposes does not undermine the physiological effects of binaural beats stimulation. There does not seem to be literature available that provides conclusive evidence white or pink noise acts as an interrupter to the positive effects of binaural beats stimulation in the studies examined.

Focus and Working Memory

In order to determine whether a consensus can be made regarding the necessary dosage needed to achieve a lasting effect of binaural beats stimulation, as it pertains to increasing focus and working memory, it would first be necessary to explore which regions of the brain are responsible for focus and working memory. Because much of the research in this review utilizes various testing measures for attention and working memory (i.e. OSPAN, TOVA, Flanker) and tests using various applications (i.e. binaural beats stimulation blended with music, nature sounds, pink noise), as well as different frequencies and durations (i.e. 20Hertz for 5 minutes, 10Hertz for 50 minutes, 9.44Hertz for 12 minutes), understanding the brain regions that are involved can provide a common thread between these conditions.

There are several areas of the brain that have been associated with attention regulation. These areas work interconnectedly in order to discriminate what is relevant versus what is irrelevant. These systems can be categorized in the way in which they process information. Typically, the brain processes information in either a "top-down" or "bottom-up" manner. Top-down information processing is slower, intentional, and usually consists of more complex information (Gaspelin & Luck, 2018), whereas bottom-up information processing consists of stimulus-driven information that is typically unexpected (Bourgeois, Chelazzi, & Vuilleumier, 2016).

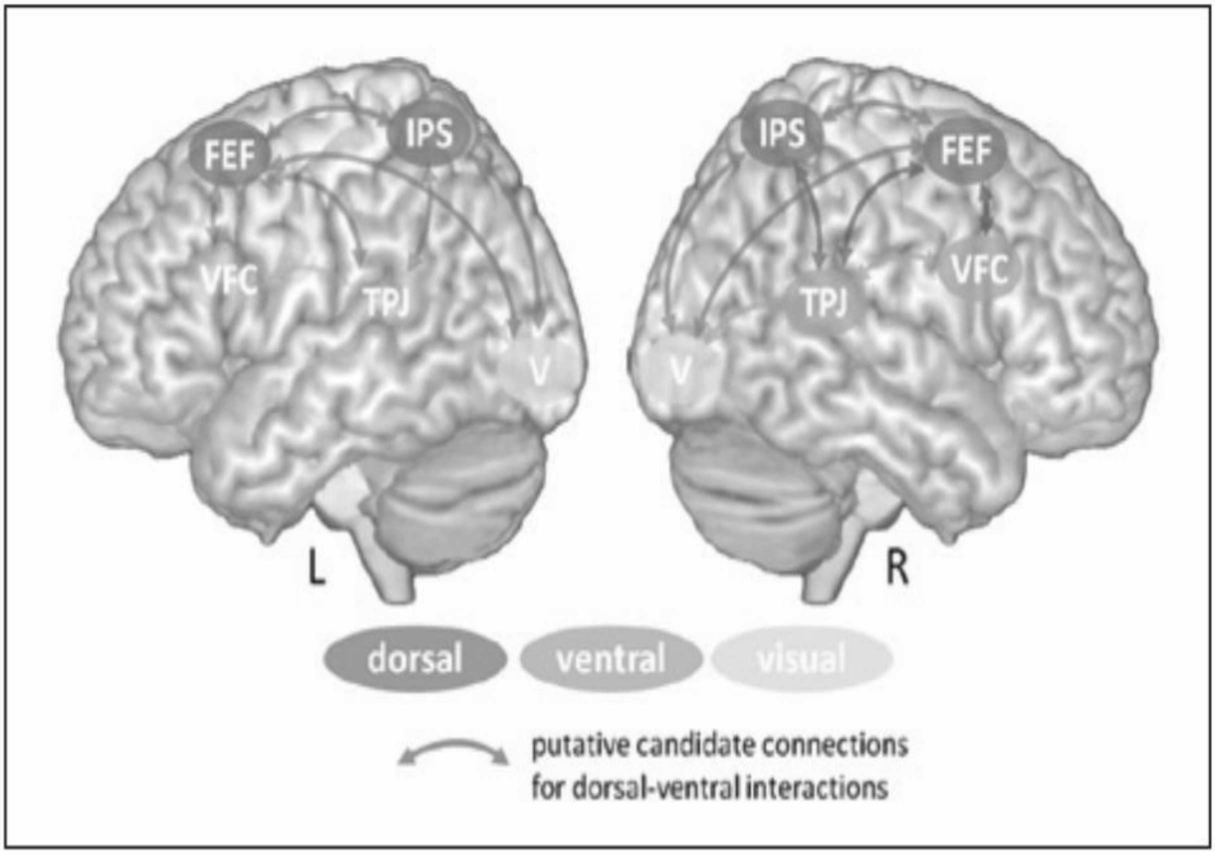
Focus

There are two networks in the brain that regulate attention, the dorsal and ventral attention systems. Each of which contain their own distinct neural circuits and process information in different ways however, both functions interdependently to one another. The dorsal and ventral control networks are typically considered "supramodal" attention systems (Macaluso, 2010). This is due to the similar effects on these networks through other sensory modalities such as physical sensations and auditory stimulation (Vossel, Geng, & Fink, 2014). These systems operate in a push-pull manner, whereas one region will deactivate when information becomes relevant to the adjacent attention network and vise-versa (Vossel, Geng, & Fink, 2014).

Though the interaction between these regions is not fully understood, recent research shows they operate in particular ways. For example, when processing relevant information, the dorsal attention network utilizes top-down processing and deactivates particular distractors in the environment in order to maintain selective attention (Frings & Wühr, 2014). This can be referred to as a "filtering mechanism" in order to maintain focus and visual short-term memory (Vossel, Geng, & Fink, 2014). One example of impairment of this filtering mechanisms is seen in individuals diagnosed with Attention Deficit Hyperactivity Disorder. These individuals experience impairment in both top-down or bottom-up control, particularly as it relates to task difficulty, where more difficult tasks results in enhance bottom-up processing, and less difficult task result in enhanced top-down processing (Schneidt, Jusyte, Rauss, & Schöneberg, 2018). These systems are believed to operate under what is called a "global hierarchy" (Markov et al., 2014), where each projection will show differing patterns of origin and termination. For example, bottom-up processing is typically carried by gamma-theta band synchronization, where top-down processing is usually carried by alpha-beta-band synchronization (Gaspelin & Luck, 2018).

The ventral attention network consists of the ventral frontal cortex (VFC) and the temporoparietal junction (TPJ) (see Fig. 2 in "orange"). This network responds to stimuli in a bottom-up manner, processing information that is segmented or occurs unexpectedly, such as someone calling your name when you are turned away. This area is activated during moments of shock, surprise, or distractibility.

The dorsal attention network consists of intraparietal sulcus (IPS) and the frontal eye fields (FEF) of both hemispheres (see Fig. 2 in "blue") (Vossel, Geng, & Fink, 2014). This network responds to information in a top-down manner.



(Figure 2: Dorsal and Ventral Attention Networks (Source: Vossel, Geng, & Fink, 2014)

There are other significant areas involved in regulation, the prefrontal cortex (PFC) has been attributed executive function by way of top-down information processing, while the thalamus has also been found to control sensory selection during moments of divided attention (Wimmer, et al., 2015). Within the PFC, the dorsal posterior cingulate cortex helps regulate attention by signaling increases or decreases in expected reward magnitude (Bourgeois, Chelazzi, & Vuilleumier, 2016).

Working Memory

Working memory is defined as the ability to temporarily and simultaneously hold on to and manipulate information. Working memory allows the individual to process information and store it temporarily in order to execute on goal-directed behaviors, thereby allowing the individual to plan for events in the future outside of the present moment (Eriksson et al., 2015). The most popular model of working memory to-date has come from Baddeley and Hitch (1974), who first developed the concept of working memory. Baddeley and Hitch's working memory model consists of a phonological loop, visuo-spatial sketchpad, and the central executive (see Fig. 3).

The phonological loop acts as a system for perceiving speech and language comprehension, utilizing mechanisms for temporary storage of speech-related pieces of information. These areas of the brain are associated with activation of the left parietal region (used for phonological storage) of the outer cortex as well as activation of the Broca's area (used as a rehearsal buffer), located in the interior frontal gyrus of the frontal lobe (Zaidel, 2001).

The visuo-spatial sketchpad is an area that perceives and temporarily stores visual images and spatial information which cannot be processed through language. Maintenance of visuo-spatial information requires top-down processing. Similar to the process of operation of the phonological loop, the visuo-spatial sketchpad coverts motor performance in a way that reactivates memory traces in sensory stores (Buchsbaum & D'Esposito, 2008).

The central executive illustrated from Braddeley's model is in a sense, the controller of all working memory, and is associated with the prefrontal cortex (PFC). The PFC processes and integrates both top-down and bottom-up information in order to accomplish a particular goal. The central executive has a multitude of functions including the division and switching of focus, connecting and integrating elements of the long-term memory, and manipulation of information in order to give birth to new concepts (Melrose et al., 2018).

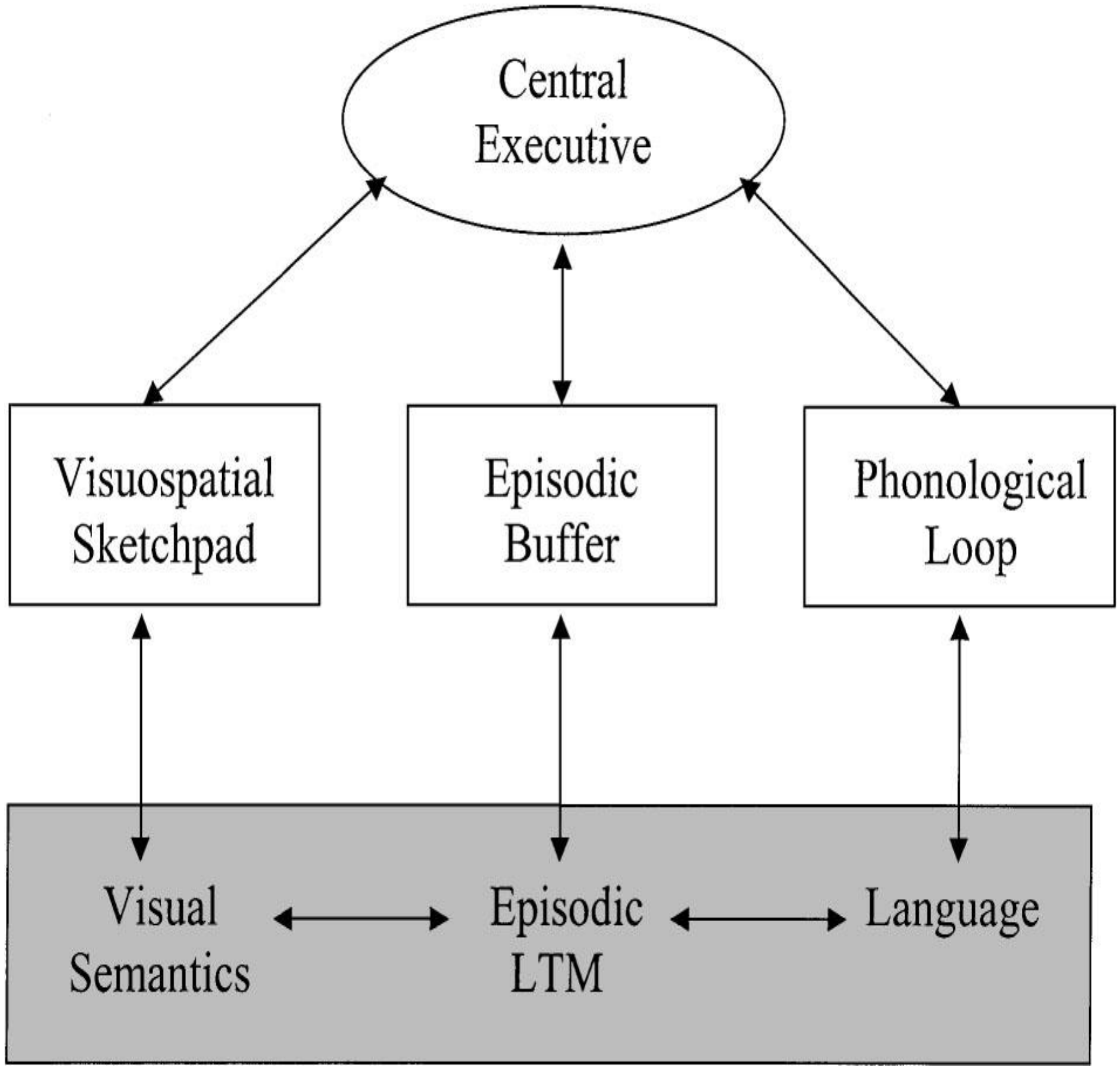


Figure 3: Working Memory Model (source: Baddeley, 2000).

Later Baddeley added an additional component referred to as the "episodic buffer" (Baddeley, 2000), which acts as a temporary storage used to integrate information that comes from the long-term memory, phonological logical loop, and the visuo-spatial sketchpad, creating a link amongst them. Together these systems constitute what is referred to as "slave components," which are dependent upon the central executive, a master component in the integration and coordination of these three slave components (Funahashi, 2017).

Brain Regions Involved in Working Memory

The main brain regions involved in working memory are typically arranged based on their primary function, and can be identified through the use of functional magnetic resonance imaging. Through fMRI imaging, researchers have identified the various areas of the brain involved in working memory. Some areas of the brain are involved in both visual and verbal aspects of working memory, which are the prefrontal cortex, secondary visual cortex, and the superior parietal cortex.

Other areas of the brain show activity exclusively during visual working memory tasks, those areas are the visual cortex and the temporal cortex. Finally, some areas of the brain are active exclusively during verbal working memory tasks, those areas are the inferior frontal cortex, inferior parietal cortex, temporal gyrus, lateral temporal lobes, and the temporoparietal cortex (Eriksson et al., 2015; Na et al., 2000). These various brain areas are identified through fMRI scans, which show activation of these various areas due to the increased blood flow and electrical activity, which is the result of multiple groups of neurons synchronizing together, resulting in brain waves (Reedijk, Bolders & Hommel, 2013).

Brainwave Activity During Focus and Working Memory Tasks

Neural oscillations are rhythmic and electrical synchronized patterns of electrical signals, which are produced by neurons occurring in various parts of the autonomic nervous systems and the brain. Some oscillations occur at the very local level, occurring as single pacemaker neurons, while others engage in rhythmic activity that spans large cortical networks. Furthermore, an oscillation requires either and excitatory or inhibitory interaction, where a positive action is followed up by negative feedback which is delayed (Ermentrout & Chow, 2002).

The neural oscillations (waves) in our brain and body form a single hierarchy, meaning they are organized linearly and are unique to each individual. Additionally, neural oscillations behave according to mathematical principles, and the frequencies within these hierarchies do not fluctuate randomly (Klimesch, 2018). For example, one individual at a given time may experience beta brainwaves at 15.56 Hertz, whereas another individual may be experiencing beta at 16.33 Hertz, both being within the confides of the beta frequency range (15-28 Hertz). Furthermore, brain and body oscillations are synchronized to each other. The manner in which oscillations interact (through phase coupling) is referred to as the *binary hierarchy brain body oscillation theory.* This theory proposes the frequencies of body oscillations can be determined from observations of brain observations because they are aligned (synchronized), and behave according to a set of mathematical principles, where if one frequency can be identified, then the remaining frequencies in the hierarchy can also be identified (Klimesch, 2018).

There are also two coupling principles that govern brain and body oscillations. The first is amplitude modulation, where (when two frequencies are present) the lower frequency will modulate the faster one. For example, if theta and gamma waves are both present, the lower frequency theta will regulate the higher frequency gamma, which is often the case during moments of top-down information processing. The second is a mathematical principal, where when two co-occurring frequencies are present, each will be a harmonic multiple of the other (Klimesch, 2018). These principals are helpful when attempting to make sense of the various brain waves that co-occur during moments of auditory and visual information processing, which govern attention and working memory. When brainwaves do not couple properly, there function could be compared to ripples of water in a pond, where just a few drops of water and the ripples interact with one another, however during a downpour of rain, the patterns become overwhelmed and scattered. This is evident in individuals with certain mental disorders such as with major depressive disorder, where subject experience decreased in theta brainwave activity (Fernández-Palleiro, et al., 2020).

It has been predicted that in order for the brain to be optimized to process incoming speech patterns, phase amplitude coupling (PAC) must occur between theta and gamma waves, where theta oscillations will record the rhythm of speech through the time-locking of theta neurons, which will modulate and readjust the peaking of gamma waves (Hyafil et al., 2015). This theta-gamma PAC will ensure there is enough neural excitability, regulated from a top-down manner to decipher incoming speech (Marton et al., 2018). This is an example of low-frequency-phase to high-frequency-amplitude coupling, which has been witnessed across various cases, attributing to the likelihood this is a universal function of auditory information processing involving speech.

In areas of the visual cortex, a similar system of external pattern recording has been shown through delta frequencies, which will entrain with the rhythm of the incoming visual information stream (Marton et al., 2018). It has been shown that the top-down beta band control is more powerful or enhanced when the cognitive load requirements are increased and additional attention is required. Additionally, top-down beta band processing is increased during moments of selective attention (Bastos et al., 2015). This increased top-down processing also has an impact on bottom-up processing, where the increase of power in low-frequency range oscillations (top-down), may enhance bottom-up rhythms (Bressler & Richter, 2015).

Top-down coupling (or control) of lower frequency phase to high frequency amplitude seems to be the hallmark of attentive and predictive information processing (Bastos et al., 2015; Marton et al., 2018). Having some familiarity with the nature and laws governing brainwave interactions is vital when attempting to determine impact binaural beats stimulation has on brain waves, and the resulting effects on attention and working memory. This is especially important considering top-down beta band control is enhanced during increased cognitive load requirements (Bastos et al., 2015), and there is some research supporting the exposure of BB in beta frequency has shown positive effects on brainwave activity (Chaieb, Wilpert, Rever, & eFell, 2015; Citaldi, 2018). As a general principle, the cognitive processes of memory are associated with theta and gamma rhythms, whereas the cognitive processes with attention are associated with alpha and gamma rhythms (Ward, 2003).

Testing Measures

There are several studies that have shown a link between the application of binaural beats stimulation and increases in focus as well as a reduction of mind wandering (Colzato, Barone, Sellaro, & Hommel, 2017; Shekar, Suryavanshi, & Nayak, 2018; Axelsen, Kirk, & Staiano, 2020). While fMRI images can show areas of blood flow, and EEG data can show fluctuations in brainwaves, these tools are only part of the equation when it comes to assessing the effects of binaural beats stimulation on focus and working memory. In order for researchers to determine if binaural beats stimulation has an effect on participants' attention or working memory, they need to utilize testing measures in order to obtain concrete data from performance on particular tasks in order to demonstrate improvements or deficits.

A common framework for testing attention and working memory consists of a control group, where there is a sham recording group (i.e. pink noise only, single-tone recording), and a testing group exposed to the desired BB frequency of interest (i.e. Gamma binaural beats stimulation at 40Hertz). When the two (or sometimes three) groups perform a testing measure and there are significant differences between the groups, a correlation as to the effect of the binaural beats stimulation exposure can be drawn.

Testing Working Memory

Testing measures used for research studies on working memory typically utilizing what is referred to a dual-task paradigm, which assesses working memory (Hommel et al., 2016). Using a dual-task measure, participants will engage in two tasks simultaneously, resulting in decreased performance due to divided attention (Watanabe & Funahashi, 2015). Another testing measure to assess working memory is an N-back test, which does not allow the individual to separate three key working memory sub-processes (encoding, maintenance, and retrieval), which interplay during N-back trials (Piccoli et al., 2015).

There are other testing measures used for accessing working memory in clinical practice such as the Wechsler Memory Scales (WMS)(Wechsler, 1945), the Rivermead Behavioral Memory Test (Baddeley, 2003), the Memory Assessment Scales (Williams, 1991), and the Wide Range Assessment of Memory and Learning —II (Sheslow & Adams, 2003). For this literature review, the assessments examined in research for the purposes of assessing working memory utilized either a dual-task measure or an n-back style measure.

Testing Attention

The ability to filter, select, and attend to relevant stimuli is essential for proper functioning. An individual must also attend to information for an appropriate amount of time. Individuals can focus on stimuli to an extent past where it becomes useful, or may not focus on the stimuli long enough. There are many testing measures designed to assess for attentional deficiencies, examining the individual's processing speed, ability to shift attention when needed, auditory and visual reaction time. The most commonly used intelligence scales used in clinical practice are the Wechsler intelligence scales (WAIS-IV/WISC-V), which have working memory indexes that access for attention (Archer, Buffington-Vollum, Strendy & Handel, 2006; Camara Nathan, & Puente, 200). These scales provide a “Full Scale” IQ (FISQ) which provides a combination score of multiple subtests. Some other commonly used assessments are the Stroop Color Word Test (Stroop, 1935), the Conners Continuous Performance Test (CPT-3)(Conners, 2015), Attentional Blink (Reedijk, Bolders, Colzato, & Hommel, 2015), Test of Variables of Attention (TOVA)(Kennel, Taylor, Lyon, & Bourguignon, 2010), Repeatable Battery for the Assessment of Neuropsychological Status (RBANS)(Randolph, Tierney, Mohr, & Chase, 1998), Sustained Attention to Response Task (Kirk et al., 2019), Global-Local Task (Colzato, Barone, Sellaro, & Hommel, 2017), and the Flanker Attention Task (Engelbregt et al., 2019). Typically, these testing measures require the testing participants to select while their attention is divided, while a distractor is present, or the correct/incorrect items are only presented for a brief moment requiring the participant to maintain focus as not to miss the correct prompt; as utilized in TOVA tests (Zhang et al., 2016).

These testing measures are often used in studies that seek to understand the impact of binaural beats stimulation exposure on the testing participant’s working memory and ability to maintain or improve focus. While observing brain scans and neural oscillations can provide valuable information as to what the brain is doing during moments of increased attentional demand and divided attention, results from these testing measures can provide researchers with a permanent performance product. Increases or decreases in scores of participants exposed to binaural beats stimulation compared to the control groups while undergoing these testing measures can provide valuable conclusions as to the effectiveness of binaural beats stimulation.

The next question that arises is what does the available literature on binaural beats stimulation conclude regarding its impact on individual levels of attention and working memory? In the following section, the aforementioned research questions will be answered, which are as follows:

(*RQ1*): What research is there supporting the effectiveness of binaural beats stimulation for the purposes of increasing attention and working memory in healthy participants?

(*RQ2*): What frequency of binaural beats stimulation is best to achieve cognitive enhancing effects in areas of the brain associated with increased working memory and focus?

(RQ3): What evidence is there regarding the dosage and lasting cognitive enhancing effect from binaural beats stimulation exposure, if so what are the boundaries of those effects.

Binaural Beats Frequencies for Increasing Working Memory and Attention

There are several studies that have shown a link between the application of binaural beats stimulation and increases in focus as well as a reduction of mind wandering (Colzato, Barone, Sellaro, & Hommel, 2017; Shekar, Suryavanshi, & Nayak, 2018; Engelbregt, et al., 2019). The following BB frequencies will be reviewed due to volume or research covering their effectiveness in affecting the attention and working memory centers in the brain; Alpha (7-14 Hertz), Beta (14–28 Hertz), and Gamma (28–56 Hertz).

Binaural Beats for Working Memory

Alpha Waves (7-14 Hertz)

Frequencies ranging from 7-14 Hertz have been shown to promote cortical entrainment and improve working memory; three studies were reviewed which assessed the effect of binaural beats on working memory. The first study examined the effects of Alpha binaural beats stimulation in the frequency of 9.55 Hertz, and compared the effects of this frequency masked with the sound of the sea to a control group exposed to just the sound of the sea. The exposure period of binaural beats stimulation was for 12 min prior to the testing period, which lasted approximately 50 minutes. Two groups of 40 participants were assessed using an Automated OSPAN test. The results of the AOPSAN test showed participants exposed to the binaural beats stimulation scored an average of 4.6 points higher than participants who listened to the sham recording (Kraus & Porubanová, 2015).

The second study reviewed was conducted by Beauchene et al. (2016), who tested participants working memory and cortical connectivity using a delayed match-to-sample visuospatial working memory task. Beauchene et al. (2016) utilized three acoustic stimulation control conditions: none, puretone, classical music; as well as three BB frequencies: 5 Hertz, 10 Hertz, and 15 Hertz. During the testing, researchers found the conditions of pure tone, classical music, and 10 Hertz (Alpha) produced the largest decreases in working memory. Fifteen Hertz (Beta) was the only condition shown to produce a significant increase in working memory task performance (Beauchene et al., 2016). It was notable, the ratio of cortical connectivity with 10 Hertz was the highest of the other conditions. This study provides a conclusion that exposure to 10 Hertz frequency for a period of five minutes, may decrease working memory task performance.

The third study reviewed by Kalyan and Kaushal (2016) using similar conditions provides evidence to the contrary. In their study, nine participants were tested using a visuospatial memory test similar to the study completed by Beauchene et al., (2016), however individuals in this study were presented with an image of a figure for ten seconds, then asked to draw the figure after ten seconds, a process that was repeated twice. The participants in the study were exposed to 10.7 Hertz for 28 minutes after listening to binaural beats stimulation in the beta frequency range for a few minutes. The results concluded audio entertainment by binaural frequency in 10.7 Hertz can impact the participants brain chemistry in a way that improves brain performance, particularly by affecting the frontal, parietal, and temporal areas of the brain through audio entrainment (Kalyan & Kaushal, 2016).

Beta Waves (14–28 Hertz)

Frequencies ranging from 14-28 Hertz have been shown to improve working memory and reduce mind wandering. In another study by Beauchene (2018), participants were exposed to three control conditions: pure tone, classical music, and none. While exposing the experiment group to three frequencies, 5 Hertz, 10 Hertz, and 15 Hertz in sequence for a period of five minutes, with a two-minute block of no sound in between. The subjects were tested for approximately 30 minutes using a delayed match-sample test and an N-back test which are used to access working memory. The results from the study found when individuals were exposed to 15 Hertz binaural beats stimulation their accuracy on the assessment increased, and remained increased past the relative increases of the other frequencies. This demonstrated 15 Hertz could sustain heightened levels of accuracy over a longer period of time, in addition to performing significantly better overall when compared to non-exposure conditions (Beauchene, 2018). Currently, there are not many studies examining the effects of binaural beats stimulation in Beta frequencies for the purpose of assessing working memory, and only previous study conducted by Kennerly (1994), addressed this topic prior to Beauchene's (2018).

Kennerly (1994) found a positive correlation between binaural beats stimulation in the beta frequency range. A total of 50 participants were divided into two groups, the experiment group (n=27) being exposed to a music tape with binaural beats stimulation in beta frequency and instrumental music, the control group (n=23) listened to instrumental music with no background. Subjects were presented with four different learning tasks, word list recall, a German vocabulary list recall, digit-span, and digit-symbol tests. The subjects were exposed to the sound conditions for 45 minutes, 15 minutes prior taking the tests, and during the tests. The results showed the binaural beats stimulation in beta waves improved the number of recalled words in the word list recall task and improved in the digit-span and digit-symbol tasks (Kennerly, 1994). One drawback to this study is the exact beta frequency was not disclosed, leaving an ambiguous range between 14-28 Hertz.

Gamma Waves (28-56 Hertz)

The effects of Gamma waves have been studied by Colzato, Steenbergen, and Sellaro (2017); who assessed whether binaural beats stimulation affects top-down control feature bindings. In this double-blinded, sham-controlled study, a total of 40 healthy adult participants were randomly distributed into two experimental groups. G1 (n=20) participants were exposed to 40 Hertz gamma-frequency binaural beats stimulation, and G2, being the control group (n=20) were exposed to a single-tone recording of 340 Hertz. Participants in both groups listened to the recording for 10 minutes prior to, and during the testing. The participants were provided with a series of tasks designed to test their visual working memory. Results from this study demonstrated gamma binaural beats stimulation enhanced visual feature binding (the binding between two visual features), but not visuo-motor; leading to improved selectivity in updating episodic memory traces (Colzato, Steenbergen, & Sellarno, 2017).

Another study conducted by Engelbregt et al. (2019), tested 24 participants, who were informed they would be assigned to either a sham recording (white noise) or controlled recording; participants listening to the controlled recording were unaware they were listening to one of two versions of the controlled recording (monural 440Hertz) and binaural beats (40 Hertz). All participants started with a Flanker Attention Task, followed by the Klingberg Task, with a two-minute break in-between. The testing period was approximately one hour. Results from the Flanker Task which aimed to measure attention, indicated participants exposed to BB and MB had significantly faster speed performance compared to participants exposed to WN. However, no evidence was found to indicate an influence of binaural beats stimulation on working memory performance (Engelbergt et al., 2019).

Binaural Beats for Attention

Alpha Waves (7-14Hertz)

Participants exposed to frequencies ranging from 7-14 Hertz have shown not only an improved working memory, they have also been shown to increase attention and top-down processing (Shekar, Suryavanshi, & Nayak, 2018). While memory is concerned with recall and learning, attention is related to the ability to focus awareness on an intended stimulus or task (Shekar, Suryavanshi, & Nayak, 2018). In the realm of attention is the concept of reaction time. Reaction time involves testing for both attention and speed of reaction time, without proper focus, reaction time will be slower. Reaction time is tested in two domains, auditory reaction time (ART) and visual reaction time (VRT).

In one comparative interventional study, researchers assessed 40 participants, consisting of 20 males and 20 females. The participants were asked to participate in three separate sessions conducted on alternate days; the participants were also requested to get an average night's sleep and refrain from any caffeinated products at least four hours prior to BB exposure. The participants were provided a sham recording of a single-tone recording of 340 Hertz during the first session and either alpha binaural beats (10 Hertz) or gamma binaural beats (40 Hertz) in either the second or third session, ensuring each participant had experienced all three conditions (Shekar, Suryavanshi, & Nayak, 2018).

The subjects were tested using "Super Lab (V5), a software designed to test their ART and VRT. A repeated measures ANOVA showed that there was a statistically significant difference in VRT before and after listening to binaural beats in both the alpha and gamma frequencies compared to the single-tone recording ($F[2,76] = 28.892$, $P < 0.001$). In the ART test, a repeated measure ANOVA showed there was a statistically significant difference in ART before and after listening to binaural beats ($F[2,76] = 8.264$, $P = 0.003$). Additionally, the individuals tested experienced shortened reaction time in both the alpha and gamma binaural beats frequencies compared to the single-tone recording (Shekar, Suryavanshi, & Nayak, 2018).

Beta Waves (14–28 Hertz)

Frequencies in the Beta range have also been shown to have marked improvements in attention related tasks. In one study, researchers Kirk, Wieghorst, Neilsen, and Staiano (2019) utilized 77 subjects broken into three groups. The first group (n=25) had no interventions, while the second group (n=25) practiced meditation for 15 minutes prior to running the test. The third group (n=25) of subjects listened to beta wave binaural beats stimulation at 14 Hertz (165 Hertz in the left ear and 179 Hertz in the right) for four minutes, four different times during the test. All three groups were provided with on-the-spot testing using a Sustained Attention to Response Task (SART), which is a Go/NoGo task test often used as a way of indirectly measuring mind wandering. The results from SART revealed a significant improvement of 21% in mind wandering compared to no increases from the non-intervention group; the results from binaural beats stimulation were comparable with the meditation group, which saw a 22% improvement in mind wandering (Kirk, Wieghorst, Neilsen, & Staiano, 2019). One drawback to this study was a "sham" recording or active control was not used, making it difficult for researchers to determine whether the increase was due to experimenter influence, or the content of the interventions.

Another study using SART was conducted by Axelsen, Kirk, and Staino (2020), which concluded the effects of SART performance were increased after subjects were intentionally exposed to a test producing fatigue symptoms. Their study reported 12 minutes exposure of 14 Hertz Beta was effective in mitigating to some degree the effects of mental fatigue on sustained attention. An interesting observation of this study was it included pre-exposure of binaural beats for a period of time prior to engaging in the SART.

Gamma Waves (28–56 Hertz)

Frequencies in the Gamma range have been related to a higher level of consciousness and may improve upon information transfer from one brain location or region to another (Kaiser & Lutzenberger, 2005), as well as increases in the visuo-spatial sketchpad areas associated with working memory and attention (Colzato et al., 2017). Several studies have attributed positive effects of attention through exposure to binaural beats stimulation in the 40 hertz range (Hessel et al., 2019; Suryavanshi, & Nayak 2018; Engelbregt, et al., 2019; Hommel et al., 2016)

One previously mentioned study by Engelbregt et al. (2019) found exposure to 40 Hertz binaural beats stimulation during a Flanker Task test was effective in improving speed performance results compared to individuals exposed to white noise alone. In addition, the before-mentioned (see *binaural beats stimulation for Attention - Alpha* section) study by Shekar, Suryavanshi, and Nayak (2018) also showed decreases in audio and visual reaction time when participants were exposed to 40 Hertz binaural beats stimulation as compared to the sham control group.

Another study conducted by Hommel et al. (2016) compared the results of 20 participants exposed to 340 Hertz monaural beats, to 20 participants exposed to 40 Hertz binaural beats stimulation against a Dual-Task Paradigm, which assesses top-down attentional information processing. The participants were exposed to the control conditions for a total of three minutes prior to engaging in the task. Afterward, researchers found the effect of binaural beats stimulation exposure compared to the control group was significant, with participants who were exposed to 40 Hertz showing faster reaction time, indicating an overall increase of cognitive flexibility.

Discussion

The following BB frequencies were reviewed due to volume or research covering their effectiveness in affecting the attention and working memory centers in the brain; Alpha (7-14 Hertz), Beta (14–28 Hertz), and Gamma (28–56 Hertz). Currently, the two most studied frequencies for the purposes of assessing attention and working memory are alpha waves in the frequency of 10 Hertz and gamma waves in the frequency of 40 Hertz. Studies assessing 40 Hertz, 14-15 Hertz, and 10 Hertz and frequency for the purposes of increasing attention and working memory have shown the highest rate of effect on attention and working memory networks (Colzato, Barone, Sellaro, & Hommel 2017; Engelbregt et al., 2019; Shekar, Suryavanshi & Nayak, 2018).

Dosage and Duration of Effect

A total of 11 studies were used in examining the dosage and duration of effect of binaural beats stimulation on attention and working memory networks. These studies were selected based off of relevancy to the research questions posed in this literature review. The aim of examining the dosage and duration of effect within the context of its effects on working memory and attention, is due to the fact this type of review has not been previously conducted. This leaves room for a potential consensus to be drawn regarding which frequency is best for a lasting effect and under what conditions. Of the 11 studies, three studies were significant, covering the topic of dosage, while also indirectly covering the topic of duration of effect.

The first study of note was conducted by Axelsen, Kirk, and Staiano (2020), which sought to assess attention levels of participants after a period of induced fatigue. The participants were dosed with 14 Hertz binaural beats stimulation for 12 minutes prior to taking the Sustained Attention to Response Task (SART), which is a commonly used testing method attributed to Robertson et al. (1997) which lasts for 6 minutes. Because there was a positive correlation of test scores compared to the control, and since binaural beats stimulation was not present during the course of testing, it can be deduced there was approximately a 6-minute lasting effect. However, there is no way to conclude the rate of effect expenditure or half-life of binaural beats stimulation after the exposure period ended.

The second study of note used the same SART testing method was used by Kirk, Wieghorst, Nielsen, and Staiano (2019). In their study, the SART was also applied after an exposure duration of 15 minutes of binaural beats stimulation in the frequency of 14 Hertz. This study concluded with a positive correlation of testing results compared to the control group. It can be decided there was 6 minutes of duration of effect after exposure to binaural beats stimulation due to similar parameters being in place.

The third study that covers the topic of the rate of expenditure or duration of effect was completed by Beauchene et al., (2016), in their study, participant's working memory was assessed using a delayed match-to-sample or visuospatial task. The dosage was applied during the testing period of 5 minutes. Researchers noted, amongst the frequencies of 10 Hertz and 15

Hertz, there was a positive initial correlation of increased accuracy scores within the first few minutes of testing, with a sharp decline in 10 Hertz frequency after the first few minutes. However, participants exposed to 15 Hertz were able to maintain their accuracy for the entire duration of testing, suggesting the benefits of 15 Hertz binaural beats stimulation frequency range not only can maintain heightened accuracy on visuospatial testing for 5 minutes. This range is also extremely close to 14 Hertz which have been shown to be effective on tests assessing attention for the same duration, when exposure ended prior to the testing. This provides some support that the 15 Hertz frequency range has a lasting effect, which maintains its effectiveness even after the dosage period has ended.

Discussion

From the available 11 studies covering binaural beats stimulation for the purposes of assessing attention and working memory, nine studies covered the topic of dosage. Of those nine studies, three contained information that can allow for a deductive conclusion related to duration of effect. Of the three studies examined, only two provided data relating to duration of effect post-exposure. However, this information was not directly addressed. There is currently much room for additional research concerning this topic, as no study has addressed the topic of duration of effect intentionally.

Theoretical Framework

Binaural beat stimulation was first discovered by Heinrich Wilhelm Dove, who discovered two tuning forks, each with a slight difference in pitch, can be perceived as one unitary tone when one fork is presented in the left ear and the other presented in the right (Dove, 1839). This phenomenon has been referred to as "entrainment." Since then, the discovery of the manipulation of brain waves through photic stimulation by English electrophysiologist Edgar

Adrian (Alastair, 2010), has paved the way for future brain stimulant technologies to be developed like binaural beats stimulation through headphones. These discoveries have been further supported with the development of functional magnetic resonance imaging (fMRI) and the electroencephalogram (EEG), which allow observers to observe functional images of the brain and monitor brain waves respectively.

With the development of the fMRI, EEG, and the discovery of brainwave entrainment, researchers have further identified how the brain functions, with top down processing of complex and intentional information, and the processing of novel or unplanned information as with bottom-up processing (Gaspelin & Luck, 2018; Bourgeois, Chelazzi, & Vuilleumier, 2016). Additionally, research has concluded brainwaves can be categorized within specific ranges according to their differing frequency and amplitude, which is as follows: Delta (0.9–3.5 Hertz), Theta (3.5–7 Hertz), Alpha (7–14 Hertz), Beta (14–28 Hertz) and Gamma (28–56 Hertz) (Jaiswalet al., 2019).

Furthermore, research has shown these waves can interact simultaneously and behave according to a set of biological and mathematical principles, which are arranged in a hierarchy. First, differing brain waves will modulate in a particular way based-off the amplitude (envelope) between frequencies, where the slower frequency will regulate the faster frequency (Klimesch, 2018). Second, the different frequencies will couple, where the faster frequency will be a harmonic multiple of the lower frequency (Klimesch, 2018). Lastly, each frequency moving up the hierarchy is always twice as fast as its predecessor (Rassi, Dorffner, Gruber, & Klimesch, 2018; Klimesch, 2018).

Knowing what areas of the brain are activated during information processing and the nature of brain waves has created an increase in research regarding the potential application of binaural beats stimulation. Research has shown each frequency useful for various purposes and is indicative of how the brain processes incoming information, leading to the stimulation of such frequencies to achieve specific cognitive changes (Bastek, 2018; Jirakittayakorn & Wongsawat, 2017; Chaieb, Wilpert, Rever, & eFell, 2015). The application of binaural beats stimulation ranges from reducing tinnitus perception (Munro & Searchfield 2019), to increasing attention (Axelsen, Kirk, & Staiano, 2020) to reducing operative anxiety (Wiwatwongwana, et al. 2016).

Summary

Since the discovery of binaural beats, there has been much research concerning their impact on the brain. This review is an attempt to cross-compare the current literature on this topic in an effort to determine if a consensus can be derived on the impact of binaural beats stimulation on focus and attention networks; with the ultimate goal of determining which frequency is most likely to create the effect, as well as the dosage needed in order to obtain a lasting effect.

The following topics were explored in detail in chapter two: *origins of binaural beats stimulation, measuring brain waves, focus/attention, binaural beats stimulation with nature/white/pink noise, binaural beats stimulation for attention, binaural beats stimulation for working memory, dosage, and duration of effect*. The topics of: *origins of binaural beats stimulation, measuring brain waves, focus, attention, binaural beats stimulation with nature/white/pink noise*, were explored to provide background and context to provide a better understanding of the later topics of binaural beats stimulation for *attention/working memory, dosage, and lasting effect.*

The body of research covering the topic of binaural beats stimulation and its effects of attention and working memory revealed frequency ranges in Alpha, Beta, and Gamma were the most commonly studied (Shekar, Suryavanshi, & Nayak, 2018; Colzato, Steenbergen, & Sellaro, 2017; Colzato et al., 2017; Beauchene et al., 2016; Kraus & Porubanová, 2015). With four studies covering alpha waves, four studies covering beta waves, and four studies covering gamma waves.

The area of dosage and lasting effect is limited to less than a handful of relevant studies (Axelsen, Kirk, & Staiano, 2020; Wieghorst, Nielsen, & Staiano, 2019; Beauchene et al., 2016). These studies provide information related to the dosage for two specific frequencies 14 Hertz and 15 Hertz. Additional research will be needed to assess the limits of the dosage and duration of effect binaural beats stimulation has on attention and memory networks; as well as additional comparisons to surrounding frequencies.

CHAPTER THREE

METHODOLOGY

Multiple studies have demonstrated a positive correlation between binaural beat stimulation and increased working memory and focus while binaural beats are being played through headphones (Calomeni et al., 2017; Gálvez, Recuero, Canuet, & Del-Pozo, 2018; Kalyan & Kaushal, 2016; Kraus & Porubanová, 2015; Shekar, Suryavanshi, & Nayak, 2018). However, these studies have not shed light on the duration of overall effect on brainwave activity post binaural beat exposure (Kirk, Wieghorst, Nielsen, & Staiano, 2019; Jirakittayakorn, & Wongsawat, 2017). Since there is a gap in research regarding the lasting effect of binaural beats stimulation, naturally there also exists a gap in research regarding the dosage (time of use) in which binaural beats were applied.

The potential gap in research on dosage and duration of effect can have future implications if not adequately addressed. Without data providing information on the dosage and duration of effect of binaural beats stimulation, future research is limited to learning only the potentialities of binaural beats while the brain is actively undergoing external stimulation. The psychological benefits of binaural beats stimulation and the future potentialities related to which frequencies last the longest and what length of stimulation is needed to achieve the lasting effects will not be fully known.

In order to fully understand the breadth of what is not known regarding the effectiveness, dosage, and lasting effect of binaural beats stimulation, the following three research questions are posited:

Research Question 1 (*RQ1*): What research is there supporting the effectiveness of binaural beats stimulation for the purposes of increasing attention and working memory in healthy participants?

Research Question 2 (*RQ2*): What frequency of binaural beats stimulation is best to achieve cognitive enhancing effects in areas of the brain associated with increased working memory and focus?

Research Question 3 (*RQ3*): What evidence is there regarding the dosage and lasting cognitive enhancing effect from binaural beats stimulation exposure, if so what are the boundaries of those effects.

Research Method

The topic of covering the necessary dosage and lasting effect of binaural beats stimulation on attention and working memory required an exhaustive review of current research to determine what is known versus not known about this topic, therefore a systematic review framework was selected. This systematic literature review is conducted using the Preferred Reporting Items for Systematic Reviews and Meta- Analyses (PRISMA) criteria (Moher, 2009). This method allows for the methodical identification of the essential components of the journal articles related to duration, frequency, dosage, and provides conclusions to the above research questions.

A systematic review was the appropriate method for the topic of dosage and duration of effect of binaural beats stimulation on attention and working memory primarily because it allows for the synthesis of multiple related studies concerning the topic of binaural beats stimulation through the use of strategies that are designed to reduce bias and errors. Furthermore, the strict guidelines for systematic review, provided accurate estimates concerning the included studies' evaluation and effects of binaural beats stimulation on attention and working memory networks. Additionally, systematic reviews can highlight areas where research is currently lacking, helping guide further research. Lastly, the process of systematic review provided general information that can be quantified with more validity than most other types of studies, and allowed the data to be applied across populations and various settings (Mulrow, 1994).

A quantitative study was not considered for this doctoral project because they rely on the emphasis of causal relationships between variables, and focus on experimental measurement with criteria including intensity, frequency, and quantity (Denzin & Lincoln, 2005). A qualitative study was not considered due to the nature of the qualitative research project, which emphasizes the qualities of various entities studied, as well as the meanings and processes, emphasizing the socially constructed nature of reality (Denzin & Lincoln, 2005). A systematic review can be somewhat limited, in that they do not provide novel data, such as with case studies or causal designs, however, the systematic review can provide conclusions based-off existing literature that can help expand the direction of future research, which is why this framework was chosen opposed to quantitative or qualitative research frameworks.

Participants

Due to the nature of a theoretical study, specifically a systematic review, there was no specific location where data from participants was collected. Furthermore, there were no direct participants gathered in this study, the only participants included were those through the studies selected for analysis. This study aimed to target populations who could effectively participate in studies involving headphones, and either attention or working memory assessment measures.

The target participants for this study were healthy subjects, with no specific age, gender, ethnicity, height, or weight. A majority of the subjects were college students, with an age range of 18-46, and a mean age of 24.3 years. Most subjects were tested within the United States, with some European and Indian studies included (Axelsen, Kirk, Staiano, 2020; Engelbregt et al., 2019; Shekar, Suryavanshi, & Nayak, 2018).

Specific criteria included individuals who possess normal hearing without any level impairment in order to ensure proper application of binaural beats, as well as individuals who are not diagnosed with any level of cognitive decline or related condition. Because the selection of participants was contingent upon the data and methods of other researchers, the breadth of this study included all races, genders, and age groups; which highlights the necessity for more specific criteria in future studies to allow for cross-comparisons.

Instrumentation

The instrumentation used for this systematic literature review is conducted using the Preferred Reporting Items for Systematic Reviews and Meta- Analyses (PRISMA) criteria (Moher, 2009). A PRISMA flow diagram was used in order to ensure the number of reviewed articles and studies were properly screened according to relevance to the topic at-hand (see Appendix A).

A PRISMA checklist created by Moher, Liberati, Tetzlaff, and Altman (2009), in order to ensure the main components of a systematic literature review was completed (see Appendix B and B2). Following both the flow diagram and the checklist ensures the minimum set of items needed for a complete systematic review were included (Moher, Liberati, Tetzlaff, & Altman, 2009).

Additional instruments used were search engines, including only the following: Google Scholar, Pubmed Central, ProQuest Psychology, OneSearch, PsychINFO, and APA PsycArticles from the American Psychological Association database. In order to access these search engines, my personal password protected laptop computer was utilized, the research information will be stored for a period of one year, or until the completion of this doctoral project, whichever arrives first. The data will be deleted using the Mac Osx file delete feature, followed by another purge by way of the trash purge software feature.

Journal articles considered in this systematic review were categorized using Mendeley software, which was used for reference management, sharing of research articles, and bibliography generation. A scan feature through Mendeley allows for the exclusion of duplicates. Any duplicates were excluded after the research was gathered and reviewed.

The instrumentation used according to the PRISMA method allows for the dissemination of all available research concerning the topic of binaural beats stimulation and the dosage and lasting effect for attention and working memory. The flow diagram allowed for discrimination of relevant versus irrelevant research specifically pertaining to dosage needed and duration of effect from binaural beats stimulation in order to achieve increased attention and working memory, against the wide spectrum of literature covering binaural beats stimulation.

Data Collection

The data collected for this literature review consisted of extensive research from the following search databases: Google Scholar, Pubmed Central, ProQuest Psychology, PsychINFO, OneSearch, and APA PsycArticles from the American Psychological Association. The majority of articles collected in this literature review area retrieved from Google Scholar, followed by the library databases from California Southern University (ProQuest, PsychArticles, and OneSearch).

Articles published within the years 2014-2020 were assessed, with some earlier seminal research studies included, as well as studies used primarily for background reference purposes.

Searches were conducted using the advanced search feature in the above search databases. The document title option was selected, and keywords were placed into the search bar. For example, in APA PsychArticles, the following criteria was applied: “Binaural Beats” (ti), and “Attention” (ti), with limits set to articles dated between September 2014 to September 2020.

Only studies that were published by peer-reviewed journals were considered. Studies printed in a foreign language were considered if they could effectively be translated and were up-to-date, as well as from credible publishers. Articles published before 2014 were excluded, unless they contained seminal research on a topic relevant to this review and provided necessary context. Relevant articles to the topic of binaural beats stimulation for the purposes of increasing attention and working memory that include criteria related to binaural beats stimulation for the treatment of certain conditions (i.e. Alzheimer's, posttraumatic stress disorder) were excluded.

Due to the importance of the screening process, articles were selected for this literature review by first identifying the year of publication and the relevance to the research questions. Articles that had little or no relevance to binaural beats stimulation, attention, or working memory were filtered out. Exclusion criteria included articles that were published prior to 2014, those in languages that did not have translation options, and those with aims of studying the effects of binaural beats stimulation on non-healthy participants (i.e. binaural beats stimulation for the purposes of decreasing the effects of tinnitus perception).

The keywords and phrases used in the above search databases were: “binaural beats stimulation,” “dosage,” “lasting effect,” “duration of effect,” “binaural beats with pink noise,” “white noise,” and “nature sounds,” “neural oscillations,” “invention of binaural beats,” “working memory and binaural beats,” “working memory and alpha waves,” “beta waves and working memory,” “delta waves and working memory,” “binaural beats entrainment,” “binaural stimulation and the brain," "binaural beats and brainwaves, and binaural beats and attention." Both descriptive and empirical peer-reviewed studies were considered. After relevant and credible studies were identified, an evaluation of related study designs, themes, and hypothesis concerning dosage and duration effect of binaural beats stimulation on attention and working memory networks in the brain was performed. The presence of dosage and duration of effect on increases in attention duration and working memory capacity while exposed to binaural beats stimulation were the primary outcome measures.

In addition, there were key concepts that were explored, which included: "effects of binaural beats stimulation on anxiety," "effects of binaural beats stimulation on working memory, "binaural beat effects on attention networks." Journals that frequently include data concerning these key concepts included: *Journal of Personality Assessment, Journal of Cognitive Enhancement, Nature Reviews, Journal of Neural Engineering, European Journal of Neuroscience, Journal of Cognition, Frontiers in Neuroscience, Studia Psychologica, Journal of Comparative Neurology*, and the *Annals of Internal Medicine*.

The risk of bias in individual and across studies is a viable concern. The process of systematic review has been created in order to reduce bias, and several versions of systematic review platforms have emerged to aid in bias reduction, including Quality of Report of Meta-Analyses (QUOROM), the Assessment of Methodological Quality of Systematic Reviews, and PRISMA, among others (Kim et al., 2015). The PRISMA method was used for this systematic literature review, however it does not guarantee the elimination of bias, as researcher bias may be present in the studies included in this review.

An effort was made to reduce bias in this study by including research which held opposing views as to the effectiveness of binaural beats stimulation for the purposes of increasing focus and attention. These articles were included in chapter two. Good faith efforts were made not to filter out relevant, yet alternative conclusions from related studies. These efforts were made during the data collection process vs. the outcome level; repeated attempts to collect the same information other researchers should yield the same results.

Risk of bias across studies is another concern, therefore a review of potential selective reporting and publication bias was conducted across the studies included in this literature review. Because the accessing the dosage and lasting effect of binaural beats stimulation for the purposes of increasing attention and working memory is a novel topic, a commonality that was presented was the inattention to dosage and lasting effect in research where the goal was simply to access the effectiveness of varying frequencies of binaural beats stimulation for the purposes increasing attention or working memory.

It does not appear the intention of the included research was to address the dosage needed and lasting effect of these exposures, so much as it was to focus on whether an effect was present. Some studies included in this systematic review did address dosage, however it did not appear to be a focal point of the research, thereby reducing the likelihood of both selective reporting or publication bias. Similarly, some studies included in this systematic review did include data relating to dosage, however not directly nor intentionally, which also is not considered selective reporting or publication bias.

Data Analysis

Data was collected using Mendeley software, which allowed for sharing and publication of datasets, as well as included a digital object identifier or web address for each of the articles included. Duplicates were filtered out. Next, articles were reviewed one by one, and starred if they covered the topic of binaural beats stimulation for the purposes of increasing attention or working memory. Next, the articles starred were reviewed and the following criteria was extracted and placed into the notes section (option for each article on Mendeley): Author(s), type of study, type of intervention (testing measure), frequency, area of focus (WM or ATN), participants (n=, age, state of health), dosage, lasting effect, and conclusions. Next, starred articles with notes were reviewed to further identification of the articles which had both healthy participants, and reported results concerning correlation data regarding binaural beats stimulation effectiveness.

Articles which meet the above criteria were sorted into an excel spreadsheet for further analysis. Next, the results from the articles reporting corollary data on the effectiveness of binaural beats stimulation for attention and working memory were grouped in an effort to provide conclusions to research question one (*RQ1*). Next, frequency ranges were reviewed, where the mean, median, and mode identified to address research question two (*RQ2*). Lastly, results concerning dosage from binaural beats stimulation were grouped and analyzed in an effort to address research question three (*RQ3)*.

CHAPTER FOUR

RESULTS

In this chapter the results are presented as well as some identified themes from the literature review section. The intended goal of this study was to identify if there is sufficient research available to support the effectiveness of binaural beats stimulation for the purposes of increasing attention and working memory. In addition, if that research provides enough data to support the necessary dosage needed to achieve the increase, as well as the lasting effect from the dosage. In response to the purpose of this study, a systematic review was attempted in order to answer the following three research questions:

RQ1: What evidence is there supporting the effectiveness of binaural beats stimulation for the purposes of increasing attention and working memory in healthy participants?

RQ2: What frequency of binaural beats stimulation is best to achieve cognitive enhancing effects in areas of the brain associated with increased working memory and focus?

RQ3: What evidence is there regarding the dosage and lasting cognitive enhancing effect from binaural beats stimulation exposure, if so what are the boundaries of those effects?

Participants

Because this was a systematic review, there were no direct participants. The only participants mentioned in this review were those through the studies selected for analysis. The participants used in earlier research included this review were healthy subjects, with no specific age, gender, ethnicity, height, or weight. A majority of the subjects were college students, with an age range of 18-46, and a mean age of 24.3 years. Most subjects were tested within the United States, with some European and Indian studies included (Axelsen, Kirk, & Staiano, 2020; Engelbregt et al., 2019; Shekar, Suryavanshi, & Nayak, 2018). Specific criteria included individuals who possess normal hearing without any level impairment in order to ensure proper application of binaural beats, as well as individuals who are not diagnosed with any level of cognitive decline or related condition. Because the selection of participants was contingent upon the data and methods of other researchers, the breadth of this study included all races, genders, and age groups.

Types of Studies Reviewed

All studies reviewed were peer-reviewed articles where research was conducted within the past five years. Of the studies selected using the Prisma Flow diagram for *RQ1* (n=23) (see Figure 4), a majority were Randomized Control Trials (RCT=10), other study designs included double-blind experimental designs, cross-over designs, comparative interventions, single-group comparisons, and one meta-analysis.

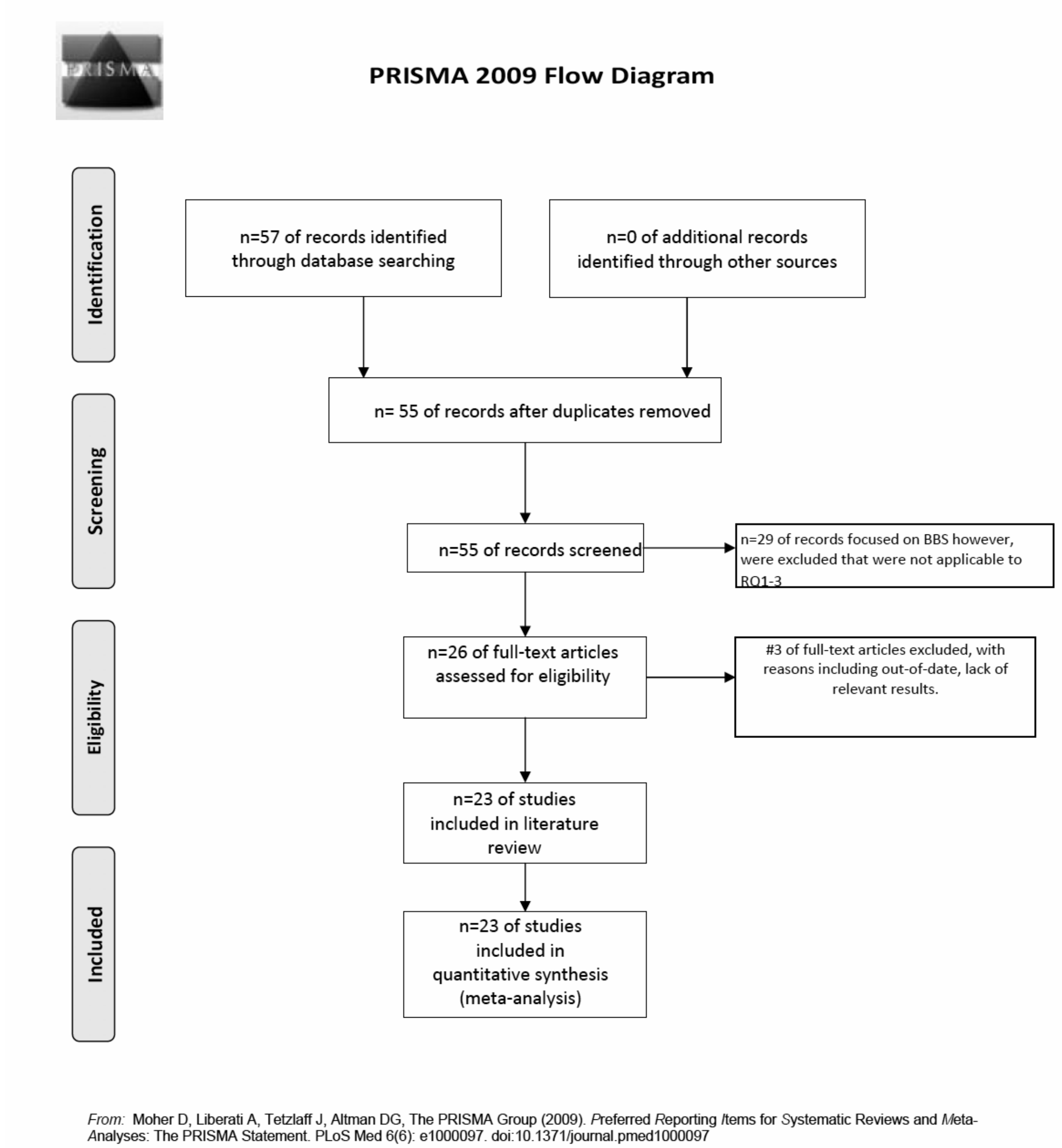


Figure 4: PRISMA Flow Diagram (source: Moher, Liberati, Tetzlaff, & Altman, 2009).

Results Research Question One

The first research question is, what research is there supporting the effectiveness of binaural beats stimulation for the purposes of increasing attention and working memory in healthy participants?

The concept of binaural beats stimulation, through the process of "entrainment" has been well established since it was first discovered by Wilhelm Dove in 1839 (Dove, 1839, p. 387). The physical effects of binaural beats stimulation can be seen through the use of various electronic devices, such as the electroencephalogram, as mentioned in chapter two. Further, the influence of binaural beats stimulation on alleviation from physical impairments/stressors has also been an area of recent exploration, with researchers exploring it's potential ranging from tinnitus perception (Munro & Searchfield, 2019) to post-deployment stress (Gant, 2016).

In order to provide clarity regarding the dosage and lasting effect of binaural beats stimulation for the purposes of enhancing focus and working memory, it is first necessary to establish if there is sufficient research covering these areas. One possibility could be there is insufficient data for one topic (i.e. attention), and sufficient data for the other (i.e. working memory). Another possibility could be there is insufficient data for both topics, which in this case, the data collected from the most relevant research will be highlighted in the discussion session. Lastly, another possibility could be there is sufficient data supporting both attention and working memory, which in this case, any emerging themes are statistical results will be reported.

Binaural Beats Stimulation Can Impact Attention and Working Memory

Research revealed more positive data results from binaural beats stimulation for the purposes of increasing attention and working memory than not. Research revealed no data presenting a negative correlation between testing measure results and exposure to binaural beats stimulation. Of the 23 studies reviewed for *RQ1,* five studies reported no positive correlation between binaural beats stimulation exposure on performance measure tasks. Additionally, there were two studies that included mixed results. For example, a study completed by Ross and Lopez (2020) assessed the effects of 16 and 40 Hertz binaural beats stimulation, finding no change in performance with 16Hertz exposure from one day to the next, however, there was a significant difference between-sessions with 40-Hertz stimulation.

Attentional Blink Tests Were the Most Used Testing Measure

Research revealed the most commonly used method of testing for attention levels with binaural beats stimulation was the attentional blink test (AB). Of the 13 studies examined that tested for attention, four utilized the Sustained Attention Response Test (SART). The frequency of attentional blink used in studies is likely due to its extensive empirical support (Wyble, Bowman, & Nieuwenstein, 2009). Attentional blink is a phenomenon that occurs when two stimuli are presented within 500ms of one another (Shapiro, 1997), resulting in the second stimuli often being missed. This is believed to be the result of attentional limited capacity (Marios, 2005), which can be measured through tests like SART. Though this testing measure was the most often used, research did not reveal any themes regarding testing measures for the impact of binaural beats stimulation on working memory.

A Carrier Tone of 300-340 Hertz Was the Most Used

Carrier waves are important because they are waveforms that are modified with information loaded signals in order to relay information (Ziemer, 2002). Carrier waves are much higher in frequency than the input signal they are carrying, and must be administered at frequency levels that are perceived, but not too distracting (Oster, 1973). The most frequently used carrier tone range was 300-340 Hertz, which is used to create the 40Hertz frequency. This carrier tone was used in a total of four out of 23 studies assessed for *RQ1*. The potential explanation as to why 300-340 Hertz is the most frequently remains unclear, however Oster's research (1973) proposed carrier tones above 440 Hertz start to become less distinct, similarly carrier frequencies that were lower than 90 Hertz would result in a confusion of the binaural beats with the tones used to carry them.

Results Research Question Two

The second research question is, what frequency of binaural beats stimulation is best to achieve cognitive enhancing effects in areas of the brain associated with increased working memory and focus?

The nature of neural oscillations is well understood, as mentioned in Chapter Two, neural oscillations arrange themselves according to a harmonically arranged hierarchy, which follows a mathematical progression from one frequency range to the next. Them middle frequency of each range is as follows: Delta waves are at 2.5 Hertz, Theta waves are 5 Hertz, Alpha waves are 10 Hertz, Beta waves are 20 Hertz, and Gamma waves are 40 Hertz (Rassi, Dorffner, Gruber, & Klimesch, 2018). Further, frequencies are subjective, meaning each person has their own frequency structure. For example, during a conversation between two people, where both are experience beta waves (common during engaging in dialogue) one person's dominant brainwaves may be at 16 Hertz, while the other may be at 18 Hz. This depends on the person's body mass, blood volume, network size in the brain, and amount of myelination, meaning each person has their own frequency structure (Klimesch, 2018). *RQ2* seeks an exploration of which frequency range has the highest correlation of increased functionality in individuals assessed for working memory and attention.

Some potential outcomes may be a lack of data in one particular frequency range and robust data in others. Additionally, there could be instances where multiple studies cover the same range but differ slightly with the particular frequency (i.e. 14Hertz and 15 Hertz), making it difficult to reach conclusions as to which Hertz is more effective. Themes and statistical results will be highlighted for relevant frequencies assessed.

Gamma Waves Are the Most Used Binaural Beats Frequency

This study revealed the most used frequency range used for assessing the effectiveness of binaural beats stimulation on attention and working memory is gamma, followed by beta, then alpha. Gamma waves were used in 11 of the 23 reviewed studies; followed by Beta (n=7), and Alpha (n=6). Within the gamma range, 40 Hertz is used almost exclusively. This study revealed studies utilizing beta waves varied between 14-25 Hertz. The studies testing using alpha waves ranged from 9.55-10.7 Hertz, with most testing using 10 Hertz specifically.

There Are Six Common Frequencies Used in Research

A theme that presented itself in this review was the similarity of frequencies used in research. The frequencies most often examined in studies are *40 Hertz*, *16 Hertz*, *15 Hertz*, *14 Hertz*, *10 Hertz*, and *5 Hertz*, with few studies examining binaural beats stimulation and working memory or attention that deviated from these frequencies. For example, Sharpe and Mahmud (2020) conducted research using 40 Hertz, a common frequency, but also included comparisons between 25 Hertz and 100 Hertz.

40 Hertz is the Most Effective Frequency for Increasing Attention and Working Memory

Among the most commonly utilized frequencies for assessing the impact of binaural beats stimulation on attention and working memory, a cross comparison revealed 40 Hertz Gamma as the most effective range. Of the studies selected to access the effects of binaural beats stimulation on attention and working memory (n=23), a total of six utilized multiple binaural beats stimulation frequency ranges, allowing for cross-comparison. In the studies examining the effects of binaural beats stimulation stimulation in the frequency of 40 Hertz (n=4), three studies showed more significant differences when exposed to 40 Hertz, compared to the other conditions 10 Hertz, 16 Hertz, 25 Hertz, and 100 Hertz (Reedijk, Bolders, Colzato, & Hommel, 2015; Ross & Lopez, 2020; Sharpe & Mahmud, 2020), while one study showed similar results between 40 Hertz and 10 Hertz (Shekar, Suryavanshi, & Nayak, 2018). There were two studies that provided a cross comparison between, *5 Hertz, 10 Hertz,* and *15 Hertz*. Of those studies, more significant results were obtained from 15 Hertz exposure compared to 5 Hertz and 10 Hertz (Beauchene et al., 2016; Beauchene, 2018).

Results Research Question Three

The third research question is, what evidence is there regarding the dosage and lasting cognitive enhancing effect from binaural beats stimulation exposure, if so what are the boundaries of those effects?

The area of dosage and lasting effect is a key area of exploration given there is a potential for binaural beats stimulation to be effective in the manipulation of brainwaves for the purposes of an array of therapeutic and cognitive enhancing benefits. With the emergence of technology used to aid in research in determining brainwave activity and moments of consciousness such as with the EEG, it is now possible to measure the lasting effect of binaural beats stimulation on the brain in both real-time (Holmes, 2014), or at a specific moment in time, as with the fMRI (Hennig, Speck, Koch, & Weiller, 2003).

It is now also possible to measure lasting effect by accessing performance during and after the binaural beats stimulation period has ended. This is achieved by administering cognitive tests prior to, during, and after exposure to binaural beats stimulation and comparing the results to draw conclusions. Research covering these areas will be explored, and any themes and statistical results will be gathered and evaluated.

The Longer the Dosage the Larger the Effect

Research revealed duration of exposure plays a pivotal role in the magnitude of effect from binaural beats stimulation. Some factors that contribute towards this magnitude are the frequency used, such as carrier tones, and whether or not binaural beats stimulation was administered “before the task,” or “before and during a task,” where applying binaural beats stimulation during a task alone may mitigate the overall effectiveness of binaural beats stimulation.

Carrier tones need to be applied in a manner that is comfortable, where the frequency is able to be perceived, but not so low that a nuisance is reported by the listener, consistent with Oster’s (1973) findings. Additionally, is currently room for exploration regarding the necessary saturation point for binaural beats stimulation to become effective.

To date, there are two studies that assess the duration of exposure, both studies reported nine minutes of exposure is needed to achieve some cognitive impact (Garcia-Argibay, Santed, & Reales 2019; Ala, Ahmadi-Pajouh, & Nasrabadi 2018). When binaural beats stimulation are not applied prior to performing a sustained attention or working memory task (i.e. OSPAN, SART) their effectiveness becomes indexed. However, when binaural beats stimulation are applied prior to testing, as well as before and during, their effectiveness is increased; An increase in exposure time equals and an increase in binaural beats stimulation effectiveness (Garcia-Argibay, Santed, & Reales, 2019; Jirakittayakorn & Wongsawat, 2017).

Binaural Beats Do Have a Lasting Effect

Research revealed there is a lasting effect from exposure to certain BB frequencies. A review of the 23 articles covering the effects of binaural beats stimulation on attention and working memory revealed seven articles providing lasting effect data (Axelsen, Kirk & Staiano, 2020; Cortez et al., 2019; Kalyan & Kaushal, 2016; Kirk, Wieghorst, Nielsen, & Staiano, 2019; Kraus & Proubanová, 2015; Jirakittayakorn & Wongsawat, 2017; Garcia-Argibay, Santed, & Reales, 2019). This data was collected by reviewing the materials and methodology sections of those articles, which highlighted the application of binaural beats stimulation prior to testing. A theme presented in the articles considered for this review was most applied binaural beats stimulation either "before testing" or "before and during testing." Studies that included "before and during" or "during testing" only could not be considered for lasting effect due to the presence of binaural beats stimulation during the course of the measure needed for collecting lasting effect data.

There Are No Studies Directly Examining Lasting Effect

Data concerning the duration of the testing measure utilized was collected indirectly, meaning dosage and lasting effect results can only be gathered deductively. Duration of effect was gathered by collecting data concerning the time elapsed from the testing measure used from the seven studies that utilized the "binaural beats stimulation before" testing was initiated. For example, Kraus and Porubanová (2015), exposed participants to 9.55 Hertz Alpha binaural beats stimulation for 12 minutes prior to taking an Operation Span Task (OSPAN), a common test used for measuring working memory.

The duration of effect of the binaural beat's stimulation was not a topic covered in their study, however the duration of the OSPAN test takes 16 minutes to complete, highlighting the duration of effect was maintained for at least 16 minutes. The studies (n=7) included enough information to gather the minimum duration (minutes) of testing, and also provided data as to whether there was a positive correlation between the testing results and binaural beats stimulation exposure.

Summary

There is evidence to support the overall effectiveness of binaural beats stimulation for the purposes of increasing attention and working memory, where a majority of studies examining this topic reported positive correlations than not. The presence of carrier tones was an emergent theme that was present in most studies, where it's potential significance will be discussed in the next section. Gamma frequency is the most studied frequency concerning its impact on attention and working memory. Additionally, gamma frequency has the most support for its effectiveness in increasing attention and working memory.

Dosage plays an impact on the effectiveness of binaural beats stimulation, where a minimum threshold must be achieved in order to achieve effectiveness, discussion of the criteria surrounding the dosage needed will be discussed in the next section. Lastly, the presence of binaural beats stimulation prior to engaging in attention or working memory allows for a determination as to the duration of effect, where there is evidence the effects of binaural beats stimulation continue beyond the period of exposure.

CHAPTER FIVE

DISCUSSION

The purpose of this systematic literature review was to determine the breadth of the effect of binaural beats stimulation on attention and working memory networks in the brain, and whether those effects can increase cognitive performance. Binaural beats are achieved through the process of entertainment, where two similar tones are presented in each ear, creating the illusion of a single tone, which is the difference between the two slightly different tones in each ear (Dove, 1839). Since their discovery, much has been learned about binaural beats stimulation and their effects on physiological functions (Shekar, Suryavanshi, & Nayak, 2018, p. 829). The tones emitted through binaural beats stimulation can be manipulated to match particular brainwaves. Additionally, it is has been determined the brainwaves fall into the following hierarchy: Delta (0.9–3.5 Hertz), Theta (3.5–7 Hertz), Alpha (7–14/15 Hertz), Beta (14/15–28 Hertz) and Gamma (28–56 Hertz) (Jaiswalet al., 2019); each of which has a particular frequency and function. For example, Alpha waves range between 7-14/15Hertz, and are emitted when we are in a restful and conscious state.

There currently exists room for exploration as to the effects of binaural beats stimulation on attention and working memory, as there are other modalities that have shown a positive effect on those areas, such as with meditation (Rahlet al., 2017) and streamlined music (Mossbridge, 2016). There is potential for binaural beats stimulation to change lives by mitigating some of the symptoms of medical concerns such as cognitive decline or attention deficit hyperactivity disorder.

This study is aimed at determining which frequencies are best for achieving positive results on attention and working memory, what duration of exposure is needed to achieve those results, and how long will that exposure be expected to last. Various frequencies were explored, for various durations, as well as various test measures and protocols were examined in order to draw conclusions to the following research questions:

RQ1: What research is there supporting the effectiveness of binaural beats stimulation for the purposes of increasing attention and working memory in healthy participants?

RQ2: What frequency of binaural beats stimulation is best to achieve cognitive enhancing effects in areas of the brain associated with increased working memory and focus?

RQ3: What evidence is there regarding the dosage and lasting cognitive enhancing effect from binaural beats stimulation exposure, if so what are the boundaries of those effects.

Discussion of Findings

Existing literature concerning binaural beats technology has found binaural beats technology to be an effective intervention to assist with various physiological states as well as cognitive enhancement. The application of binaural beats stimulation ranges from reducing tinnitus perception (Munro & Searchfield 2019), to increasing attention (Axelsen, Kirk, & Staiano, 2020) to reducing operative anxiety (Wiwatwongwana et al. 2016). These findings are helpful in laying the groundwork for exploring other potentialities of binaural beats stimulation, and encourage additional research in these areas.

Though there is exploration into the effects of binaural beats technology for the purposes of enhancing cognition, there is currently room to address the dosage and lasting effects of its impact on cognitive function, particularly attention and working memory networks in the brain. Some of the most prominent highlights of this study are as follows. There is clear evidence that binaural beats stimulation does have an impact on physiological function through brainwave manipulation (Góes, 2018; Jirakittayakorn, & Wongsawat, 2017). Additionally, the presence of carrier tones may be an important factor to take into consideration when applying binaural beats stimulation, where the degree in which binaural beats stimulation impacts brain waves may rely heavily on the frequency used in carrier tones (Garcia-Argibay, Santed, & Reales, 2019). Furthermore, dosage matters, playing a pivotal role in either indexing or enhancing the effects depending on the duration of exposure (Garcia-Argibay, Santed, & Reales, 2019; Jirakittayakorn & Wongsawat, 2017). Lastly, most literature concerning binaural beats stimulation for the purposes of increasing attention and working memory falls into six common frequencies, which is helpful in providing context and making cross comparisons.

Research Question One

Research question one was, what research is there supporting the effectiveness of binaural beats stimulation for the purposes of increasing attention and working memory in healthy participants? Research exploring the effectiveness of binaural beats stimulation for the purposes of increasing attention and working memory revealed some encouraging results, supporting its effectiveness under several different testing conditions and frequency ranges. The exploration of binaural beats stimulation for manipulating various cognitive states has become increasingly popular, with most studies covering binaural beats stimulation and attention/working memory reporting positive associations. It appears that overall from this research, when assessing the effectiveness of binaural beats stimulation for the purposes of increasing attention and working memory, the likelihood of an increased measurable impact on cognitive performance is high, but varies depending on the methodology.

Inconsistencies amongst research methods exploring binaural beats stimulation may contribute towards mitigating their potential effectiveness. Research from this study revealed there were several inconsistencies related to dosage information, frequency used, carrier tones, and testing methods. These inconsistencies may be contributing factors towards the magnitude of the results, either significant or consistent with the null hypothesis.

This study revealed binaural beats seem to be particularly effective in stimulating attention and working memory networks overall, where a majority of the studies examined this this literature review highlighted the significance of their positive effect. Attention is better regulated with certain BB frequencies over others. For example, 40 Hertz (gamma waves) and 14 Hertz (alpha/beta waves) are shown to be effective (Axelsen, Kirk & Staiano, 2020; Kirk et al., 2019; Ross & Lopez, 2020; Colzato, & Hommel, 2015).

Beta waves are associated with typical information transfer commonly seen when two people are engaging in focused conversation with one another. The presence of alpha waves could help reinforce this process. Research from this study confirmed this by showing exposure to alpha/beta waves in the bridge frequency of 14Hertz (both beta and alpha) effectively reduces mind-wandering and increases focus (Axelsen, Kirk, & Staiano, 2020; Kirk, Wieghorst, Nielsen, & Staiano, 2019).

The effectiveness of these frequencies may be due to coupling principles mentioned in chapter two, where top-down information processing is achieved by deactivating particular distractors in the environment (commonly associated with bottom-up processing), which helps the individual maintain selective attention (Frings & Wühr, 2014). Top-down processing is typically associated with alpha-beta-band synchronization (Gaspelin & Luck, 2018), where the presence of lower frequencies regulates higher frequencies and travel over larger regions of the brain. Top-down coupling (or control) of lower frequency phase to high frequency amplitude seems to be the hallmark of attentive and predictive information processing (Bastos et al., 2015; Marton et al., 2018).

Chapter two highlighted how working memory can be increased through application of binaural beats stimulation through the same principles, where the central executive function of working memory switches and divides focus while connecting and integrating elements of long-term memory, short-term, visual, and spatial information. Brainwaves over the prefrontal, visual, secondary-visual, parietal, and temporal cortices during these functions are seen operating in a top-down manner, where the presence of theta-gamma band synchronization is present. Top-down theta waves are believed to operate by time-locking rhythms of speech, allowing for the modulation and readjustment of peaking gamma waves (Hyafil et al., 2015). This may provide a clue as to why gamma waves are so effective in studies for increasing working memory, where introducing gamma waves continuously supports and maintains enhanced cognitive control. The results from this study agree with studies highlighted in chapter two, which support binaural beats stimulation effectiveness for increases of attention and working memory (Calomeni et al., 2017; Gálvez, Recuero, Canuet, & Del-Pozo, 2018; Kalyan & Kaushal, 2016; Kraus & Porubanová, 2015; Shekar, Suryavanshi, & Nayak, 2018). For example, Kalyan and Kaushal (2016), exposed nine healthy adults to 10.7 Hertz binaurally for approximately 28 minutes, followed by a recovered resting state for 5 minutes, followed by taking the visual spatial memory post-test (a pre-test was administered prior to any intervention). The result from their study revealed alpha frequency stimulation (10.7 Hertz) created positive effects on theta brain oscillations, specifically in the frontal, parietal, and temporal lobes. Additionally, post-test scores were increased from pretest scores on the visual spatial memory test.

Research Question Two

Research question two was, what frequency of binaural beats stimulation is best to achieve cognitive enhancing effects in areas of the brain associated with increased working memory and focus? Research revealed the most effective frequency for increasing attention and working memory is 40 Hertz gamma. This may be due to the fact 40 Hertz is the most tested frequency overall. Why this frequency is the most effective compared to other freuqncies that are commonly studied (i.e. 14 Hertz, 10 Hertz) is likely due to the presence of gamma wave bursts in the brain associated with moments of higher cognitive function, commonly associated with insight or "aha" moments (Rosen & Reiner, 2017; Benjaboonyazit, 2016). However, apart from 40 Hz, there exists a gap in current research for the remaining frequencies within the gamma range. One explanation as to why 40 Hetz is studied almost exclusively is researchers may be adding to the data pool examining Gamma waves for the purposes of enhancing cognition, and due to the positive results from those studies, preference may have been to test 40 Hertz against other testing parameters versus testing a different gamma range frequency against the same testing parameters at the original. For example, researchers Engelbregt, et al. (2019), Hommel, et al., (2016), and Ross and Lopez (2020), all used 40 Hertz at the specific frequency of choice in the gamma range; testing it against various parameters (i.e. rapid serial visual presentation, dual-task, and flanker attention task). Of the 23 selected studies for this literature review, 11 utilized 40 Hz as the gamma frequency range choice. No studies examined other gamma range frequencies (i.e. 41, 45, 44.4, 50.1).

Another consideration for the influence of 40 Hertz on attention and working memory has to do with the relationship between gamma and theta waves. In chapter one a seminal study by George Miller (1956) was mentioned, highlighting that the average person can hold seven units of information at a time (plus or minus one). Interestingly enough, a 40 Hertz gamma cycle is approximately 7 theta cycles. Theta waves work by updating information, while gamma waves are storing it, thereby creating a harmonic relationship that increases memory (Góes, 2018). With this information at mind, one of the mechanisms in which binaural beats may be effective is by enhancing the updating and storing information process previously mentioned through providing a constant stream of external binaural gamma stimulation.

Gamma waves are most active during unconscious states such as sleep, as they are strongly related to the presence or absence of high amplitude slow waves, such as theta waves, however are independent of the state of arousal (Vanderwolf, 2000). Furthermore, gamma oscillations are typically in specific regions or localized to particular parts of the brain, working to support particular tasks. This process is linked by low-frequency oscillations, which modulate higher frequency waves like gamma. Since there are multiple areas of the brain associated with working memory and attention, localized gamma bursts combined with global or long-range neural oscillations attributed to low-frequencies, such as theta waves, create cross-frequency coupling, which has been associated with increased attentional control (Clayton Yeung, & Kadosh, 2015). This study examined research by Sharpe and Mahmud (2020), which highlighted the contrast between gamma and beta waves (25 Hertz, 40 Hertz, 100 Hertz) by testing participants across four customized tests, mathematics, problem solving, memory, and mood. Duration of effect was not measured and the carrier tone used in the three conditions was not specified however, results indicated 40 Hertz binaural beats stimulation showed a statistically significant increase in post-scores versus pre-scores ($p=0.0027$) on both cognitive and memory tasks.

Another important factor to consider is the fact that working memory and attentional focus is typically associated with top-down processing vs. bottom up. This poses somewhat of a conundrum since gamma waves are typically associated with bottom-up processing (Richter, Thompson, Boseman, & Fries, 2017). In chapter two it was highlighted that bottom-up processing is associated with moments of distraction or insight, where the attention pivots from intentional focus to unintentional focus. There seems to be a relationship present between two different frequencies that allows for the processing of bottom-up gamma information with top-down theta control. Furthermore, in chapter two it was highlighted that lower frequencies typically regulate higher frequencies according to *binary hierarchy brain body oscillation theory* (Klimesch, 2018). Gamma waves are a sensory binder, meaning to enhance attention and working memory, gamma waves are usually carried by theta waves though coupling principals to areas of the brain associated with awareness (Gyorgy & Xiao-Jing, 2012). Since gamma waves originate in several areas of the brain to include cortical and subcortical areas such as the hippocampus (Belluscio et al., 2012) they are associated with visual, auditory and tactile stimuli (Góes, 2018). Visual, auditory, and tactile stimuli are often reactive stimuli. For example, a moment of gamma burst may occur when you hear a certain song coming from a nearby restaurant, which makes you immediately recall a fond childhood experience associated with that song.

Another example, highlighting a combination of top-down theta and bottom-up gamma processing is when reading a book, which requires top-down processing, gamma-theta coupling may occur when you start to draw conclusions from what you've learned in the book, identified patterns in the text, or connect the words with personal experiences you've had, allowing for moments of insight to occur; this would highlight the effect of gamma burst-theta coupling in real-life.

Earlier it was mentioned that gamma waves are associated with moments or flashes of insight, the moments need to be carried into the awareness of our frontal lobe, and the faster the gamma the more information can be stored in short term memory for later processing (Góes, 2018). However, as Klimesch (2018) highlighted regarding harmonics and coupling principles, there needs to be an effective harmonic relationship between different frequencies. For example, meditation, a mental act that requires the clearing of the mind results in decoupling of phase synchronization and the lowering of harmonic relationships, whereas activities that involve attention and working memory require the harmonic relationship between two frequencies to increase (Rodriguez-Larios & Alaerts, 2019). Furthermore, inconsistent gamma activity has been associated with neurological disorders such as Parkinson's and Alzheimer's disease (Jia & Kohn, 2011).

This information may provide a clue as to why direct exposure to gamma waves through binaural beats stimulation has been shown to be effective in stimulating the neural networks involved with attentional control and working memory. Binaural beats stimulation provides a source of phase synchronization due to its ability to create entrainment, helping to a degree, of providing a maintenance of continual phase locking so desired states of focus and attention can be maintained or enhanced. Lastly, researchers may be more interested in stimulating gamma waves like 40 Hertz, compared to other frequency ranges due to their ability to excite and stratify certain brain regions for moments of peak clarity and insight.

Another area that is important to highlight from this study was the fact that, while binaural beats in the 40 Hertz range do seem to be effective in temporarily increasing attention and working memory, the boundaries of those effects remains unclear; 40 Hertz frequency (specifically) is studied almost exclusively. There may be potential for other gamma frequencies to be effective as well (i.e. 43 Hertz or 51 Hertz), however there are no studies that focus on those frequencies to support results. Perhaps this is due to the variety of factors that go into testing one single frequency such as 40 Hertz. Carrier tones, dosage, sex of the participant, individual physiological makeup, testing measures, and presence of masking sounds are all variables that may alter results. With these considerations in mind, 40 Hertz alone is still under studied, however other frequencies in the gamma range should be explored to provide cross-comparisons.

This study sought to make cross-comparisons to similar research methodologies in order to provide as clear data as possible, that data was limited to a small number of studies (n=23). However, having considered the variables, there does seem to be enough evidence to support the overall effectiveness of 40 Hertz, where more studies examining the effectiveness of 40 Hertz showed positive results (n=9) compared to the studies that found none (n=2). It should be noted, one of the two studies that reported no significant findings, did not specify the carrier tones used in the study (Parciauskaite, et al., 2019), which may have had an impact on effectiveness.

Carrier Tones

The importance of carrier tones was first discussed by Oster (1973), who discovered carrier tones presented too low (<90 Hertz) would confuse the listener, making it difficult for them to distinguish between the beat and the tones used to present them. Tones presented too high (>1000 Hertz) become difficult to perceive and seem to vanish. Oster determined the best frequency to perceive binaural beats stimulation was at about 440 Hertz (Oster, 1973). Another study discussed the potential impact of carrier tones. Garcia-Argibay, Santed, and Reales (2019), highlighted there is a difference in perception of binaural beats stimulation between males and females, as well as individual mesostriatal dopamine levels, which may impact the degree gamma binaural beats stimulation affects cognition. These dopamine levels can be detected through spontaneous blink rate, where introverts are more reactive to changes in dopaminergic activity compared to extraverts, highlighting a potential variable researchers should take into consideration in future studies. Garcia-Argibay, Santed, & Reales (2019) discussed one way to mitigate these variables is to use higher frequency carrier tones, where less differences in sensitivities between introverts and extroverts are observed. This research supports the effectiveness of carrier tones within these ranges, most of the studies examined in this literature review achieved positive effects from binaural beats stimulation by using carrier tones that were above 240 Hertz and below 480 Hertz.

This could potentially explain differences in results between one study reporting positive results from 16 Hertz and 15 Hertz (two close frequencies). For example, Robinson et al. (2020) reported no significant changes with 16 Hertz compared to a pure tone control. The carrier tone was lower than most other studies, at 200-216 Hertz. This contrasts the results of two other studies utilizing 15 Hertz, completed by Beauchene, et al. (2016) and Beuchene (2018), where positive results on testing working memory were seen with 15 Hertz exposure using slightly higher carrier tones of 240-255 Hertz. Both of Beuchene’s studies (2016; 2018) focused on testing for working memory, using the delayed match-to-sample, N-back, and visuospatial tasks, while Robinson’s et al. (2020) study tested for attention using a sustained attention task test. Whether or not this slight difference in frequency (15 or 16 Hertz) and slight increase in carrier tones has a significant impact is unknown, but should be explored in further research.

Research Question Three

The third research question was, what evidence is there regarding the dosage and lasting cognitive enhancing effect from binaural beats stimulation exposure, if so what are the boundaries of those effects? Research revealed only one resource for determining the effectiveness of binaural beats stimulation on the cognitive functions of attention and working memory with an examination of dosage. Garcia-Argbay, Santed and Reales (2019) examined alpha, beta, gamma, and theta waves used through binaural beats stimulation and revealed effectiveness in all frequency ranges with the exception of theta waves. The study highlighted key aspects that are relevant to this study, which are the use of carrier tones, dosage, and masking, which was highlighted in chapter two. This situdy is significant because there exists a gap in research covering these areas. Garcia-Argibay, Santed, and Reales (2019) highlighted a correlation between dosage of exposure and effect sizes, where under exposure can index results, further suggesting the minimum dosage of exposure should be at least 9-10 minutes in order to achieve maximum effect.

Lastly, it was highlighted that carrier tones should be taken into consideration for future studies, revealing there may be differences between male and female perception and level in which Hertz should be applied. Garcia-Argibay, Santed, and Reales' (2019) research supports the information presented in this literature review concerning dosage, carrier tones, and effective frequencies. When it comes to the effectiveness of binaural beats stimulation it is critical in determining what dosage is applied. Some studies examined in this review did not examine dosage at all (Reedijk, Bolders, Colzato, & Hommel, 2015; Shekar, Suryavanshi, & Nayak, 2018), which prevents any possible cross comparisons amongst other similar studies.

This is the first study to date that has highlighted the significance of accessing the dosage, which is critical in determining when and how long to apply binaural beats stimulation. Furthermore, dosage is vital in determining lasting effect, another area examined during this study. Research revealed a lasting effect does seem to be present after exposure, where increases in exposure can lead to a lasting effect. In chapter one the importance of determining a lasting effect was discussed. The results from this literature review highlight some parameters of those effects, the breadth of which remains unclear. Data collected concerning lasting effect was limited to deductive reasoning, as no research has sought specifically to address duration of effect. One meta-analysis completed by Garcia-Argibay, Santed, and Reales (2019) specifically discussed this topic, revealing longer dosage creates an enhanced effect. Research revealed additional data supporting this conclusion (Ala, Ahmadi-Pajouh, & Nasrabadi, 2018; Jirakittyakorn, & Wongsawat, 2017), both of which highlighted the importance of increased dosage. This is promising since this area of research remains currently underexplored.

Minimum Dosage

Research revealed promising data concerning minimum dosage need for effect, as well as the necessary parameters of those effects. Minimum exposure was originally Ala, Ahmadi-Pajouh, and Nasrabadi (2018), who sought to examine to topic of minimum dosage needed to achieve cumulative effects on brain power and functional connectivity. Their study found that exposure to 7 Hertz theta waves for three minutes was not enough to stimulate cognitive changes, however, at six minutes an impact was observed and with nine minutes connectivity was altered. This study was significant because it provided some key data regarding what the threshold currently is for binaural beats exposure.

Ala, Ahmadi-Pajouh, and Nasrabadi's (2018) study was later reinforced by Garcia-Argiibay, Santed, and Reales (2019), who conducted a meta-analysis on 22 studies that explored the effects of binaural beats exposure on cognition, anxiety, and pain perception. Garcia-Argiibay, Santed, and Reales (2019) suggested exposure should occure for at least 9-10 minutes in order to achieve maximum benefit.

Maximum Dosage

If the minimum duration of exposure is 9-10 minutes, what is the maximum duration of exposure? According to Jirakittayakorn and Wongsawat (2017), listening to 40 Hertz binaural beats stimulation for too long can create over-stimulation of the brain resulting in fatigue, concluding listening to 40 Hertz over 20 minutes may index its effectiveness. Lastly, the brain perceives binaural beats stimulation differently, where the right hemisphere responds to binaural beats stimulation than the left hemisphere. Unfortunately, research revealed the topic of maximum dosage was the most underexplored area of this literature review. There was no data providing evidence for maximum exposure outside of this study highlighting the potential effect of overexposure to 40 Hertz binaural beats stimulation.

Timing of Exposure Matters

Not only does minimum and maximum dosage matter, but the timing of exposure matters, where application of binaural beats stimulation before testing or before and during testing created a greater effect versus applying binaural beats stimulation during testing alone (Garica-Argibay, Santed, & Reales, 2019). This data is consistent with the findings in this literature review, where 15 of the 23 examined studies included data concerning whether or not binaural beats stimulation was applied either before only, during only, or before and during testing.

This is significant because it appears binaural beats applied prior to engaging in an attention or working memory task has similar effects to other popular attentional focusing techniques such as mindfulness meditation. Mindful meditation has been shown to increase attentional awareness by reducing mind wandering. Kirk, Weighorst, Nielsen, & Staino (2019), conducted a side by side comparison study with on-the-spot binaural beats and mindfulness meditation, where 15 minutes of exposure (or meditation) reduced mind wandering while taking a sustained attention response test under both conditions. This is promising because not only are binaural beats effective when they are played prior to engaging in a cognitive load task, but unlike mindfulness meditation, exposure can continue during the task, in fact this research is suggesting both, exposure to binaural beats both prior to and during engaging in a cognitive load task.

Of the 15 studies, 12 reported improvements from binaural beats stimulation exposure before only or before and during testing. Two studies utilizing exposure “during testing only,” with no exposure prior to testing reported no impact from binaural beats stimulation exposure on testing results, and only one study reporting exposure “before only,” reported no significant increases in attention or working memory. These numbers support Garica-Argibay, Santed, and Reales’ (2019) study, and highlight the importance of timing of exposure. Exposure to binaural beats stimulation before or before and during testing seems to improve its overall effects on attention and working memory.

Duration of Effect

The lasting effects of binaural beats stimulation are more difficult to identify, ranging from as little as five minutes to 24 hours. For example, in the study completed by Jirakittayakorn and Wongsawat (2017), dosage was clearly identified at 40 minutes (40 Hertz), followed by a word list recall test, which duration of completion was subjective. The only data provided was the test consisting of 2 sets of 15 words, presented at two seconds each, with a two-minute gap period between the presentation of the words and the recall period, therefore 2 sets x 15 words = 30 seconds x 2 sets = 60 seconds + 4 minutes (gap for each test) = 5 minutes minimum of duration of effect. Their results from the study showed a positive effect of binaural beats stimulation exposure compared to the word list recall test prior to exposure, meaning the duration of effect lasted for a minimum of 5 minutes, however the duration is probably much longer given the recall period was not recorded in the study.

Another example of this is the study completed by Ross and Lopez (2020), who sought to measure the differences of binaural beats stimulation exposure on attentional blink performance from one day to the next. The researchers reported subjects were exposed to three days of binaural beats stimulation (which could be spread out up to seven days). Each day of testing consisted of 4 blocks consisting of 10-12 minutes exposure each. Where one day students would be exposed to either 16 Hertz, 40 Hertz, or no sound, in random order. The students were randomly placed in exposure groups. For example, group A would be exposed to 16 Hertz the first day, 40 Hertz, the second day, and no sound the third day. The results indicated an increase in test scores in the group exposed to 40 Hertz the first day had the highest rate of improvement from the first day to the second compared to the other groups, concluding the improvement of binaural beats stimulation at 40 Hertz is not evident immediately but after a night's sleep. Meaning the duration of effect could last as long as 24 hours.

Duration of effect was not only limited to the two studies mentioned above, Kayan and Kausal (2016), reported increases in working memory from binaural beats stimulation exposure of 10.7 Hertz after 25 minutes of exposure, followed by five minutes of rest, then a visual spatial memory test, which typically runs for 30 minutes. Another study completed by Kraus and Porubanová (2015), reported positive effects of exposure to 9.55 Hertz binaural beats stimulation after a dosage of 12 minutes, followed by administering an OSPAN test which takes 16 minutes to complete. Another study conducted by Axelsen, Kirk, and Staiano (2019) reported positive results from 12 minutes exposure of 14 Hertz binaural beats stimulation, followed by a SART test, which takes six minutes to complete. Similarly, Kirk, Wieghorst, Nielsen, and Staiano (2019) concluded positive effects of 14 Hertz binaural beats stimulation after 15 minutes of exposure, followed by a SART test of six minutes in duration. Lastly, Cortez et. al (2019), reported positive effects of 5 Hertz binaural beats stimulation after 15 minutes of exposure consecutively across five days, where a post intervention (binaural beats stimulation exposure) RBANS test was administered at the end of the fifth day. The RBANS takes approximately 30 minutes to administer (GLA, 2015), meaning the duration of effect is at least 30 minutes.

Overall there were seven of the 23 studies selected for this review that contained data that could be used to determine a minimum duration of effect. The studies that provide enough data to draw deductive conclusions related to lasting effect supported the hypothesis that there is a lasting effect of binaural beats stimulation to some degree, however the parameters of duration remain unknown. It was clear from the literature reviewed that not enough is being done to address this topic, which in itself is a crucial piece of needed information when assessing the overall effectiveness of binaural beats stimulation on cognitive enhancement.

Considerations

The results presented in this literature review are correlated to the findings presented in chapter two. The findings overall support the literature presented in chapter two concerning the impact of binaural beats stimulation on attention and working memory networks, through the process of cortical entrainment, via coupling and phase synchronization. Binaural beats are effective in creating cortical entrainment. This research has highlighted the suggested parameters regarding minimum dosage needed in order to create a cognitive enhancing effect. The research presented in chapter four presented limitations to particular frequencies, as well as challenges associated with missing key pieces of data that were needed to draw clear conclusions for this study. Although there were challenges presented in finding conclusions for all the research questions, specifically related to maximum dosage, several conclusions were made, which can create a platform for additional research in these topics. For example, deductive reasoning was used for concluding there is an overall lasting effect of binaural beats stimulation, however future research will need to continue to monitor participants' brain waves after a period of testing has ended, as well as retesting after a period of time to determine the rate of decline.

This study has shed some light on the potential reasons as to why 40 Hertz gamma is the most effective frequency. There is some supporting research that connects gamma theta synchronization to the rate in which information is stored and the speed in which information is processed, where the typical adult can store up to seven pieces of information at any given time, which is the rate of each theta cycle. Additionally, gamma waves are attributed to higher amplitude and localized areas of activity in the brain, which are associated with moments of insight. Because theta couples with gamma, and carries it to other parts of the brain, this may explain why external stimulation via binaural beats stimulation excites and elicits cognitive clarity. However, more research will be needed to support these possible explanations.

Significance of Findings

Improving attention and working memory capacity is a topic of concern for almost anyone. The cognitive load requirements on humans today is great, where our brains have remained relatively the same over the past millennia, while the complexities of life have expanded exponentially. Globally, our attention span is declining (Microsoft, 2015), and individuals experiencing attention working memory deficits are in particular need of effective interventions. With conditions like attention deficit hyperactive disorder it has been reported up to one-third of all children diagnosed with ADHD have received no medication or behavioral treatment (Danielson, et al., 2018). On the other end of the age spectrum, working memory tends to decline with age, negatively affecting seniors (Clapp & Gazzaley, 2012). Therefore, the potential benefits of binaural beats stimulation apply to not only those seeking to improve their mental edge, but extends to those who are experiencing impairment.

Research has indicated the effects of binaural beats stimulation can be applied in various scenarios and can achieve a positive impact on attention and working memory (Calomeni et al., 2017; Gálvez, Recuero, Canuet, & Del-Pozo, 2018; Kalyan & Kaushal, 2016; Kraus & Porubanová, 2015; Shekar, Suryavanshi, & Nayak, 2018). Their ease of use, low cost, ability to cancel out outside noises due to their overdubbing effect, ability to be masked with other sounds (i.e. ocean, pink noise) without indexing their effectiveness, and countless variations specific frequencies can make them an ideal intervention for numerous settings. Binaural beats have the potential for immediate and wide-spread intervention for many fields of study, as well as the lay person in general.

Findings of significance included several areas of this study. First, binaural beats are overall effective in creating cognitive entrainment and various frequencies of binaural beats are effective in creating many measurable physiological changes (Mcconnel et al., 2014; Munro & Searchfield, 2019; Chaieb, Wilpert, Rever, & eFell, 2015; Bastek, 2018; Citaldi, 2018). Second, the findings presented in this literature review support the effectiveness of binaural beats for increasing attention and working memory, particularly in the alpha (7-14 Hertz), beta (14-28 Hertz) and gamma (28-56 Hertz) ranges, with gamma waves at 40 Hertz being the most widely studied frequency and the most effective. Third, there is an association between duration of exposure on their overall effectiveness, where the parameters of exposure time are starting to be explored. Fourth, frequency matters, where different frequency ranges, and the specific frequencies in those ranges can elicit various physiological effects.

Probably the most significant finding is binaural beats are more effective when applied prior to and during a cognitive task, opposed to during the task only; even playing binaural beat prior to a cognitive task (without any exposure during the task) is more effective than playing them during only. This is significant because the tendency is to place headphones on participants heads and a start binaural beats stimulation at the start of a cognitive task (i.e. memory game), however this may actually undermine their results. The best response is to pre-condition the attention and working memory networks in the brain with exposure to binaural beats stimulation prior to engaging in the cognitive task. This is similar to techniques used in meditation to precondition the mind to achieve a desired state of consciousness. However, it is recommended binaural beats also be applied during the cognitive task, until it has been completed.

Findings of significance also included a lack of consistency amongst research on this topic of binaural beats stimulation for the purposes of increasing attention and working memory. Several studies did not include some necessary data (i.e. timing of exposure, duration of effect, carrier tones). All studies varied in some degree regarding the carrier tones, frequencies, and testing methods used in examining the effects of binaural beats stimulation on attention and working memory. The variations in methodology made it difficult to make accurate cross-comparisons. Studies which examined multiple binaural beats stimulation frequencies with the same control conditions were helpful because they allowed for clear cross-comparisons, however there were very few of these studies available in the current pool of literature. Additionally, there were several studies that lacked the sufficient data needed to draw consensus regarding effectiveness, dosage, and lasting effect. Several studies did not report the exposure time of binaural beats stimulation (Sharpe & Mahmud, 2020; Parciauskaite et al., 2019; Shekar, Suryavanshi, & Nayak, 2018; Larsson, 2020; Dy et al., 2020; Kalyan & Kaushal, 2016). While several other studies did not include the carrier tones they used (Sharpe & Mahmud, 2020; Parciauskaite, et al., 2019; Shekar, Suryavanshi, & Nayak, 2018 Larsson, 2020; Dy et al., 2020; Kalyan & Kaushal, 2016). With one study not including the specific binaural beats stimulation frequency tested, only providing the range tested (Dy et al. 2020).

Limitations and Delimitations

Highlighted in Chapter Two was the potential limitations and delimitation of the study. Research confirmed a potential limitation, which was the lack of available literature concerning the topic of binaural beats stimulation for the purposes of increasing attention and working memory. Additionally, one area of limitation was unreported data from the studies included in this research, where dosage, carrier tones, and duration of testing were often not reported, making it difficult to draw themes and conclusions. Lastly, research was limited to the most common frequencies assessed, where many other frequencies may hold potential, however remain unexplored. There are several studies that highlight the effectiveness of 40 Hertz binaural beats stimulation for the purposes of increasing attention and working memory, however the minimum and maximum dosage needed remains in the early stages of exploration. Additionally, there does seem to be evidence to support a lasting effect from binaural beats stimulation, specifically with Alpha, Beta, and Gamma waves, however existing research does not address duration of effect outright.

The delimitations of this study remain from those highlighted in chapter two. The potential negative effects of binaural beats stimulation were not explored. Additionally, the problems associated with working memory and attention were limited to the potential of binaural beats stimulation to mitigate some of those effects, where other potential methods were not explored.

Implications for Professional Practice

The potential for binaural beats stimulation to aid in increasing attention and working memory across a variety of conditions is promising. There is sufficient data concerning 40 Hertz to support its overall effectiveness, as well as the potential for a lasting effect with Alpha, Beta, and Gamma binaural beats stimulation. These applications may assist in helping those who need to temporarily improve their attentional focus or working memory capacity to perform related tasks.

Application Outside Research

Research has revealed the ease in use in which binaural beats stimulation can be applied, usually consisting of putting on headphones and playing sounds from an app, sound file, or online resource. Familiarization with headphones is common, and there are several online resources that provide binaural beats tracks. Which can be found on resources such as Audacity, Spotify, Youtube, and online tone generators. Because of the ease of application, the benefits for binaural beats could be extended to students of various age groups, within the clinical counseling field, or even the lay person with little familiarization. Those in counseling or teaching capacities should be encouraged by the potential for the enhancing cognitive effects from binaural beats stimulation.

Implication Potential

There is an untapped potential for binaural beats stimulation to be marketed and applied across a variety of circumstances, this current state may be due to the lack of sufficient research to support their effectiveness over the past decade. However, upon evaluation of numerous sources concerning binaural beats stimulation for the purposes of increasing attention and working memory, research has revealed the pool of literature has greatly expanded in this area over the last five years and mostly concludes with binaural beats being effective in certain frequencies for in increasing attention and working memory the most effective being the Alpha and Gamma ranges.

Until now, a clear determination as to the overall effectiveness of binaural beats stimulation could not be concluded. Although there is a present need for future research to include key areas concerning dosage and lasting effect, the key studies highlighting these areas and deductive reasoning from existing studies now show exposure before and before and during testing, as well as increased duration of exposure allows for binaural beats stimulation to be the most effective. This is promising because some clear methodologies are not present that were not available before that highlight how to apply binaural beats in the most effective manner. This study highlights the potential of binaural beats stimulation for the purposes of increasing attention and working memory, allowing for an increase in new studies circulating around this topic.

This information is easily disseminated amongst mental health practitioners due to straightforward methodology and ease of application of binaural beats stimulation in diverse settings. The principles of binaural beats stimulation could be very beneficial for those seeking to help patients suffering from physiological issues related to attentional control and working memory function. For example, in education settings where children are diagnosed with attention deficit disorder or other specific learning disorders (associated with focus and working memory) may have several behavioral supports in place to help them stay on task (i.e. individual classroom aide, extra time to complete assignments, wobble chair). Binaural beats not only can assist with filtering out distraction due to the nature of application through headphones, but can be easily administered and set to a frequency of choice, before and during a child engages in an undesired task. Additionally, the results from binaural beats application could easily be collected through data sampling methods performed during behavioral analysis such as interval timing.

There are some factors that should be highlighted in environments where binaural beats application is considered. These factors include understanding the fundamentals of binaural beats technology, tools used for application (i.e. noise cancelling headphones), most effective frequencies for particular desired mental states, duration of exposure needed, and carrier tones used. These factors would be helpful in ensuring binaural beats technology is applied correctly in the field.

Recommendations for Research

The goal of this study was to explore research into the areas of dosage and lasting effect concerning binaural beats stimulation. In chapter one the metaphor of a physician prescribing medication without knowing the dosage and duration of the effect of that medication was used, highlighting the necessity to have such vital information. Future recommendations are highlighted here and fall into two categories one, the need for exploration of dosage and duration of effect, and two, the need for consistent methodologies across future studies.

The findings of this study have laid the groundwork for the importance of dosage in future research using binaural beats stimulation. One area that is particularly at need is the consistency in methodology in studies that seek to explore the potential benefits of binaural beats stimulation for the purposes of increasing attention or working memory. One suggestion to achieve consistency in future studies is including data in three key areas, time of testing (during or before and during), frequency of carrier tones, and specific frequency used (i.e. 14.5 Hertz). The importance of including data in these areas will help draw conclusions from future cross-comparisons.

This study also demonstrated a possible trend in potentially undermining binaural beats stimulation using a common testing method. There were two articles reviewed that revealed no correlation between binaural beats stimulation exposure and improvements in attention. Once consideration for these studies is the conclusions may have been due to the testing measure used, where attentional blink performance could have potentially undermined the results of the study. Undermining could come from the same principle of photic stimulation presented in chapter two, where the process of intermittent photic stimulation was found to have an impact on brain waves (Alastair, 2010), and since there is evidence photic stimulation can create emotional and mental changes (Walter & Walter, 1949), it would be important to consider the potential undermining effects of RSVP as testing measure for attention while exposed to binaural beats stimulation. For example, Ross and Lopez (2020), conducted a study using an RSVP stimulus, presenting a rapid succession of letters at 10 per second, which is the same as Alpha 10 Hertz. The results from the study revealed a positive correlation between 40 Hertz binaural beats stimulation, but not 16 Hertz. Another example is with Reedijk, Bolders, Colzato, and Hommel's (2015) study which reported the rate of the RSVP stream with the attentional blink task was 10 items per second, consistent with Alpha 10 Hertz, which may have caused all participants to become entrained, even those in the control conditions. Whether or not a visual presentation streamed at the same frequency rate as the audible binaural beat stimulation rate affects the results is unclear.

The impact of SART in indexing results will need to be further explored as it is a commonly used testing method, being used in four of the 23 studies examined for this literature review. One way to prevent the negative impact of SART is testing frequencies outside the rate of rapid photic stimulation, which is at a rate of 10 frames per second, or 10 Hertz. binaural beats stimulation frequencies outside of this range (i.e. 12 Hertz) would likely not be indexed due to the difference in hertz.

Exploration of whether some frequencies of binaural beats stimulation are universally effective in increasing attention and working memory networks is a topic of importance due to the potential applications to the general population. However, identification of whether or not a specific frequency should be modified to match a particular person's existing brain wave frequency pattern may be the key to unlocking their maximal effects.

If this is the case, it may be beneficial to apply biofeedback and neurofeedback into the binaural beat's stimulation process due to the constant changing of our internal neural oscillation rhythms. In chapter two the nature of neural oscillations was discussed. One area of important consideration is the way in which they behave, which is according to a set of mathematical and harmonical principals. New research has identified a binary multiple frequency relationship between alpha waves, an individual's heart rate, and breathing rate (Rassi, Dorffner, Gruber, & Klimesch, 2018). One suggestion could be applying an electrocardiogram, heart-rate monitor, pulsometer, or another similar device to monitor the subjects resting heart rate, providing real-time feedback during the application of binaural beats stimulation, and allowing for adjustment of binaural beats stimulation frequencies to the designated harmonic multiple of the subject's heart rate. This information could be seen in real-time with neurofeedback devices revealing brainwave activity such as the electroencephalogram.

Lastly, it is recommended that future studies examine duration of effect from binaural beats stimulation. This apart from dosage was the focal point of this literature review. One suggestion is highlighting the time elapsed between the end of binaural beats stimulation and duration of testing period (for studies that only have exposure prior to testing). For example, binaural beats stimulation exposure before testing for 10 minutes, followed by an OSPAN test, which takes 6 minutes to complete, can provide data related to duration of effect up to 6 minutes, depending on the presence of an increase in attention compared to the control group. Other potential measures could be spread out much further. For example, in Ross and Lopez' (2020) study, participants were tested over three separate instances or three days total (although not necessary consecutive). The participants exposure time was at total of 10-12 minutes, participants who were exposed to 40 Hertz on day one outperformed participants on an attentional blink task who were exposed to 16 Hertz beta. This was significant because the participants who were exposed to 40 Hertz on the first day were exposed to 16 Hertz the second day. A common assumption may be that it was the 16 Hertz exposure the second day that caused the effect and not the 40 Hz exposure from the first day. However, if this was the case the participants who were exposed to 16Hz the first day should have done better and they did not. It was only under the specific instance where there was 40 Hertz exposure the day prior that led to the cognitive enhancing effect. This fall align with another point presented in this study where exposure prior to engagement in a cognitive task is more effective than during the task only.

Ultimately Ross and Lopez' (2020) study is an outlier because no other studies capture a duration of effect longer than a series of minutes. The duration of effect was not the focal point of this study either, however the duration of effect can be deduced due to the established testing parameters. This particular area of duration of effect well-past exposure may need to be covered by future research in order to allow for cross-comparisons to Ross and Lopez' (2020) study. Future studies can examine improvements in binaural beats stimulation post exposure, further expanding knowledge in the area of binaural beats stimulation by framing their methodology around the topic of duration of effect exclusively.

There are now more opportunities available due to this study's highlighting of several areas of needed exploration. In Chapter One a comparison to prescribing medications was made, where the prescription of medication without knowing the pharmacodynamic and pharmacokinetic information concerning dosage and duration of the effects would be unethical, as well as potential dangerous. With anything area of interest in exploratory science there is a natural human curiosity to explore cause and effect between a dependent and independent variable, once an effect is discovered, the next step would be to highlight the parameters of those effects. In the case of binaural beats, their physiological effects have been studied and are currently being researched more in-depth. However, currently there are no studies that seek to understand how long the effects of binaural beats stimulation last in humans.

Conclusions

This systematic review of current literature showed the full extent of the benefits and limitations of utilizing binaural beats technology for the purposes of increasing attentional focus and working memory ability. This study helped shed light on the most studied and effective frequencies to achieve increases, where 40 Hertz Gamma has the most potential for increasing attention and working memory, followed by 15 Hertz Beta.

The effectiveness of Gamma is due to the coupling principles highlighted in chapter two, where the presence of gamma waves is carried by the process of synchronizing and coupling with theta waves, which are associated with selective attention. Gamma waves are typically localized and occur in smaller portions of the brain and are carried to other parts of the brain by coupling with Theta waves according to harmonic principles. Theta waves are lower in frequency, and travel globally. The interaction between theta and gamma waves seems to be present during moments of top-down processing. Furthermore, this study shed light on the parameters needed to achieve increases in attention and working memory. It is recommended a minimum of 10 minutes of exposure (dosage) of binaural beats stimulation in order to achieve maximum benefits. Additional research is needed to support the findings regarding minimum dosage of this literature review. Future side-by-side comparison studies providing identification as to whether certain frequencies have faster absorption rates and longer half-life than others could be invaluable, as chapter one described how different frequencies impact the body in various physiological ways

Additionally, it was highlighted there may be a potential for other frequencies in gamma to have similar effects if they are tailored to an individual’s frequency hierarchy via neuro and biofeedback. However, without these potential future interventions, the data concerning 40 Hertz is promising and seems to be global due to the diversity of participants included in these studies, although not fully exhaustive. 40 Hertz gamma waves seem to be effective in healthy participants ageing from 18-40 in western cultures.

This is encouraging because it can provide a framework for future research to build upon. More research should be performed with older adults, seniors, and other non-western cultures to add more groundwork to the potentialities of frequencies like 40 Hetz. Future research may also benefit from utilizing side by side comparisons of lesser dosages in order to confirm these findings presented in this study.

The information highlighted in this literature review is promising because it clearly identifies areas of needed exploration, and adds to the current literature by exploring the areas of effectiveness for binaural beats stimulation for the purposes of increasing attention and working memory, as well as the topics of dosage and lasting effect, which have not been previously explored exclusively. This research has provided an additional framework for future studies to explore. Ultimately the goal of applying binaural beats is to improve our mental state. There currently remains large swaths of frequencies yet unexplored, however a niche is starting to gain traction in the research community with some empirical evidence to support binaural beats stimulation effectiveness.

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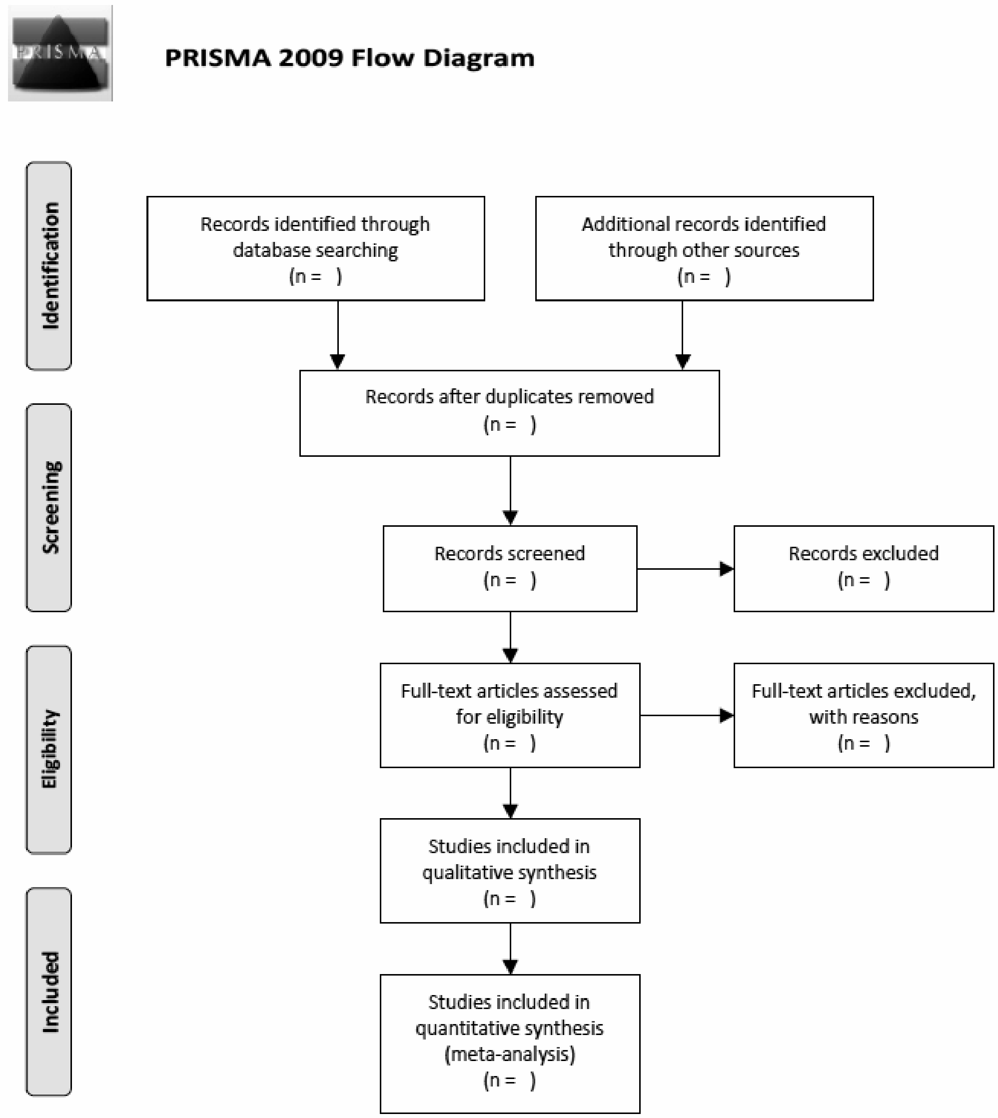
Appendix A



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Appendix B

PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	

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Appendix B2

PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

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