A proposed methodology for measuring the effects of binaural beats in music on concentration, working memory, and calmness following the Garcia-Argibay Protocol

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ABSTRACT

Binaural beats are perceived when two different frequencies are presented dichotically to a listener, causing the perception of a beating sound. They have been associated with beneficial effects on cognitive functions such as learning, concentration, and creativity. Studies however often yield incomparable or inconclusive results, due to inconsistent methodologies. Through a systematic examination, following the Garcia-Argibay Protocol, we aim to provide a more detailed understanding of the effects of binaural beats in music on cognitive functions. Specifically, we will compare auditory stimulation with music containing binaural beats of the alpha and gamma frequencies to a control condition presenting music without binaural beats. We will measure the differential effect of 12 Hz and 40 Hz binaural beats on working memory performance, operationalized through the N-back task, and investigate the impact of these frequencies on concentration levels measured via the global-local task. Lastly, heart rate will be used as a continuous measurement throughout the experiment in order to evaluate the effectiveness of the different frequencies in inducing calmness.

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1. INTRODUCTION

Binaural beats (BB) emerge when two distinct pure tones are presented dichotically (i.e., one to each ear), leading to the perception of a third tone corresponding to the mathematical difference between the two frequencies [1]. For instance, presenting a frequency of 420 Hz to one ear and 400 Hz to the other, results in the perception of a 20 Hz beat. BB are thus a subjective percept that can only be perceived by the combined action of both ears and exist solely in the brain (originating in the medial superior olivary nuclei). This makes BB distinctly different from physical beats, such as isochronic tones or monaural beats [2,3].

In recent years, the phenomenon of BB has gained significant interest within the academic community, as evidenced by an increasing volume of research, reviews, and meta-analyses [4,5]. Studies suggest that BB can positively influence cognitive functions and affective domains, such as creativity, concentration, working memory, and anxiety [3,5]. They have even shown quite robust analgesic effects on acute and chronic pain [6,7]. To conclude her dissertation, Krasnoff [8] states that there is now enough evidence to support that our brains and nervous systems can be influenced by BB. Thanks to these effects, BB are considered a digital drug by some [9] and even a threat to national security by others [10].

Despite their effects on behavioral outcomes, how BB achieve this exactly remains a mystery. For a long time, the brainwave entrainment hypothesis was the leading explanation. Entrainment is the natural tendency of physical and biological systems to synchronize their rhythms [11] and the activity in our central nervous system happens to follow rhythmic patterns, known as neural oscillations or brainwaves. The various frequencies of brainwaves (e.g. delta, beta, gamma) are associated with specific functions like sleep, attention, or memory, and as such it was presumed that the synchronization of brainwaves to BB could induce certain desired mind states [8]. However, research shows little evidence for actual entrainment, as illustrated in a recent review of fourteen EEG studies by Ingendoh and colleagues [4]. Krasnoff [8] proposes instead that the process of resonance might be at the root of it all, but since we consider a detailed neuropsychological analysis outside the scope of this paper, we will skip this for now.

Many, if not all, authors of reviews and meta-analysis on the topic of BB reflect on the inconsistencies in methodologies and therefore results of the included studies. Consequently they all emphasize the importance of standardization in testing [3-5], but even Oster did so in 1973 and we haven't seem to internalize his advice just yet. Based on the extensive meta-analysis of Garcia-Argibay and colleagues [5], Krasnoff [8] recommends adoption of what she calls the "Garcia-Argibay Protocol", which provides guidelines for frequency, duration of exposure, and type of masking. Following this protocol as much as possible, this study aims to investigate the effect of BB in music on cognitive processes in non-clinical settings.

2. METHOD

2.1. Participants

We aim to include 30 participants in this study. All participants will be undergraduate psychology students with various cultural backgrounds. We strive for an equal number of men and women. They will sign up voluntarily and their participation will be compensated through the assignment of SONA credits, which the participants need to fulfill their study program. The level of noise sensitivity will be assessed prior to the experiment by the Sound Sensitivity Symptoms Questionnaire [12], which assesses individual sound sensitivity over the preceding two weeks on a five-point scale. Formal ethical approval was obtained from the local Ethics Committee and ethical procedures were followed through. Prior to the experiment, all participants signed an informed consent form and they received a debriefing post-study.

2.2. Design and procedure

The study will implement a within-subjects design, employing binaural beat frequencies (12 Hz, 40 Hz, and a control condition without BB) as the independent variable to assess their effects on concentration, working memory, and calmness.

According to the Garcia-Argibay Protocol, BB exposure prior or prior and during the task yields the best results, and therefore an induction phase with BB prior to the task is recommended. As a positive relation between time under exposure and effect sizes was found, BB exposure should last 9 to 10 minutes [5]. To adhere to these guidelines, we designed the conditions to follow three three-minute blocks. The first block is the induction phase that consists of three minutes in which the participants only listen to the auditory stimuli without having to perform a task. In the second and third block, the participants have to perform one of two tasks, which will be described below, in randomized order. So in total, a condition will last for about 9 minutes.

Concentration will be measured using a global-local task, in which participants indicate whether certain letters ("H" and "O") were present in either global (a large letter composed of many small ones) or local (small single letters) features [13]. Participants press "B" on a keyboard if both letters are present and "N" if neither of the two letters are present. In total, 16 different stimuli will be presented in random order, with four stimuli including both letters as a global feature, four including them as a local feature, and the remaining eight not displaying "H" or "O" at all. Each trial will last for a maximum duration of 4000ms, with 750ms of feedback at the end of each trial. A correct answer is indicated in green, an incorrect answer in red, and slow answers by a yellow "Slow". The task will automatically end after three minutes. Reaction times and the proportion of correct responses are used as outcome measures.

To assess the effects of BB on working memory, an N-back task (more specifically 2-back task) is utilized. The task requires individuals to monitor a sequence of letters and identify whether the current stimulus matches the stimulus two letters earlier [14]. Each letter is presented for 750ms, with an inter-stimulus time of 1000ms. The sequence of letters is randomized to ensure the reliability and validity of the results, with the programming set up to display a match 25% of the time. Participants are instructed to respond to matching letters according to the 2-back rule by pressing "B" or "N" on a keyboard. The primary outcome measure for this task is accuracy (i.e. correct identifications of matches and correct rejections of non-matches), with the task ending after three minutes.

Calmness is measured through continuous heart rate monitoring, with the premise that lower heart rates indicate a state of calmness, while higher rates suggest tension or anxiety [15]. The participant´s heart rate is measured with the Polar H9 heart monitor. Heart rate measurements are registered consistently throughout the experiment, with the monitoring system configured to recognize the onset of new conditions and experimental tasks. Baseline heart rate measurements are gathered for each participant during the induction phases of every condition, before any tasks are performed.

Figure 1 shows an overview of the entire experimental procedure. Participants are not informed about the BB prior to or during the experiment; they are only told that they will have to perform some tasks while listening to sounds. Before the onset of the auditory stimuli, participants fill out the informed consent forms, and complete the Sound Sensitivity Symptoms Questionnaire [12]. The procedure continues with a practice trial to familiarize participants with the 2-back- and global-local tasks. Following this, the induction phase starts where participants are exposed to three minutes of music embedded with either 12 Hz, 40 Hz, or no BB. During this phase, the participants are asked to just sit and listen, and baseline heart rate measurements are registered. After the induction phase, participants are instructed to either perform as accurately as possible on the 2-back or the global-local task for three minutes. With a short delay due to the provided instructions on screen, participants proceed to perform the other task for another 3 minutes. The two tasks are presented in randomized order. This process is repeated twice more to ensure that participants complete every experimental condition (music with 12 Hz, 40 Hz, and without binaural beats) in a sequence randomized by a Latin square. Both the participant and the researcher do not know in which order the conditions are presented. The auditory stimulus (music) is a constant factor and plays continuously without breaks during the whole experiment starting at the onset of the first condition.

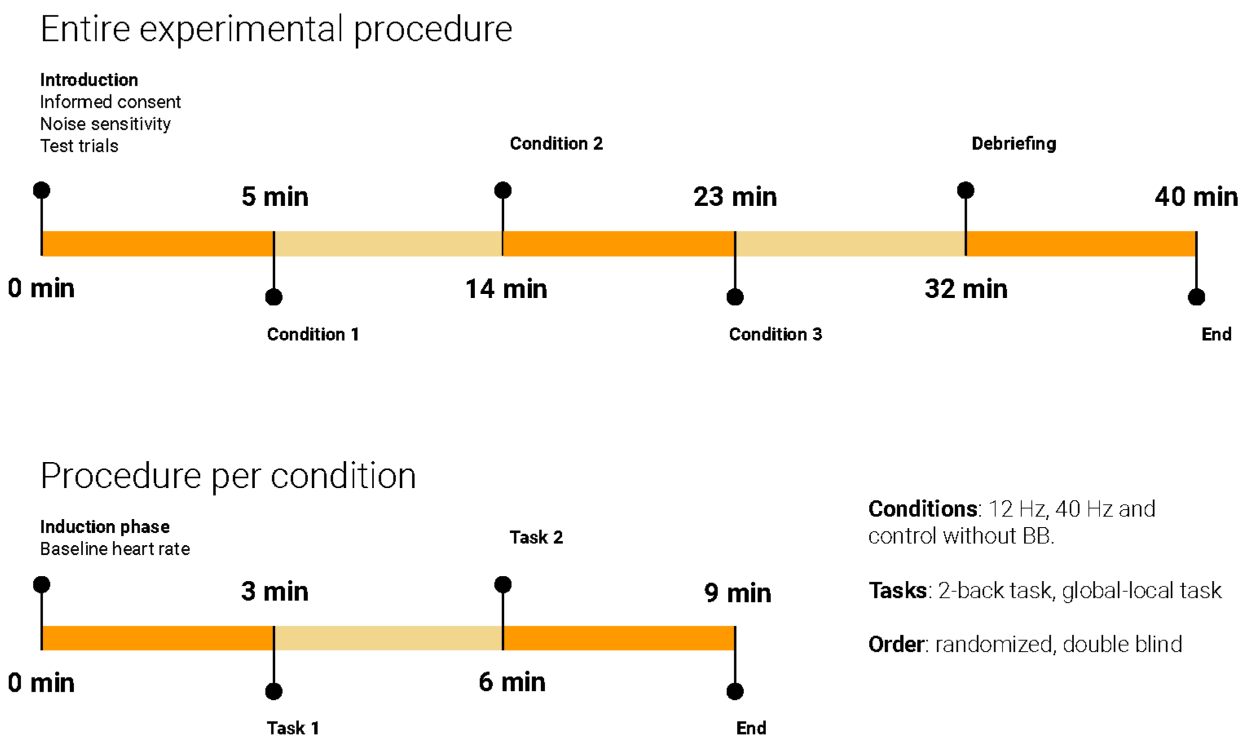

Figure 1. Overview of the entire experimental procedure and procedure per condition.
Notes. The timelines are an approximation.

2.3. Materials

Research shows that unmasked BB, or BB masked with pink or white noise produce larger effects sizes than BB masked with music, possibly caused by interference from the frequencies and rhythms present in the music [5]. As we feel that BB embedded in music could have a larger adoption rate with a bigger audience (and therefore create more impact), we wanted to test the effects of BB masked with music specifically created for this purpose. The stimuli for this experiment were thus created by Peter and Huda Blom, music producers in The Netherlands. They created a music piece specifically for this experiment to accommodate the frequencies and rhythms of the BB as well as possible. By doing this, we hope to avoid additional entrainment effects of listening to the music (as opposed to solely listening to the BB). The music piece contains a slow abstract vocal melody with a subtle underlying beat of 216 BPM. It lasts for 3 minutes and 3 seconds, has a break section in the middle, and is written in such a way that it can be repeated seamlessly throughout the experiment. This way, the music is identical during each phase and condition of the experiment, without being overly repetitive.

For the experimental conditions, the BB were embedded in the music with carrier frequencies set at 378Hz (left) and 390Hz (right) for the 12 Hz condition and 390Hz (left) and 430Hz (right) for the 40 Hz condition. Carrier tones around 400 Hz are often chosen due to their audibility and minimal contributions to brainstem responses [16]. These specific carrier frequencies were chosen to align the BB tonally as much as possible with the music for a better blend-in. The 12Hz (alpha) and 40Hz (gamma) BB frequencies were selected in accordance with the Garcia-Argibay Protocol. Their meta-analysis showed that BB in the alpha, beta, and gamma frequency bands positively affect performance in memory tasks. Alpha, beta, and specifically gamma BB frequencies have positive effects on attention. That is why we choose the alpha and gamma frequencies for our experiment. Usually, frequencies within the delta and theta ranges are employed (successfully) in studies focusing on the reduction of anxiety [5]. We let however pragmatism and curiosity lead us in our choice to measure the effects of other BB frequencies on calmness levels. The music and the BB were generated with the software program Logic including the 'Test Oscillator' plugin.

2.4. Analysis

Our independent variable is the BB frequency with three levels: 12 Hz, 40 Hz, control condition. The dependent variables are: Concentration (measured by reaction times and the proportion of correct responses on global-local task), Working memory (measured by the accuracy on the N-back task), and Calmness (indicated by the Heart Rate Variability).

We will perform a repeated measure ANOVA to compare reaction times and accuracy in the 2-back and global-local tasks across the three conditions. For the continuous heart rate data, we will also use a repeated measures ANOVA model to compare mean heart rate variability across conditions. For all significant findings, we will calculate the effect sizes (Cohen´s d) to quantify the magnitude of the differences observed. Lastly, a correlation analysis will examine the relationship between individual differences in age, gender, sound sensitivity and the effectiveness of BB on concentration, working memory, or calmness.

3. RESULTS

As a matter of course, unfortunately data collection faced some delays. Therefore it was not possible at the time of writing to perform the intended analysis and present the results. We are confident to share our results in August during the Internoise 2024 congress in Nantes, France.

4. DISCUSSION

Clearly we cannot discuss the outcomes of this study and their untapped potential just yet, but we can nevertheless reflect on some methodological choices we made. While we tried to adhere to the Garcia-Argibay Protocol as much as possible, there are obviously some recommendations we did not take into account. In part this can be justified by the fact that we are using this study as a pilot to prepare ourselves for experiments on a larger scale specifically designed to accommodate a larger sample size (N > 100), as this is one of the common suggestions for future research [5,17].

In the future, we aim to include design choices that can better address individual differences in the perception of BB, specifically assigned sex differences and personality traits. It became clear very early on that BB are perceived differently by women and men as the upper limit of audible BB frequencies is about 200 Hz higher for men [18]. Also, multiple studies have demonstrated that BB perception in some women fluctuates during their menstrual cycle, while BB perception in men does not show any monthly variations [1,18]. Furthermore, a relation was found between the effectiveness of BB and dopamine levels measured indirectly through spontaneous eye blink rates [19]. Individuals with lower dopamine levels, which are associated with introversion, benefit more from BB compared to individuals with higher dopamine levels, although these differences disappear with higher carrier tones [5]. Combined, these findings call for the inclusion of personality traits in BB research [8] and the adjustment of BB frequencies to the listener [5]. Failing to cater to these individual differences will lead to the underestimation of the effectiveness of BB [19].

One way to overcome the individual difference in BB perception might be to utilize multilayered (or complex-frequency) BB. While it is one of the least studied 'frequencies' it does seem to be the most effective, at least when it comes to analgesic effects in surgical contexts [5]. This phenomenon is sometimes attributed to the fact that brain waves do not exist in isolation in the human brain, but rather coincide and influence each other [8]. Some brain waves seem to even work in tandem to improve performances in cognition-related tasks [17]. Therefore, when offering multiple BB frequencies simultaneously they might enhance each other on the one hand, and deal with individual differences on the other, as there might be an effective frequency in there for everyone.

In conclusion, while our study on the effects of BB on cognitive functions and calmness faced delays in data collection, we have gained valuable insights into the methodological considerations necessary for future research. Our adherence to the Garcia-Argibay Protocol laid a foundation, yet we expect that the results will give us the opportunity to further refine this protocol. We will present these results during the conference and make appropriate suggestions at the time.

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