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Vigilance research dates back to WWII when psychologists attempted to explain why sonar radar operators were missing signals allowing German U-boats to pass undetected. This error in vigilance was termed the vigilance decrement. Since WWII the vigilance decrement has been responsible for a number of military, commercial, and industrial accidents and deaths. One possible area of interest which may help to solve this problem is called binaural beat technology. Binaural beats operate by entraining the brain in a frequency following response. Depending on the frequency of the binaural beat, different psychological and physiological results can occur. The current study examined the effects that beta binaural beats had on vigilance task performance, mental workload, and psychological stress. Results indicated that, under certain situations, participants listening to binaural beats during the vigilance task had significantly increased vigilance performance but rated the task as more challenging than the control group.

Vigilance can be defined as the ability to sustain attention and respond appropriately to demands in the environment (Shaw, Matthews, Warm, Finomore, & Silverman, 2010). Until recently, psychologists tended to view vigilance tasks as mentally undemanding (Heilman, 1995). Researchers believed that activity in brain systems were suppressed by the monotonous and repetitious nature of vigilance tasks. New research examining task type, perceived mental workload, resource demand, and task-induced stress has challenged this view (Warm, Parasuraman, & Matthews, 2008). Warm, Dember, and Hancock (1996) conducted a series of experiments showing that vigilance tasks are very resource demanding. They found that the vigilance decrement is accompanied by a linear increase in overall workload. Studies using neuroimaging methods, such as TCD, PET, and fMRI, also support the assertion that vigilance tasks are mentally demanding (Parasuraman, Warm, & See, 1998; Warm et al., 2008; Warm & Parasuraman, 2007). In addition, Szlama, Warm, Matthews, Dember, and Weiler (2004) found that scores on the NASA-Task Load Index were increasing significantly throughout the course of vigilance tasks. Since the discovery and acceptance of vigilance as a mentally demanding activity, research has been better able to explain the causes of the vigilance decrement. However, the issue of how to reduce or eliminate the vigilance decrement still remains largely unsolved.

One area of research that may be able to help solve this problem is brainwave entrainment (BWE). This term refers to the use of rhythmic stimuli with the intention of producing a frequency-following response of brainwaves to match the frequency of the stimuli (Huang & Charyton, 2008). Binaural beats are a particular type of BWE that has often been used in psychological research. When two similar, but different, frequencies are presented separately to each ear, the difference between them is perceived as a binaural beat (Wahbeh, Calabrese, & Zwickey, 2007). For example, if 300 hz are presented to the left ear and 290 hz are presented to the right ear, the listener will perceive a 10 hz binaural beat. In this scenario, the listener will have increased brainwave activity at the 10 hz frequency. Depending on the frequency of the binaural beat, different psychological and physiological effects will occur. The most commonly studied frequency ranges are delta frequencies (1-4 Hz) which are associated with deep sleep; theta frequencies (4-8 Hz) which are associated with light sleep, creativity, and insight; and beta frequencies (13-30 Hz) which are associated with a thinking, focused state and increased arousal (Huang & Charyton, 2008; Rangaswamy et al., 2002).

Past studies have demonstrated the effects of binaural beats on different psychological variables (Atwater, 2009, Wahbeh et al., 2007, Huang & Charyton, 2008); however, only one published study has ever examined the effects of binaural beats on vigilance performance (Lane, Kasian, Owens, & Marsh, 1998). This study found marginal support for the use of binaural beats to improve vigilance task performance; however, the study also posed several methodological concerns and raised questions as to why no one has replicated this study or conducted any other vigilance/binaural beat studies since. The current study aims to provide further support for the use of binaural beats to improve vigilance performance and open up new directions for future research.

Purpose and Hypotheses

The purpose of this study was to examine whether binaural beats have significant effects on vigilance task performance, psychological stress, and workload. This study replicated and expanded upon Lane et al. (1998) by using a between subjects design and by examining the effects of this technology on perceived workload and stress. It was hypothesized that participants listening to beta binaural beats would have better scores on the vigilance task as measured by hit rates and false alarms, as well as having lower scores on measures of psychological stress and mental workload when compared to the control group. The binaural beat and control conditions were further separated by a vigilance task that was either easier or more difficult based on event rate. The purpose of this was to determine whether event rate moderated the relationships between audio condition, perceived workload and stress, and vigilance performance.

Method

Participants

One hundred and thirty individuals participated in the experiment; 38.5% of participants were male, 50% were female, and 11.5% did not respond. The mean age for participants in this study was 20.87. All participants were enrolled at a large, public university in Southwest Ohio and completed the experiment for partial course credit. Participants were required to have normal or corrected-to-normal hearing and vision. These inclusion criteria ensured that participants could see and hear the stimuli presented. The online study sign-up included a section that explained these requirements to the participants. They were not able to participate in the study if the hearing and vision criteria were not met.

Design

This experiment utilized a 2x2x6 mixed design with two between subjects independent variables (audio condition, event rate) and one repeated measures independent variable (period) to examine vigilance performance across time and between conditions. Audio condition had two levels: a control condition with pink noise coupled with no binaural beats and an experimental condition with pink noise coupled with beta binaural beats. Event rate also had two levels: one fast and one slow event rate task. Period was a within subjects factor with each subject completing six continuous 5-minute trials. Participants were randomly assigned into one of four conditions: binaural beat, slow event; binaural beat, fast event; pink noise, slow event; pink noise, fast event.

Stimuli

Audio. The two audio tracks used in this study were created using MATLAB (The MathWorks Inc., 2010). Following procedures used in similar studies (Lane et al., 1998; Wahbeh, Calabrese, & Zwickey, 2007), the tracks contained a background of pink noise to mask the binaural beats. Binaural beats of 16 and 24 hz were used in this study for the binaural beat track. The tracks were played using stereo headphones and the intensity was set to a comfortable level, as determined by the participant. All audio stimuli and administration procedures were consistent with stimuli and procedures uses in Lane et al. (1998).

Vigilance Task. The vigilance task was created using MATLAB (The MathWorks Inc., 2010). The task involved participants watching the computer monitor and reacting when a target was present. Replicating Lane et al. (1998), individual capital letters were presented on the screen from a list of twenty six. The target occurred whenever a letter was repeated. For example, if the letters "A, R, G, M, M" were presented, the second "M" would be the target. The experimental vigilance task included six periods lasting five minutes each for a total of 30 minutes. In addition, the two different event rates used in this task were a quick 75 events/minute event rate representing the hard task and a slower 20 events/minute event rate representing an easier task. Both tasks used a 100ms display rate and 6% critical signal rate with the rule that two critical signals could not occur back to back. Participants were instructed to respond as quickly as possible to a critical signal.

Vigilance Performance Data

Vigilance performance was measured as the proportion of correct responses to critical signals (hits) and incorrect responses to noise signals (false alarms). Hits were determined by whether a participant responded to the critical signal within the allowed time (800ms).Responses in the absence of critical signals were coded as false alarms. Each participant had 800ms to respond to an event, regardless of which condition they were in.

Psychological Outcome Measures

Psychological stress was measured before and after the vigilance task using the Short Stress State Questionnaire (SSSQ; Helton, 2004). The SSSQ is a 24-item multidimensional questionnaire based on the Dundee Stress State Questionnaire (DSSQ; Matthews et al., 1999). The SSSQ factors include Distress, Engagement, and Worry. They are meant to closely reflect the concept of a mental trilogy composed of affect, conation, and cognition. Stress was also measured before and after the vigilance task using the Stressor Appraisal Scale (SAS; Schneider, 2008). The SAS is a ten item scale representing primary and secondary stressor appraisals. Primary appraisals are evaluations of how personally significant and relevant the situation is and items ask about situational threat, demand, stressfulness, exertion, effort, importance, and uncertainty. Secondary appraisals are evaluations of the amount of resources one has to cope with the situation and measures manageability, ability, and performance. Mental workload was measured after the vigilance task using a computerized version of the NASA Task Load Index (TLX; Hart & Staveland, 1988). The TLX is a multi-dimensional rating procedure that provides an overall workload score based on an average of ratings on six subscales: Mental Demand, Physical Demand, Temporal Demand, Own Performance, Effort, and Frustration.

Procedures

Participants were told that they were testing a new computerized vigilance task to assess its usefulness. They were not informed about hearing binaural beats and were told that the purpose of the audio track and headphones was simply to block out background noise. Before starting the vigilance task, participants completed pre-measures of the SSSQ and SAS. Participants then completed a short practice vigilance task. This practice task was 5 minutes in length and participants were trained in this short trial until they had at least an 80% hit rate and, at most, a 6% false alarm rate. Each participant was assigned at random to one of four treatment conditions. Participants either listened to an audio track containing only pink noise or a track containing pink noise with beta binaural beats. In addition, participants either completed the slow or fast event rate version of the vigilance task. The experimental vigil was 30 minutes long and involved participants sitting at a computer, pressing the spacebar as quickly as possible when the target was presented. Once the vigilance task was completed, the workload measure was presented followed by a second administration of the stress measures.

Results

Manipulation Check

Of the 130 participants in this study, data from 82 were analyzed, while 48 were excluded. In lieu of not having access to EEG technology, the participants were asked at the end of the experiment if they heard a “wobbly” noise or “beat” in their headphones. This “wobbly” noise was indicative of the presence of binaural beats. Participants in the binaural beat condition who did *not* report hearing this noise were excluded from analyses. In addition, data from participants in the pink noise condition were randomly selected to be included in the analyses to achieve equal *n*’s within conditions. Using these selection criteria, near equal *n*’s were obtained (PN, Slow: n = 20; BB, slow: n = 20; PN, fast: n = 21; BB, fast: n = 21).

Vigilance Performance

A 2 (audio condition) x 2 (event rate) x 6 (period) mixed-ANOVA was performed on the arcsines of the percentages of correct detections. For these, and all subsequent analyses, Box’s Epsilon was used to correct for violations of sphericity. There were no significant main effects for audio condition, event rate, or their interaction. A significant main effect was found for period ($F(3.71,289.15) = 52.84$, $p < .001$), indicating that a vigilance decrement was present in this study. Significant interactions were found for period by audio condition ($F(3.71, 289.15) = 3.05$, $p<.05$), period by event rate ($F(3.71, 289.15)= 2.95$, $p<.05$), and period by audio condition by event rate ($F(3.71, 289.15)=2.60$, $p<.05$). The 3-way interaction can be seen in Figure 1.

Figure 1.
Period by audio condition by event rate interaction for correct detections

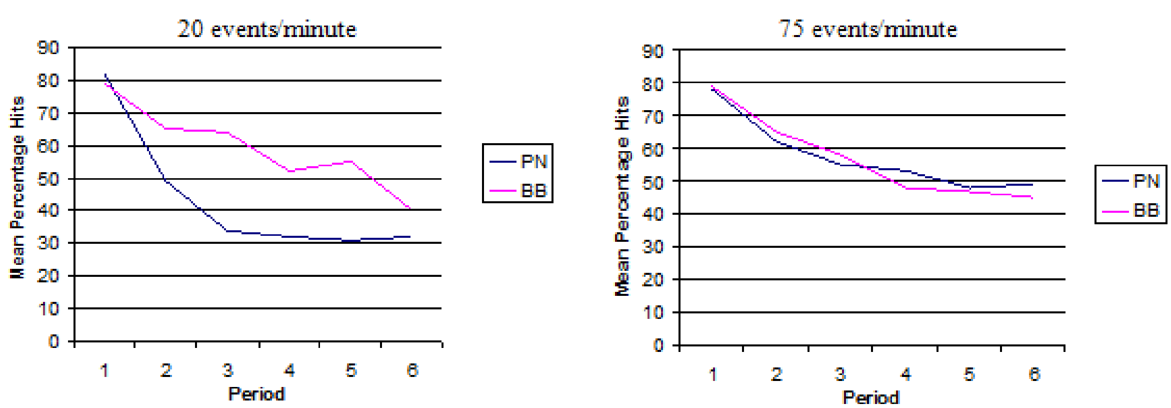

Figure 1 illustrates that participants listening to binaural beats performed somewhat better on the vigilance task than those listening only to pink noise, but for the slow event rate condition only. A series of follow-up t-tests indicated significant differences in the hypothesized direction during period two ($t(38) = 1.80$, $p < .05$), three ($t(38) = 2.65$, $p < .05$), four ($t(38) = 1.86$, $p < .05$), and five ($t(38) = 2.42$, $p < .05$). No significant effects were found for false alarms.

Psychological Outcome Variables

For the SSSQ, 2 (audio condition) x 2 (event rate) between-subjects ANOVAs were performed on the pre test scores of each subscale. No pre-test differences existed between groups. To test whether the experimental manipulations had any effect on psychological stress, difference scores were computed by subtracting pre-manipulation scores from post-manipulation scores. A 2 (audio condition) x 2 (event rate) between-subjects ANOVA was then conducted on the difference scores of each subscale. For Engagement, the pre-post change significantly varied by event rate ($F(1,78) = 10.17$, $p < .01$) with participants in the slow event rate ($M = -.41$, $SD = .50$) showing stronger decreases than participants in the fast event rate ($M = -.09$, $SD = .40$). There were no significant differences for Distress or Worry. Similarly, 2 (audio condition) x 2 (event rate) between-subjects ANOVAs were conducted on the pre-test scores of the SAS subscales and revealed no significant differences. For post-pre difference scores, 2 (audio condition) x 2 (event rate) between-subjects ANOVAs revealed that, for primary appraisals, there were main effects for both audio condition ($F(1,78)=5.22$, $p<.05$) and event rate ($F(1,78)=4.28$, $p< .05$), but not their interaction. Results indicate that mean difference scores were higher in the binaural beat condition ($M = 1.03$, $SD = .96$) than the pink noise condition ($M = .48$, $SD = 1.17$) and in the fast event rate condition ($M = 1.0$, $SD = 1.1$) than the slow event rate condition ($M = .51$, $SD = 1.1$). These difference scores indicate that participants in the binaural beat and fast event rate conditions thought that the completed task was more challenging than they originally expected. No significant effects were observed for secondary appraisals.

For the NASA-TLX, a 2 (audio condition) x 2 (event rate) x 6 (subscale) mixed-ANOVA revealed a significant main effect for subscale ($F(4.07, 317.58) = 20.95$, $p<.001$) and a significant subscale by event rate interaction ($F(4.07, 317.58) = 2.41$, $p<.05$). Subsequent analyses revealed that the subscales contributing to the significant factor by event rate interaction were Effort ($t(80) = -2.19$, $p<.05$) and Temporal Demand ($t(80) = -3.05$, $p<.01$). Scores for Temporal Demand were higher in the fast event rate condition ($M = 57.53$) than the slow event rate condition ($M = 39.33$), and scores for Effort were higher in the fast event rate condition ($M = 59.70$) than the slow event rate condition ($M = 43.9$). No significant effects were observed for audio condition.

Discussion

This study sought to investigate the effects of binaural beat audio technology on vigilance task performance, psychological stress, and mental workload. This study also sought to replicate the vigilance performance results of Lane et al. (1998). Hypothesis 1 stated that individuals listening to beta binaural beats would have improved vigilance task performance compared to individuals listening only to pink noise. Results of this study partially confirmed this hypothesis. Although no significant main effect differences existed for hit rate, a significant factor by audio condition interaction revealed hit rate differences as time on task continued. Participants in the binaural beat condition experienced a delayed vigilance decrement compared to participants in the pink noise condition, and this effect was moderated by event rate. In contrast, Lane et al. (1998) found significant main effects for binaural beats, but no interaction effects. Although both studies demonstrated significant performance increases for participants listening to binaural beats, the mechanism for increased performance varied. Hypothesis 2 stated that participants listening to binaural beats would have decreased psychological stress and workload after the task when compared to those listening to pink noise. This hypothesis was not confirmed.

The results of this study indicate that during a slow event rate task, binaural beats have the ability to reduce the negative effects that the vigilance decrement has on performance. When a fast event rate is used, this effect disappears. Although these initial results are promising, more research needs to be conducted to validate and expand on this study. Specifically, subsequent experiments should be conducted which examine if these effects can be replicated with shorter or longer vigils, different binaural beat frequencies, and different types of vigilance tasks. Ultimately, if these effects can be consistently demonstrated, the deleterious effects of the vigilance decrement on workplace performance may be reduced.

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