

## **N1 to Distractor Tones is Affected by Tone Salience and Primary Task Difficulty**

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### **Abstract**

Attention exists on a balance between available cognitive resources and a need to remain responsive to non-task related information. Therefore, the limited capacity of attention is automatically selective in that it is a function of both the nature of the distracting stimulus and an individual's focal task engagement. Based on previous research suggesting a tug-of-war between automatic and selective attention, selective attention was manipulated by engaging participants in a 1-back (easy) or 3-back (difficult) memory task. Automatic attention (salience of distractor stimuli) was manipulated by presenting 5-tone trains that either remained constant ("same") or varied in pitch ("different") through the train. For each of the four conditions, the researchers examined the N1 component of the event-related brain potential (ERP)—an automatic response elicited by stimuli even in the absence of overt attention—to each tone. Analysis also involved a comparison of participant performance (accuracy and response time) among conditions. The researchers hypothesized that N1 amplitudes would attenuate less across tones in the "different" trains than the "same" ones. Additionally, "different" trains would be more distracting than "same" trains, producing a decrease in performance. Furthermore, the researchers predicted that N1s would be smaller during the difficult task than the easy one because more attentional resources would be required by the more challenging task. As predicted, N1 amplitudes were larger to "different" trains than to "same" trains. This difference was greater in the 1-back than in the 3-back condition, and became larger to later tones in the trains. In addition to performance being better on the 1-back task than on the 3-back task, accuracy was also better during the "same" trains than during the "different" trains. In contrast to the prediction, N1s were larger during the difficult task than the easy task.

**Keywords:** ERP, Attention, Distractibility

### **1. Introduction**

The ability to distinguish between relevant and irrelevant information is a critical aspect of human functioning. Without it, one could hardly walk and chew gum at the same time, much less drive a car. Similar unfortunate consequences would ensue without the ability to perceive and orient to new and unexpected stimuli, as falling objects or even our own name would escape our perception. These dual processes of focusing on a specific task to the exclusion of distracting stimuli, referred to as selective attention, and automatic orientation towards particularly salient stimuli, referred to as automatic attention, are essential neurological mechanisms.

As stated, attention is divided into two main factors: automatic attention and selective attention. Automatic attention is commonly defined as an automatic shift of attention towards a salient stimulus, whereas selective attention is typically characterized as a conscious shift or maintenance of attention towards a stimulus, usually with the goal of completing a task that demands focus. Theoretically, attention is limited and automatic and selective attention compete for limited cognitive resources. Previous research suggests attention is largely a function of automatic processes such as automatic inhibition of repeated iterations of a stimulus<sup>22</sup>. Automatic processing of novel stimuli largely occurs in

the absence of overt attentional awareness<sup>25, 20</sup>; however, the limited capacity of attention is automatically selective in that it is both a function of the nature of the distracting stimulus and an individual's focal task engagement<sup>2, 10</sup>. In other words, attention exists on a balance between the selection of available cognitive resources and a need to remain responsive to non-task related information. Previous research on the mechanisms involved in task engagement has tended to apply the principles of automatic and selective attention as individual processes; however, there is a growing body of evidence to the contrary. That is, task engagement is mediated both by the ability to consciously direct our attention and the ability to successfully diminish the impact of distractor interference<sup>4, 5, 10</sup>. Despite knowledge of the mechanism for filtering distractors, little research has focused on how the processing of stimuli to which we are consciously attending differs from stimuli that this mechanism filters from conscious perception.

Attention can be assessed using non-invasive electroencephalography (EEG) techniques<sup>17, 19</sup>. Using these methods, researchers can use scalp electrodes to measure the cortical activity of synchronously firing neurons in the brain. The electrodes are then connected to a system that both amplifies the brain activity and converts it from an analog electrical signal to a digital signal that can be read and analyzed using computer software. From the continuous EEG data gathered using this method, event related brain potentials (ERPs) can be extracted. ERPs are responses that are time-locked to specific sensory (or sometimes motor) events. Because EEG/ERPs can be recorded in the absence of overt behavioral responses, they are ideal methods for measuring automatic attention, as automatic attention typically occurs in the absence of overt attention<sup>18</sup>.

Researchers manipulate distractibility by including sound deviants in their studies, such as the random placement of a single male voice in a sequence of otherwise distinctly female voices; this will be more distracting than a sequence of similar sounds, such as a sequence of only female voices<sup>10</sup>. The distinct differences in pitch and tonal quality cause the unfamiliar sound to be more distracting than a sequence of familiar sounds<sup>10</sup>. Based on similar principles, more recent research has employed a tone-train paradigm to manipulate auditory attention<sup>22</sup>. By varying qualities such as pitch, frequency, and the intervals between tone presentations, researchers are able to either increase or decrease salience across the train (i.e., over time), thereby providing a paradigm to assess automatic attention to auditory distractors. More specifically, the first tone after a delay is relatively salient (i.e., it draws more attention), but that salience decreases with repetition of the same tone. Tone salience could be further manipulated by varying tone frequency (pitch) as well as duration, although there has been a lack of research on such a paradigm. Previous research investigating automatic attention to sound has focused specifically on the auditory-evoked N1, a negative potential ERP that typically occurs around 100 ms after the onset of a tone stimulus. In line with information previously mentioned, the N1 amplitude is highest to the first tone, as this is a novel stimulus, but decreases with repetition. Put another way, the N1 is larger when a person is attending to a stimulus than if her or his attention is directed elsewhere<sup>4, 9, 16</sup>. Similarly, rapid repetition of unattended stimuli results in N1 attenuation, or a decrease in N1 amplitude<sup>22</sup>. Attenuation of N1 amplitudes after the initial stimulus provides a physiological basis for the attentional mechanism of inhibition. In this way, inhibition provides an explanation for the initial distraction to a task-irrelevant or novel stimulus—as well as a return to focal task engagement following automatic de-orientation<sup>4</sup>. This mechanism, and deficits thereof, has been associated with several clinical disorders. In adults with ADHD, for example, the initial N1 is relatively small, indicating reduced attention to even the most salient stimuli<sup>12, 23</sup>. A lack of N1 attenuation has also been established as one of the most reliable biological indicators of Schizophrenia<sup>1, 21</sup>. Although the N1 has been used as a neurological marker for certain psychiatric symptoms, deficits in N1 attenuation have also been associated with the normative effects of aging. In older adults, the initial N1 is intact but remains relatively large to tone repetitions, indicating that older adults are less effective at filtering out redundant, and environmentally distracting, information<sup>6</sup>. Given this information, the N1 amplitude reflects the encoding of a sound into sensory memory, as well as the amount of attention applied to a stimulus<sup>16</sup>. The N1, therefore, can be employed as a way to measure the degree of attentional capture, or the unintentional shift of attention.

Attentional capture by auditory distractors is also influenced by focal task engagement, or the amount of attention required to perform well on a task<sup>15</sup>. Intuitively, increasing a task's difficulty increases the degree of attention needed to perform well on the task<sup>10, 24</sup>. With more specificity, greater task difficulty has been shown to promote selective attention, or focal task engagement, and to shield performance from attentional capture by task-irrelevant stimuli (i.e., distractors).

## 1.1. Proposed Study

For the purpose of this study, selective attention was manipulated by engaging participants in a 1-back (easy) and 3-back (difficult) task. Automatic attention and salience of distractor stimuli was manipulated by presenting tone trains that either remained constant (“same”) or varied in pitch (“different”). Due to its relation to attention, we hypothesized

that N1 amplitudes would attenuate, or decrease, more across “same” tone trains than “different” tones trains, and that N1 Amplitudes would be lower in the 3-back (difficult) task condition. We also hypothesized that “different” tone trains would result in a decrease in task performance.

## 2. Methodology

### 2.1. Participants

Participants ( $N = 22$ ; 13 females, 9 males) consisted of 18-21 year-old students ( $M = 18.7$ ) sampled from a private mid-Southern university. Participants signed up to participate in the study using Sona Systems (Sona Systems, Ltd., Tallinn, Estonia), an online research management system, and received partial credit towards a course requirement for participating. Participants provided written informed consent. This study and its procedures were approved by the appropriate university Institutional Review Board.

### 2.2. Materials

#### 2.2.1. EEG recording

Continuous electroencephalographic (EEG) data were acquired using 32-channel active electrodes mounted into an EASYCAP elastic electrode cap, and referenced offline (EASYCAP, Wörthsee-Ettersschlag, Germany). The electrode cap was connected to an actiCHamp system used to amplify the signal; PyCorder, an open-source data acquisition program was used to record EEG data (Brain Vision, Morrisville, NC). A StimTracker (Cedrus Corporation, San Pedro, CA) was used to mark the onset of tone trains. Data were sampled at 500 Hz and bandpass filtered at 0.01-100 Hz with a 60 Hz notch filter. Impedance for each channel was below 15 k $\Omega$ .

#### 2.2.2. stimuli

Participants completed two  $N$ -back tasks (1-back and 3-back) while listening to sequences of five-tone trains (“same” vs. “different”). Instructions and the  $N$ -back tasks were presented on a 54cm desktop monitor using SuperLab software (Cedrus Corporation, San Pedro, CA). Participants were seated approximately 3ft from the monitor. Tone trains were delivered binaurally through over-ear, noise-cancelling headphones. The study incorporated a blocked presentation design, meaning each participant was exposed to both tasks and both types of tone train for 10 min each; the whole study lasted approximately 44 min, with optional breaks in between tasks. The order in which the  $N$ -back tasks and tone trains were presented to each participant was counterbalanced to avoid a potential order effect.

The  $N$ -back task (Figure 1) consisted of two conditions: (1) a 1-back (“easy”) condition in which participants were required to identify symbols that appeared twice in a row, and (2) a 3-back (“difficult”) condition in which they were required to identify symbols that appeared three presentations previously. Symbols consisted of nine simple, black-and-white shape outlines (square, circle, star, trapezoid, diamond, triangle, rectangle, and cross). The shapes appeared for 500 ms, with 2000 ms between shapes (2.5 s from the presentation of one symbol to the presentation of the next). A central fixation cross was present on the screen between shape presentations. Participants were instructed to press the spacebar as quickly as possible to indicate a correct response. In all, there were 492 shapes per condition, with 82 possible correct responses in each condition. The sequence of shapes was identical for the two tasks; only the task itself differed.

The tone trains consisted of sets of five tones played for 50 ms each (including 5-ms Gaussian rise and fall times), with 350 ms tones within a train (400 ms onset-to-onset). A randomized period of 4-5 s was incorporated between each train. Tones were presented at ~70 dB SPL. As previously mentioned, the study consisted of two tone train conditions (i.e., “same” and “different”). Tones in the same condition consisted of tones with a fixed frequency (i.e., pitch) within the train. Tones in the “same” tone train were either 500, 1000, or 1500 Hz. The “different” trains consisted of sets of tones that began and ended with the same pitch, while the three tones in between were randomized among 500, 1000, and 1500 Hz. Each of the tone conditions lasted approximately 10 minutes, and was played in a randomized order during the  $N$ -back tasks.

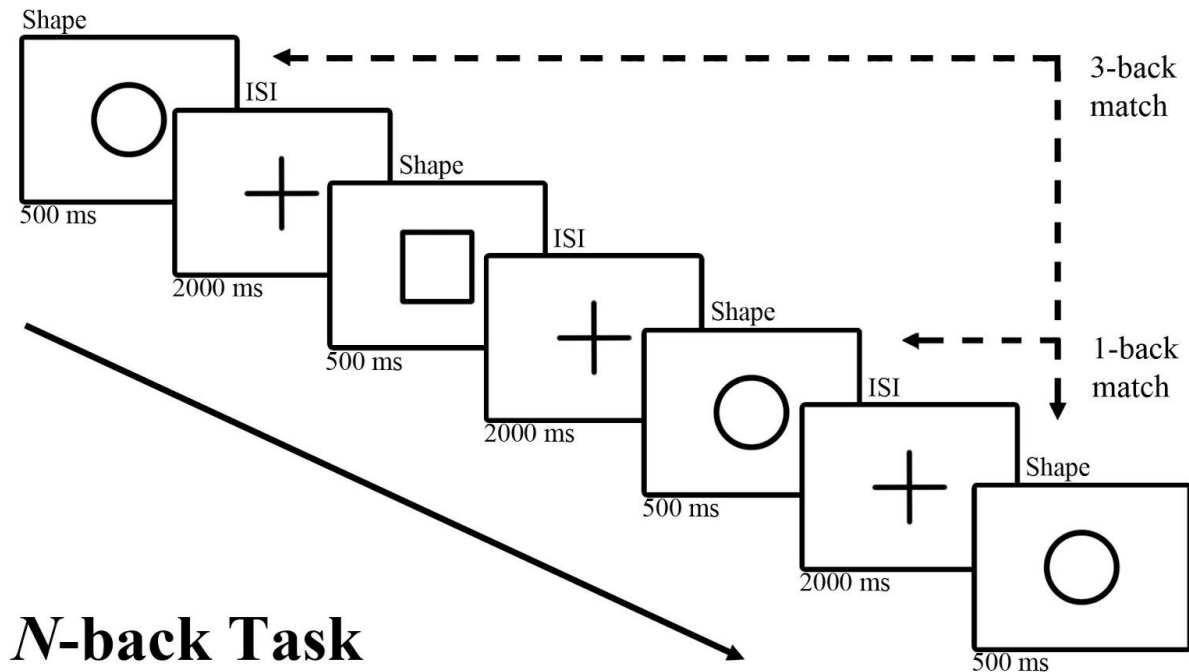


Figure 1. Example of an  $N$ -back task proceeding

### 2.3. Procedure

Upon arrival, participants provided written consent and completed a basic demographic survey (e.g., sex, race, age, years of education, dominant hand, visual and auditory acuity). A tape measure was used to determine the circumference of the participant's head in order to fit the participant with the proper cap size<sup>11</sup>. A syringe with a blunt-tipped needle was used to abrade the scalp and inject conductive electrolyte gel into each electrode; this was done to make contact between the scalp and the electrodes. A flat electrode was attached below the participant's left eye using a double sided adhesive disk; this was done to facilitate the measurement (and later removal) of blinks and vertical eye movements. Headphones were then placed on the participant.

The participants were seated in front of a computer monitor where they participated in the task under the conditions that were previously described. Prior to beginning the study, participants were instructed to respond to the visual stimuli by pressing the keyboard spacebar while ignoring the task-irrelevant tones. After completion of the study, participants were presented with a debriefing statement on the screen.

### 2.4. EEG Analysis

Data were processed offline using EEGLAB<sup>3</sup> and ERPLAB<sup>13</sup>. All other electrodes were referenced to the average of the mastoid electrodes (TP9 and TP10) and bandpass filtered at 0.01-30 Hz. Channels with excessive noise were removed and later interpolated using data from other electrodes. Eye-blinks and other eye-movement artifacts were identified and removed through an independent component analysis (ICA) procedure in EEGLAB. The resulting data were then segmented into 2200-ms epochs, including 200 ms before and 2000 ms after the onset of each tone train. Epochs were averaged separately for each participant, electrode position, task (1-back or 3-back), and train type (same or different). This produced a set of four event related potential (ERP) waveforms for each participant at each electrode site. N1 peaks were identified in each participant and electrode as the most negative peak between 80 and 180 ms. Values at Fz, Cz, and Pz were statistically analyzed in SPSS (IBM-Analytics, New York, USA) using a repeated-measures ANOVA (Train x Task x Tone). For visualization, waveforms for each participant were combined to produce grand average waveforms for each train type and task.

Participant performance data on the  $N$ -back tasks were gathered from SuperLab software. Response time was defined as the total amount of time between the onset of a target stimulus and the onset of a bar press to that stimulus by the

participant (i.e., time it took for participant to push button). Accuracy was defined as the ratio between the total number of correct responses identified by the participant and the total number of possible correct responses. Only correct responses were analyzed. Accuracy and reaction time were analyzed using a repeated-measures ANOVA (Tone x Task).

### 3. Results

#### 3.1. N1 Peak Amplitudes

N1 peak amplitudes at Cz statistically differed in response to both task and train manipulations. Across tones within the trains, the N1 amplitude was smaller to same-tone trains during the 1-back task than any of the three other conditions,  $F(1,21) = 8.209, p = .009, \eta_p^2 = .281$  (Fig. 2). This Task x Train interaction (Fig. 2) drove two main effects: (1) the N1 amplitude was larger during the 3-back task than the 1-back task,  $F(1,21) = 4.373, p = .049, \eta_p^2 = .172$ , and (2) the N1 was larger to “different” than “same” tone trains,  $F(1,21) = 17.766, p < .001, \eta_p^2 = .458$ .

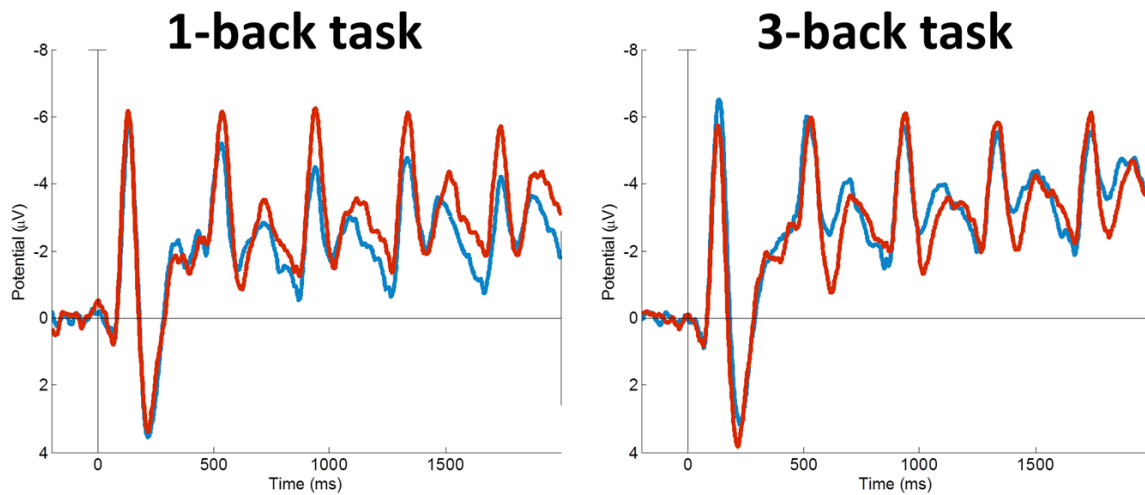


Figure 2. N1 peak amplitudes for “same” (blue) and “different” (red) tone train conditions during each  $N$ -back task.

Analyses at Cz also reflects statistically significant differences in N1 peak amplitudes across tones in each train condition (Fig. 3). The N1 amplitude attenuated across tones in the “same” train condition, but this effect was not present in the “different” train condition (Tone x Train interaction,  $F(4,82) = 5.883, p = .002, G-G \epsilon = .678, \eta_p^2 = .219$ ). Task difficulty did not significantly affect the attenuation of N1 peak amplitudes across tones in each train (Task x Tone interaction:  $F(4,82) = 2.159, p = .100, G-G \epsilon = .771, \eta_p^2 = .093$ ), regardless of the Train condition (Tone x Train x Task interaction:  $F(4,82) = .194, p = .804, G-G \epsilon = .455, \eta_p^2 = .009$ ). Moreover, there was a general tendency across all conditions for the N1 response to remain large throughout tone iterations instead of attenuating over time (main effect of Tone:  $F(4, 82) = 2.047, p = .147, G-G \epsilon = .448, \eta_p^2 = .089$ ).

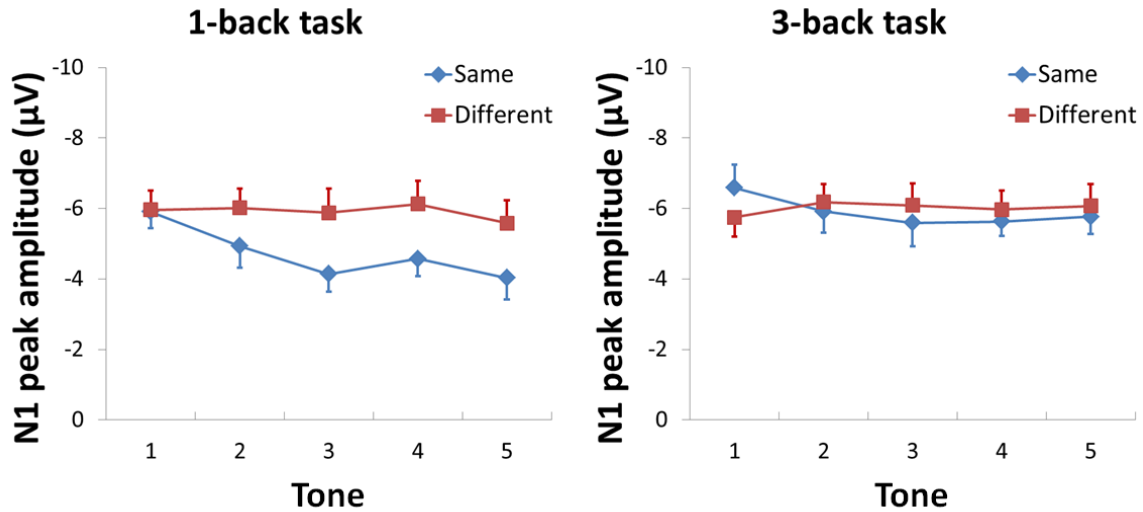


Figure 3. N1 peak amplitudes to individual tones in the “same” (blue) and “different” (red) train conditions during each  $N$ -back task. Individual tones are represented by blue and red shapes. Error bars indicate standard errors of the means.

### 3.2. Behavioral Performance

Behavioral performance data (Fig. 4) reveal a main effect of task on accuracy such that accuracy was higher on the 1-back than the 3-back task,  $F(1,16) = 73.471$ ,  $p < .001$ ,  $\eta_p^2 = .821$ . There was also a main effect of tone condition on accuracy; this revealed greater accuracy during the same trains than the different trains,  $F(1,16) = 6.497$ ,  $p = .021$ ,  $\eta_p^2 = .289$ . Response times (Fig. 4) were also faster during the 1-back than the 3-back task,  $F(1,15) = 11.674$ ,  $p = .004$ ,  $\eta_p^2 = .438$ .

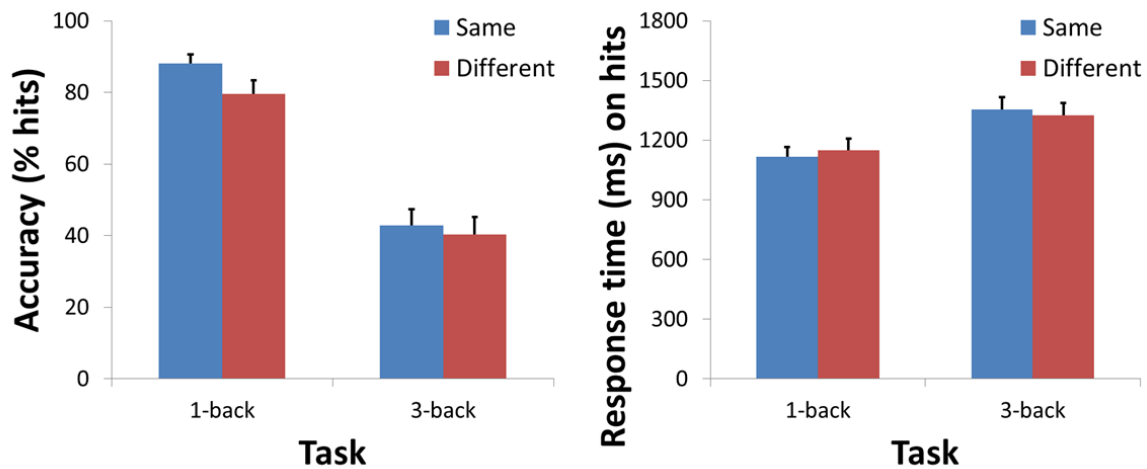


Figure 4. Mean accuracy and response time to stimuli presented during the “same” tone train (blue) and the “different” tone train (red) conditions in each  $N$ -back task.

## 4. Discussion

In support of our initial hypothesis, N1 peak amplitudes decreased more across “same” trains than in “different” trains, but this pattern of activity was present only in the 1-back condition. The decrease in N1 amplitudes in the “same” train condition is in line with the concept of inhibition, as it reflects a decrease in attention to repeated tones after the initial presentation of the novel stimuli (i.e., first tones in the train). Conversely, N1 amplitudes to tones in the “different” condition remained large across tones in the train. Given the present data, varying tones in the “different” condition causes the brain to process the individual tones as distinct stimuli as opposed to iterative presentations of the same stimulus<sup>16,25</sup>. Therefore, the lack of attenuation to tones in the “different” condition indicates more sustained attention to those tones.

There is a substantial amount of research documenting the effects of task-irrelevant stimuli on behavioral performance; that is, the concurrent presentation of novel stimuli during a directed focus task, such as the *N*-back, results in prolonged response times and an increase in the number of observable errors<sup>4,26</sup>. As predicted, accuracy was higher on the 1-back than on the 3-back task, indicating that the task difficulty manipulation was successful. Response times were also faster during the 1-back condition. In regards to behavioral performance according to tone condition, the “same” condition resulted in fewer errors; however, there was not a statistically significant difference in response time between the two train types. These results may be indicative of a reduced ability to modulate attention towards more goal-directed motives when there are salient stimuli in the environment.

Contrary to our predictions, N1 amplitudes to tones presented during the 3-back task was larger than N1 amplitudes to tones presented during the 1-back task. Previous research<sup>7,15</sup> on automatic attention to task-irrelevant distractors as a function of focal task engagement would suggest that increasing task difficulty, thereby increasing the amount of attention needed to perform well on a task, would decrease perceptual sensitivity to distractor stimuli. That is, more attentional resources required from a difficult task results in fewer attentional resources available for the conscious processing of environmental distractors. However, despite the decrease in performance that was exhibited during the 3-back condition, the present data demonstrate an increase, rather than a decrease, in attention to auditory distractors in the “difficult” condition.

In this study, the more difficult task did not decrease the ability of participants to unconsciously process incoming task-irrelevant stimuli. A contributing factor to the present data could be that participants were not fully engaged in the 3-back task; a lack of directed focus on the task would allow for more attentional resources to be dedicated to attending to the distractor stimuli, hence the sustained N1 response. Another possible explanation is that participants became frustrated or discouraged by the difficulty of the 3-back task and simply gave up, resulting in lower performance as well as an increase in the availability of resources for processing task-irrelevant stimuli<sup>8,14</sup>. In other words, the relative uniformity of N1 amplitudes to distractors during the 3-back task condition could have been due to participant overload, making all tones highly distracting. Further research should implement a medium difficulty task that is challenging enough to require higher degrees of attention but simple enough to maintain active engagement with the participants. In addition, it would be informative to examine visual N1 amplitudes to the task stimuli.

## 5. Acknowledgments

The authors wish to express their appreciation to Dr. Jeffrey J. Sable, who served as primary investigator and research mentor. The authors would also like to thank the student members of the Christian Brothers University Cognitive Neuroscience Lab for their assistance in data collection. This material is based upon work supported by the National Science Foundation under grant number BCS-1429263.

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