Cognitive Load Reduces Detection of Auditory Stimuli

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Abstract

The influence of cognitive load on signal detection has generated vast amounts of research suggesting that as load increases, ability to detect signals is impaired. Although most cognitive load research focuses on visual stimuli, we present an experiment testing the influence of cognitive load on signal detection via auditory stimuli. A group of university students completed mathematical and symbolic n-back tasks while sets of audio clips were randomly presented. In the high load condition, participants completed a 2n-back task, while in the low load condition a 0n-back task was completed. We demonstrate that as task demand increases, ability to detect auditory signals decreases. These results imply a limited capacity in cognitive ability that when reached, hinders perception of non-relevant stimuli.

Key words: cognitive load, working memory, task demand, auditory stimuli

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Certainly everyone has experienced at one time or another a situation where they were so focused on a task such as watching television or reading a book that they completely failed to hear someone talking to them or trying to get their attention. This rather common phenomenon might seem easily explained as a matter of inattention but is it purely a matter of not attending to the information or is there something more to the story that is interfering with detection?

Attention and its relation to signal detection has been a topic of great interest in the realm of psychological research for many years (Logan D., 2004). The term signal detection simply refers to the ability of an individual to determine whether or not a stimulus—signal—has been detected (Logan D., 2004). There are many theories of attention each providing unique ways of explaining how signal detection can be obstructed (Posner, Snyder, & Davidson, 1980). Cognitive load theory shows that high load tasks are those that require focused attention taking up nearly all of the limited capacity in working memory, while low load tasks are those which only use some of the working memory's capacity (Sweller, 2010). Working memory is a system of the brain that allows short term storage and management of information during difficult or complicated tasks (Baddeley, 1992). Once the limited capacity of working memory is reached there is no additional store to process non-task related information. This would explain the situation described above, where an individual failed to notice someone talking or trying to capture his attention, by defining the task being attended to as a high load task taking up all of working memories capacity and blocking out irrelevant stimuli.

Attention has a limited capacity which restricts the amount of information that can be attended to at any one time in working memory (Broadbent, 1958). This limited capacity in working memory explains why the inability to identify or perceive a presented stimuli is taking place. Selectively attending to one stimulus will block the perception of other surrounding stimuli signals from being perceived (Broadbent, 1958). Other research has described attention as a searchlight of illumination. Relevant stimuli within the area of illumination can be selectively attended to while irrelevant stimuli are outside of the focus of the spotlight and are therefore not being attended to (Posner, Snyder, & Davidson, 1980). From the cognitive load point of view in high load tasks the searchlight of attention would remain focused on the task at hand due to the level of difficulty and would not shift around to irrelevant stimuli. In low load tasks, working memory is not using all of its capacity and would therefore provide available resources for the searchlight to shift capturing additional stimuli regardless of relevance. According to the searchlight of illumination, the outside stimulus or signal is still being processed at some level but is being classified as irrelevant and is thus not entering the realm of perception. This point ties in to another theory proposed by Treisman and Gelade (1980), known as the feature integration theory of attention, by describing stimuli outside of attention as free floating. The stimuli not in the focused attention area of the beam are not being semantically processed but remain adrift until the beam shifts attention to focus on the other stimuli.

According to the feature integration theory, features are perceived first and are registered early, automatically and in parallel for visual sensory perception. However, focused attention is needed in order to identify objects and in the absence of attention features can randomly join together creating illusory conjunctions. (Treisman & Gelade, 1980). Attention is key in the perception of stimuli and focusing attention on one stimulus does not entail that other stimuli are not being processed in parallel even though they may not be perceived. In the feature integration theory of attention (Treisman & Gelade, 1980), illusory conjunctions are created by the lack of focused attention. In the case of signal detection this negatively impacts the quality of the signal being detected by allowing non-relevant information to influence the stimuli. When testing whether increased cognitive load decreases signal detection, it is very important that the high load task be of a certain level of demand to ensure the participant is maintaining focused attention on the task. Ensuring the participant's focused attention on the task will allow for a more reliable measure of signal detection.

The previous theories form a segregation into two distinct classes of thought regarding attention and perception. First, are those who describe signal detection as being entirely dependent on focused attention with all other stimuli being either completely ignored or simply not processed on any level. Second, those who suggest that all stimuli are perceived automatically and in parallel with focused attention acting as the factor combining relevant stimuli into a cohesive entity. With these two classes of attention in mind, how do we explain situations that produce results conflicting with both ideas such as when unattended stimuli are perceived and interfere even in the presence of focused attention?

In answer of the previously stated question, another theory has suggested taking both ideas, of only attended stimuli getting perceived and all stimuli getting perceived, and adding a third factor. This third factor is the perceptual load of the task being attended to. According to the perceptual load theory the perception of stimuli is dependent upon attention, however, it is not the case where attention can only focus on a single stimulus ignoring all others but rather attention can perceive multiple stimuli until the capacity is reached. All other stimuli cannot be perceived because there is no longer space in the attention span to hold them (Lavie, Zokaei, Lin, & Thoma, 2009). According to the perceptual load theory the demand of a task increases as the number of items presented are increased, and the demand of a task is decreased as the number of items presented decreases (Lavie, 2005).

In regards to the perceptual load theory, the idea is that signal detection is not only dependent upon attention but also on the level of demand of the task that is being attended to. In low load tasks there are left over attentional capacities due to not having to use all of working memories store which allow for the detection or perception of other stimuli that are not being attended to. In high load tasks the entirety of attentional capacity is being used by the task being attended to which in turn does not allow or afford any additional stimuli to enter into perception, or be detected, due to the fact that all of the working memory is being devoted to the task at hand. This theory would explain how an individual did not hear someone talking to, or trying to get his attention not only by the fact that attention is directed elsewhere but also due to the load or demand of the task being completed.

The goal of this study is to demonstrate the negative effect that cognitive load has on the detection of auditory signals by having participants run in both high cognitive load and low cognitive load conditions. Participant’s ability to detect on a semantic level a set of auditory signals randomly played throughout the different conditions was measured. We expect to see from this study a main effect of type of cognitive load where signal detection will be lower on the mathematical n-back task in comparison with the symbolic n-back task. Also expected is a main effect of cognitive load where signal detection will be higher for low load tasks in comparison to high load tasks. We also expect to see an interaction effect between cognitive load and the type of cognitive load where low cognitive load using the symbolic n-back task will result in the highest levels of signal detection compared to all other conditions. However, low cognitive load using the mathematical n-back task will have higher levels of signal detection compared to both high cognitive load symbolic n-back task and high cognitive load math n-back task with the latter resulting in the lowest level of signal detection compared to all other conditions.

Method

Participants

Thirteen participants were selected to take part in our study. All participants were students at California State University Long Beach and enrolled in the research in a cognition and learning course. Out of the participants who took part in the study nine were females and four were males ranging in age from 21 to 33 with the average age being 24. Active participation in the study was part of the course requirements for the research in the cognition and learning class effecting the participant’s final grade.

Materials and Apparatus

The apparatus used was a standard HP desktop computer equipped with speakers. A decibel meter was used to ensure that all speakers were producing audio at the selected level of 60 decibels. The materials given to participants included a pen, answer sheets to record responses for the n-back tasks and questionnaire response sheets. The answer sheets consisted of a single sheet of paper with the title of the task being completed, either Mathematical n-back or Symbolic n-back. For the mathematical n-back answer sheet, numbered lines were provided corresponding to serial location in the task. The symbolic answer sheet had numbered pair box selections, labeled either yes or no, to indicate whether or not the symbol was the same. This corresponded to the serial location in the task. Questionnaire response sheets consisted of a single sheet of paper with the title matching the task just completed and three questions. The first question asked if the participant heard any audio clips during the task and the participant was to reply with a yes or no response. The second question stated if yes, how many were heard and the participant was to write a number accordingly. The final question asked the participant to identify the audio clips by naming or describing as much about the audio clip as possible. A final response sheet was completed by the participant at the conclusion of the study which rated on a 5 point scale the familiarity of music from the western world with 1 as very unfamiliar and 5 being very familiar.

Procedure and Stimuli

Participants arrived for the first session of the study and were asked to write their name, age and sex on a participant sign in sheet. After completing this the participant was taken into a separate room equipped with a single chair and desk and was instructed to sit directly in front of the computer. The participant was then informed of the task that he would be completing, either a mathematical or symbolic n-back task (with a 1n-back as a practice condition and a 2n-back as a high load condition).

The mathematical 1n-back task was used as practice and consisted of adding a number presented center screen in standard black coloring with a white background to the number that immediately preceded it. Once the participant had the sum of these two numbers he recorded it on the corresponding space of the answer sheet. The mathematical 2n-back task required the participant to add the currently presented number to the immediately preceding two numbers. The symbolic 1n-back task was also used as practice and involved the participant identifying whether or not the symbol currently being presented was the same as the symbol that immediately preceded it. The symbols used were presented in the center of the screen in bold black print on a white background and were obtained from Microsoft Word symbols font. Responses were recorded by checking either a yes or no box on the corresponding space of the answer sheet. The symbolic 2n-back task required the participant to identify whether or not the currently presented symbol was the same as the symbol presented two symbols back.

After being informed of the task to be completed the participant was then handed a pen and an answer sheet to record responses and was asked if any further explanation was required or if he had any questions before beginning. The participant was then instructed to click start on the computer screen when ready to begin the trial and to inform the experimenter once the task had been completed. After the collection of the answer sheet the participant was informed that he would be completing another n-back task, depending on which type was taken first, either a visual or mathematical n-back task. Another answer sheet was provided and similar instructions were explained. Once the second trial was completed the participant was informed that he must return at another time to complete the second half of the study and was thanked for participating.

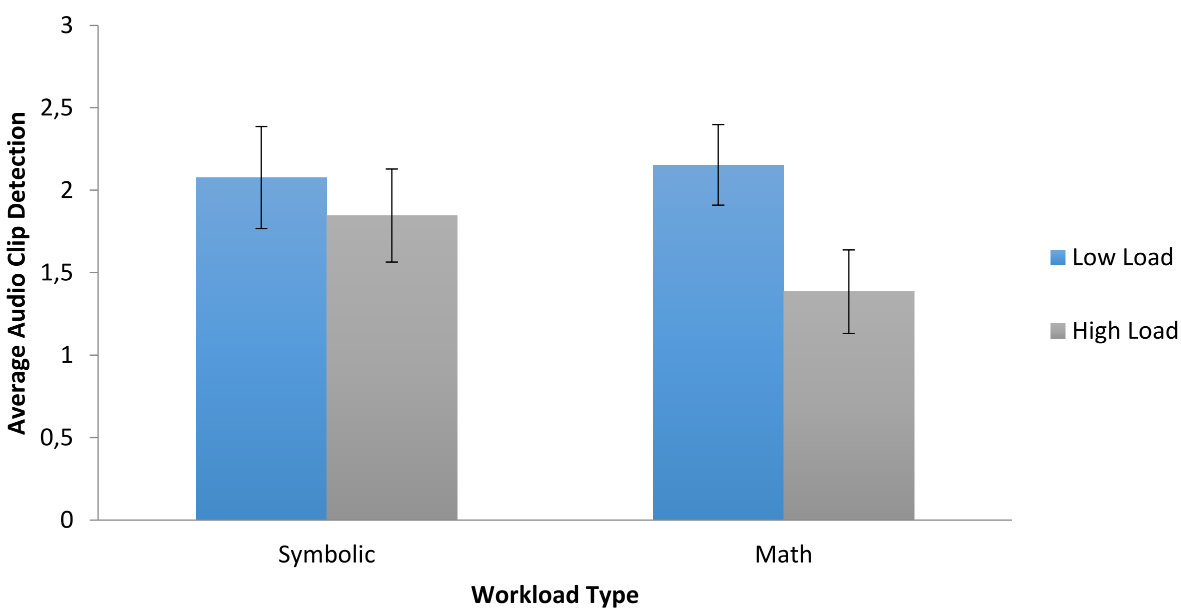
The procedure for the second session of the study followed that of the first except for two differences in task completion. Although1n-back tasks were once again used as practice runs, they were followed by matching low load baseline 0n-back tasks, either mathematical or symbolic. The mathematical baseline task simply required that the participant record the number being presented on screen onto the corresponding space of the answer sheet. The symbolic baseline task required indicating whether or not a symbol was being presented and marking yes or no on the answer sheet. Upon completion of the final session of the study participants completed the final questionnaire and were thanked for their participation.

Design

The experiment is a 2 X 2 repeated measures analysis of variance (ANOVA) looking at main and interaction effects of cognitive load type and difficulty of cognitive load. The independent variables were cognitive load type being either mathematical or symbolic and difficulty of cognitive load being either a hard high load (2n-back) task or an easy low load (0n-back) task. The dependent variable is the detection of four sets of auditory stimuli with each set containing four unique and familiar audio clips.

Results

It should be recalled that increased cognitive load resulted in the decreased ability of participants to detect auditory stimuli. More specifically, participants should be able to correctly name and describe sets of audio clips more while engaged in the n-back tasks defining low load (0n-back) than in the n-back tasks defining high load (2n-back). Although findings were not significant and a main effect of difficulty of workload could not be established, there was a trend towards greater ability in detecting auditory stimuli in low load tasks as compared to high load tasks as seen in Figure 1. Thus, participants tended to identify or detect the audio clips more in the baseline 0n-back conditions, $F(1,12) = 3.39$, $\eta_p^2 = .22$, $p = .09$, than in the 2n-back conditions



which is in accordance to our hypothesis.

Figure 1. High Load vs. Low Load: Auditory Signal Detection. This figure illustrates the trend of participants' ability to better detect auditory stimuli in low load tasks compared to high load tasks.

We determined that there should be a main effect in the workload type with participants in the mathematical conditions detecting less auditory stimuli than in the symbolic conditions. There were however no significant findings regarding a main effect of workload type for mathematical n-back task and symbolic n-back task, $F(1,12) = 0.22$, $\eta_p^2 = .018$, $p = .648$. It should be recalled that an interaction effect should exist between cognitive load type and difficulty of cognitive load. In particular, participant's performance in detecting auditory stimuli in the symbolic low load baseline task should be greater compared to all other comparisons. However, signal detection of auditory stimuli for the mathematical high load task should be the lowest compared to the symbolic high load and mathematical low load tasks which increase in auditory stimuli detection respectively. No such interaction effect was determined to be present, $F(1,12) = 1.28$, $\eta_p^2 = .097$, $p = .279$.

Discussion

In search of an answer as to why a common phenomenon such as not hearing someone talking while being intently engaged in another task, we undertook a study aimed at determining whether increased task demand resulted in a decreased ability to detect auditory signals. Although our findings were not statistically significant, our data concerning difficulty of workload in high and low load tasks trended towards significance according to our initial hypothesis that increased load would result in decreased ability in detecting auditory stimuli. Other research has shown that increases in the level of demand or load in a given task does lead to a reduction in participant's ability to detect signals for visual stimuli (Posner, Snyder, & Davidson, 1980). In spite of non-significant data, our results trending towards supporting our hypothesis indicate that we are on the right path and may possibly be getting non-significant results due to poor experimental design. The importance of this trend is still applicable in everyday situations.

One importance of this finding in an everyday application would be in regards to product design and warning signals. If a product requires completing a task that has high load or difficulty, items that require action should be displayed around the area where attention is primarily being focused. Aside from this, if warning signals are present indicating error or any such situation, having simply an auditory signal to indicate a warning may not be enough in high load difficult tasks. In such situations a visual warning signal should be presented, along with an audio signal, at the focal point of attention to ensure detection.

There are several factors that could be influencing our data and effecting our results, one such factor in particular being that of having such a small sample size. Sample size has no strict rule governing the exact number of participants that should be in each study but there is an agreed upon number indicating the least amount of participants and that number tends to be thirty (Morse, 1999). Another issue that could be interfering with obtaining a significant result could be that the participant is not focusing attention to the task being completed. This could be due to the task being too simple so that the participants do not have to use all of their working memory capacity. The task may be too difficult so that the participants cannot properly complete the task or choose to skip or ignore portions of the task. A third factor that could be leading to non-significant results could be that the audio clips being used as a means to determine signal detection are not familiar to the participant. This would interfere with the participant's ability to name and or describe the audio clips when asked on the questionnaire response sheet. A final factor that may possibly be interfering with our finding could be that our study is testing more of a distraction on memory function rather than the negative influence of cognitive load on signal detection.

To address these issues a future study should obtain a larger sample size and should add two additional conditions, one slightly less difficult and the other slightly more difficult than the current high load task to control for maintaining participant attention. To ensure familiarity with the audio clips, perhaps sounds found in everyday situations could be used.

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