

An Inhibited Recognition Performance for Explicitly Presented Target-Aligned Irrelevant Stimuli in the Auditory Modality

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Abstract

Overtly presented, but ignored visual stimuli are inhibited in a later recognition task if previously presented synchronously with an attended visual target. Here, we extend these findings to auditory presentations. Participants were required to respond to immediate sound repetitions in a stream of simultaneously presented spoken words, and later given a surprise recognition test that measured recognition for the unattended words. Words that had been simultaneously presented with a sound repetition in the previous repetition detection task were later recognized at levels significantly *below* chance. These data suggest the existence of an inhibitory mechanism that is exhibited in later recognition tests for salient auditory information that was previously unattended and had been simultaneously presented with an attended auditory target in a separate task.

Introduction

Anecdotal and scientific evidence suggest that stimuli that receive attention are more efficiently processed than stimuli that go unattended (Ahissar & Hochstein, 1993; Broadbent, 1953; Cherry, 1953; Mack & Rock, 1998; Moray, 1954; Sinnett, Costa, & Soto-Faraco, 2006; Spence & Squire, 2003; Triesman, 1960). However, a number of investigations have demonstrated that unattended information can nevertheless be processed and affect behavior. For instance, researchers have explored how information is processed when it is explicitly or implicitly presented, and the fate of this information when it receives or does not receive direct and focused attention (Rees, Russell, Frith, & Driver, 1999; Seitz & Watanabe, 2003; 2005; Sinnett et al., 2006; Tsushima, Sasaki, & Watanabe, 2006; Tsushima, Seitz, & Watanabe, 2008; Swallow & Jiang, 2010). However, the findings from these investigations fail to yield a clear picture as to the degree to which unattended stimuli can influence behavioral processing. That is, while the presentation of unattended information has consistently lead to behavioral effects, the nature of these effects have ranged from facilitation to inhibition depending on whether it was presented above or below threshold (i.e., explicit awareness).

Watanabe, Náñez, and Sasaki (2001, see also Seitz & Watanabe, 2003; 2005) demonstrated significant perceptual learning enhancements in the absence of focused attention for stimuli that were presented below the threshold for

visual awareness. Yet, more recently and contrary to these findings, Tsushima and colleagues (Tsushima, Sasaki & Watanabe, 2006; Tsushima, Seitz & Watanabe, 2008) demonstrated that when the implicit stimulus is made explicit (i.e., observable), a later inhibition is observed. Accordingly, behavioral facilitation or inhibition appears to be partly dependent on whether or not stimulus presentation is sub- or superthreshold. Furthermore, collectively these investigations indicate that the temporal relationship between the irrelevant stimulus and an attended target in a separate task is critical to observing these facilitatory or inhibitory effects in a later recognition task.

Highlighting the need for temporal synchronicity between attended and unattended stimuli, Seitz and Watanabe's (2003) participants viewed random moving dot displays with a subthreshold amount of coherent motion (see also Watanabe et al., 2001 for further examples using a similar paradigm). Critically, the subthreshold motion did not influence post exposure motion detection unless it had previously been presented simultaneously with targets from a secondary task (identify white target letters occurring in a rapid serial visual presentation (RSVP) of black and white letters). When this temporal alignment occurred, motion detection improved when subsequently recognizing that same direction after exposure, suggesting that the subthreshold motion had been processed to a degree to facilitate future judgments. Note, the exposure motion was always subthreshold, thereby suggesting that the direction of the motion was implicitly learned to a level sufficient to affect later decisions on motion discrimination.

Being that performance enhancements for motions that were not temporally aligned with targets from the secondary task were never observed, the temporal relationship between the task-relevant stimulus (presence of white letter) and the task-irrelevant exposure stimulus (motion) appears to be critical to the effect (Seitz & Watanabe, 2003; 2005). Thus, it would appear that if two stimuli were presented simultaneously, then the learning associated with attention being directed to one stimulus would spill over to the other, thereby facilitating processing of this unattended stimulus. However, it is important to note that the irrelevant stimuli in these investigations were exclusively implicit in nature. As the mechanisms involved in implicit and explicit information processing are likely different, it is important to

explore what happens when the irrelevant motion stimuli is explicitly presented during the exposure stage.

A recent investigation addresses this very question. Tsushima et al (2008) conducted a similar experiment using explicit rather than implicit motion during the exposure stage. In this case, half of the dots in the motion display moved in coherence, while participants simultaneously performed the letter identification task. Interestingly, the exact opposite findings were observed. That is, while facilitation for subthreshold presentations were still observed, performance for superthreshold motions that were simultaneously presented with a task target from the letter identification task was later inhibited. This is contrary to what one might have expected, as higher motion coherence would possibly be expected to lead to increased learning effects due to the stronger coherence inducing a strengthened perceptual signal (Britten, Shadlen, Newsome, & Movshon, 1992). The behavioral findings were supported by fMRI data showing an inhibition in brain activity in brain areas associated with processing motion direction (Tsushima et al., 2006). The authors concluded that if the irrelevant stimulus is subthreshold in nature, then no inhibitory mechanism is engaged, whereas an inhibitory mechanism would be in place for superthreshold displays as attention would be needed to be directed towards the task target (letter detection) while at the same time ignore the superthreshold and possibly distracting motion stimulus.

Assuming that the inhibitory and facilitatory effects for simultaneously presented, but ignored, stimuli are driven by whether the irrelevant stimulus is implicitly or explicitly presented, it is important to extend these results to other sensory modalities. Despite humans being dominated by the visual sense (Colavita et al., 1974; Posner et al., 1980; Sinnett et al., 2007; Spence et al., 2003), it is apparent that the human perceptual experience is a result of multisensory information. Thus, it is important to explore whether other sensory modalities also process irrelevant information in the same manner as the visual sense. For instance, Sinnett et al. (2006) demonstrated that when attentional reservoirs were depleted by a primary task, inattention blindness (IB) for spoken word perception was interrupted to the same degree as visual word recognition.

A recent investigation by Dewald et al (2010) replicated Sinnett et al.'s (2006) investigation in the visual modality, but included an additional analysis for items that appeared simultaneously with targets in the separate task. In this case, an inhibition for visually presented words (explicitly presented) was observed. That is, despite their overt presentation and high degree of saliency (i.e., words), later recognition performance was below chance levels. In the present experiment we adapted the same IB paradigm to an auditory presentation in which spoken words were overtly presented at the same time as common everyday sounds, with the primary task to detect target repetitions in the sound stream, and the secondary task to recognize the previously ignored words. If an inhibitory mechanism operates in the visual modality for overtly presented

irrelevant information that is simultaneously presented with a task target from a separate task (i.e., immediate sound repetition), then an inhibition should be observed for that irrelevant information in the auditory modality as well, given evidence for a common encoding system for both written and spoken words (Hanson, 1981). Alternatively, a facilitatory mechanism similar to that observed for subthreshold motion displays (Seitz & Watanabe, 2003), would suggest improved perception rates for the irrelevant, but simultaneously presented, words. However, it is difficult to speculate that mechanisms observed for implicit information will extend to explicitly presented stimuli. Lastly, it should be noted that we are extrapolating findings from a recognition task to elucidate mechanisms of perception for previously presented, task-irrelevant, explicit stimuli. Despite the possibility of a slight disconnection in this argument, there are a number of studies that utilize this same framework (i.e., Rees et al., 1999). This is strengthened by findings that show a convergence between recognition tasks and online fMRI findings suggesting that depletions of attention affect word processing itself, rather than any process (e.g., memory) during the later presented recognition task (see Rees et al., 1999).

Method

Participants. Sixty participants ($n=60$) were recruited from the University of Hawai'i at Manoa in exchange for course credit. Participants were naïve to the experiment and had normal or corrected to normal hearing. Written informed consent was obtained before participation in the experiment occurred.

Materials. A total of 150 one to two syllable, high-frequency English words (average length of 5 letters) were selected from the MRC psycholinguistic database (Wilson, 1988). The overall average frequency of the 150 selected words was 120 per million, ranging between 28 and 686. A native English speaker's voice was recorded reading the list three times, after which three blind listeners chose the best exemplar of each spoken word. In the event that the three exemplars of a specific word were chosen by the listener, a fourth listener was asked to decide which one was best. The selected recordings were edited using sound editing software so as to all contain the same length of presentation length (350 ms) and average amplitude. The sound stimuli were extracted from a database of 100 familiar sounds and were also edited to 350 ms and for average amplitude (downloaded from www.a1freesoundeffects.com, 01/02/2003, see Sinnett et al., 2006).

Design. To ensure an enhanced level of randomization, the 100 sounds were randomly separated into two equal groups, while the 150 words were randomly divided into three equal groups (similar average frequency). In each group of sounds, half (25) were pre-selected and duplicated. These repeated sounds acted as targets as each pair occurred in the

auditory presentation as an immediate repetition. The remaining 25 sounds were also duplicated, but their positioning in the stream never allowed for an immediate repetition. One hundred of the 150 words were overlaid on each of the sounds, creating a block size of 100 sound-word items. Across two blocks of presentation, half of these words (i.e., 50) were *target-aligned* with a sound repetition while the other half was *non-aligned*. Half of the different sounds (25) were repeated in one block, while the other half were repeated in the other block. The same 100 randomized words superimposed were used in each block (note, a superimposed word was never repeated within a block). Therefore, across both blocks, each sound was displayed a total of four times (once as a repeat and then two other times as non-repeats in the complementary block). The words were presented a total of two times throughout the experiment, once in each block respectively.

The same principle was used when making streams of items when the words were repeated (attending to words condition). As there were 150 words and 100 sounds, six different versions of the sound-word superimposed stimuli were created for use in the attending to sounds condition as well as the attending to words condition.

The surprise recognition test, administered after the completion of the repetition detection task, consisted of 100 words from both the previously heard stream (50) as well as never heard before foil words (50). The foils were words that were used in a different version of the experiment (fully randomized). The 50 non-foil words (i.e., words that had been presented) in the surprise recognition test were words that had either been temporally aligned with the task-relevant target, (i.e., *target-aligned*; superimposed over the immediate repetition of a sound), or had not been temporally aligned with the task-relevant target (i.e., *non-aligned*; superimposed over non-immediately repeating sounds) in the previous repetition detection task. The surprise word recognition tasks were randomized and presented by DMDX software, (<http://www.u.arizona.edu/jforster/dmdx.htm>), one at a time, written in bold, capitalized letters in Arial font at a size of 24 points (see also Sinnett et al., 2006 for a similar design). An analogous version of the experiment was created where the repeated targets were words rather than sounds. All word repetitions followed this design. Care was taken to ensure that sound-word combinations did not have any semantic relationship.

Procedure

Participants were randomly assigned to one of two conditions and required to perform a recognition detection task (i.e., respond to immediate repetitions of either a word or picture). One group was required to attend to the sound stream (i.e., ignore the overlaid spoken words) and respond to immediate sound repetitions, while the other group was required to respond to immediate repetitions in the spoken word stream, while ignoring the sounds. Participants

responded to repetitions by pressing the ‘G’ key on the keyboard.

Each item in the sound-word presentation was presented for 350 ms with a 150-ms inter-stimulus interval (ISI; silence) between each item for a stimulus onset asynchrony (SOA) of 500 ms (see Figure 1). Before the first experimental block, a training block of eight trials was given and repeated until participants were familiar and comfortable with the task. Immediately after the repetition detection task the surprise word recognition test was administered. Participants were instructed to press the ‘V’ key if they had heard the word during the repetition detection task or instead the ‘B’ key if they had not heard the word before.

The recognition test consisted of either foils and target-aligned words, or foils and non-aligned words. Each group of, respective of the focus of attention during the repetition detection task (attending to sounds $n=30$ vs. attending to words, $n=30$), was divided in half and given one of the two recognition tests ($n=15$ per group). Note, the presentation of conditions and recognition tests was fully randomized.

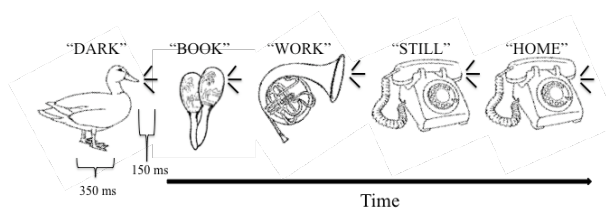


Figure 1. Example of the task in which each sound-word stimulus was presented for 350 ms and was then replaced by silence for 150 ms. Both the word- and sound-repetition detection tasks were performed on the same streams. In the above figure, the word “HOME” serves as the *target-aligned* word.

Results

Target detection accuracy in the primary task. An analysis of the overall accuracy of the primary task of immediate target repetition detection revealed that participants were accurate at detecting target repetitions in the primary task, (73% hit rate vs. 25% miss rate, $t(59) = 11.57$, $p < .001$).

Two-factor ANOVA of overall performance. A two-factor ANOVA was conducted with all factors between participants and as follows: focus of attention (attending to sounds or attending to words) and alignment of targets (target-aligned or non-aligned). A main effect for focus of attention confirmed that word recognition performance was significantly better when attention was directed to the detecting repetitions in the word stream rather than the picture stream, ($F(1,59) = 23.37$, $p < .01$). The main effect of target alignment failed to reach significant ($F(1,59) = 2.24$, $p < .11$). Importantly, there was an interaction between focus of attention and alignment of targets ($F(1,59) = 5.01$, $p < .02$). In order to understand the interaction a series of planned t-tests were conducted.

Overall surprise recognition performance. Recognition performance for *target-aligned* words was compared with *non-aligned* words and also against chance. Overall, performance was significantly better after attending to the spoken words when compared with after attending to the sounds (56.3%, $SE = 1.09$ vs. 48.2%, $SE = 1.05$, $t(29) = 6.85$, $p < 0.001$). Performance after attending to the words was significantly better than chance ($t(29) = 5.76$, $p < 0.001$) while performance after attending to the sound stream failed to be significantly better than chance ($t(29) = 1.62$, $p = 0.115$). Further demonstrating the enhancement of word recognition when attention had been directed to the word stream, significantly fewer false alarms (FAs) were made when compared with hits (hits: 56%, $SE = 1.05$, FAs: 33%, $SE = 2.25$, $t(19) = 5.89$, $p = 0.001$), while there was no difference between hits and false alarms when attention was directed to the sounds (hits: 48%, $SE = 1.09$, FAs: 50%, $SE = 3.55$, $t(19) = 1.39$, $p = 0.11$).

Target-aligned and non-aligned word recognition performance. Recognition performance for *target-aligned* words (i.e., words previously paired with immediately repeated sounds) was compared with *non-aligned* words and also against chance. When attending to spoken words in the repetition task (rather than sounds), subsequent recognition for *target-aligned* as well as *non-aligned* words were both significantly better than chance performance (*target-aligned*: 58%, $SE = 3.32$, $t(14) = 2.43$, $p = .029$; *non-aligned*: 59%, $SE = 1.66$, $t(14) = 5.69$, $p < .001$). There were no significant differences between *target-aligned* and *non-aligned* word performance after attending to the words ($t(14) = .37$, $p = .712$; see Figure 2). Additionally, the hit rates after attending to the words for *target-aligned* (58%) and *non-aligned* (59%) words were both significantly greater than the false alarm rates (33%, $SE = 2.56$, $t(9) = 3.68$, $p = .001$ and, 36%, $SE = 2.81$, $t(9) = 3.25$, $p = .002$, respectively). Analysis of recognition performance after attending to the sound stream confirmed that participants were not different than chance at recognizing *non-aligned* spoken words (50%, $SE = 3.68$, $t(14) = 0.21$, $p = .831$). Critically, recognition performance was significantly different from chance for *target-aligned* spoken words (40%, $SE = 3.38$, $t(14) = 2.54$, $p = .023$). When compared to each other, recognition for *non-aligned* words was significantly better than *target-aligned* words ($t(14) = 2.30$, $p = .037$; See Figure 2). Furthermore, when attending to the sound stream the hit rate for *target-aligned* words (40%) was significantly lower (i.e., inhibition) when compared with the FA rate (51%, $SE = 4.51$, $t(9) = 3.52$, $p = 0.01$), while there was no difference between hits and FAs in the *non-aligned* recognition test (hits: 50%, $SE = 3.68$, FAs 52%, $SE = 5.90$, $t(9) = .223$, $p = 0.829$).

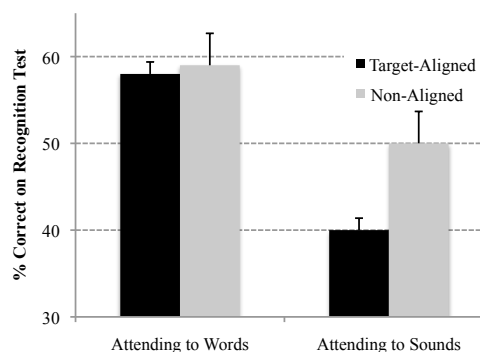


Figure 2. Recognition percentages and standard error bars for Target-Aligned (grey bars) and Non-Aligned (black bars) words in the surprise word recognition test after attending to either the spoken word stream (Left) or the sound stream (Right).

Discussion

The present experiment extends the findings of Sinnott et al. (2006) in a number of ways. First, and in-line with their report, we demonstrated that the auditory modality is susceptible to inattention blindness (i.e., deafness). Despite not having the analogous visual condition (although, see Dewald et al., 2010; Rees et al., 1999; Sinnott et al., 2006 for examples with this condition), it is reasonable to conclude that auditory word recognition is significantly better after attending directly to the word stream as opposed to attending to a distracting stream of sounds. More specifically, participants were unable to later recognize the words that had been simultaneously presented with the sound stream, if attention had been directed to the sound stream during the repetition detection task.

The second critical finding pertains to recognition performance for words, after having attended the sound stream, that had been presented at the same time as a sound target in the primary task. Here we replicated the visual findings of Dewald et al (2010) in the auditory modality. That is, after having attended to the sound stream (rather than a picture stream as in Dewald et al., 2010) in the repetition detection task, subsequent word recognition for *target-aligned* words (i.e., words presented at the exact same moment as a sound repetition) was significantly below chance. This suggests, as does Dewald et al (2010), a possible inhibitory mechanism for overtly presented irrelevant information that appears simultaneously with an attended target.

The potential inhibition of the auditorily presented target-aligned words when attention was directed to the sound stream is of key interest. Many investigations have demonstrated that unattended and irrelevant stimuli are often not perceived when attentional resources are depleted (Mack & Rock, 1998; Rees et al., 1999; Sinnott et al., 2006), however only recently have investigators directly compared the performance for target-aligned and non-aligned stimuli. In this case, it appears that either a facilitation or inhibition can be observed, dependent on

whether the irrelevant stimuli are presented above or below threshold. Here, word recognition was inhibited for target-aligned words, despite word perception being arguably an automatic process (Stroop, 1935; Lupker, 1984, see also Shor, 1975 for an example of an auditory Stroop task). Moreover, these investigations have typically focused on visual presentations, whereas the present investigation extends these results to the auditory modality.

While the inhibition effect observed here supports research by Tsushima et al (2006, 2008), it fails to coincide with recent findings by Swallow and Jiang (2010), suggesting an “attentional boost” (i.e., facilitation) for simultaneously presented information in a dual-task paradigm (see also Lin et al., 2010 for a similar example of a paradigm utilizing temporally aligned targets). In their experiment, participants monitored a stream of pictures of various scenes. While monitoring the stream, a series of distractor items (small black superimposed squares) were simultaneously paired with the presentation of each picture presentation. Participants were required to remember as many of the presented scenes as possible, in addition to monitor the distractor stream for the presence of an “odd-ball” color change (i.e., the presence of a white square rather than black squares). In a subsequent forced choice recognition test for the picture scenes, an enhanced recognition for pictures that had been presented simultaneously with the presence of the target (i.e., the ‘odd-ball’ color change) in the distractor stream was observed (i.e., the attentional boost effect).

Of particular note to Swallow and Jiang’s (2010) findings is the fact that the pictures were presented explicitly, much like the unattended words in our investigation. The question then remains as to why they observed a facilitation for target-aligned stimuli while our findings demonstrate an inhibition? However, it should be noted there is a significant procedural difference that could explain the contradictory findings. Specifically, participants in Swallow and Jiang’s experiment were required to attend to both streams, whereas the participants here were specifically instructed to attend to only one stream (i.e., ignore the other). This limitation alone could drive the differences in findings between paradigms, but could also be exacerbated by the nature of the stimuli chosen for the recognition test (i.e., pictures in their experiment and words in the present investigation).

It could be argued that the inhibition of previously heard words that had been paired with a sound repetition target does not follow the conclusions drawn by Seitz and Watanabe (2003; see Seitz & Watanabe, 2005 for a review). According to the framework provided by their experimentation, an enhanced recognition performance for words synchronized with task-relevant targets should have been observed. That is, while the necessary temporal synchronization between task-relevant and task-irrelevant stimuli was present, enhanced perception for task-irrelevant stimuli was not observed. The exact opposite was seen here, in that there was an inhibition of performance for the

recognition of previously temporally aligned words with repetition targets in the primary task. However, it should be noted that participants were overtly presented with highly salient words here, whereas Seitz and Watanabe utilized subthreshold motion displays, making a direct comparison from their experiment to ours difficult at best.

Accordingly, our findings dovetail with Tsushima et al. (2008; see also Tsushima et al., 2006), who presented motion displays with superthreshold (i.e., overt) motion coherence. In this case, they observed an inhibition when detecting similar motions that had been earlier presented with task targets from a separate task, akin to the inhibition we observed for auditory words. Therefore, the present findings extend their findings not only to the auditory modality, but also when using a stimulus arguably much more salient than simply dot motion displays.

Although the conclusions of Tsushima et al (2006, 2008) and the findings here both suggest that a strong irrelevant feature will be inhibited rather than facilitated if presented simultaneously with a target from a separate task, future research could employ the paradigm from the present study to investigate prolonged exposure rates through the utilization of a larger number of trials and a smaller number of *target-aligned* words to see if perception is enhanced, rather than inhibited.

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