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Abstract

Overtly presented, but ignored visual and auditory stimuli presented within the same sensory modality are inhibited in a later recognition task if previously presented synchronously with an attended visual target (Tsushima, Sasaki & Watanabe, 2006; Tsushima, Seitz & Watanabe, 2008; Dewald, Doumas & Sinnett, 2010; Dewald & Sinnett, 2011). We extend these findings to conditions in which task irrelevant stimuli (written or spoken words) were presented in a separate sensory modality than task-relevant targets (picture or sound repetitions). A subsequent recognition task was given for the previously presented irrelevant stimuli (words). Words that had been simultaneously presented with a target in the previous repetition detection task were later recognized at chance levels, demonstrating a bolstered recognition of task-irrelevant items (e.g. *target-aligned* words) when compared with performance under unimodal presentation.

Key words: Attention, Multimodal Presentation, Recognition

Introduction

It has been demonstrated throughout cognitive psychology's history that attention is a limited resource (Broadbent, 1954; Cherry, 1953; James, 1890; Mack & Rock, 1998; Rees, Russell, Frith, & Driver, 1999; Sinnett, Costa & Soto-Faraco, 2006; Triesman, 1960). Interestingly, the capacity of the attentional system seems to be modulated if a difficult unisensory task is divided across multiple sensory modalities (i.e., a multiple resources theory, see Wickens, 1984). For instance, Sinnett et al. (2006) showed that under multimodal presentations, inattentional blindness for words was ameliorated (i.e., perception improved) when compared with unimodal conditions, regardless of the modality of word presentation (see also Toro, Soto-Faraco, & Sinnett, 2005 for a similar example involving statistical learning). These findings seem to provide support for an attentional system that is segregated, such that each sensory modality has access to individualized attentional resources (see Wickens, 1984).

Providing support for a multiple resource view, Duncan, Martens, and Ward, (1997) demonstrated that participants had difficulty identifying target items presented 300 ms or less after previous targets under unimodal presentations (auditorily or visually), due to the well-documented phenomenon termed the *attentional blink* (AB; see Shapiro, 1992). However, when targets were presented across sensory modalities (that is, when first identifying a visual target and then an auditory target, or vice versa), typical AB effects were not observed. That is, participants were able to detect an auditory or visual target even when it was immediately preceded by a target occurring in the other modality (i.e., visually or auditorily respectively), whereas they were unable to do so under unimodal presentations. This finding suggests that attentional costs are reduced if a difficult task is divided across sensory modalities.

Further investigating this issue, Sinnett et al. (2006) explored a multiple resource view of attention by means of an inattentional blindness (IB) paradigm. IB is a well-studied phenomenon in attention research that illustrates a situation in which an individual fails to detect an explicitly presented event due to attention being directed elsewhere (Mack & Rock, 1998; Simons & Chabris, 1999). The overwhelming conclusion of IB research is that if attention is deployed to a difficult or demanding primary task, information not relevant to the primary task goes unprocessed, at least not to levels of explicit awareness. A curious finding by Sinnett et al. (2006), however, was that when irrelevant information was presented in a sensory modality separate from the target information, levels of IB was reduced for irrelevant items (i.e., performance improved when compared to unimodal presentations).

Sinnett et al. (2006) utilized an IB paradigm (see also Rees et al., 1999) incorporating multisensory presentations in which participants detected immediate repetitions in a stream of rapid serially presented items in either visual, auditory, or bimodal conditions. In the unimodal conditions (visual only or auditory only streams) the primary task was to monitor either pictures (or sounds) presented simultaneously with written words (or spoken, respectively) and detect immediate repetitions in either the word or the distractor stream. Immediately following this task, a surprise word recognition test was administered for unattended words (after having attended to pictures or sounds). In the crossmodal condition words were presented either visually or auditorily, with a distracting stream of either overlaid/superimposed sounds or pictures in the opposite modality. Unimodal performance (both auditory and visual) yielded high and comparable levels of IB. However, when attention was divided across modalities (that is, attending to visual pictures while ignoring spoken words, or attending to sounds while ignoring written words), participants performed significantly better in subsequent word recognition tests for the unattended words. Thus, despite the accepted notion that attentional capacity is limited, recognition performance for irrelevant stimuli can often be improved as long as it had been presented in a separate sensory modality (e.g., Duncan et al., 1997; Sinnett et al., 2006; Wickens, 1984).

Although a plethora of scientific evidence suggests that stimuli that receive attention are more efficiently processed than stimuli that go unattended (Ahissar & Hochstein, 1993; Mack & Rock, 1998; Sinnett et al, 2006; Spence & Squire, 2003) a number of investigations have demonstrated that unattended information can nevertheless be processed and affect behavior. 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, the nature of these effects has ranged from facilitation to inhibition depending on whether the unattended stimuli were presented above or below threshold. Moreover, a critical relationship between whether or not the irrelevant stimuli occur synchronously with a relevant target has been recently uncovered.

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 from visual awareness (i.e. implicitly presented). However, when using explicit stimuli, Tsushima and colleagues (Tsushima, Sasaki & Watanabe, 2006; Tsushima, Seitz & Watanabe, 2008) demonstrated a later inhibition. Accordingly, behavioral facilitation or inhibition appears to be partly dependent on whether or not stimulus presentation is sub- or superthreshold. Critically, the facilitatory and inhibitory effects in both of these examples appear to be contingent on the temporal relationship between the irrelevant stimulus and an attended target in a separate task. That is, performance changes for irrelevant stimuli were observed only when temporally aligned with relevant stimuli (i.e., task targets). For instance, Tsushima and colleagues (Tsushima et al., 2006, 2008) demonstrated that the detection of ignored, but explicitly presented coherent motion displays, is inhibited when the motion display is temporally aligned with the presence of an attended task-relevant target in a simultaneously presented task. The same inhibition was not observed for non-aligned presentations, and was further supported by functional magnetic resonance imaging (fMRI) data showing an inhibition in brain activity in brain areas associated with processing motion direction (Tsushima et al., 2006).

We have recently published behavioral data also showing an inhibition for temporally aligned, but irrelevant stimuli (Dewald et al., 2010). In this example we modified the paradigm utilized by Sinnett et al (2006) investigating inattentional blindness to include an additional analysis for items that had appeared simultaneously with targets in the separate task. When doing so, an inhibition for visually presented words (explicitly presented) was observed. In an ensuing investigation, the same IB paradigm was adapted to auditory presentations 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 later recognize the previously ignored words (Dewald & Sinnett, submitted). Again, the findings demonstrated that akin to visually presented words, word recognition was inhibited for spoken words that had previously been temporally aligned with sound repetitions.

In the present investigation, we extend these unimodal examples of inhibited performance for task irrelevant but target-aligned stimuli to multimodal presentations. As increased performance has been observed for such presentations (see Duncan et al., 1997; Sinnett et al., 2006), we would expect that previously documented inhibition might disappear, or perhaps even lead to enhanced recognition performance for task-irrelevant words, as long as they had previously been presented with a target repetition. To address this, we presented participants with multisensory visual and auditory streams (adapted from those used in the unimodal conditions in Dewald et al., 2010 and Dewald & Sinnett, 2011). Here, one of the streams included spoken words with distracting pictures, and the other had written words with distracting sounds. The task was to respond to repetitions in the target stream (i.e., sounds or pictures) and then to subsequently recognize as many words that had been previously presented (i.e., ignored) in the repetition detection task.

Method

Participants. Sixty participants (n=60) were recruited from the University of Hawai'i at Manoa in exchange for course credit. A total of 30 participants were used for each condition (visual words and sounds or auditory words and pictures). Participants were naïve to the experiment and had normal or corrected to normal vision and hearing. Written informed consent was obtained before participation in the experiment occurred.

Materials. The multimodal streams were concatenated using the same stimuli as used in the visual (Dewald et al., 2010) and auditory (Dewald & Sinnett, 2011) experiments that previously showed inhibitory results. 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. The words were presented either visually (Arial font at a size of 24 points) or auditorily. For the auditory presentation, a native English speaker's voice was recorded reading the list of selected words 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.

A total of 100 pictures were selected from the Snodgrass and Vanderwart (1980) picture database. The pictures (on average 5 to 10 cm's) were randomly rotated +/-30 degrees from upright so as to ensure task difficulty (see also Rees et al., 1999). A database of 100 familiar sounds were edited to 350 ms and for average amplitude and served as the auditory analog of the visual pictures in the visual stream.

The exact same stimuli and design to create streams were used here as in Dewald et al. (2010, for visual stimuli) and Dewald & Sinnett (2011, for auditory stimuli). The 100 sounds/pictures were randomly separated into two equal groups, while the 150 words (both visual and auditory) were randomly divided into three equal groups (similar average frequency). In each group of sounds/pictures, half (25) were pre-selected and duplicated. These repeated sounds/pictures acted as targets as each pair occurred in the auditory/visual presentation as an immediate repetition. The remaining 25 sounds/pictures were also duplicated, but their positioning in the stream never allowed for an immediate repetition. One hundred of the 150 words were overlaid/superimposed on each of the sounds/pictures, creating a block size of 100 sound-word/picture-word items. Across two blocks of presentation, half of these words (i.e., 50) were *target-aligned* with a sound/picture repetition while the other half were *non-aligned*. Each block of 100 items was created in which the 25 sounds/pictures not immediately repeated in the first block now served as the sounds/pictures that were immediately repeated, with the same 100 randomized words superimposed as in the first block (note, an overlaid/superimposed word was never repeated within a block). Therefore, across both blocks in each experiment, each sound/picture was played/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 (both written and spoken) were repeated (attending to words condition). As there were 150 words and 100 sounds/pictures 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.

Participants were administered a surprise recognition test immediately following the repetition detection task. This task consisted of 100 words from both the previously heard/viewed stream (50) as well as never heard or seen before foil words (50). These words 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*), or had not been temporally aligned with the task-relevant target (i.e., *non-aligned*) in the previous repetition detection task. The surprise word recognition tasks were randomly presented by DMDX software, one at a time, written in bold, capitalized letters in Arial font at a size of 24 points (see also Dewald et al., 2010; Dewald & Sinnett, 2011; 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.

Power analysis. An a priori power analysis indicated that a minimum of 10 subjects in each condition would yield a 95% confidence for detecting a medium sized effect when employing the traditional .05 criterion of statistical significance. As we predict a possible amelioration of the inhibition witnessed in Dewald et al (2010) and Dewald & Sinnett (2011), it is important that there is sufficient power.

Procedure

Participants were randomly assigned and completed only one of the repetition detection tasks. That is, half of the participants were given the stream of visual words and auditory sounds, while the other half were given the stream of visual pictures and auditory words. Importantly, superimposed/overlaid irrelevant stimuli (visual or auditory words), were presented in a different sensory modality from the targets in the repetition detection task. The primary task of detecting immediate repetitions in either the sound or picture stream was presented as follows, respectively: a visual–auditory condition with a visual word stream and an auditory sound stream; and an auditory-visual condition with spoken words and visual pictures. Participants were required to detect immediate repetitions in either the sound (or picture) or the word stream.

Participants were randomly assigned to either condition, and then again randomly assigned to one of two attention conditions. One group was required to attend and respond to repetitions in the sound/picture stream (i.e., ignore the words), while the other group was required to respond to immediate repetitions in the spoken/written word stream and ignore the sounds/pictures. Participants responded to repetitions by pressing the 'G' key on the keyboard.

Each item in the sound/picture-word presentation was presented for 350 ms with a 150 ms inter-stimulus interval (ISI; silence/blank screen) between each item for a stimulus onset asynchrony (SOA) of 500 ms. A repeatable training block of eight trials was given before the experiment started. Immediately after the repetition detection task the surprise word recognition test was administered. Participants were instructed to press the "V" key if they recognized the word from the repetition detection task or instead the "B" key if they did not see/hear the word before.

Results

Target detection accuracy in the primary task.

An analysis of the overall accuracy (for both experiments and across all conditions) of the primary task of immediate target repetition detection revealed that participants were accurate at detecting target repetitions in the primary task, (78% hit rate vs. 22% miss rate, $t(59)= 21.09$, $p<.001$).

Visual words and auditory sounds

Overall visual surprise recognition performance. The results of the surprise recognition test were compared between conditions (attending sounds vs. attending written words), and also against chance levels. Overall recognition performance was significantly better after attending to the written words when compared with after attending to the sounds (63.1% SE=2.57 vs. 53.7%, SE=1.40, $t(29)=2.25$, $p<0.05$). Additionally, recognition performance after attending to the words was significantly better than chance ($t(29)=5.08$, $p<0.001$) while performance after attending to the picture stream was not ($t(29)=1.14$, $p= 0.26$).

Target-aligned and non-aligned words. When attending to written 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:* 66.0%, SE=2.68, $t(14)= 5.97$, $p<.001$; *non-aligned*: 61.3%, SE=4.45, $t(14)= 2.55$, $p<.005$). Despite the 4.7% trend in the data for improved performance with target-aligned words, there was no significant difference between *target-aligned* and *non-aligned* word recognition ($t(14)= .804$, p=.44; see Figure 1).

Most importantly, the analysis of recognition performance after attending to the sound stream confirmed that participants were not better than chance at recognizing *non-aligned* words (55.4%, SE=4.69, $t(14)= 1.26$, p=.228). And critically, recognition performance was not significantly different from chance for *target-aligned* words (51.0%, SE=4.18, $t(14)= .197$, p=.847; see Figure 1). Furthermore, when compared to each other, recognition for *non-aligned* words was not significantly different from *target-aligned* words ($t(14)= -.762$, p=.459) .

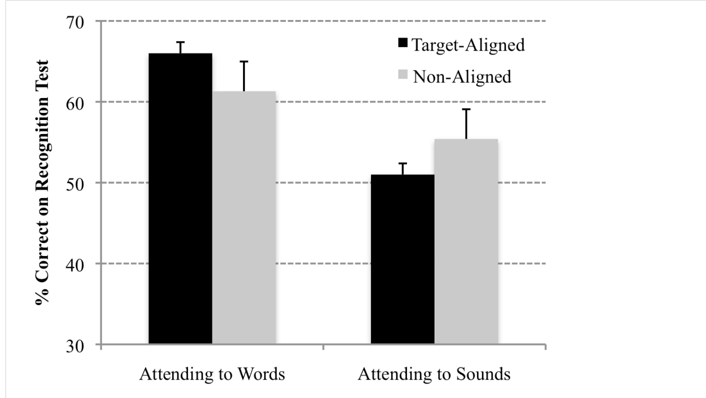

Figure 1. Recognition percentages for *Target-Aligned* (black bars) and *Non-Aligned* (grey bars) words in the surprise word recognition test after attending to either the visual word stream (left) or the sound stream (right).

Visual pictures and auditory words

Overall visual surprise recognition performance. The results of the surprise recognition test were analyzed in the same manner as above. Overall recognition performance was significantly better after attending to the spoken words when compared with after attending to the pictures (68.4%, SE=2.08 vs. 52.6%, SE=3.47, $t(29)=-4.97$, $p<0.01$). Additionally, recognition performance after attending to the spoken words was significantly better than chance ($t(29)=8.85$, $p<0.001$) while performance after attending to the picture stream failed to be significantly better than chance ($t(29)=.754$ $p= 0.457$).

Target-aligned and non-aligned words. When attending to spoken words in the repetition task, ensuing recognition for *target-aligned* as well as *non-aligned* words was significantly better than chance performance (*target-aligned:* 70.7%, SE=2.31, $t(14)= 4.31$, $p<.001$; *non-aligned*: 65.5%, SE=3.54, $t(14)= 8.95$, $p<.001$). Again, despite the 5.2% difference, there was no significant difference between *target-aligned* and *non-aligned* word recognition performance after attending to the words ($t(14)= 1.04$, p=.316; see Figure 2).

Recognition performance after attending to the picture stream showed that recognition of *non-aligned* words was not better than chance (52.8%, SE=5.39, $t(14)= .539$, p=.599). Moreover, analogous to the other condition (visual words and sounds), recognition for *target-aligned* words was not significantly different from chance (51.0%, SE=4.81, $t(14)= .206$, p=.840; see Figure 2). There were no significant differences when compared to each other ($t(14)= .272$, p=.790).

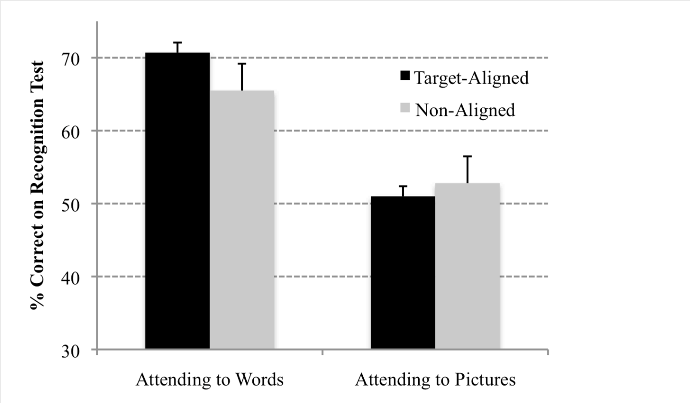

Figure 2. Recognition percentages for *Target-Aligned* (black bars) and *Non-Aligned* (grey bars) words in the surprise word recognition test after attending to either the spoken word stream (left) or the picture stream (right).

Discussion

There are a number of key findings that merit discussion. First, we have replicated previous findings on inattentional blindness under multimodal presentations, showing that performance after attending the distracting stream (either sounds or pictures) lead to the inability of participants to recognize previously presented words above chance levels. This is a particularly relevant finding given that, in a virtually identical task, Sinnett et al. (2006) did find above chance results for both of these multimodal conditions. It is difficult to speculate as to why we found contradicting results, although, it should be noted that under certain conditions equivalent levels of IB were observed when comparing unimodal to crossmodal conditions in Sinnett et al. (2006; see Experiment 2). Regardless of this difference, it is apparent that attending to the words resulted in enhanced word recognition levels. Furthermore, the present experiment expands on Sinnett et al. by directly measuring the fate of irrelevant stimuli presented simultaneously with or without a task-relevant target.

Recall that Dewald et al (2010), showed support for a possible inhibitory mechanism for overtly presented but irrelevant visual information that appeared simultaneously with an attended target within the same sensory modality (recognition performance was 36%). Furthermore, Dewald and Sinnett (submitted) extended this finding to auditory presentations (recognition performance was 40%). In the present study, the same inhibition was not observed. Instead, performance for irrelevant words simultaneously presented with an attended target in a separate modality remained at chance levels (51% in both conditions). While a confirmatory analysis across experiments was done, indeed showing improved performance for multimodal conditions when compared to unimodal conditions (both collapsed or not across modalities), it should be acknowledged that the unimodal experiments were conducted and reported separately making a direct comparison challenging.

The present findings are of particular interest considering the recent documented inhibition observed for target-aligned, explicitly presented superthreshold stimuli in numerous investigations (Dewald et al., 2010; Dewald & Sinnett, submitted; Tsushima et al., 2006, 2008). Recall that Tsushima et al (2006) demonstrated that performance for superthreshold motions that were simultaneously presented with a task-target were later inhibited when compared to motions not presented with a task-target. This finding was further supported by word recognition performance in an inattentional blindness paradigm showing inhibition for previously aligned words in a repetition detection task; for both visual (Dewald et al., 2010) and auditory (Dewald & Sinnett, submitted) presentations. However, here, target-aligned irrelevant stimuli were recognized no differently than non-aligned irrelevant stimuli in both experimental conditions (Visual words: 55% Non-Aligned vs. 51% Target-Aligned; Auditory Words: 52% Non-Aligned vs. 51% Target-Aligned), suggesting that the previously observed inhibition seemingly disappears when attention is divided across sensory modalities. This could arise due possibly to the existence of individualized attentional reservoirs for each sensory modality (see Wickens, 1984).

Interestingly, recent research by Swallow and Jiang (2010) suggests an "attentional boost" (i.e., facilitation) for simultaneously presented information in a dual-task paradigm (see also Lin et al., 2010). Although in their experiment, participants were required to divide their attention across both streams, rather than only pay attention to one of the streams, our results are somewhat analogous to this notion. It is perhaps possible that by dividing the task across modalities, an analogous boost emerges.

To conclude, the findings presented here provide an outcome that aligns with most literature regarding divided attention across sensory modalities. That is, while attentional capacity is limited for stimulus processing within the same sensory modality, tasks presented to different sensory modalities may in fact increase that capacity by enabling access to individualized reservoirs (e.g., Duncan et al., 1997; Lavie, 2005; Sinnett et al., 2006; Wickens, 1984). It seems to be that the additional attentional resources were directed towards irrelevant stimuli and therefore, recognition of the irrelevant stimuli was enhanced, or at the very least, not inhibited.

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