Involuntary auditory attention capture in a cross-modal oddball paradigm: Novelty and semantic processing.

by

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Abstract

The current study was designed to investigate the effect of an expected or unexpected sound on performance of a visual perception task. On each trial, listeners were required to indicate whether an arrow presented on a computer screen directly in front of them was pointing to the left or right. The arrow stimulus was immediately preceded by a to-be ignored auditory event that was either a pure tone, the word 'left' or the word 'right'. The probability that the arrow was preceded by a tone, a congruent word, or an incongruent word was manipulated across experiments. Congruent words facilitated classification of the arrow stimulus regardless of whether or not they were expected. Incongruent words slowed classification regardless of whether or not they were expected. These results revealed that both expected and unexpected auditory events receive involuntary semantic processing in a cross-modal oddball task.

Keywords: oddball, semantic, involuntary processing

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Imagine driving to work. For the experienced driver, navigating from home to the office is a seemingly automatic process. From starting the car and driving a particular route to parking the vehicle, the tasks are executed without much conscious thought or awareness. However a simple honk of a horn from a nearby vehicle is capable of quickly capturing one's attention. This simple everyday occurrence illustrates an important point about human cognitive processing; namely, that efficient cognitive functioning requires the ability to focus and perform one task such as driving while still allowing redeployment of attention to a novel, unexpected event.

Psychologists have studied the cognitive mechanisms of attending to and remembering sounds for many years. For example, in the 1950s, Broadbent (1954) performed a series of experiments to examine the limits of "immediate memory" for auditory stimuli. Broadbent presented lists of spoken digits to listeners in three conditions. In the first condition, six digits were presented in succession to both the left and right ears. For example, the listener might hear a sequence comprised of 6, 7, 3, 5, 4, 9. In the second condition, three pairs of digits were presented with one member of each pair presented to each ear; this is referred to as dichotic presentation. For example, the digit 6 might be presented in one ear and the digit 7 in the other ear at the same time. This would be followed by a 3 presented in one ear and a 5 in the other ear. In the third condition, listeners were presented with trials from both the first and second conditions; however, an eight digit list and four digit-pairs were used as opposed to a six digit list or three digit-pairs. Participants were divided into three groups. Listeners in the first group were presented with a series of lists within which there was a half second interval between each successive digit or digit-pair. Listeners completed six blocks of trials. In the first block, participants completed five trials each comprised of a sequence of six digits. In the second block, participants completed five trials each comprised of a sequence of three digit-pairs. In the third block, participants completed five trials each comprised of a sequence of six digits. The final three blocks were identical to the first three, except that listeners were presented with sequences of eight digits or four digit-pairs rather than six digits or three digit-pairs. At the end of each trial, participants attempted to recall the digits they had been presented in any order (i.e., free recall). Listeners in the second group completed 12 trials each comprised of a sequence of three digit-pairs. After every three trials, the interval between successive digit-pairs was reduced. The interval was initially set at two seconds and was reduced to one and a half seconds, then to one second, and finally to one half second. After each of the 12 trials, participants attempted to recall the digits in the order in which they had been presented (i.e., serial recall). Listeners in the third group heard five trials comprised of eight digit sequences as well as an additional series of 10 trials, each comprised of a sequence of eight digit-pairs. The sequential digits and digit-pairs were presented a half second apart. Participants were instructed to write the first four digits heard in one ear and the last four digits heard in the other ear.

In every group, participants more accurately recalled digits presented sequentially than digits presented in pairs. Broadbent argued that performance was better for single digits because digit-pairs were more difficult to attend. Performance on trials comprised of three pairs of digits was not significantly different from trials comprised of four or eight digit-pairs. Overall, when listeners were presented with digit-pairs they tended to report digits presented to one ear before reporting any digits presented to the other ear. According to Broadbent this demonstrates that spatially separated sounds pass through the perceptual mechanism in succession and not simultaneously. In this context, the results indicate that when two different simultaneous sounds arrive at the ears, the sound at one ear is processed before that at the other ear.

Broadbent's early experiments into the nature of auditory attention and processing of acoustic information set additional research in motion. Research expanded dramatically to dissect the trade-offs between consciously focusing attention on one stimulus, and having attention automatically captured by a sudden, new event. For example, Moray (1959) used a dichotic listening technique to explore the nature of involuntary attentional capture. In his first experiment, one channel was comprised of a male speaking a simple prose message. In the other channel, the same male speaker repeated a short list of words 35 times at roughly the same speech rate of the other channel. Participants were presented the word list and the prose passage simultaneously and their task was to repeat the prose passage out loud while ignoring the word list. This is generally referred to as a shadowing task. The repeating list of words faded in thirty seconds after the prose passage began and faded out thirty seconds before it ended. A half-minute after the prose passage ended, participants were asked to report what they had heard in the to-be ignored channel. Following this recall task, participants were given a simple recognition task including words from the prose passage as well as new words similar to those presented in the word list and prose message. Moray's results showed that listeners were unable to recall or recognize any significant amount of information from the to-be ignored channel.

In Moray's second experiment, participants were required to shadow a passage that was presented in one ear while a to-be ignored passage was presented in the other ear. Eighty percent of trials began with the instructions "listen to your right ear" (p. 57). Twenty percent of trials began with the instructions "listen to your right ear, you will receive instructions to change ears" (p. 57). So, participants began each trial by shadowing their right ear and at some point during the trial, instructions were inserted in the non-shadowed ear to switch attention to the left ear. On 30 percent of trials the inserted instructions included the listener's name (e.g., "John Doe, change to your other ear"). On 30 percent of trials the inserted instructions did not include the listener's name (e.g., "change to your other ear"). On 40 percent of trials no instructions were inserted in the non-shadowed ear. Thus, in total, 60 percent of the trials had instructions inserted into the to-be ignored passage, while the remaining 40 percent did not. Participants were required to shadow the passages while minimizing errors. Once listeners had completed shadowing 10 passages, they were asked to indicate how many times instructions had been inserted in the non-shadowed ear. Instructions that included the participant's name were detected significantly more often than those that did not. Participants also switched shadowing from the right to the left ear more often when the instructions to do so included their own name than when they did not. Moray interpreted these results as evidence that a person's own name breaks through the auditory attentional barrier in shadowing tasks. Moray conducted a follow-up experiment using a similar shadowing task. However, instead of instructions being presented, sometimes accompanied by the listener's name, digits were presented in the non-shadowed ear. In this experiment, listeners did not notice digits presented in the non-shadowed ear. Overall, Moray concluded that the digits were not important enough to break through the attentional barrier, only listener's names were. It seems as if one's own name can capture attention involuntarily. Similar conclusions were drawn by Mackay (1973) who found that the meaning of unattended words was analyzed to some extent, even though participants could not recall the words themselves.

These early experiments into auditory attention provided an initial insight into the nature of both voluntary and involuntary attention. Shortly thereafter, interest in auditory attention diminished with the visual modality becoming the popular choice to study. However, near the turn of the century, a renewed interest in auditory selective attention was evident (e.g., Mondor, Breau, & Milliken, 1998; Mondor & Terrio, 1998; Mondor, 1999).

Much of the more recent research into auditory attention relied on a relatively simple paradigm in which a single cue sound is followed by a single target about which listeners are required to make some type of identification or detection judgment (e.g., Mondor, 1999). The cue and target were identical in all aspects except one feature, such as spatial location. Usually, there was no predictive relation between the cue and target in the manipulated feature. A trial consisted of the cue presented to one location followed by the target presented to either the same or different location. A valid trial was one on which both the cue and target locations matched. An invalid trial was one on which the cue and target locations did not match. Also, the time period between the onset of the cue and the onset of the target (stimulus onset asynchrony [SOA]) was often varied. The similarity of the cue and the target were examined for its influence on the speed and accuracy of responding to the target. Results typically showed at brief SOAs (e.g., 100 ms), targets preceded by a valid cue were detected and identified more quickly and accurately than targets preceded by an invalid cue. In contrast, at longer SOAs (e.g., 750 ms), targets preceded by an invalid cue were detected and identified more quickly and accurately than targets preceded by a valid cue (Mondor, Breau, & Milliken, 1998; Mondor, 1999).

A possible explanation of this pattern of performance has to do with the way in which attention is oriented in response to the cue (Posner & Snyder, 1975; Posner, 1980). One explanation is that listeners' attention was initially attracted to the location in which the cue was presented. At brief SOAs, when the target was presented in the same location as the cue, responses were facilitated because attention had already been drawn to that location. In contrast, at longer SOAs, attention had drifted away from the cued location and there was an active inhibition against returning attention to that position. Therefore, performance was impaired at longer SOAs when the target was presented in the same location as the cue. Whereas cognitive methods have solely been used to study inhibition of return, the addition of electrophysiological methods has been used to study involuntary attention capture.

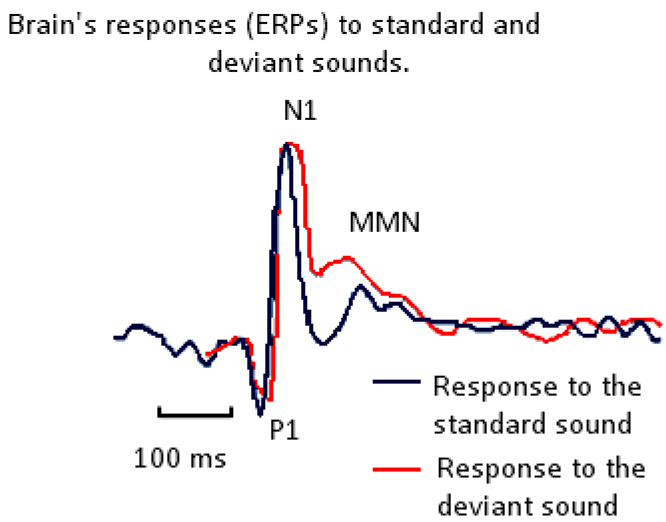
The extent to which auditory attention may be captured involuntarily by new events has been studied using both basic cognitive and electrophysiological methods. Electrical activity in the brain associated with the sudden occurrence of a sound began to be studied intensively in the late 1970s using scalp-recorded event-related brain potentials (ERPs) (e.g., Näätänen, Gaillard, & Mäntysalo, 1978). ERPs are measured using electroencephalography (EEG). This procedure involves placing a network of electrodes in various locations across the scalp. Once in place, the EEG measures the overall electrical activity through the electrodes. Since the electrodes are placed over the majority of the scalp, they are capable of measuring brain activity in multiple locations. In order to isolate a response to a particular stimulus or series of stimuli, upwards of a hundred trials are averaged to obtain a relatively stable assessment of activity.

ERPs reflect small positive and negative voltage fluctuations (1-30 millionths of a volt) in the electrical activity of the brain that arise in response to specific events (Friedman, Cycowicz, & Gaeta, 2001). ERPs provide both temporal information about the time-course of activity following an event, and the general location in the brain of this activity. An ERP may be defined by amplitude, latency and scalp distribution, and this information may be used to infer the sensory, cognitive, and/or motor process involved (Besson, Faïta, Peretz, Bonnel, & Requin, 1998; Friedman, Cycowicz, & Gaeta, 2001).

Researchers have used ERP information to examine auditory attention. For example, Näätänen, Gaillard, and Mäntysalo (1978) performed two dichotic listening experiments while measuring ERP signals. In the first experiment participants were presented with a random sequence of 16 tones over headphones. Each tone was randomly presented to one ear with silence in the other ear. Only two different tones were used, both a regularly-occurring standard tone (70 dB) and a rarely-occurring louder deviant tone (80 dB). Both tones were 31 ms long with a frequency of 1000 Hz. Participants were presented with six blocks of 200 trials each. Within each block, the standard was presented 97.5 percent of the time and the deviant tone was presented 2.5 percent of the time. Trials were completed over a period of several days. The second experiment was the same to the first except that the standard and deviant tones differed in frequency (1000 and 1140 Hz) rather than intensity. Participants were told to attend to one ear only, and to count the number of deviant tones presented to that ear.

The only reported behavioural results were hits rates. Participants made errors in 7.7 percent and 10.2 percent in the first and second experiments, respectively.

As shown in the figure below, Näätänen et al. (1978) found that if the tone was a deviant, there was a negative shift in the evoked potential waveform. They argued that this shift is due to the deviant being different from the established template created for the standard tone. Conversely, there was no negative shift for the standard tone presumably because it matched the established template. This negative shift in the evoked potential caused by a rare deviant tone being introduced into a pattern of standard tones is labeled the mismatch negativity (MMN).



The findings of Näätänen et al. (1978) revealed the occurrence of the MMN phenomenon for auditory attentional capture by relatively novel sounds. As the participants were told to attend to a particular ear, the authors' findings accounted for rare deviant sounds within a voluntary attention task.

These findings initiated additional research into the neural response of unexpected auditory change in the acoustic environment. For example, Erich Schröger (1996) also used the dichotic listening technique to study the MMN.

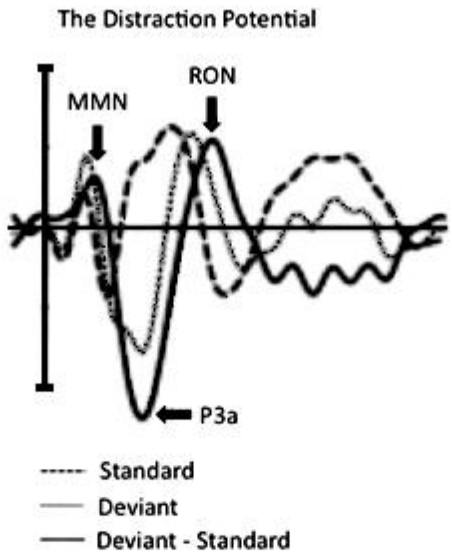
In his first experiment, listeners were presented with a sequence of tones over headphones. Two tones were presented on each trial with the first presented in the left ear and the second presented in the right ear. The sounds were 60 ms in duration with 140 ms of silence between them (inter-stimulus interval [ISI]). The tone presented in the left ear had an intensity of 80 dB and usually a frequency of 700 Hz (standard). On some trials the frequency of the standard could be 50 Hz (small deviant) or 200 Hz (large deviant) higher or lower. The standard was presented on 88 percent of the trials and each deviant was presented on 6 percent of the trials. The tone presented in the right ear (target) had an intensity of either 70 dB or 80 dB and a frequency of 1500 Hz. The participants' task was to ignore the sounds presented to the left ear and to respond only to the lower intensity target tone presented to the right ear and to withhold a response to the higher intensity tone.

The speed with which participants detected the lower intensity target tone in the right ear was influenced by the tone presented to the left, presumably unattended, ear. Performance was fastest when the standard tone was presented to the left ear, was slower for the small deviant, and slowest for the large deviant. The accuracy with which participants detected the lower intensity target tone in the right ear was also influenced by the tone presented to the left ear. Accuracy was highest when the standard tone was presented to the left ear, lower for the small deviant, and lowest for the large deviant. Schröger also found that the MMN occurred in response to both the small and large deviants, with a larger effect for the larger deviant.

Schröger's second experiment was the same as the first with one difference; namely, the ISI was increased from 140 ms to 500 ms. In contrast to the first experiment, in this experiment the tone presented to the left ear had no effect on the time to detect the low intensity target tone. However as in the first experiment, the MMN registered for the large deviant tone had a larger amplitude than that measured for the small deviant tone.

Schröger’s studies provided evidence that an unexpected sound can impair responses to an auditory item presented immediately following it. Moreover, it appears that the magnitude of this impairment increases as the frequency between the standard and deviant increases. Because the MMN arises in response to stimuli that participants are told not to attend to, it is considered to reflect an automatic pre-attentive response to unexpected change in the auditory context (Friedman, Cycowicz, & Gaeta, 2001).

ERPs reflect the entire neural response to a sound from the initial distraction to attending and finally to completing a task such as classifying the relative intensity of a sound. According to Parmentier et al. (2008) (as cited in Escera & Corral, 2003), Escera and Corral dubbed the complete ERP pattern which arises when an unexpected sound occurs as the distraction potential. As discussed by Escera, Alho, Schröger and Winkler (2000) the distraction potential can be decomposed into three main components (see figure below).



As previously mentioned, the MMN has been viewed as reflecting initial attentional capture. There is also an electrophysiological response called the P3a or novelty-P3 that is thought to reflect an orientation of attention towards a deviant or novel event. Lastly, there is a reorientation negativity (RON) that is thought to reflect the reorientation of attention toward the main task after a momentary distraction. Researchers have consistently interpreted all three ERP components as reflecting involuntary attentional capture (see Escera & Corral, 2007 for a review).

Schröger's (1996) research reinvigorated the basic oddball paradigm that has been used frequently to study involuntary auditory attentional capture. In a typical oddball experiment, participants are presented with at least two types of stimuli, a frequently-occurring sound called the standard and a rarely-occurring sound often called the deviant. During an oddball task participants are required to detect the occurrence of deviant stimuli either by silently counting them or by making a manual response to each one (Friedman, Cycowicz, & Gaeta, 2001). During an experimental session, participants are usually told to attend to only some of the information presented.

Using a standard oddball task paradigm, Schröger and Wolff (1998) and Escera, Alho, Winkler, and Näätänen (1998) provided further evidence for the existence of MMN. However, whereas Schröger and Wolff (1998) required participants to classify some sounds while ignoring others. Escera et al. (1998) required participants to classify visual stimuli, while ignoring sounds. In both experiments the characteristic MMN arose in response to deviant sounds embedded in the unattended auditory information.

Schröger and Wolff (1998) used an oddball paradigm with two main goals in mind. First, they wished to assess the efficiency of deviant sounds in creating a distraction with the physical difference between the standard and deviant sounds varying from small to medium to large. Secondly, they tested the possibility that the distraction effects are in fact due to costs in having to process a deviant sound immediately prior to a target sound.

Participants were presented with either a 100 ms or 200 ms tone over headphones with an ISI of 1000 ms between successive tones. Nine blocks of 300 tones were presented. A standard tone was presented 90 percent of the time and a deviant tone was presented 10 percent of the time. In three different conditions deviant tones differed in frequency from the standard by 50 Hz (small), 300 Hz (medium), or 500 Hz (large). The participants' task was simply to identify the occurrence of the long duration tone (200 ms) by pressing a key on the keyboard while ignoring sound frequency.

Participants' response times (RTs) were significantly longer when the deviant differed from the standard in frequency, even when this difference was as small as 50 Hz (as low as seven percent). However, RTs did not significantly increase as a function of the size of the frequency difference between the standard and the deviant (Schröger & Wolff, 1998). In contrast with the RT data, accuracy did decrease as the size of the difference between the standard and the deviant increased. As expected, the MMN was elicited when a deviant was presented. The amplitude of the MMN increased with the size of the frequency difference relative to the standard. Schröger and Wolff (1998) interpreted these results as evidence of an automatic change-detection mechanism. This mechanism involves an attention allocation to the novel event triggered by an unexpected change in the acoustic environment. This leaves fewer processing resources available for performing the relevant task, which in turn results in an impairment of performance.

Additional research using the auditory oddball paradigm has provided increased insight into the nature of involuntary attentional capture and the resulting affect on task performance. Other than auditory frequency changes as novel events, tone location and duration (Roeber, Berti, & Schröger, 2003) and sound intensity (Rinne, Särkkä, Degerman, Schröger, & Alho, 2006) have also been used to define deviant sounds, and these have produced an MMN along with a disruption in primary task performance.

The distraction that occurs during an oddball paradigm is not limited to audition. Distraction can occur across modalities, such as a sound distracting an immediately following visual task. Researchers have explored the nature of distracting across modalities using a cross-modal oddball paradigm.

Escera, Alho, Winkler, and Näätänen (1998) used a cross-modal oddball task to evoke the MMN potential. Participants were presented with both auditory and visual stimuli and told to completely ignore the sounds. Each sound stimulus preceded a visual stimulus with SOA of 300 ms and a 1200 ms delay between each trial. The visual stimuli were digits 1-8 presented randomly and one per trial for 200 ms. Participants were required to classify each visually presented digit as odd or even, while ignoring all sounds. The sound sequences were comprised of 80 percent standard sounds, 10 percent deviant sounds, and 10 percent novel sounds. The standard sound was a binaurally presented 200 ms tone, with a frequency of 600 Hz and an intensity of 75 dB. The deviant tone had a frequency of 700 Hz, and an intensity of 75 dB. Sixty unique environmental sounds, such as a telephone ringing, a glass breaking, and an electric drill drilling, were used as novel sounds. The novel sounds were condensed to 200 ms in duration with a maximum intensity of 80 dB and only occurred once within a block of trials. Participants were presented with four blocks of 400 audio-visual stimuli pairs. Audio-visual pairs that included either deviant or novel sounds were preceded by at least a pair that included the standard tone.

The authors found that novel sounds evoked both MMN and P3a waves. Deviant tones also elicited an MMN of similar size to the novel sounds but a smaller P3a wave. Overall, accuracy was over 90 percent, but surprisingly, participants' performance was worse for deviant tone trials, while novel sound trials were comparable to the standard trials. However, behavioural distraction was evident in the longer RTs following deviants and novels compared to standards. The amount of distraction caused by deviant and novel sounds was not proportional to the magnitude of their difference from the standard tone. These results have been found in previous research (Alho, Escera, Diaz, Yago, & Serra, 1997).

Most importantly Escera et al. (1998) provided evidence that using a cross-modal oddball paradigm demonstrated the same essential MMN and P3a components as had been shown to arise with novelty distraction in studies of involuntary auditory attentional capture. Thus, it appears that involuntary distraction caused by novel sounds occurs within both unimodal and cross-modal oddball paradigms.

Irrelevant stimuli need not occur at the same time or in the same modality as a primary task in order to cause distraction. Even when intensely focused on a task, a sudden change in sound can interrupt selective attention and cause a decrease in performance on a primary task.

Much of the research on involuntary attentional capture in an oddball paradigm has been focused primarily on the collection of electrophysiological information with relatively little attention paid to the collection of behavioural data. Parmentier, Elford, Escera, Andrés, and San Miguel (2008), designed three experiments to explore the cognitive mechanisms of distraction in a cross-modal oddball paradigm. Using a familiar task of classifying a visual digit as odd or even, Parmentier et al. (2008), examined whether performance of a visual classification task could be affected by a preceding novel sound which was irrelevant to the task, presented in a different modality and a different time, and did not prime any mental representation related to the visual task. Based on previous ERP findings Parmentier et al. (2008) set out to determine which of the two hypotheses might best explain behavioural distraction.

The first hypothesis accounts for the distraction as arising from a competition for attentional resources between the processing of the unexpected novel sound and the processing of the visual target. According to this first hypothesis, the delayed RTs to the visual task are due to a decrease in processing speed caused by a lack of attentional resources. The second hypothesis accounts for the distraction with a bottleneck of attention in that the onset of processing of the visual target is delayed until attention orients from the unexpected novel sound to the visual task. The delayed RTs to the visual task are due to the time required to shift from the auditory modality to the visual modality. The listener unintentionally engaged in the analysis of a novel sound, and then returned attention to a visual task. The shift of attention between modalities increased RTs.

The first two experiments were designed to test if the depletion of attentional resources caused impaired processing and the longer RTs in a cross-modal oddball task (Parmentier et al., 2008). Parmentier et al. (2008) defined visual processing consisting of two steps, perceptual analysis and categorization. Perceptual analysis of a visual stimulus was defined by Parmentier et al. (2008) as beginning with a pattern of light on the retina and ending with the identification of the stimulus. Categorization, again according to Parmentier et al. (2008), occurs after identification of the visual stimulus when the appropriate response is determined and executed.

Parmentier et al. (2008) manipulated the difficulty of the primary task to assess the extent to which perceptual analysis affects the magnitude of distraction caused by a novel sound. The consequences of losing attentional resources to a novel sound should have a greater effect on a more difficult task. There were two conditions for the visual digit classification task. In the control condition, the digits were presented as a clear black number. In the visual interference condition, the digits were degraded by increasing its transparency and with the addition of a visual mask to the background. In both conditions, digits were presented in a box on a white background. Twenty participants were required to classify digits (1-8) as odd or even. In all 1600 trials participants ignored sounds while completing the visual classification task. All trials consisted of a 200 ms sound presented 300 ms prior to the onset of the digit. Following the onset of the digit, participants had 1000 ms to respond, and 100 ms after the response the next trial automatically began. The sound presented on each trial was either a standard sound or a novel sound. The standard sound was a 200 ms pure tone with a frequency of 600 Hz. The novel sound could be any one of 60 different environmental sounds each 200 ms long. The standard sound was presented on 90 percent of the trials and a novel sound was presented on the remaining 10 percent of trials with each novel sound repeating a maximum of three times.

Participants' RTs to classify the digit following a novel sound were longer compared to those that followed a standard sound. The degradation of the digits made the classification task more difficult resulting in longer RTs compared to the non-degraded digits. However, the distraction effect, defined as the difference in mean RTs between the novel sound trials and the standard sound trials was no larger when the digit was degraded than when it was not. Thus, visual interference due to degradation did not increase distraction. Interestingly enough, accuracy did not vary significantly as a function of visual interference or the nature of the sound preceding the digit.

The results of Experiment 1, then, showed that distraction in the cross-modal oddball task was independent of the perceptual analysis of the digit. Since there was no increase in the distraction effect at the stage of perceptual analysis, Parmentier et al. (2008) suggested the distraction could be related to the categorization of the digit.

Parmentier et al. (2008) manipulated difficulty of the digit categorization while keeping the difficulty of visual analysis constant. The overall structure of the second experiment was similar to the first, except that participants classified digits into either four categories (i.e., 1 or 2, 3 or 4, 5 or 6, and 7 or 8) or two (i.e., odd or even). Participants completed two blocks of each of the four-choice and two-choice categories in alternation. Half of the participants received the four-choice categorization followed by the two-choice categorization; the other half completed the task in reverse order. The authors reasoned that the increased demand associated with a four-choice decision should increase classification difficulty. If this is correct, then increasing the demands of categorization should increase the magnitude of the distraction effect. The four-choice decision condition tested whether the locus of distraction was at the point of digit classification by demanding more attentional resources than the two-choice condition.

As expected, classifying digits into four categories produced significantly longer RTs and lower accuracy than classifying digits into two categories. In addition, RTs to digits that followed a novel sound were longer than to digits that followed the standard sound. The magnitude if this distraction effect decreased when categorization difficulty increased from the two-choice decision condition to the four-choice decision condition. This result is, of course, inconsistent with the prediction advanced by Parmentier et al. (2008). To explain these results, Parmentier et al. (2008) suggested that with a more difficult categorization task, working memory can reduce distraction during an oddball task. Supported by a previous study (Berti & Schröger, 2003) they argued that the two choice category is over learned while the four choice category may orient some of the mental resources to the task that would be otherwise drawn to the novel sound.

Neither the difficulty of perceptual analysis of the degraded visual digit nor the difficulty of classification had a significant effect on distraction. According to Parmentier et al. (2008) an increase in the difficulty of perceptual analysis or classification should have increased the demand for attentional resources, and this should have resulted in a larger distraction effect. The results suggested that the distraction effect is independent of visual processing. Since novel sounds affected performance in the categorization task but not any stage of visual processing Parmentier et al. (2008) reasoned that the distraction must precede visual analysis. It could be that the distraction effect is due to the shifts of attention from the novel sound and the visual task.

The third experiment was designed to test the bottleneck hypothesis. This hypothesis is essentially that the onset of processing of the visual target is delayed until attention orients from the unexpected novel sound to the visual task. The listener unintentionally engaged in the analysis of a novel sound, and then returned attention to a visual task. Specifically, they tested whether distraction could be reduced by drawing attention back to the visual modality just prior to the presentation of the to-be-classified digit. To accomplish this, Parmentier et al. (2008) inserted an irrelevant visual stimulus between the irrelevant sound and the digit classification task. This irrelevant visual stimulus, designed to recapture attention, was an 'X' with a sudden onset that seemed to recede from the viewer by changing in size (a reduction in size from 2.6° to 1.6° over 50 ms). The third experiment was essentially the same as the first experiment, but with the addition of an auditory-visual ISI of 200 ms in order to incorporate the irrelevant visual stimuli into a trial. The 'X' was presented 75 ms after the offset of the sound with an additional 75 ms between the offset of the 'X' and the onset of the digit. Participants were presented with both trials that included the 'X' and trials that did not.

Participants displayed significantly faster RTs on the classification task when the brief 'X' was presented, than when it was not. There was also an overall significant distraction effect. Participants' RTs were longer after a novel sound was presented prior to the digit classification task, relative to the standard sound. Most notably there was a reduction in distraction effect when the 'X' was briefly presented. Planned comparisons confirmed that there was no significant distraction when the 'X' was briefly presented. However, there was significant distraction when the 'X' was not briefly presented. Overall accuracy was high at 90 percent with no significant differences between conditions. These results revealed that a sudden irrelevant visual event immediately after an irrelevant sound eliminated the distraction effect in an oddball task. Parmentier et al. (2008) reasoned that participants processed the visual 'X' and used it as a cue to the impending digit. Parmentier et al. (2008) claimed that these results support the bottleneck hypothesis in that behavioural distraction in an oddball task is caused by participants having to switch attention from the irrelevant novel sound to the relevant visual digit and not from a lack of attentional resources.

In another study, Parmentier (2008) examined whether task-irrelevant novel sounds are analyzed in a way that affects subsequent behaviour. Previous ERP studies have suggested that brain activity differs for identifiable and unidentifiable novels sounds as well as semantic incongruities in sung passages (Besson, Faïta, Perez, Bonnel, & Requin, 1998). For example, Escera, Yago, Corral, Corberra, & Nuñez (2003) reported that their participants showed a larger P3a for identifiable relative to unidentifiable novel sounds, and suggested that this difference was due to semantic processing. Parmentier (2008) designed a series of cross-modal oddball experiments to examine this claim.

In the first experiment participants were presented with an arrow on the computer screen either facing left or right. Immediately prior to the arrow a sound was presented binaurally through headphones with an intensity of roughly 70dB. On 80 percent of trials the standard sound was presented. The standard sound was a 600 Hz pure tone, 200 ms in duration. On 20 percent of trials, novel sounds were presented. The novel sounds were the words 'right' and 'left' spoken by a male voice digitally edited to 200 ms in length. During half of the novel trials the word presented matched the direction of the arrow on the screen. For example, when the novel sound 'left' matched the immediately following left facing arrow on the computer screen the trial was part of the novel-congruent condition. During the other half of the novel trials, the word did not match the direction of the arrow on the screen. These trials comprised the novel-incongruent condition.

Participants completed four blocks of 306 trials with each trial structured in the same way. A fixation cross was displayed for the duration of the trial except during the arrow presentation and a brief visual mask. On each trial a sound was presented for 200 ms. The arrow would appear on the screen 100 ms after the offset of the sound for a duration of 200 ms. Immediately after the offset of the arrow an 8 x 8 black and white squared checkered mask was displayed for 100 ms. Following the visual mask the fixation cross reappeared for 600 ms before the next trial automatically began. Thus, listeners had a total of 900 ms to identify whether the arrow pointed left or right by pressing corresponding keys on the keyboard. Participants were told to ignore all sounds while focusing on the visual task and to respond as quickly and as accurately as possible.

Both accuracy and RT were analyzed for the standard, novel-congruent, and novel-incongruent conditions. Significantly longer RTs were observed when either novel sound was presented relative to the standard sound. Also, longer RTs were observed in the novel-incongruent condition than in the novel-congruent condition. Accuracy was high across all conditions, with hit rates around 90 percent. However, the only significant difference was that accuracy in the novel-congruent condition was higher than in the novel-incongruent condition.

On the basis of these results, Parmentier (2008) claimed that novel sounds delayed responses to the visual task and that the semantic content of the novel sounds impacted listeners' performance. The novel sounds may be involuntarily attended to, followed by a semantic analysis that interfered with the visual task. The difference between the novel conditions averaged together and the standard condition demonstrated an effect of novelty. As discussed earlier, the presence of a task-irrelevant sound just prior to a task impairs performance. Parmentier argued that the difference in performance between the novel-congruent and novel-incongruent conditions demonstrated the effect of semantic analysis, and this seemingly automatic semantic processing resulted in the corresponding longer RTs.

The next three experiments were conducted to determine whether acoustic, lexical, or source components of the novel sounds induced semantic analysis. The second experiment examined the acoustic differences between the novel and the standard sounds. A fundamental acoustic difference between the sounds was that a recorded voice was used for the novel sounds and a pure tone was used for the standard sound. This experiment differed from the first only in the standard sound used. The new standard was the word 'up' spoken by the same male voice as the novel words ‘left’ and ‘right’. The same male voice was the source for all sounds. Both the standard and novel sounds were words from the same source; the only difference was the acoustics of the stimuli.

RT results revealed both a significant semantic effect and a significant novelty effect. Participants were faster at correctly identifying the direction of the visual arrow immediately following a novel-congruent sound than following a novel-incongruent sound. This difference in performance between the novel-congruent and novel-incongruent conditions demonstrated the effect of semantic analysis. Also, RTs were longer for the visual task following either novel sound relative to the standard sound. The difference between the novel conditions averaged together and the standard condition demonstrated a novelty effect. Although overall accuracy was approximately 10 percent lower than in the first experiment, again, accuracy was significantly greater in the novel-congruent condition than in the novel-incongruent condition. Accuracy was also significantly higher in the novel conditions averaged together than in the standard condition. However, this appeared to be due to the congruent condition having the highest overall accuracy and skewing the combined novel conditions scores. There was no significant difference in accuracy between the novel-incongruent and standard condition.

The third experiment was the same as the previous two, except that the standard used was the word ‘up’ played in reverse. This new standard was designed to eliminate any semantic processing of the standard sound. The novel sounds were still spoken words while the standard sound had no lexical content. Since the source of all the sounds remained the same (recorded male voice), the differences between the novel sounds and the standard sound were the acoustic and lexical features.

Results were similar to those obtained in the first two experiments. For RTs there was a significant novelty effect and semantic effect. Overall accuracy was high at roughly 90 percent. Participants' accuracy was very similar to the previous experiment. As with the RT data, there was still a significant semantic effect as well as novelty effect.

The fourth experiment was essentially the same as the previous three, except that the source of the recorded words differed. The words 'up', 'left', and 'right' were recorded in both a female and male voice. Half of the participants heard the standard sound in the female voice and the novel sounds in the male voice. The other half of the participants heard the standard sound in the male voice and the novel sounds in the female voice. The difference between the novel sounds and the standard sound was both the source and the acoustics of the spoken words.

Again, RTs revealed both significant novelty and semantic effects. Overall accuracy was high at approximately 90 percent. There was no difference observed when averaging the novel conditions together and comparing that to the standard as there was in the first three experiments. However, accuracy was significantly higher in the novel-congruent condition relative to the standard condition.

Acoustics, lexicality, and source of the standard sound and the novel sounds were manipulated across the four experiments. The results across all four experiments were very similar. RTs consistently revealed the novelty effect and semantic effect regardless of which features differed between the novel sounds and the standard sound. Although the results were qualitatively the same, Parmentier (2008) conducted an analysis to compare the novelty effect and the semantic effect across all four experiments. This analysis revealed that the novelty effect was significantly larger for the first experiment when the standard and the novel sounds differed in all three features than in the following three experiments. However, the novelty effect was similar across the second, third, and fourth experiments. The magnitude of the semantic effect did not differ significantly across the four experiments.

When examining the novelty effect and the semantic effect across experiments, Parmentier (2008) tested the possibility that as participants completed experimental trials that the novelty of a sound could decrease and affect task performance. This decrease in novelty due to repeated exposure is an effect of practice.

When practice effects were examined across the four experiments there was a decrease in the novelty effect. There was approximately an 8 ms reduction in the novelty effect (roughly a 33 percent) from the first block of trials averaged together from all four experiments to the last block of trials also averaged together from all four experiments. Using this same analysis Parmentier found that the magnitude of the semantic effect did not change with practice. In all four experiments, both a significant novelty and semantic effects were apparent in the last block of trials. These differences between the novelty effect and the semantic effect provided additional support for Parmentier's (2008) claim that the two effects are distinct from one another.

Parmentier (2008) conducted one more experiment to determine whether words are semantically processed regardless of the frequency of their presentation. In this experiment the standard sounds were the word 'left' or 'right' presented on 80 percent of trials and the novel sound was a pure tone presented on the remaining 20 percent of trials. Half of the participants heard the word 'left' as the standard sound while the other half heard the word 'right' as the standard sound.

The results revealed a significant novelty effect but no significant semantic effect. Participants were slower at classifying the visual arrow when a novel sound was presented immediately before the task, compared to when either the standard-congruent sound or the standard-incongruent sound was presented prior to the task. Overall, accuracy was 82 percent with no significant variation across conditions.

The results of the fifth experiment supported the claim that the semantic analysis of irrelevant auditory words does not occur regardless of their frequency of occurrence. Rather, the semantic analysis of auditory words appeared to depend on the capture of attention due to novelty. Thus, there was no semantic analysis of the frequently occurring standard word as the word was no longer novel. In contrast, distraction due to novelty occurred even though the novel sound was a pure tone and acoustically different from the standard. These results, albeit a null finding, support the claim that auditory words are not subjected to an automatic analysis of its content regardless of their frequency of occurrence (Parmentier, 2008).

Taken together, the five cross-modal oddball experiments conducted by Parmentier (2008) demonstrated that listeners were slower to classify a visually presented arrow when it was preceded by a task-irrelevant novel sound than when it was preceded by a task-irrelevant standard sound. Also, RTs were longer when the novel sound and the visual arrow were semantically incongruent than when the novel sound and the visual arrow were semantically congruent. This result suggests that the semantic content of the novel sounds was analyzed even though the sound itself was irrelevant to the required task.

When the standard sound and the novel sound differed in source, lexicality, and acoustics the effect of novelty was the largest. The magnitude of the semantic effect did not vary across experiments.

These results were in line with the hypothesis advanced by Parmentier et al. (2008) that novel sounds distract listeners from their primary task and that these sounds are semantically processed in spite of their irrelevance. Parmentier

(2008) argued that in a cross-modal oddball task, the novelty effect and the semantic effect are distinct from one another.

The current study was designed to examine the nature of the novelty and semantic effects described by Parmentier. Experiment 1 was an attempted replication of the results reported by Parmentier (2008) using the same cross-modal oddball paradigm and an arrow classification task.

EXPERIMENT 1

Method

Participants

Twenty undergraduate students were recruited from the University of Manitoba's Introduction to Psychology participant pool to participate in the experiment. One participant performed worse than chance and was not included in the analysis. All participants received partial course credit in exchange for participating.

Materials

The experiment was run on Dell Precision T5400 computers and programmed using E-prime (Psychology Software Tools, 2002) software. Sounds were presented binaurally through Sony MDR-7508 headphones at approximately 70 dB SPL. All visual stimuli were presented on a 22-inch Dell P2210 computer monitor at a viewing distance of roughly 60 cm. The arrows occupied a horizontal visual angle of approximately 7.79° and a vertical visual angle of approximately 6°.

All sounds were synthesized at a sampling rate of 44,100 Hz using Adobe Audition 1.5 (Adobe Systems Incorporated, 2004). The 'standard' sound was a 600 Hz pure tone that was 200 ms in duration. The 'novel' sounds were the words 'right' and 'left' spoken by a male voice and compressed and edited to 200 ms in duration. All sounds included 10 ms linear onset and offset amplitude ramps to eliminate onset and offset clicks.

Design and Procedure

The experimental design and procedure were almost identical to those used by Parmentier (2008). Participants were tested in sound-attenuating chambers where they were seated directly in front of a computer keyboard and monitor. Each trial began with either the standard tone or one of the two novel words presented over the headphones. Immediately after the sound, a left- or right-pointing arrow was presented in the centre of the screen for 200 ms. The arrow was followed immediately by a visual pattern-mask comprised of a black and white checkerboard grid that covered the entire computer screen and persisted for 100 ms. The fixation cross was not presented when the arrow and mask were shown, but was otherwise visible. Participants were asked to indicate the direction in which the arrow pointed as quickly and accurately as possible by pressing '1' or '2' on the keyboard (for left and right, respectively).

There were three different types of trials. On 80 percent of trials, the standard pure tone was presented ('standard' trials) immediately prior to the arrow. On 10 percent of trials, a novel word that matched the arrow stimulus was presented ('novel-congruent' trials). On 10 percent of trials, a novel word that did not match the arrow stimulus was presented ('novel-incongruent, trials). Both of the novel words, as well as the immediately following left- and right-pointing arrows were presented equally often on the novel-congruent and novel-incongruent trials.

Participants completed 20 practice trials prior to 320 experimental trials. The computer program randomly determined trial order for each participant. Participants were instructed to completely ignore the sounds while doing the visual task.

Results & Discussion

Response Times

In all experiments, for each participant outlying response times (RTs) defined as those more than 2.5 standard deviations above or below the mean were excluded from analyses. Statistical analysis of mean RTs for correct responses was performed using a repeated measures ANOVA in which Trial Type (standard, novel-congruent, novel-incongruent) served as the within-subjects factor. This analysis revealed a significant main effect of Trial Type, *F* (1,

36) = 11.00, $p < .01$. Overall, listeners responded most quickly when the arrow was preceded by the standard tone.

The effect of novelty was assessed by comparing performance on the standard trials with the average of the novel-congruent and novel-incongruent. This analysis revealed significantly slower RT on novel trials than on standard trials, $F(1, 18) = 9.76$, $p < .01$. Thus, participants were slower when a novel sound was presented immediately before the visual task. The largest distraction effect was apparent when participants switch their attention from the irrelevant novel sounds to the relevant visual digit.

The effect of semantic processing was examined by comparing performance on novel-congruent and novel-incongruent trials. This analysis revealed significantly slower RTs on novel-incongruent trials than on novel-congruent trials, $F(1, 18) = 14.95$, $p < .01$. Thus, participants were slower when the spoken word ‘left’ or ‘right’ was incongruent with the following visual arrow (see Figure 1a). These results suggest that the spoken words were subjected to semantic processing in spite of their irrelevance to the task at hand and that this interfered with performance of the visual task.

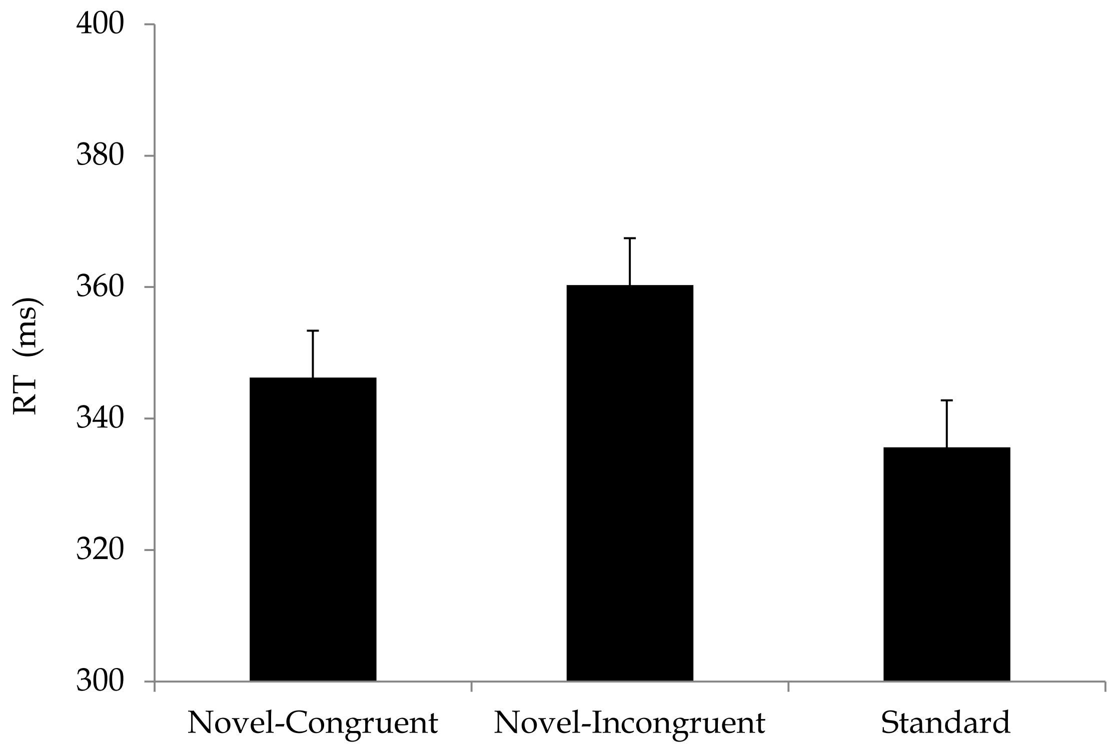


Figure 1a. Mean RT performance for Experiment 1, in the novel-congruent condition, the novel-incongruent condition, and the standard condition.

Percentage Errors

Error rates were statistically analyzed in the same way as were the RT data. This analysis revealed that the main effect of Trial Type was not significant, F (2, 36) = 2.20, p = .125. Further analysis however, showed that participants made significantly more errors on standard trials than on novel trials, F (1, 18) = 7.17, p = .015. A direct comparison of performance on novel-congruent and novel-incongruent trials revealed no significant difference, F (1, 18) = .383, p = .544 (see Figure 1b).

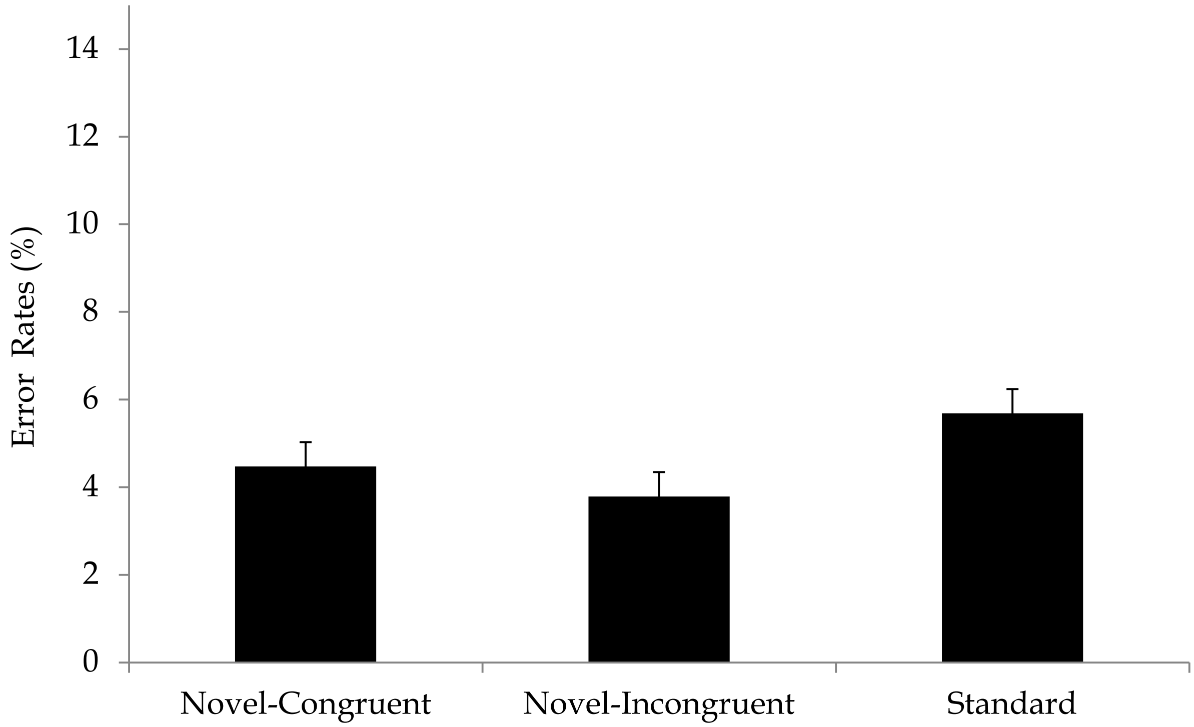


Figure 1b. Mean error rates for Experiment 1, in the novel-congruent condition, the novel-incongruent condition, and the standard condition.

As expected that the results from Experiment 1 replicated those reported by Parmentier (2008). Specifically, using the same cross-modal oddball paradigm and arrow classification task, participants exhibited both the novelty effect and the semantic effect.

EXPERIMENT 2

Experiment 2 was designed to test Parmentier's (2008) claim that the semantic effect cannot occur when the sounds are no longer novel.

Method

Participants

Twenty-five undergraduate students volunteered from the University of Manitoba's Introduction to Psychology participant pool. None of the participants had participated in Experiment 1. All participants received partial course credit in exchange for participating.

Materials

The materials used in the experiment were the same as those used in the Experiment 1.

Design and Procedure

The experimental design and procedure were the same as those used in Experiment 1, except that the pure tone sound, used as the standard sound in Experiment 1, was presented on 20 percent of trials instead of 80 percent, and the words 'right' and 'left', used as novel sounds in Experiment 1, were presented on 80 percent of trials instead of 20 percent. Thus, in Experiment 2 the pure tone was used as the novel sound, and the spoken words were used as standard sounds. The three trial types were the novel tone (pure tone), standard-congruent (matching spoken word and visual arrow), and standard-incongruent (mismatching spoken word and visual arrow).

Results & Discussion

Response Times

Statistical analysis of mean RT for correct responses was performed using a repeated-measures ANOVA using Trial Type (standard-congruent, standard-incongruent, novel tone) as a within-subject factor. The analysis revealed a significant main effect of Trial Type F (2, 48) = 11.65, $p < .01$. Overall, listeners responded more quickly when the arrow target was preceded by a congruent spoken word than either the incongruent word or novel tone trials. The standard-congruent trials caused the least amount of distraction when participants switched attention from the irrelevant standard spoken word to the visual digit. It is also possible that both the often-occurring spoken word trials as well as the congruency of the sound and the arrow facilitated the visual task.

These results did not replicate the results reported by Parmentier (2008). Specifically, using the same cross-modal oddball paradigm and arrow classification task, it appears that participants exhibited both the novelty effect and the semantic effect.

The effect of novelty was assessed by comparing performance on the novel tone trials with the average of the standard trials. This analysis revealed significantly slower RT on novel tone trials than on the standard spoken word trials, F (1, 24) = 11.83, $p < .01$. Thus, participants were slower when a novel sound was presented immediately before the visual task. Participants responded more slowly when a novel sound was presented immediately before the visual task. The novel sound caused the most distraction when participants switch their attention from the irrelevant novel sound to the relevant visual arrow.

The effect of semantic processing was examined by comparing performance on standard-congruent and standard-incongruent trials. This analysis revealed significantly slower RT on incongruent trials, F (1, 24) = 7.38, p = .012. Thus, participants were slower when the spoken word 'left' or 'right' was incongruent with the following visual arrow (see Figure 2a). This would suggest that the spoken words were still involuntarily attended, and processed semantically, and that this interferes with the visual task.

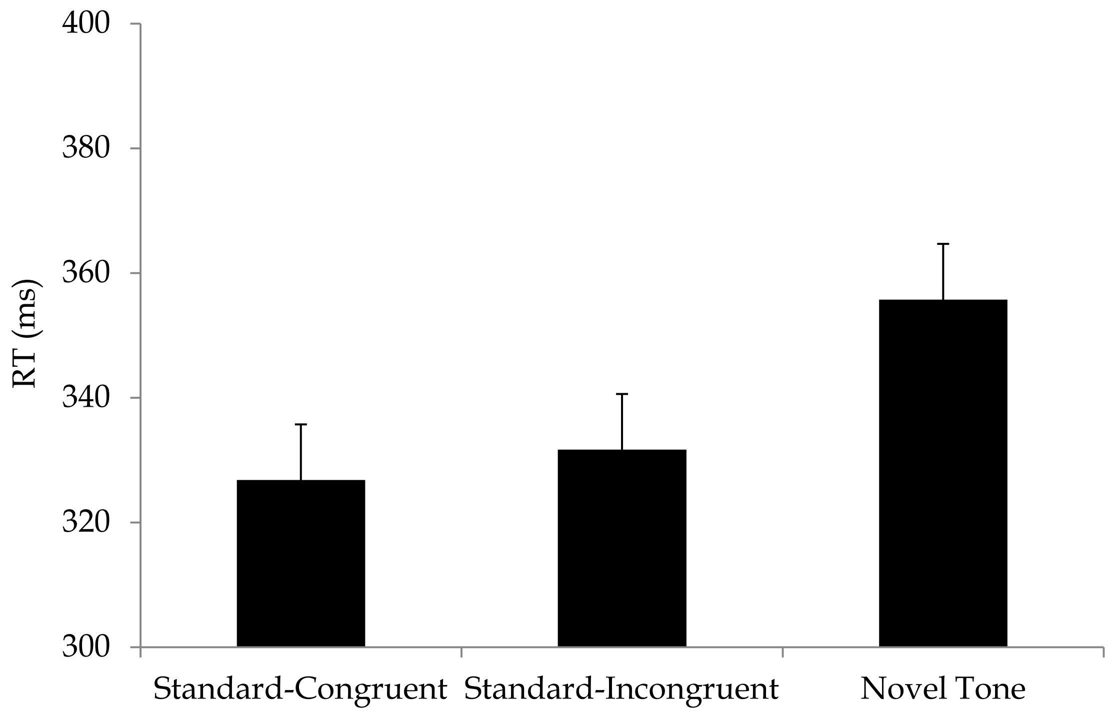


Figure 2a. Mean RT performance for Experiment 2, in the standard-congruent condition, the standard- incongruent condition, and the novel tone condition.

Percentage Errors

Error rates were statistically analyzed in the same way as were the RT data. This analysis revealed that the main effect of Trial Type was not significant, F (2, 48) = .865, p = .427. Further analysis however, showed that participants made significantly more errors on standard-incongruent trials than on standard-congruent trials, F (1, 24) = 7.46, p = .02. A direct comparison of performance on novel tone trials and the average of the standards revealed no significant differences, F (1, 24) = .255, p = .618. Since the task was relatively simple, participants committed relatively few errors with no significant speed accuracy trade-offs (see Figure 2b).

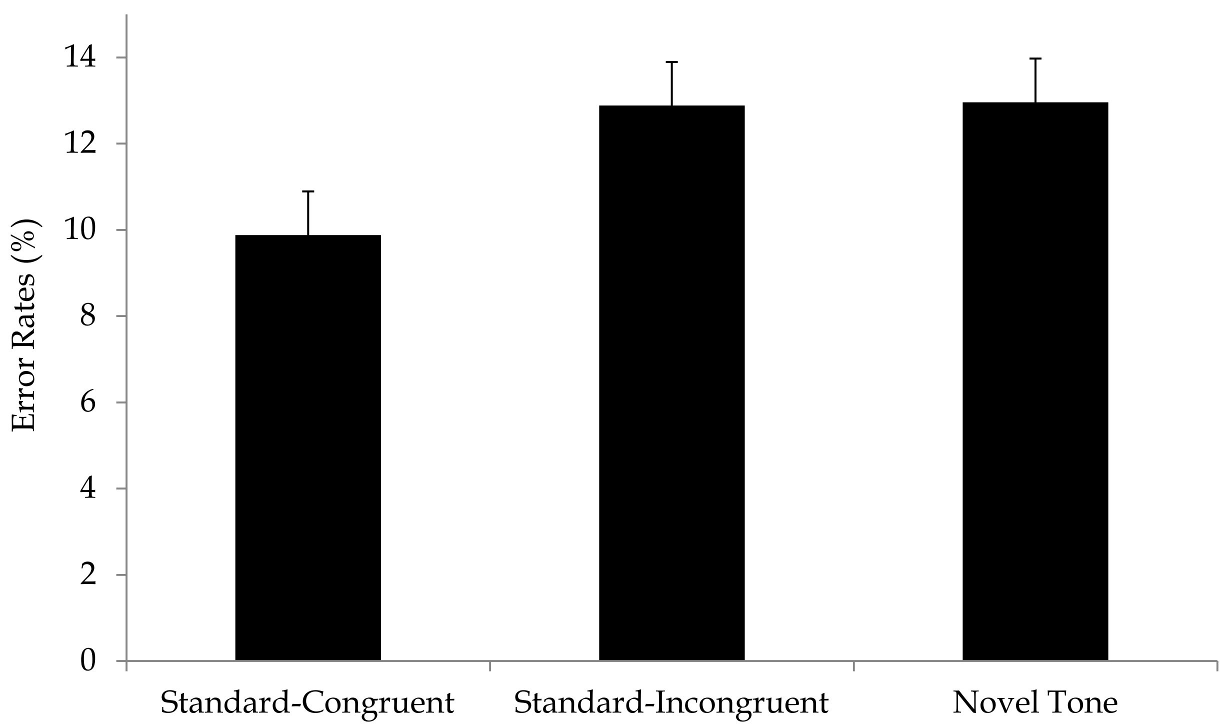


Figure 2b. Mean error rates for Experiment 2, in the standard-congruent condition, the standard-incongruent condition, and the novel tone condition.

In contrast with the method employed by Parmentier (2008), Experiment 2 used two spoken words ('left' and 'right') as standard sounds, as opposed to one spoken word ('left' or 'right') as the standard sound. Because two different words were presented in the experiment, it is possible that each word maintains some level of novelty even though together they occur on 80 percent of the trials. Experiment 3 was designed to address this possibility.

EXPERIMENT 3

In Experiment 3 the percentage of word utterance trials was increased to 90 percent and the percentage of tone trials was decreased to 10 percent. These changes should reduce even further than in Experiment 2 the possibility that the word utterances maintain any residual degree of novelty even though they are the regularly occurring sounds.

In addition to the change in the proportion of trials, the ISI between the sound and the visual arrow varied at either 0 ms or 200 ms. In the two previous experiments, the ISI was fixed at 0 ms. Parmentier (2008) suggested that an increase in ISI should increase the magnitude of the semantic effect. He reasoned that the involuntary capture of attention by a novel sound is followed by an involuntary spread of activation across phonological and semantic processing. The 200 ms ISI should allow more opportunity for semantic processing than the 0 ms ISI.

Method

Participants

Thirty undergraduate students volunteered from the University of Manitoba's Introduction to Psychology participant pool. None of the participants had participated in either Experiment 1 or Experiment 2. All participants received partial course credit in exchange for participating.

Materials

The materials used in the experiment were the same as those used in the two previous experiments.

Design and Procedure

The experimental design and procedure were similar as Experiment 2. The pure tone sound was presented on 10 percent of trials and the words 'right' and 'left' were presented on 90 percent of trials. Also, the ISI between the sound and the arrow varied as either 0 ms or 200 ms. Participants completed 400 experimental trials blocked by ISI, 200 trials with an ISI of 0 ms and 200 trials with and ISI of 200 ms. Half of the participants received the 0 ms ISI block first and the 200 ms ISI block second. The other half of the participants completed the experiment in the reverse order.

Results & Discussion

Response Times

Statistical analysis of mean RT for correct responses was performed using a two-way repeated-measures ANOVA with ISI (0 ms, 200 ms) and Trial Type (standard-congruent, standard-incongruent, novel tone) served as within-subjects factors. The analysis revealed a significant main effect of Trial Type F (2, 58) = 67.38, $p < .001$, as well as a significant interaction between ISI and Trial Type, F (2, 58) = 5.78, $p < .01$. Overall, listeners responded more quickly when the arrow target was preceded by a congruent spoken word than either the incongruent word or novel tone trials. In order to decompose the interaction the novelty effect and the semantic effect were compared separately for the 0 ms ISI and 200 ms ISI conditions (see Figure 3a).

The effect of novelty was assessed by comparing performance on the novel tone trials with the average of performance on the standard sound trials and ISI separately using two-way within-subjects repeated-measures ANOVA. This analysis revealed a significant effect of Novelty, F (1, 29) = 73.11, $p < .001$, as well as a significant ISI X Novelty interaction, F (1, 29) = 6.36, $p < .005$. Participants were slower when a novel sound was presented immediately before the visual task. The interaction was decomposed to examine the Novelty effect at both ISIs using a within-subjects repeated-measures ANOVA. There was a significant Novelty effect for both the 0 ms ISI and the 200 ms ISI, F (1, 29) =

65.35, $p < .001$, and $F(1, 29) = 41.71$, $p < .001$ respectively. The effect of novelty was 28 ms for the 0ms ISI and 46 ms for the 200 ms ISI.

The effect of semantic processing was examined by comparing performance on standard-congruent and standard-incongruent trials and ISI using a within-subjects repeated- measures ANOVA. This analysis revealed a significant Semantic effect, $F(1, 29) = 7.74$, $p < .001$. Regardless of ISI, participants were slower when the spoken word 'left' or 'right' was incongruent with the following visual arrow. The Semantic effect was examined at both ISIs using a within-subjects repeated-measures ANOVA. There was a significant Semantic effect for the 200 ms ISI, $F(1, 29) = 6.57$, $p < .005$. Although the Semantic effect was not significant for the 0 ms ISI, the RTs trended in the right direction. Participants responded more slowly when the spoken word 'left' or 'right' was incongruent with the direction in which the subsequent arrow (see Figure 3a). This decrease in RT was significantly larger when the ISI increased from 0 ms to 200ms. Even with the word utterances trials increased to 90 percent and the tone trials decreased to 10 percent, the Semantic effect was generated across the two ISIs. The increased magnitude of the semantic effect from the 0 ms ISI to the 200 ms ISI is in line with what Parmentier (2008) suggested.

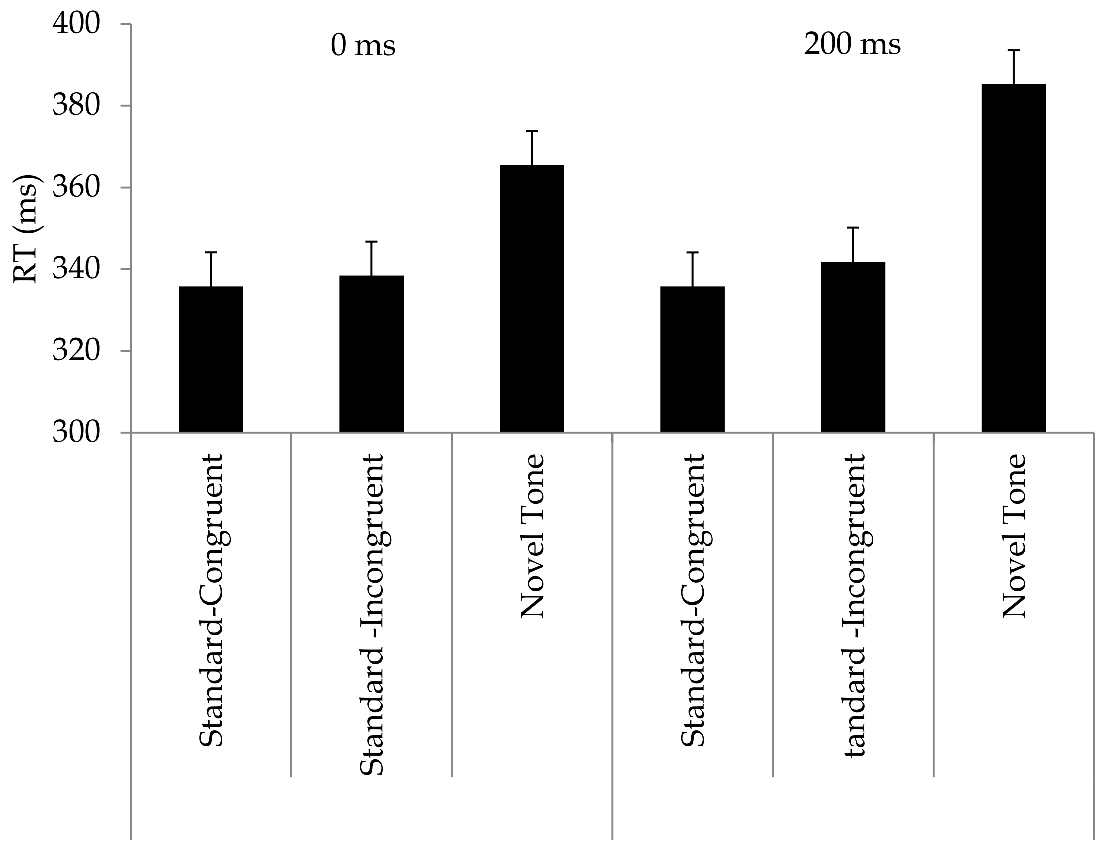


Figure 3a. Mean RT performance for Experiment 3, in the standard-congruent condition, the standard-incongruent condition, and the novel tone condition for both the 0 ms and 200 ms ISI.

Percentage Errors

Statistical analysis of error rates for correct responses was performed using a two-way repeated-measures ANOVA with ISI (0 ms, 200 ms) and Trial Type (standard-congruent, standard-incongruent, novel tone) served as within-subjects factors. The analysis revealed a significant main effect of Trial Type F (2, 58) = 5.14, $p < .01$. No other effects were significant. Overall across ISI, listeners performed fewer errors when the arrow target was preceded by a novel tone than either the incongruent word or congruent word trials (see Figure 3b).

The effect of novelty was assessed by comparing performance on the novel tone trials with the average of performance on the standard sound trials and ISI using a within-subjects repeated-measures ANOVA. This analysis revealed a significant effect of Novelty, F (1, 29) = 4.25, p < .05. No other effects were significant. A planned comparison of the effect of novelty for each ISI revealed a significant effect of Novelty, F (1, 29) = 5.65, p < .05, for the 0 ms ISI condition. Participants made fewer errors when the arrow target was preceded by a novel tone than by either the incongruent word or congruent word trials in the 0 ms ISI condition. This result is inconsistent with the RT results, and therefore suggests a speed-accuracy tradeoff in performance of the task. It is important to note, however, that this inconsistency was not apparent in Experiment 1 or 2 or, to anticipate somewhat, in Experiment 4.

The effect of semantic processing was examined by comparing performance on standard-congruent and standard-incongruent trials and ISI using a within-subjects repeated- measures ANOVA. This analysis revealed a significant Semantic effect, F (1, 29) = 9.01, p < .001. No other effects were significant. A planned comparison of the effect of semantic processing for each ISI revealed a significant Semantic effect, F (1, 29) = 7.35, p < .05 for the 0 ms ISI and F (1, 29) = 5.31, p < .05 for the 200 ms ISI. For both ISI, participants made fewer mistakes in the standard-congruent trials compared to the standard-incongruent trials. These results are consistent with the RT data.

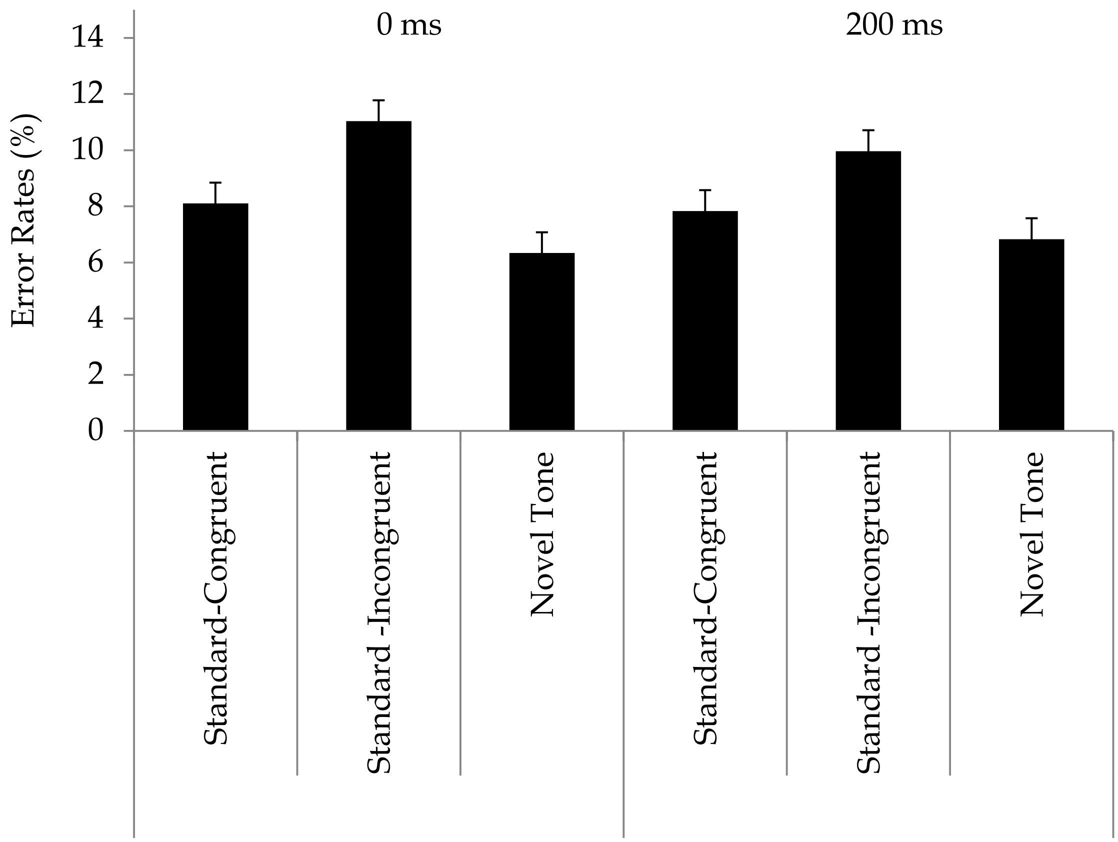


Figure 3b. Mean error rates for Experiment 3, in the standard-congruent condition, the standard-incongruent condition, and the novel tone condition for both the 0 ms and 200 ms ISI.

Experiment 3 provided evidence of a semantic effect with 90 percent word utterances which directly contradicts Parmentier's (2008) claim that there should be no semantic effect when the spoken words are no longer novel. It is possible, however, that a very large number of trials are required in order to completely eliminate any novelty associated with the spoken words. This possibility arises because whereas Parmentier (2008) presented his participants with 1200 trials, only 400 were used in Experiment 3. Experiment 4 was designed to address this possibility by presenting participants with 1600 trials.

EXPERIMENT 4

Method

Participants

Forty undergraduate students volunteered from the University of Manitoba's Introduction to Psychology participant pool. Six participants were excluded from analysis due to performing worse than chance. Thirty-four participants remained for analysis. None of the participants were involved in any of the previous three experiments. All participants received partial course credit in exchange for participating.

Materials

The materials used in the experiment were the same as those used in the previous experiments.

Design and Procedure

The experimental design and procedure were similar to those used in the previous experiments. Half of the participants were presented with the pure tone sound on 10 percent of trials, and the other half of the participants were presented the word 'car' on 10 percent of trials. All participants were presented with the words 'right' and 'left' on 90 percent of trials. Participants completed four blocks of 400 trials with a brief break in between each block.

Results & Discussion

Mean RT and percentage errors are summarized in Table 1 as a function of Condition, Block, and Trial Type.

Response Times

Omnibus ANOVA

Statistical analysis of mean RT for correct responses was performed using a mixed-design repeated measures ANOVA with one between-subjects factor (Condition [car, tone]), and two within-subjects factors, (Trial Type [standard-congruent, standard- incongruent, novel sound]), and (Block, [1, 2, 3, 4]). The analysis revealed that sphericity was violated in some conditions, and, therefore, all the results reported below are based on use of the Greenhouse-Geisser correction. The analysis revealed significant main effects of Trial Type F (2, 64) = 25.46, $p < .001$ and Block F (3, 96) = 5.49, $p < .05$. Overall, listeners responded more quickly on the last block of trials than the first and when the arrow target was preceded by the congruent spoken word than by either the incongruent word or a novel sound.

Condition	Block		Standard – Congruent	Standard – Incongruent	Novel
Tone	1	RT	332 (6.22)	336 (5.60)	374 (14.98)
		Errors	11 (1.35)	12 (1.61)	11 (1.62)
	2	RT	331 (5.47)	334 (5.26)	357 (9.53)
		Errors	11 (1.52)	12 (1.45)	10 (1.77)
	3	RT	331 (6.03)	336 (6.53)	342 (7.10)
		Errors	10 (1.77)	12 (2.12)	11 (2.54)
	4	RT	330 (5.49)	334 (6.36)	339 (7.22)
		Errors	7 (1.12)	10 (1.36)	11 (2.62)
'Car'	1	RT	344 (13.49)	349 (13.55)	354 (14.15)
		Errors	12 (2.49)	12 (2.35)	9 (2.25)
	2	RT	332 (8.06)	338 (9.07)	339 (9.26)
		Errors	10 (2.15)	11 (2.37)	7 (1.96)
	3	RT	336 (8.50)	338 (8.75)	341 (8.17)
		Errors	8 (1.51)	9 (1.46)	6 (1.06)
	4	RT	328 (7.16)	335 (7.34)	332 (7.56)
		Errors	6 (1.44)	7 (1.84)	5 (1.02)

Table 1. A block-by-block breakdown of mean RTs in ms and percentage errors, with standard errors for each measure in parentheses for each trials type and sound condition in Experiment 4.

Two-way interactions between Trial Type and Condition, F (2, 64) = 9.85, $p < .01$, and between Trial Type and Block, F (6, 192) = 6.90, $p < .01$, were also statistically significant. As was the three-way interaction between Condition, Trial Type and Block, F (6, 192) = 3.76, $p = .023$.

In order to decompose the 3-way interaction, the novelty and semantic effects were examined separately as a function of Condition and Block.

Novelty Effect

The novelty effect is defined as the difference in performance for trials on which a novel sound is presented and trials on which a standard sound is presented. In order to make this comparison, a mixed-design repeated-measures ANOVA was performed using Condition as the between–subjects factor (tone and 'car') and Blocks (1 - 4), and Trial Type (novel trials, average of standard trials) as independent variables.

This analysis revealed significant main effects of Trial Type, F (1, 32) = 24.57, $p < .001$, and Block, F (3, 96) = 6.65, $p = .005$, as well as a significant interactions between Trial Type and Block, F (3, 96) = 7.74, $p = .001$, and Trial Type and Condition, F (1, 32) = 10.48, $p = .001$. Moreover, the 3-way Trial Type X Block X Condition interaction was also significant, F (3, 96) = 4.01, $p < .05$. In order to decompose the 3-way interaction the effects of Trial Type and Block were examined separately for both the tone and 'car' conditions.

Analysis of the tone condition revealed significant main effects of Trial Type, F (1, 16) = 19.25, p < .001, and Block, F (3, 48) = 4.15, p < .05, and a significant interaction between the two, F (3, 48) = 6.74, p = .007. Further examination revealed that participants responded significantly more slowly on novel trials than on standard trials on block 1, 2, and 3 (p < .01) but not on block 4 (p= .065). Thus, a significant novelty effects was apparent on three of the 4 blocks of trials. Direct comparison of the novelty effect on block 1 and block 4 revealed a significant change (p < .05).

Analysis of the 'car' condition revealed a significant main effect of Trial Type, F (1, 16) = 5.82, p < .028, and a marginal effect of Block, F (3, 48) = 2.95, p = .085 (p = .042 without the Greenhouse-Geisser correction). Although the interaction between Trial Type and Block did not reach statistical significance, planned comparisons were performed to determine whether the novelty effect was apparent for all four blocks. These comparisons showed that participants responded more slowly on novel trials than on standard trials on block 1, (p < .05) but not on blocks 2,3,4, (p > .05). Direct comparison of the novelty effect on block 1 and block 4 revealed no significant change (p > .05).

Additional planned comparisons performed to determine whether the magnitude of the novelty effect differed for the 'car' and tone conditions, revealed a significantly larger effect on blocks 1 and 2 for the tone condition (p < .05).

A block-by-block analysis was performed to assess the effect of novelty across the experiment using a mixed-design repeated-measures ANOVA with Block and Novelty as within-subjects factors and Condition as a between-subjects factor. There was a significant Novelty X Condition interaction for the first two blocks ($p < .05$), but not for the last two blocks ($p > .05$). This interaction was decomposed by examining Novelty block-by-block, separately for both the 'car' and tone condition (see Figure 4a).

The effect of novelty was found to decrease with practice, its magnitude was reduced when the novel sound was similar to the standard sounds (i.e., when 'car' was used as the novel sound).

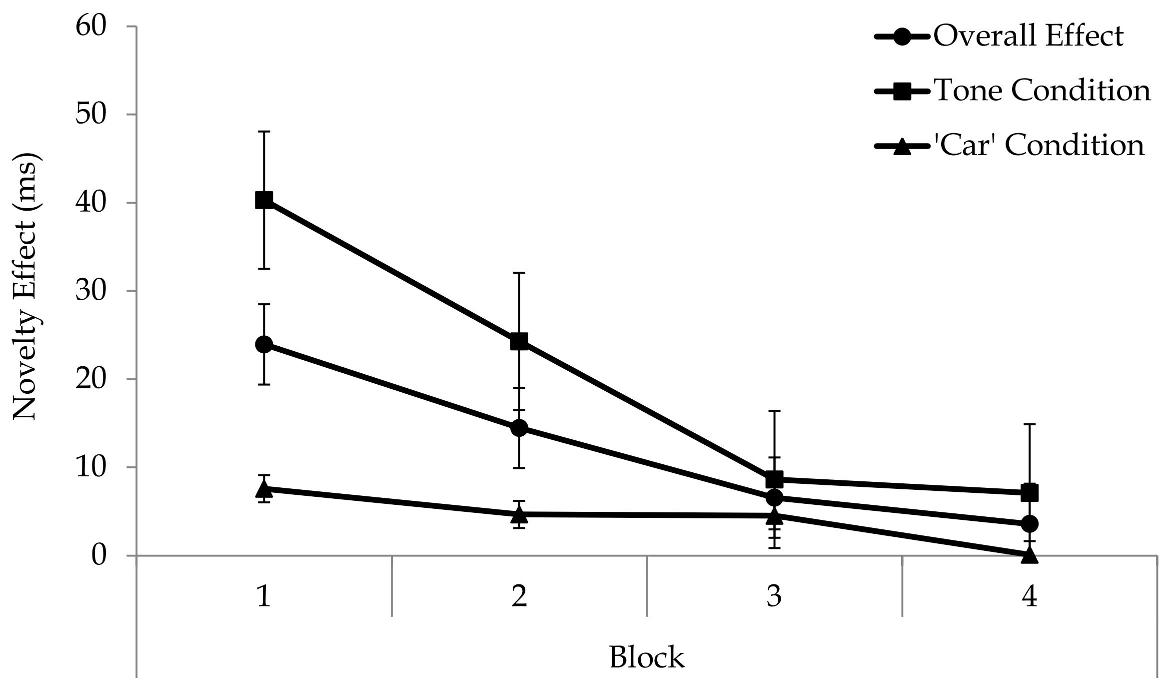


Figure 4a. A block-by-block breakdown of the overall effect of novelty (difference of performance on the novel trials and the average of the standard trials) as a function of novel sound in Experiment 4.

Semantic Effect

The semantic effect is defined as the difference in performance for trials on which a standard-congruent sound is presented and trials on which a standard-incongruent sound is presented. In order to make this comparison, a mixed-design repeated-measures ANOVA was performed using Condition as the between–subjects factor (tone and 'car') and Blocks (1 - 4), and Trial Type (standard-congruent trials and standard-incongruent trials) as independent variables.

This analysis revealed a significant main effect of Trial Type, F (1, 32) = 38.94, $p < .001$. No other effects were statistically significant. Overall, participants responded more slowly on standard-incongruent trials than on standard-congruent trials.

A block-by-block analysis was performed to assess the effect of semantic processing across the experiment with a mixed-design repeated-measures ANOVA with Block and Semantic Effect as within-subjects factors and Condition as a between-subjects factor. There was a significant Semantic Effect for all blocks ($p < .01$). There were no significant interactions of Semantic Effect and Condition for any blocks. When analyzed block by block, participants were roughly 4 ms slower at responding to standard-congruent trials than standard-incongruent trials for the entire experiment (see Figure 4b).

In the present experiment there was evidence of semantic processing even though 90 percent of the 1600 trials were the standard spoken words ‘left’ or ‘right’. This evidence is in direct conflict with Parmentier’s (2008) claims.

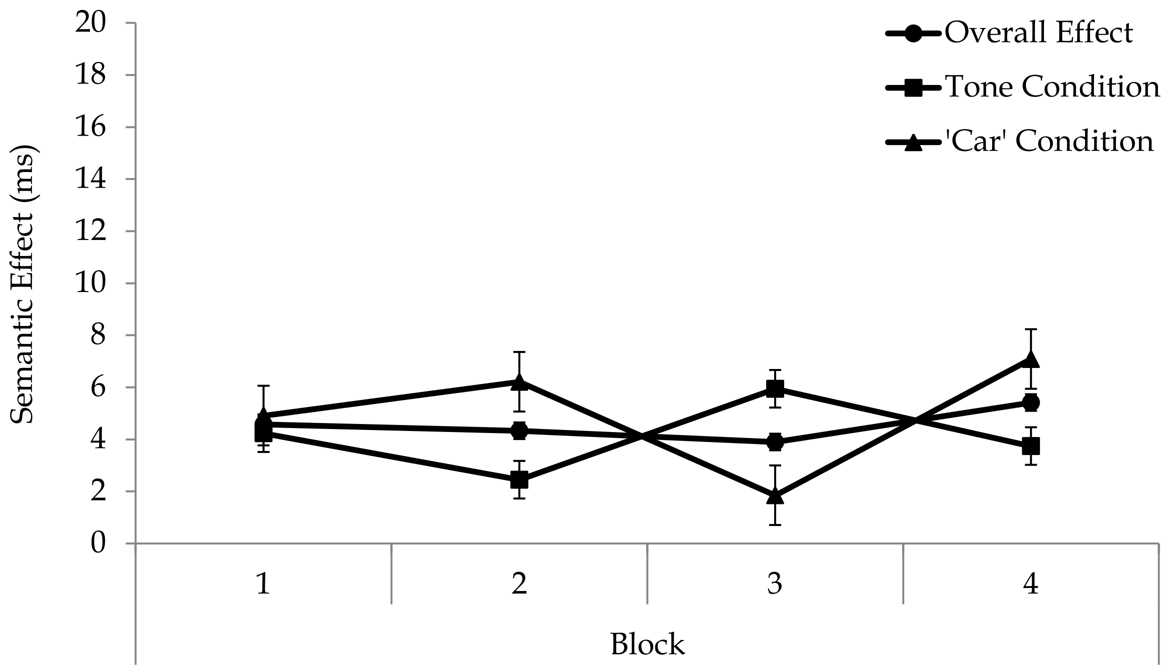


Figure 4b. A block-by-block breakdown of the effect of semantic processing (difference of performance on the standard-congruent trials and the standard-incongruent trials) in Experiment 4.

Percentage Errors

Omnibus ANOVA

Statistical analysis of error rates was performed using a mixed-design repeated measures ANOVA with one between-subjects factor (Condition [car, tone]), and two within-subjects factors, (Trial Type [standard-congruent, standard- incongruent, novel tone]), and (Block, [1, 2, 3, 4]). The analysis revealed that sphericity was violated in some conditions, and, therefore, all the results reported below are based on use of the Greenhouse-Geisser correction. The analysis revealed significant main effects of Trial Type F (2, 64) = 6.37, $p < .01$ and Block F (3, 96) = 9.85, $p < .01$. Overall, listeners made fewer errors on the last block of trials than the first. There was also a significant 2-way interaction between Trial Type and Condition, F (2, 64) = 4.28, $p < .05$. In order to decompose this interaction, Trial Type was examined separately for both the tone and the 'car' conditions.

Although there were no significant effects for the tone condition, there were significant main effects of Trial Type, F (2, 32) =12.59, $p < .01$, and Block, F (3, 48) = 9.59, $p < .01$ for the 'car' condition. A block-by-block analysis revealed that participants made significantly fewer errors on the novel tone trials than on the standard-congruent and standard-incongruent trials for the blocks 1,2, and 3 ($p < .05$), but not 4 (see Table 1).

GENERAL DISCUSSION

The four experiments described above were performed to investigate the effect of an expected or unexpected sound on performance of a visual perception task. Specifically, a cross-modal oddball paradigm was used in which participants categorized visually presented arrows immediately following a to-be ignored irrelevant sound.

The results from Experiment 1 replicated those reported by Parmentier (2008). Listeners more slowly classified the direction of a visual arrow that followed a novel spoken word (20 percent of trials) than one that followed a standard pure tone (80 percent of trials). In addition to this effect of novelty, participants were impacted by the semantic content of the novel sounds. Participants responded more slowly when the auditory novel word and the immediately following visual arrow were incongruent (e.g. 'right' followed by a left arrow) than when they were congruent (e.g. 'right' followed by a right arrow). Thus, the novel sound was processed semantically even though it was irrelevant to the task. This semantic processing delayed the classification of the visual arrow. This semantic processing effect also replicated results reported by Parmentier (2008).

Parmentier claimed that the effect of semantic processing could not occur when the sounds are no longer novel and this was tested in Experiment 2. The experimental design and procedure used in Experiment 2 were the same as those used in Experiment 1, except that the pure tone was used as the novel sound (20 percent of trials), and the spoken words were used as standard sounds (80 percent of trials). Participants responded most quickly when the arrow target was preceded by a congruent spoken word than when it was preceded by either an incongruent word or a novel tone. Participants exhibited both the novelty effect and the semantic effect even when the spoken words were the regularly occurring sounds as opposed to being the novel sounds as in the previous experiment. The spoken words were still involuntarily attended, processed semantically, and interfered with the visual task. These results, of course, do not match Parmentier’s (2008) claim that the semantic effect should not arise for standard sounds.

In Experiment 2, two spoken words (‘left’ and ‘right’) were used as standard sounds, as opposed to one spoken word (‘left’ or ‘right’) as was used as the standard sound by Parmentier (2008). Because two different words were presented in the experiment, it is possible that each word maintained some level of novelty even though together they occurred on 80 percent of the trials. Experiment 3 addressed this possibility by increasing the percentage of spoken word trials to 90 percent and reducing the percentage of tone trials to 10 percent. These changes reduced even further than in Experiment 2 the possibility that the spoken words maintained any degree of novelty even though they were the regularly occurring sounds. In addition to the change in the proportion of trials, the ISI between the sound and the visual arrow was varied at either 0 ms or 200 ms to determine whether time available for semantic processing may have any influence on the magnitude of the effect. In the two previous experiments, the ISI was fixed at 0 ms. The results of this experiment showed that participants responded more quickly when the arrow target was preceded by a congruent spoken word than when it was preceded by an incongruent word. In addition, for both ISIs participants responded more slowly when a novel sound was presented immediately prior to the visual task than when either of the standard words was presented. This effect of semantic processing was significantly greater at 200 ms ISI than at 0 ms ISI. This result is in line with Parmentier’s (2008) suggestion that 200 ms ISI should allow more opportunity for semantic processing than 0 ms ISI. The effect of novelty was generated across the two ISIs (but only approached significance at 0 ms). These results are clearly inconsistent with Parmentier's (2008) claim that semantic processing of irrelevant auditory information occurs only under conditions of novelty. In Parmentier's view, only novel sounds will capture attention and therefore only such sounds will receive semantic processing. The results of both Experiments 2 and 3 demonstrate that novelty is not required for semantic processing.

Experiment 3 provided evidence of a semantic processing effect even though words were presented on 90 percent of trials and this directly contradicts Parmentier's (2008) claim that there should be no semantic effect when the spoken words are no longer novel. It is possible, however, that a very large number of trials are required in order to totally eliminate any novelty associated with the spoken words. This possibility arises because whereas Parmentier (2008) presented his participants with 1200 trials, only 400 trials were used in Experiment 3. Experiment 4 addressed this possibility by presenting participants with 4 blocks of 400 trials. In addition, half of the participants were presented with the pure tone sound on 10 percent of trials, and the other half of the participants were presented the spoken word 'car' on 10 percent of trials. The spoken word 'car' was used to determine if using a spoken word as the novel sound would reduce the magnitude of the novelty effect because of its similarity to the standard sounds. All participants were presented with the words ‘right’ and ‘left’ on 90 percent of trials.

The results of Experiment 4 revealed that although there was a practice effect with participants responding more quickly on the last block of trials than the first block of trials there was also an overall effect of novelty. As might have been expected, the magnitude of the novelty effect was reduced, but still significant when the novel sound was similar to the standard sounds (i.e., when ‘car’ was used as the novel sound). Planned comparisons showed that participants responded significantly more slowly on novel trials in the first block, however statistical significance was lost ($p > .05$) for the remaining three blocks. Direct comparison of the novelty effect on block 1 and block 4 revealed no significant change ($p > .05$). This effect and the practice effect are both consistent with some of Parmentier’s (2008) results.

Experiment 4 also provided evidence that is inconsistent with Parmentier’s (2008) predictions. Specifically, participants responded significantly more slowly on standard-incongruent trials than on standard-congruent trials during all four blocks of trials. This provides strong evidence of semantic processing even though 90 percent of the 1600 trials were the standard spoken words ‘left’ or ‘right’. This evidence is in direct conflict with Parmentier’s (2008) claims.

Taken together, the results of the four experiments demonstrate that irrelevant sounds, even when presented often, are semantically processed and influence categorization of a subsequent visual stimulus. In direct contrast with previous claims made by Parmentier, (2008), it appears that this involuntary semantic processing of sounds is not contingent on the capture of attention by novelty.

This evidence of semantic processing of unattended words is quite consistent with a great deal of previous research. For example, in an early study using dichotic presentation, Moray (1959) asked participants to ignore sounds presented to one ear, while attending to, and repeating, the words presented concurrently to the other ear (this is referred to as a shadowing task). Usually words presented to the unattended ear are not detected or remembered. However, Moray found that when the participant's own name was presented to the unattended ear, it was noticed. Moray concluded that listeners' names were important enough to break through the attentional barrier and capture attention involuntarily.

Treisman (1960) provided additional evidence of semantic processing of unattended words. Again, a dichotic listening task was used involving two spoken word passages. Participants were asked to ignore the sounds presented to one ear, while shadowing the word passages presented to the other ear. While the participants were performing the shadowing task, the word passages switched from one ear to the other. Once the passage switched, roughly one third of the time, participants inadvertently switched from shadowing the to-be-attended ear to shadowing the to-be-ignored ear. Listeners followed the presentation of the passage from one ear to the other and shadowed a few words before reverting back to correct ear. Treisman (1960) claimed that the participants rarely were aware of their behaviour. These results provide additional evidence that participants involuntarily process semantic information presented to a presumably unattended ear.

Lewis (1970) provided additional evidence of semantic processing of unattended word passages by measuring RTs during a dichotic listening task. Participants shadowed words that were presented to an attended ear and were told to ignore the words presented to the other ear. Words presented to the to-be ignored ear were unrelated, semantically related or associatively related to the words presented to the attended ear. Both the to-be ignored words and the shadowed words were presented at the same time. The results of the study revealed that participants' shadowing RTs were reduced by roughly 30 ms when the to-be ignored word was semantically-related to the corresponding shadowed word. For example, listeners shadowed the word 'strange' more quickly when it was paired with 'weird'. Conversely, RTs were increased by roughly 30 ms when the to-be ignored word was associatively-related to the corresponding shadowed word. For example, listeners shadowed the word 'doctor' more slowly when it was paired with 'nurse'. With these results, Lewis (1970) argued that participants inadvertently processed semantic information of the to-be ignored words.

As the studies described above illustrate, semantic processing of unattended information is not unusual, and this is quite consistent with the results of the present study. The classic Stroop effect (Stroop, 1935) provides related evidence of semantic processing despite a conscious effort against it. In Stroop's study the basic task required participants to name the ink colour in which words were printed. Participants found this was much more difficult when the word itself and the colour in which it was printed did not match (e.g., the word 'red' printed in green ink), than when the word and colour did match. This classic result provides a strong indication of semantic processing even though participants are actively trying not to do so.

The current results are similar with other distraction effects of attention, for example, the auditory attentional blink. The auditory attentional blink occurs when the participants' task is to identify two consecutive target sounds within a rapidly presented series of filler sounds (e.g., Shen & Mondor, 2008). The 'blink' refers to a deficit in processing of the second target sound when it is presented immediately following the first. There is some evidence that the attentional blink may occur even when participants are instructed to ignore the first target. This result is, of course, similar to those described in the present study, and suggests that sudden sounds presented in isolation may be automatically attended and processed, even when irrelevant to the task at hand. Studies of semantic priming similarly provide evidence of automatic processing of auditory information, in this case of verbal information. In these studies, participants are often presented with two words in succession with a requirement to read aloud or make a speeded judgment (such as categorization) about the second of these. Responses are more quickly made to the second word when it is semantically-related to the first, even when participants are instructed to ignore the first word (e.g., Reisberg, 2010).

As these brief discussions of the attentional blink and semantic priming illustrate there is evidence form a variety of different areas of research that have revealed that processing of presumably unattended information is the norm rather than the exception. The results reported in the present study are quite consistent with this literature; it is Parmentier's claim that there is no processing of verbal information unless it is 'novel' that is inconsistent with it.

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