Auditory Attentional Capture by Sound Appearance and Disappearance

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ABSTRACT

In two experiments, the extent to which abrupt onsets and abrupt offsets of a sound capture attention was examined. In both experiments participants were required to detect the occurrence of an amplitude modulated sound (i.e., a target sound). On each trial, listeners were presented with two channels, one to the left ear and one to the right ear. The target sound occurred on 50% of the trials and was presented equally often in the left and right channels. On different trials, a target sound could be preceded by the abrupt appearance of a cue sound, or the abrupt disappearance of a cue sound, in either the same channel (valid trial) or in the other channel (invalid trial). The results of Experiment 1 showed that the target sound was detected more quickly and accurately on valid trials than on invalid trials for both appearance and disappearance cues. In Experiment 2 target sounds were more often presented in one channel to determine whether such foreknowledge would attenuate the effect of the cues on performance. However, the results revealed that this was not the case as robust effects of both appearance and disappearance cues were apparent for both the expected channel and the unexpected channel. Overall, the two experiments demonstrate that the abrupt appearance of a sound and the abrupt disappearance of a sound both capture auditory attention.

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INTRODUCTION

Attentional capture can happen in several different ways. Attention itself can be affected or guided by bottom up processes (stimulus-driven or exogenous) or by top down processes (goal-directed or endogenous). Bottom-up processing refers to attentional capture based on the appearance of new objects. Top-down processing refers to directing attention voluntarily based on current goals and knowledge of object characteristics, such as form, colour, or location. During visual search tasks, certain features of a target, such as its abrupt occurrence, may cause attention to be directed in a bottom-up fashion. "Attentional processes are responsible for controlling the sampling of the perceptual representation" (Samuel & Weiner, 2001).

Perceptual processes generate representations of objects and events in our environment which need to be updated continuously to enable us to perform appropriate behaviors. This updating process highlights any relevant changes that may be occurring in the surrounding environment. According to Samuel and Weiner (2001), in order to keep the representation of the visual environment current, four types of changes must be taken into account. An object can appear in some location (onset), disappear from a location (offset), be replaced by a new object (morph), or an existing object can move to a different location (move; Samuel & Weiner, 2001). Evolutionarily speaking, attentional capture is of great importance. For example, it would be evolutionarily advantageous to be alerted to a stimulus onset, as the sudden appearance of an object may pose a threat that requires a fight or flight response. In contrast, disappearance of an object that has already received attention would not require rapid processing as failure to respond rapidly to the disappearance of a threat would only result in continued threat response behavior, which would not likely impair an animals' probability of survival (Atchley, Kramer, & Hillstrom, 2000). Therefore, it would stand to reason that object onsets might be processed more quickly and with a higher priority than object offsets. Onsets also tend to signal novel stimulus information, and this information can quite often be of importance for survival (Yantis & Jonides, 1990).

Visual cuing studies

Yantis and Hillstrom (1994) addressed the importance of onset stimuli in vision. They conducted two experiments to study stimulus-driven attentional capture. The main purpose of the first experiment was to observe the time it takes to detect a target when it is new as opposed to when it is old. The subjects were split into three groups, each of which was presented with equiluminant stimuli that were outlined clearly by differences in texture, motion, or depth. Subjects were required to make a decision as to which of two target letters appeared in the display. The general trial sequence consisted of a placeholder display, presented for 1 second, made up of several block figure eights which camouflaged letters. There were 5 figure eights for the texture group, 6 for motion, and 3 for depth. The placeholder display was then replaced by a search display consisting of letters which appeared by removal of segments from the block figure eights, which are referred to as 'old' elements, and another object appeared in a location that had not contained anything previously, which is referred to as a 'new' element. There was always a target letter presented with the others and it could be either H or U. If the subjects detected an H, then they were required to press the left response button and if it was a U, then they pressed the right response button. Display sizes differed due to the fact that different equipment was used for each section of the experiment. Thus, the number of elements in each display was 2, 4, and 6 for the texture group, 3, 5, and 7 for the motion group, and 2, 3, and 4 for the depth group. The computer made a beep sound if a response was incorrect or if the subject did not respond within 6 seconds. Results showed that the effect of display size on reaction time (RT) was much smaller when the target was a new element compared to when it was an old element. This suggested that the abrupt appearance of a new equiluminant object, differing in texture, motion or depth from the 'old' object, captured attention.

Experiment 2 was designed to address the possibility that the old items in Experiment 1 were perceptually more difficult to discriminate than the new items. On each trial, a single letter was presented at fixation. The letter could be either an H or a U and subjects were again required to press the right button if it was an H and the left button if it was a U. On half the trials the letter was preceded by a figure eight placeholder, which changed to produce an 'old' element. On the other half of the trials the letter was preceded by background texture, on which the 'new' element appeared. Results indicated that there was no significant difference in RT for old compared to new letters. This suggested that old elements were no more difficult to detect than new elements.

Yantis and Hillstrom (1994) suggested that "stimulus-driven visual selection is mediated by an attentional interrupt signal that is generated whenever a new object file is created" (p. 106). Although studies have found that appearance of an object in a previously empty location will generate a new object file, less is known about the processes that occur when the characteristics of an object change. Yantis and Jonides

(1990) suggested that abrupt onsets may capture visual attention automatically and cause the observer to process abrupt visual events with high priority. This hypothesis was based on two ideas. First, there is a mechanism that detects the abrupt onset and signals the visual attentional system to allocate attentional resources accordingly. Second, the allocation of attention due to the signal is automatic. However, this allocation may not be strongly automatic. There are two main criteria that must be satisfied in order for a process to be considered strongly automatic. First, the load-insensitivity criterion states that an automatic process is not hindered when concurrent information load is increased. Second, the intentionality criterion states that an automatic process is not subject to voluntary control (Yantis & Jonides, 1990). Three levels of automaticity were defined by Kahneman and Treisman (1984). A process can be strongly automatic if it is not facilitated by focusing attention on a stimulus and is not inhibited by focusing attention away from it. It can be partially or occasionally automatic if either of the criteria mentioned above is violated, or it may not be automatic at all.

Several experiments were performed by Yantis and Jonides (1990) to assess this automaticity issue. The first experiment was designed to see if abrupt onsets satisfy the intentionality criterion for automaticity. Based on this criterion, an abrupt onset should capture attention even if it is focused elsewhere. The basic sequence of each trial consisted of a central arrow cue which indicated a position to the left or right of fixation, followed after 200 ms, by either an E or an H which appeared at one location to the left or right with an irrelevant letter at the other location. Subjects were required to determine whether an E or H appeared. The initial cue was considered valid if it pointed to the correct position of the target letter, which was the case on 80% of the trials. Letters were presented in two different ways. They could be onset letters, which were presented by illuminating a five segment letter in a location that had not contained any segments, or they could be no-onset letters, generated by removing two segments from a seven segment box figure eight to make a five-segment letter. There were four placeholders in each display at the beginning of the trials, a box figure eight on each side of the fixation cross which was used as camouflage for a no-onset letter. The other two placeholders were six dots, on each side of the fixation cross, placed at the vertices of a box figure eight which could be used for the onset letters. Subjects were required to maintain their gaze on the fixation cross at the center of the screen. The placeholders were then replaced by two letters, either side of fixation, one irrelevant letter and one target letter. Subjects responded by pressing the period key with their right index finger if an H was displayed and by pressing the slash key with their right middle finger if an E was displayed.

As mentioned earlier, the intentionality criterion for automaticity suggests that the presence of an abrupt onset should capture attention even if the subjects' attention is directed elsewhere. Therefore, the valid and invalid cues used in Experiment 1 should have no effect on performance when there is an abrupt stimulus onset. However, results indicated that RTs were faster on trials with valid cues than with invalid cues, and also when the target was an onset and the distractor was not, compared to when the distractor was an onset and the target was not. In addition, it was found that the effect of target type, onset versus no-onset, was larger when the cue was invalid compared to when it was valid. In other words, the subjects' state of attentional readiness did affect the extent to which abrupt onsets captured attention.

The second experiment reported by Yantis and Jonides (1990) looked at the effectiveness of attentional cues by varying the temporal position of those cues relative to the target letter E or H. Past research has shown that subjects are able to direct attention to a spatial location that is likely to contain task-relevant information within 200 ms of receiving that information, and that this allows for faster target identification (e.g., Eriksen & St. James, 1986). Past research has also shown that a location cue that occurs 50-300 ms before display onset produces from 40 to 120 ms of facilitation in choice reaction time, with the magnitude of the facilitation depending on the number of elements in the display (Colegate, Hoffman, & Eriksen, 1973; Eriksen & Hoffman, 1972). According to the automaticity hypothesis, an abrupt onset object appearing in an uncued location should capture attention and slow the response to cued stimuli that do not have abrupt onsets, regardless of the subject's state of attentional readiness. It was suggested that if the preliminary allocation of attention is dominant over performance, then effects of abrupt target onsets will not be found. The second experiment was constructed with a leading cue that put subjects in a state of attentional readiness to the target stimulus. There were three stimulus onset asynchronies (SOA) between the onset of the cue and a letter display. These were 200 ms preceding the onset of the display (-200 ms), 0 ms, and 200 ms after the display. The trailing cue did not provide subjects with any information as to the location of the letter. Presentation of each trial began with a fixation point displayed for 500 ms followed by a display of three box figure-eight placeholders at three positions forming a triangle pointing up or down. The test display was made up of three letters, which replaced the placeholders, and these were no-onset letters as they were formed by removing segments from the box figure eights. A fourth letter, an onset stimulus, appeared at the same time as the others but in a location that was previously blank. The placeholders were presented for 1000 ms, after which the cue was presented. The cue always pointed to the target letter, whether it was presented 200 ms preceding, with the display, or 200 ms after the display. Subjects were required to press the right response button with the index finger of their right hand if an E was displayed, and press the left button with their left index finger if an H was displayed.

Results showed that when the cue preceded the onset of the display by 200 ms, and attention was focused in response to that cue, any effect of abrupt onset in the discrimination task was negligible. When the cue was presented at the same time as the display or 200 ms after the display, the subjects could not focus their attention with respect to the target item, and in this case, responses to the target were quicker when it had an abrupt onset than when the distractors had an abrupt onset. In other words, in the event of unfocused attention, onsets produce better performance. In contrast, when attention is focused, onsets have very little effect, if any, on performance. This lends support to the suggestion that the preliminary allocation of attention may dominate performance.

The third experiment reported by Yantis and Jonides (1990) examined cue effectiveness, but without varying the temporal position of the cue which always preceded the display by 200 ms. The predictive validity of the cue was varied at 100%, 75%, or 25%. It was hypothesized that high-validity cues would prevent the disruption of performance by an abrupt onset object because attention would be focused on the cued location of the target item. In contrast, if there was a low-validity cue, subjects would direct their attention over the entire display and the appearance of an abrupt onset would capture their attention. The structure of each trial was similar to that used in Experiment 2, with a fixation point displayed for 500 ms followed by three box figure eights. Subjects in the 100% cue validity condition were told that the cue always pointed to the location of the target and subjects in the 75% cue validity condition were told that the cue pointed to the target most of the time. Those subjects in the 25% cue validity condition were instructed to ignore the cue because the target could appear in any location despite the location indicated by the cue.

Results indicated that there was no effect of target type in the 100% cue validity condition, replicating results found in Experiment 2, which shows that focused attention can overcome attentional capture by abrupt onset. On 75% valid trials, RTs were faster with abrupt onset targets compared with no-onsets. On 25% valid trials this effect was even more pronounced. The authors suggested that when presented with low-validity cues subjects would direct attention over the entire area and appearance of an abrupt onset should therefore capture attention. Results from the 75% and 25% cue validity conditions indicated that this was, indeed, the case because onset targets were acknowledged more quickly than were offset targets.

The fourth experiment reported by Yantis and Jonides (1990) examined a different, weaker, version of automaticity. This version suggests that an abrupt onset may be registered as a high priority event, but when attention is directed somewhere else the onset does not cause an interruption until the task is completed. In other words, the abrupt onset may be queued, and dealt with only after attention is no longer required for the current task. It was suggested that onset stimuli may cause a greater interruption to focused attention than no-onset stimuli, which would lend support to the view that onset stimuli are registered as high priority. On the other hand, if the interruption does not depend on whether or not the letter is abruptly presented, then this is inconsistent with the idea that onsets capture attention automatically. In this experiment, each trial began with two target letters which appeared on the screen for 500 ms, located above the right and left response keys. This was followed by a display made up of three placeholders and a fixation cross which was presented for 1000 ms, after which a 100% valid cue was displayed for 200 ms. Lastly, a four letter display was presented, with one letter being an abrupt onset and the other three being no-onsets. One of the two target letters was always presented in the cued location on each trial, and subjects were required to press the response key that corresponded to the cued target letter. On half the trials, the cued target letter was an onset, and on the other half of trials one of the uncued letters was an onset. In addition, on half of each of these types of trials, an interfering target letter was presented in one of the uncued locations and on the other half of each of these types of trials neutral letters were presented in the uncued locations. Finally, if the cued letter was a no-onset presented with an interfering letter, then the interfering letter was a no-onset on half the trials and an onset on the other half.

The results revealed that when attention was focused on the cued location, RT when the cued target was an onset was not significantly different from RT when an uncued neutral letter was an onset. Again, the results indicate that abrupt onsets do not capture attention if attention is directed to a different location beforehand. However, on trials where an interfering target was presented, RT was 525 ms when the interfering target was an onset, compared to 513 ms when it was a no-onset. Thus, interfering targets that were onsets slowed performance more than interfering targets that were no-onsets. It appears that attention is first allocated to the cued location, after which it is shifted to the next highest priority location which would be the location of an abrupt onset. Taken together, results from the four experiments in this study indicate that attentional capture by abrupt onsets may not be completely or strongly automatic.

In addition to focused attention effects, there may also be effects of attentional set on attentional orienting. A central point suggested by Folk et al. (1992) is that bottom-up control of attention interacts with the observer's state of attentional readiness. They proposed the contingent-capture hypothesis, which states that attentional capture by any attribute (including an abrupt onset) is contingent on the observer's adoption of an appropriate attentional set in advance. An attentional set is defined as an expectancy for a change or difference in a particular stimulus characteristic (Colcombe, Kramer, Irwin, Petersen, Colcombe, & Hahn, 2003). A contrasting theory is the broadened scope hypothesis, which states that attentional capture may occur for stimulus characteristics other than abrupt onsets (Yantis, 1993; Folk, Remington, & Johnston, 1992). However, both of these hypotheses are incompatible with earlier findings by Jonides and Yantis (1988), that attention is captured by an abrupt onset when observers are in a "neutral" state of attentional readiness, and that abrupt onsets may be unique in capturing attention. Jonides and Yantis (1988) used a display of letters which appeared either as no-onset stimuli created by removing segments from a block figure eight, or as onset stimuli which appeared abruptly in a previously empty location. There was a physically unique item presented on every trial which could be either the target or a distractor. There were three conditions in which unique items were defined by their onset, light intensity, or colour. With the onset condition, targets could be presented as either onsets, no-onsets or absent.

In the Intensity condition, targets could be of either a greater intensity than the distractors, the same intensity, or they could be absent. In the colour condition, targets could be of either the same or different in colour from the distractors, or they could be absent. It was unlikely that participants adopted a specific attentional set because the target was a unique item only a small percentage of the time, and it would not be beneficial to prepare for such an infrequent stimulus. Results from their experiments indicated that a unique characteristic of a stimulus is not enough to capture attention by itself. In fact it is the type of characteristic that is important. It was found that intensity and colour differences do not capture attention whereas onsets will, which suggests that abrupt onsets can capture attention in a purely stimulus-driven manner.

Yantis (1993) defines stimulus-driven attentional capture as attentional capture by an attribute that is independent of either the defining or reported attribute of the target. Goal-directed attentional capture involves selecting which areas or objects in a visual display will be processed to a further extent, given a set of goals and beliefs about the task. Previous research has demonstrated that when attention is focused at a different location than the one at which an onset stimulus subsequently occurs, or when an attentional set has been adopted, onsets do not capture attention (Martin-Emerson & Kramer, 1997). The main distinction that Yantis (1993) makes between stimulus-driven attentional capture and goal-directed attentional capture is that goal-directed attention is dependent on what observers are intending to do given task instructions. In contrast, stimulus-driven attentional capture occurs only when the attribute that elicits it is independent of the defining and reported attributes of the target. Yantis (1993) has summarized stimulus-driven attentional capture as follows. When an attentional set for a singleton is required for a specific task, attention is captured by relevant and irrelevant singletons of any kind. If an attentional set is not required, then onset singletons capture attention and other types will not. If attention is focused on a specific location, then singletons appearing in other locations will not capture attention.

Based on these past results (Folk et al., 1992; Martin-Emerson & Kramer, 1997; Yantis & Jonides, 1990), the suggestion has been made that attentional capture by new objects may be overridden by top-down or goal-directed processing (Yantis, 1993). The suggestion that onsets are unique does not mean that they have total control over attention. As the experiments reported by Yantis and Jonides (1990) illustrate, when participants anticipate a target and direct their attention to the likely location accordingly, an abrupt onset that occurs somewhere else does not immediately capture attention. This shows that there may be some sort of top-down mechanism that overrides attentional capture by the abrupt appearance of an object which may lead to an adaptive advantage (Yantis, 1993).

The results of other experiments have suggested that attentional set modulates the type of information that captures attention for both onsets and offsets (Atchley, Kramer & Hillstrom, 2000). Atchley et al. (2000) performed several experiments to look at whether attentional set affects attentional capture by visual onsets and offsets. The first experiment was constructed to observe the extent to which non-informative onset or offset cues preceding the display would affect attentional capture when the targets were in cued locations or uncued locations. Different attentional sets were created by associating onsets or offsets with the appearance of the target display. Two types of variables were used for the experiment, type of non-informative cue and type of target display transient. The non-informative cues could be onsets, which were filled circles around a location, or offsets, which were filled circles removed from a location. The type of target display differed in that it could be an onset, which consisted of letters that appeared in empty placeholder boxes, or an offset, in which line segments were removed from block figure eights positioned inside placeholder boxes. Each trial in Experiment 1 began with the fixation display, which was presented until the subject pressed the space bar to begin the trial. Next, a precue display was presented for 500 ms. Filled circles surrounded two randomly chosen target placeholders on half the trials, which made up the non-informative onset cue trials. Filled circles surrounded all target placeholders on the other half of the trials, which made up the non-informative offset cue trials. The cue display was presented next, for 100ms, and it consisted of one set of dots that was either added or removed from the display. Non-informative cues appeared around one of the two remaining uncued target placeholders, in addition to the two cued placeholders that were already surrounded, to make up the non-informative onset cue trial. A non-informative cue, filled circles surrounding one of the cued placeholders, was removed to make up the non-informative offset cue trials. Lastly, the target display was presented for 200 ms, and it consisted of a search array that was added to the cue display. If the boxes contained figure eight placeholders, then segments were removed to create the target letters H or U and the distractors E, P and S. If the boxes were empty, then the target and distractors were placed in the boxes. The target display always had one target letter and three distractors. Subjects were required to press the 'Z' key for one target and the '?/' key for the other target. Results indicated that for offset targets, RTs were faster when the target occurred in the same location as the offset cue, compared to when the target and cue occurred in different locations. The same result was found for onset target displays, where RTs were faster when cue and target appeared in the same location as opposed to different locations. In addition, RT was faster on the target-display onset trials, at 599 ms than on the target-display offset trials, at 660 ms, indicating an onset advantage. These results suggest that offset and onset cues can capture attention, however the target display also had to be an offset or onset respectively. On trials where the cue and target type were different, namely onset cue & offset target trials and offset cue & onset target trials, onset and offset cues did not capture attention. This may be due to subjects creating an attentional set for certain characteristics in the target display and stimuli with those specific characteristics evoke attentional capture.

The second experiment reported by Atchley et al. (2000) was designed to look at whether subjects can change their attentional set quickly, and whether attentional capture by onsets is more affected by a well-developed attentional set than are offsets. The method used in this experiment was similar to that of Experiment 1. However, the target display transient was random for each trial, rather than blocked as in the first experiment. When non-informative cue transient type and target transient type matched, and when non-informative cue and target appeared in the same location the subjects were able to respond more quickly than when either the transient types or the locations differed. The first two experiments, then, suggest that the type of change that causes attentional capture is influenced by the subjects' attentional set. Thus, subjects were faster at identifying the target when it was of the same transient type as the preceding cue.

Experiment 3 reported by Atchley et al. (2000) was constructed to see whether removing predictable information could eliminate an attentional set programmed for a specific type of stimulus change. In order to eliminate predictable information, displays were created that did not signal the transient type of either the non-informative cue or the target before their appearance. For the non-informative cues, dots were presented at only two potential locations at the beginning of each trial. One dot was removed to create an offset cue. One dot was added to create an onset cue. In addition, in order to remove potential display-guided top-down influences, figure eight placeholders were positioned at two of four possible target locations at the beginning of the trial, and when the target was presented these placeholders changed to letters while at the same time a letter appeared in a previously empty location. This was different from the first two experiments in which there were four peripheral boxes that were either empty or contained figure eights, depending on whether target and distractors were to be added or segments removed from the figure eights. The target had an equal probability of occurring in a placeholder location (no-onset) or in an empty location (onset). The procedure was otherwise similar to that used in the first two experiments. The target display transient and type of non-informative cue varied on each trial.

Main effects were found for target display type, indicating that onset targets were identified more quickly than offset targets. In addition, a significant main effect of cue type indicated that performance was slightly better with offset cues compared to onset cues, at 606 ms and 614 ms respectively. It was again found that RTs were faster when the cue and target were in the same position, which indicated that both onsets and offsets can capture attention. In addition, without any predictable target feature information which could be used to construct an attentional set, onsets and offsets both captured attention in spite of the type of target change. As was mentioned earlier, attentional capture by non-informative cues may result from stimulus-driven processes, which do not require the use of an attentional set. On the other hand, when an attentional set has been formed, attention may be guided by goal-directed or endogenous processes.

Visual Onset and Offset Stimuli

The evidence reviewed above suggests that, in the absence of a defined attentional set onset targets tend to capture attention to a greater degree than no-onset targets (Yantis & Jonides, 1984; Yantis & Jonides, 1990). Yantis and colleagues have suggested that onsets are unique in their ability to capture attention. Onsets represent the appearance of a new perceptual object in the visual field and this seems to capture attention in a stimulus-driven manner (Yantis & Hillstrom, 1994; Chastain & Cheal, 1999). In the auditory domain, many studies have examined the effect on attention of abrupt sounds. However, it appears that there has been no investigation of the effect on attention of the disappearance of a sound.

Samuel & Weiner (2001) examined the effect of object appearance and disappearance in vision using true disappearances instead of no-onsets as in the studies described above. They explored a variety of combinations of object onset and offset conditions. For each of the experiments in the study, subjects were first presented with a fixation X in the center of a computer screen for 250 ms, and then 8 grey circles, each of which contained 0, 1, or 2 smaller figures, appeared in circular formation around the X for an additional 750 ms. each of these figures could be a solid circle or the outline of a square, and could be either red or blue. After 750 ms, an object either appeared (onset) or disappeared (offset) from one of the grey circles (cue event). After a variable SOA, another object appeared or disappeared from the same circle or from a different one (target event). Subjects were required to detect the target event by pressing a response button as quickly as possible.

Samuel & Weiner (2001) found that there were no early facilitative effects at very short SOAs. For SOAs longer than 300 ms, slowest responses were made to targets in the same location as the initial stimulus, which is characteristic of inhibition of return or IOR (Christ, McCrae, & Abrams, 2002; Jordan & Tipper, 1998). As could be seen in the results, with onset cues, there was a strong inhibitory effect and responses were slower to the second stimulus in the same location as the cue regardless of whether it was an onset or an offset. With offset cues followed by onsets, inhibition appeared to be constant across the SOAs. Inhibition was present with offset cues followed by offset targets, however the effect disappeared within 300 ms. In addition, offset targets in the same location as an offset cue produced the slowest responses at the shortest SOAs, and performance improved as SOAs increased. The entire study lends support to the suggestion that onsets are stronger perceptual events than offsets, even though onsets and offsets produced similar perceptual results, onsets tend to be more salient perceptual events. Onset cue events produced more noticeable effects on the response made to the second event. On the other hand, if onsets are indeed more powerful stimuli, then it may be that more attentional resources are allocated to their location, and this may be followed by an especially strong inhibitory effect at that location.

Models of Attentional Capture

Several models of attentional capture include the 'strong capture' and 'weak capture' models (Martin-Emerson & Kramer, 1997). The 'strong capture' model suggests that if an onset item is present, it is identified first; otherwise, search occurs in a serial, self-terminating fashion through the objects in a display. In contrast, the 'weak capture' model suggests that attentional capture by new objects may fail on some proportion of trials, and on trials where capture does not occur, the display is searched in a serial fashion for the target.

The attentional priority model, proposed by Yantis and colleagues, states that attention is directed to objects based on their magnitude of priority which is established, on a moment to moment basis, by both-goal directed and stimulus-driven factors (Yantis & Hillstrom, 1994). Yantis and Hillstrom also suggested that stimulus-driven selection is controlled by an interrupt signal that occurs when a new object appears in the field. This signal enhances the priority of the new object thereby increasing the probability that it will be processed early during visual search. They refer to object-based theories of visual attention, which suggest that attention is drawn to objects in a display not by a spatial location but because of their "status as objects in a representation that has already been parsed by preattentive perceptual organization mechanisms; attention is directed to new objects in a visual scene" (Yantis & Hillstrom, 1994; p. 96).

Results from the experiments described above indicate that the appearance of an object in a previously empty location will create a new object file (Kahneman & Treisman, 1984). "If attention is drawn because a new object is perceived, a singleton that is not an abrupt onset should not control attention exogenously because it does not appear as a new object" (Chastain & Cheal, 1999, p. 412). Studies have shown exactly this, which has led to the suggestion that onset items that appear with offset items, will exogenously control attention because they signal the appearance of a new perceptual object. Miller (1989), on the other hand, put forth a different view. He argued that any abrupt change in the visual field can cause attention to be exogenously controlled. He also found that offsets attract attention to some extent even though onsets attract it more strongly. Therefore, an offset single character may have some exogenous control over attention. As was stated by Yantis and Jonides (1984), attentional capture is considered one of the critical indicators of exogenous control. In addition, attentional capture could be affected by attentional set as was suggested by Folk et al. (1992) with their contingent-capture hypothesis.

Auditory Attentional Capture

Past studies in audition have found that a wide variety of auditory stimuli will attract attention. One experiment by Greenberg and Larkin (1968) looked at the ability of subjects to detect sounds of certain frequencies. They used a probe-signal method which consisted of presenting subjects with a sound embedded in one of two intervals of white noise. This sound could be a primary signal, a pure tone which the subjects were introduced to before the experimental trials, or a probe signal, a pure tone of a different frequency. Results indicated that subjects were able to detect the primary signal 75% to 90% of the time. However, performance dropped as the distance in frequency of the probe signal from the primary signal was increased, with 50% or chance detection occurring at a frequency distance of around 150 to 200 Hz. Greenberg and Larkin concluded that there is a critical band of frequencies around the primary signal that the subject is able to detect, and when a probe frequency is presented outside of this critical band it can no longer be detected.

Spence and Driver (1994) conducted a study which also utilized pitch discrimination tasks, and in addition, gives a good account of exogenous versus endogenous control of auditory attention. They conducted several experiments in which subjects were presented with a cue followed by a target, about which they needed to make a judgment. There were three speakers on the left and right side of the subjects with the two middle speakers lined up with the interaural axis, which is the location directly opposite each ear. An LED was illuminated at the beginning of each trial on which subjects were to focus until a response was made. A 2000 Hz cue was presented from one of two middle speakers after a random delay of 750 ms to 1000 ms, and was 100 ms in duration. After a variable SOA, a white-noise target was presented for 100 ms from one of the other four speakers. Subjects were to make a response by pressing a key furthest from them if the sound came from one of the two front speakers, or by pressing the key nearest to them if the sound came from one of the speakers behind them. In their first experiment, subjects were told to ignore the cue, as it contained no useful information. There was an equal chance that the target would be presented on the same side as the cue (valid trials) or the other side (invalid trials). Therefore, the cue did not provide any predictive information about the location of the target. Spence and Driver reasoned that any effect that the cue may produce should be exogenous or under stimulus control. This would be indicated by faster and more accurate responses on valid trials than on invalid trials.

Results showed that subjects were quicker to determine whether a sound was in front of, or behind them when it was preceded by a cue that was on the same side. This indicates a significant cuing effect even though the cue contained no predictive information. It was also found that the effects of the cue were apparent at short SOAs but disappeared at longer SOAs. Spence and Driver interpreted the RT advantage found for valid trials as evidence of an exogenous orienting mechanism being turned on by the onset of the uninformative cue. In other words, the abrupt onset of a cue served to speed RT when it correctly indicated the location of the target, and this suggests that auditory attention can be captured by exogenous processes.

Spence and Driver performed a second experiment using a cued location and pitch judgment. The design was similar to that used in the first experiment, except that both target and cue sounds were presented through the middle speakers on either side. The cue sound was a pure tone of 2000 Hz and the target sounds were pure tones of either 345 Hz or 385 Hz. Subjects were asked to make a speeded judgment as to whether the target sounds were high or low pitch. Results indicated that there was no reliable advantage for pitch discrimination on valid versus invalid trials.

Spence and Drivers' first two experiments used uninformative peripheral cues that they assumed engaged only exogenous orienting processes. Their subsequent experiments examined endogenous orienting processes by using informative spatial cues. Experiment 3 was set up the same way as Experiment 1 in that subjects were required to make a front-behind discrimination. However, they were now told that on 75% of trials the cue would be followed by the target on the same side (valid trials). On the remaining 25% of the trials, the cue occurred on the opposite side from the target (invalid trials). Based on results from the first two experiments, the assumption was made that this informative cue should engage both endogenous processes and exogenous processes. Cue sounds were presented from the middle speakers while targets could come from any of the other four speakers. Subjects were given explicit instructions to listen to the first sound (the cue) on each trial and to remember what side it was on because the target would probably be on that side as well. Results indicated that there was an increased RT advantage when the cue predicted the laterality of the target. The effect was now found at larger SOAs (400 ms and 1000 ms) as well as at shorter SOAs (100 ms). Spence and Driver suggested that this enhanced facilitation may be due to a voluntary shift in attention, because of the informative cue.

The fourth experiment reported by Spence and Driver was performed in order to put exogenous and endogenous orienting processes in competition with each other. The setup was the same as in Experiment 3 in that a front-rear discrimination task was required. However, on 75% of trials the cue was on the opposite side from the target. Spence and Driver expected an advantage to be found at longer SOAs for invalid trials due to endogenous orienting. However, they thought that there may also be an advantage for valid trials at short SOAs due to exogenous orienting. Subjects were given instructions to listen to the first sound and concentrate on the side opposite. The results showed that front-rear discrimination was quicker in invalid trials at SOAs of 400 ms and 1000 ms, which indicates operation of an endogenous orienting process. No difference in performance on valid and invalid trials was apparent at briefer SOAs.

Experiment 5 was conducted to examine whether informative cues could affect pitch discrimination. 75% of the trials were valid with the target on the same side as the cue, and 25% were invalid with the target presented on the opposite side from the cue. The sounds could come from one of two speakers which were positioned opposite the left and right ears. The cue pitch was always 2000 Hz, and the target sounds could be either 345 Hz or 375 Hz. Results indicated that endogenous spatial orienting processes affected pitch discrimination. Responses were faster and more accurate after presentation of a valid cue. Interestingly, the results do not correspond with the findings of Experiment 2, which showed no effect of uninformative cues on pitch discrimination,suggesting potential qualitative differences between exogenous and endogenous orienting. It is possible however that these contradictory results may have occurred because the pitch discrimination used in Experiment 5 was slightly harder than that used in Experiment 2. All results reported by Spence and Driver (1994) taken together provide support for the suggestion that covert spatial orienting exists in audition and that there is an attentional shift from exogenous to endogenous as SOAs increase.

Whereas the experiments above looked at the effects of location and pitch characteristics of auditory stimuli on attention, Dalton and Lavie (2004) have used onset stimuli to observe the effects of a non-target with a unique feature on focused attention. Their first experiment consisted of two parts, part A and part B. In part A, subjects were required to listen to a sequence of four sounds and to make a decision as to whether a target was present. Targets were higher in frequency than non-targets for half of the subjects and lower in frequency for the other half. In addition, half of the trials for each group of subjects contained a non-target that was presented at a higher intensity than the others and this served as a distractor singleton. It was reasoned that if this distractor singleton captures attention, then RT to detect the target should be longer on singleton-present trials than singleton-absent trials.

Each trial began with the word 'ready' displayed for 500 ms, after which four sounds were presented in succession for 100 ms each. At the end of the trial, subjects were to respond by pressing the '1' key if they heard the target or the '2' key if they did not. They were told to focus on the target frequency, which could be either 520 Hz presented with 440 Hz non-targets, or 440 Hz with 520 Hz non-targets, depending on which group they were in. Both target and non-target sounds were presented at an intensity of 72 dB, whereas the distractor was presented at an intensity of 83 dB.

Results for Experiment 1, part A, indicated that RTs were longer for singleton present trials than for singleton absent trials, which suggests that attention was indeed captured by the singleton even though it was irrelevant. Target presence, by itself, did not have an effect on RT but there was a significant interaction between singleton presence and target presence. This interaction arose because the presence of a singleton had a stronger effect on target absent trials than on target present trials. Dalton and Lavie (2004) suggested that this may be due to competition for attention between the distractor and target.

Part B of Experiment 1 was done to determine whether interference effects would also be found for singleton distractors of lower intensity than the other sounds. The method and procedure were identical to those in part A, with the exception that the distractor singleton was presented at an intensity of 72 dB while the rest of the sounds were presented at an intensity of 83 dB. Similar results were found as those apparent in part A. Target RTs were longer when the distractor was present than when it was absent, and this effect was similar in magnitude to that apparent in part A. These findings demonstrate that a sound different in intensity from others can capture attention.

Experiment 2 was also split into parts A and B and was performed to examine whether interference effects would be found for singletons with a unique frequency. For half of the subjects, the target sound was a higher intensity (83dB) than the non-targets (72dB) and, for the other half, it was a lower intensity (72dB) than the non-targets (83dB). In part A, one of the non-targets was a higher frequency (520 Hz) than the other sounds (440 Hz) for half the trials, and in part B it was of a lower frequency (440 Hz) than the other sounds (520 Hz) for half the trials. The method and procedure were, in all other respects, the same as in the first Experiment. Results for both parts of the experiment indicated that RTs were longer when the frequency singleton was present than when it was absent, and this suggests that a sound of an unexpected frequency can capture attention. The effects were similar for both low frequency and high frequency singletons. It was again found that singleton effects were greater when the target was absent than when it was present, as was indicated by longer RTs on singleton present, target absent trials and shorter RTs on singleton present, target present trials. In other words, there was a greater RT cost when the singleton was present and the target was absent. This may have been due to divided attention effects or to competition for attention between the target and singleton.

Dalton and Lavie (2004) noted that subjects may have been listening for the appearance of any odd sound, instead of directing their attention to the relevant target feature. Experiments 3 and 4 were designed to address this possibility. A discrimination task was used in which one of two targets was always present, and subjects were required to indicate which target they had heard. Experiment 3 was done to look at whether frequency discrimination would be affected by an intensity singleton. Subjects were told to respond to targets by pressing the '1' key or the '2' key depending on whether the target was high frequency (520 Hz) or low frequency (440 Hz). Non-targets and singletons were presented at a frequency of 480 Hz, with singletons presented at a higher intensity (83 dB) than the targets and non-targets (72 dB) for part A, and at a lower intensity (72 dB) than the targets and non-targets (83 dB) for part B. Results for both parts A and B demonstrated longer RTs for singleton-present than for singleton-absent trials. This result indicates that significant interference was produced by the intensity singleton in a frequency-discrimination task, and it shows that attention can also be captured by this type of sound characteristic.

Experiment 4 was performed to determine whether intensity discrimination would be affected by a frequency singleton. Subjects were required to respond to target sounds, which were presented on every trial, based on whether they were of higher (83 dB) or lower intensity (72 dB) than the non-targets and singletons (78 dB). Singletons were of a higher frequency (520 Hz) than the targets and non-targets (440 Hz) in part A, and of a lower frequency (440 Hz) than the targets and non-targets (520 Hz) in part B. Again, it was found that RTs were longer for singleton-present trials than for singleton-absent trials, which indicated that irrelevant frequency singletons can capture attention.

Experiment 5 was performed to determine whether attentional capture would still be found when a singleton was presented either directly before or after the target, as well as when it was separated from the target by one intervening non-target sound. Dalton and Lavie (2004) suggested that if interference produced by the singleton in the previous experiments was the result of difficulty comparing targets with singletons instead of comparing targets with non-targets, then it should not be found if the singleton is separated from the target by a non-target. On the other hand, if the interference occurred because of attentional capture, then it should still be apparent.

Targets used in Experiment 5 were judged on duration with a long target classified as 150 ms long and a short target classified as 50 ms long. Non-targets and singletons were 100 ms long. All of the sounds were presented at a frequency of 520 Hz except for the singletons, which were presented at a lower frequency of 440 Hz. Subjects were required to listen to a sequence of seven sounds and to make a decision as to whether they heard a short or long target by pressing the 1 or 2 keys respectively. Targets were presented on every trial and were in either the fourth or fifth position in the sequence of sounds. Singletons were presented on half of the trials, and could come before or after the target. In addition, the singleton could come directly before or after the target, or it could be separated by a non-target.

Longer RTs were again found when a singleton was present versus when it was absent. It was also found that attentional capture occurred regardless of any separation between the target and singleton, indicating that interference effects were not caused by difficulty in comparing the target with a preceding sound that was different from the other non-target sounds.

Dalton and Lavie (2004) conducted a final experiment to determine whether interference caused by attentional capture by an irrelevant singleton, could be changed to facilitation when the singleton feature coincides with the target. A discrimination task was used, which required the subjects to listen to a sequence of five sounds and to make a decision as to whether a target was long or short. Target sounds were presented at a higher frequency than the non-targets on a third of the trials and therefore incorporated the irrelevant high frequency singleton. The high frequency singleton was presented in a position directly before or after the target on another third of the trials. The high frequency singleton was not presented at all on the final third of trials. Results indicated that RTs were longer when the singleton coincided with the non-targets, as was seen in the previous experiments. However, when the target was presented at a high frequency, RT was facilitated relative to when one of the non-targets was a high frequency.

Taken together, the results from all of the experiments reported by Dalton and Lavie (2004) provide evidence of attentional capture and behavioral costs and benefits in the auditory domain caused by the presence of an irrelevant feature singleton. Furthermore, this result has been found with singletons of high and low frequency and high and low intensity for both detection and discrimination tasks.

Other experimenters have also found that attention is affected not only by location and frequency cues but also by abrupt duration, intensity and timbre cues (Mondor & Breau, 1999; Mondor & Lacey, 2001). For example, Mondor and Breau (1999) conducted a target identification experiment in which subjects were required to make a decision as to whether the rise time of a target was fast or slow. Rise time refers to the speed it takes for maximum amplitude to be reached. A cue and target were presented on every trial, with the target appearing after a variable SOA of 150, 450, or 750 ms. There were ten different types of cues which were presented at either 500 Hz or 713 Hz and could have onset and offset times of 5 and 45 ms, 15 and 35 ms, 25 and 25 ms, 35 and 15 ms, and 45 and 5 ms. There were four targets, two of which were presented at 500 Hz and two at 713 Hz, in a background of white noise. The pure tone of each target had onset and offset times of either 95 and 5 ms, or 5 and 95 ms. On trials in which the frequency or location of the cue and target were manipulated, the cue and target matched on 50% of the trials and differed on the other 50% of the trials. In the location condition, sounds could come from either the left or right speakers, with a distractor (white noise) being presented simultaneously with the target but in the opposite speaker. In the frequency condition, the cue and target were presented in the same location but their frequencies could be different. Subjects were to press the 1 key if the target had a fast onset time (sharp sound), or the 2 key if it had a slow onset time (dull sound). The results showed that at short time intervals, performance was facilitated when abrupt cues and targets were the same than when they were different. These results have also been found with abrupt cues of sound duration, intensity and timbre (Mondor & Lacey, 2001).

The experiments mentioned above looked at the exogenous effects of abrupt cues on attention whereas the following experiments examined voluntary attentional orienting to cues. A series of experiments performed by Mondor and Bregman (1994) examined the influence of attentional orienting on frequency sensitivity. They sought to determine whether the perception of sounds in a specific frequency range would be facilitated if subjects were able to orient their attention to that cued frequency range. In their first experiment subjects were required to make a decision as to whether a target sound was short or long in duration. Each trial included a 1000 Hz cue sound which was presented for 65 ms. A target sound was presented 500 ms later and it was the same frequency as the cue on 75% of the trials (valid trials) and a different frequency on the remaining 25% (invalid trials). On invalid trials, targets could be a frequency of either 600, 925, 1075, or

1500 Hz, and they were classified as near (925 Hz & 1075 Hz) or far (600 Hz & 1500 Hz) from the frequency of the cue. Subjects responded to the target by pressing the 1 key if it was short or the 0 key if it was long. Results indicated that subjects performed better on valid trials than on invalid trials. However, the authors noted that it was possible that the targets on valid trials were presented much more often than targets on invalid trials so that subjects may have performed better with these sounds because they were more familiar with them.

Mondor and Bregman (1994) conducted their second experiment to eliminate the potential confound in Experiment 1. The design was similar to that of Experiment 1, with the exception that on valid trials the target could be either 667, 1000, or 1500 Hz. Targets on invalid trials could also be one of these three frequencies. The rationale behind this design was that subjects would now be familiar with each target to the same degree, and therefore, if performance was again found to depend on the similarity between the cue and target, then this would support the proposal that attention can be allocated to a specific frequency range. A second objective of Experiment 2 was to determine if the time interval between the cue and target affected frequency sensitivity. This was done using SOAs of 500, 1000, and 1500 ms which were varied from trial to trial. Each trial began with a frequency cue followed by the target, which was the same frequency on 75% of the trials and a different frequency on remaining 25% of trials. Again, on invalid trials, targets could be near or far in frequency from the cue. Subjects were again required to make a decision as to whether the target was long or short. The obtained results were similar to those found in Experiment 1 in that performance was much better on valid trials than on invalid trials. This indicates that the cue serves to direct attention to a specific frequency range. It was also found that performance improved as the SOA increased suggesting that a certain amount of time is required to completely allocate attention to a cued frequency region.

Mondor and Bregman described two models, an attentional gradient model and an attentional spotlight model, which might explain their results. Gradient models suggest that processing efficiency varies over a perceptual field, with a center to periphery gradient of declining sensitivity. In other words, the density of attentional resources is reduced as distance increases from the center of the attended area (Anderson & Kramer, 1993; Henderson & Marquistan, 1993; Mondor & Zatorre, 1995; Tsal, 1983). The spotlight model, on the other hand, suggests that only stimuli that are located in the spotlight beam of attention are attended (Anderson & Kramer, 1993). Experiment 3 examined these possibilities by using three different frequency separations.

Experiment 3 differed from Experiment 2 in that three different frequency separations were used on invalid trials. In addition, the duration of the frequency cue was lengthened so it was much longer than the two targets and its duration was varied across trials. This was done to make sure that subjects could not use it as a measure of comparison for the target. Target sounds and cues were presented at frequencies of 667, 876, 1145, or 1500 Hz, and cues varied in duration at 150, 175, or 200 ms. Four SOAs of 500, 750, 1000, and 1500 ms were used to assess the time required to orient attention. Results again indicated that RTs for duration judgments were made more quickly when the targets were preceded by valid cues than by invalid cues. In addition, superior performance was found for invalid trials when the target frequency was near that of the cue, compared to when it was far from the cue. All three experiments provide good evidence that subjects can allocate their attention to a specific frequency range, and that this can facilitate responses to target sounds. In addition, findings from Experiments 2 and 3 supported the gradient model of attention, with attentional resources declining as the frequency separation from the center point of attention increased.

Thus, previous experiments have shown that attentional capture does indeed occur for auditory stimuli. Moreover, it is clear that auditory attention may be oriented both endogenously and exogenously based on several different auditory features. The present study was designed to expand on this knowledge base by comparing the effects on attentional capture of the abrupt appearance of a sound and of the abrupt disappearance of a sound.

EXPERIMENT 1

Although a great deal of research has focused on attentional capture in vision, much less is known about attentional capture in the auditory domain. Research that has been done in audition has focused only on the effect of abrupt onset cues. Based on previous research, it has already been established that attentional capture can occur to a wide variety of stimuli in both audition and vision. Certain characteristics of a sound such as frequency, duration, and intensity are able to capture attention (e.g., Greenberg & Larkin, 1968; Mondor & Lacey, 2001; Patton, unpublished undergraduate research, 2003). In addition, attention can be captured exogenously by non-informative cues and directed endogenously by informative cues (Atchley et al., 2000; Spence & Driver, 1994; Yantis & Jonides, 1990). Past results in vision have shown that onsets tend to capture attention better than offsets (Chastain & Cheal, 1999; Jonides & Yantis, 1988; Yantis & Jonides, 1984).

The main purpose of the first experiment was to determine whether the abrupt disappearance of a sound also captures attention. The basic method required listeners to press a key on a computer keyboard in response to a target sound which appeared in one of two channels, either following a silent period or following the disappearance of another sound. It was hypothesized, based on previous research in vision and audition that there would be faster responses to targets that appeared abruptly following silence than to those that followed the disappearance of a sound.

Method

Participants

Sixty-five undergraduate psychology students enrolled at the University of Manitoba participated voluntarily in exchange for course credit. One restriction was that participants had to have adequate hearing, with no physical problems that would prevent them from performing the task, and each signed a consent form.

Materials

Computer and Sound System: A Dell Dimension L733r Pentium computer was used to run E-prime (Psychology Software Tools, Inc., 1999), and the sounds were presented through Sony Dynamic Stereo Headphones, model number MDR-V600.

Sounds: The sounds that were used had fundamental frequencies of 300 Hz, 519 Hz, and 898 Hz. These sounds had either a constant amplitude ('steady') or were amplitude modulated (AM). Amplitude modulation consisted of a 100 ms sine-wave cycle that ranged from a maximum intensity of 75% of non-AM sounds to a minimum of 50% of non-AM sounds. Each of the sound files was 200 ms in length. 5 ms onset and offset amplitude ramps were used to eliminate onset and offset clicks. The sounds were synthesized using Cool Edit (Syntrillium Software Corporation, 1999) and all stimuli were presented at a comfortable listening level of approximately 70 dB.

Procedure

On each trial, participants were presented with two streams of sound, one to their right ear and one to their left ear. Listeners were instructed to listen to both channels for the occurrence of a rapid modulation in the amplitude of a sound. This was used to allow an orthogonal response. In other words the amplitude modulation feature had no relation to any other characteristic of the stimuli and was used only as a basis for the subject's response. They were instructed to press the 'H' key on a computer keyboard as quickly as possible when they heard this amplitude modulation. The experiment was designed to examine the effects of sound onset and sound offset on attentional capture.

Six unique trial types were used in this experiment (see Appendix A for a visual representation). There were two different types of valid, invalid and catch trials. The first of the valid trials had an amplitude modulation that was 900 ms in duration and which occurred in one channel following an initial 1000 ms steady tone and a 100 ms silent period. The other channel contained a steady sound of a different frequency, presented for 2 seconds. For this particular trial, then, the target feature (amplitude modulation) occurred 100 ms following an abrupt disappearance of the initial sound. On the second type of valid trial, amplitude modulation occurred in one channel for 900 ms following 1000 ms of silence and 100 ms of a steady tone of the same frequency. A steady sound of a different frequency was presented in the other channel for 2 seconds. For this trial, then, the target sound appeared after 1.1 seconds. The first of the invalid trials had a steady sound presented in one channel that changed into an amplitude modulated sound after 1.1 seconds. A steady sound was presented in the other channel for 1 second, followed by 100 ms of silence, and then presentation of the same sound again for 900 ms. On the second type of invalid trial, a steady sound presented in one channel changed into an amplitude modulated sound after 1.1 seconds. There was silence in the other channel for 1 second, after which a steady sound was presented for the remainder of the trial. The first of the catch trials did not have an amplitude modulated sound. However, the trial was constructed exactly as the first experimental trial, except without the target feature. Finally, the second catch trial had the exact same construction as the second experimental trial, but did not contain the target feature. For each of these trials, there were six combinations based on the three frequencies and they were counterbalanced between the left and right ears.

The experiment consisted began with a welcome screen and then a demonstration of the steady and amplitude modulated (AM) sounds. This was followed by a brief test to see if the participant could detect amplitude modulated sounds. During this test a single sound was presented in isolation and participants were required to press the 1 key if they heard an AM sound or the 0 key if they heard a steady sound. After performing adequately on this test they were permitted to continue with the rest of the experiment. Most participants completed this test with near perfect performance. However, those who performed poorly were run through the test trials again until they could discriminate AM from steady sounds. On each trial, the participants had to perform a detection task in which they were presented with one of the conditions described earlier. They were required to push the 'H' key on the keyboard as fast as they could after hearing the presentation of an AM sound. They then had to press the space bar to begin the next trial. On trials without AM sounds the participants were to refrain from responding and to press the space bar after the trial ended. On practice trials participants were given feedback as to whether the correct response was made. On experimental trials, no feedback was given and participants proceeded with the next trial at their own pace by pressing the space bar. There were 16 practice trials, and 192 experimental trials comprised of 24 valid appearance trials, 24 valid disappearance trials, 24 invalid appearance trials, 24 invalid disappearance trials, and 96 catch trials, and 16 practice trials.

Data analysis

The effect of sound disappearance and appearance on target detection was examined. Trials on which the participants anticipated the target were excluded as were outliers. Trials on which no target was presented (catch trials) were examined separately and the number of responses on these trials was recorded. Analysis of the rest of the data was based on the number of correct responses on trials left after the outliers, catch, and anticipated trials were taken out.

Results

Separate two-way within-subjects ANOVAs (cue type [appearance, disappearance] x trial type [invalid, valid]) were used to evaluate performance using RTs and errors. An error analysis was performed to make sure that there were no speed-accuracy tradeoffs. Analysis of the catch trials indicated that participants responded, on average, to 4% of appearance and 6% of disappearance catch trials.

Response Times

Analysis of the RT data revealed significant main effects of trial type, $F(1, 64) = 154.67$, $p < .001$, and of cue type, $F(1, 64) = 20.38$, $p < .001$, as well as a significant interaction between these factors, $F(1, 64) = 11.70$, $p < .01$. Overall, RTs to targets were speeded immediately following an appearance/disappearance manipulation, which would indicate an RT benefit for valid trials compared with invalid trials

Table 1

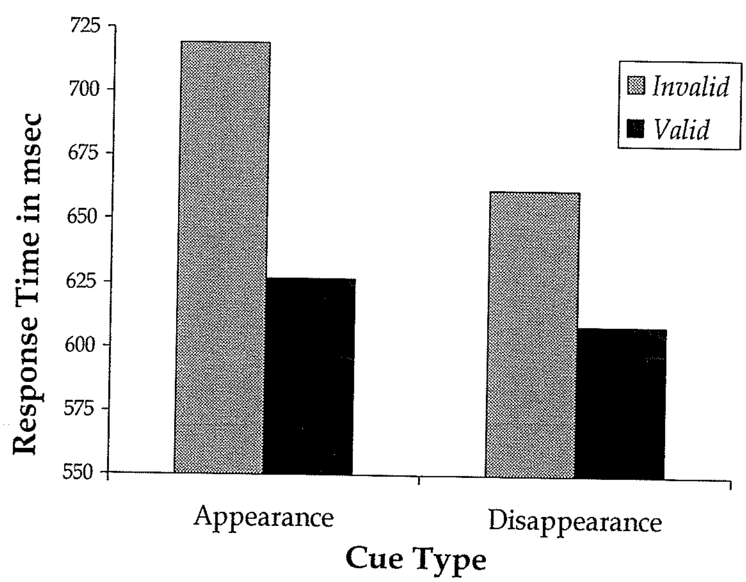
Mean RT and percent errors (%E) as a function of sound appearance and disappearance cues and trial type in Experiment 1

Trial Type	Cue Type	RT	%E
Invalid	Appearance	719	0.87
	Disappearance	662	0.91
Valid	Appearance	627	0.96
	Disappearance	609	0.97

Planned comparisons were performed to examine the significant interaction between trial type and cue type. This analysis showed that both appearance and disappearance cues speeded RT ($p < .001$ in both cases). There was a substantial difference in RT between invalid appearance and valid appearance trials, with a 92 ms facilitative effect for valid trials. There was also a large difference in RT between invalid disappearance and valid disappearance trials, at a 53 ms facilitative effect for valid trials.

Comparisons were also performed to determine whether invalid appearance and disappearance trials differed, and whether valid appearance and disappearance trials differed. Again both of these differences were significant, $F(1, 64) = 23.73$, $p < .001$, and $F(1, 64) = 4.892$, $p < .05$, respectively. RTs on trials containing the disappearance cue were slightly faster than RTs on trials containing the appearance cue, in both invalid and valid conditions. There was a 57 ms difference between invalid appearance and disappearance trials, and an 18 ms difference between valid appearance and disappearance trials.

Figure 1. Visual representation of mean response time on invalid and valid trials as a function of cue type in Experiment 1



Errors

Analysis of the error data also revealed significant main effects of trial type, F (1, 64) = 34.81, $p < .001$, and of cue type, F (1, 64) = 4.55, $p < .05$. The interaction between cue type and trial type approached significance, F (1, 64) = 3.35, $p = .072$. Significant differences were found between invalid appearance and valid appearance trials, F (1, 64) = 28.881, $p < .001$, and between invalid disappearance and valid disappearance trials, F (1, 64) = 22.12, $p < .001$. Errors decreased significantly on valid trials compared to invalid trials. A difference was also found between invalid appearance and disappearance trials, F (1, 64) = 4.593, $p < .05$. More errors were made on invalid appearance trials than on invalid disappearance trials. The difference between valid appearance and disappearance trials was not significant, $F < 1$, indicating that there was not a significant increase or decrease in errors related to cue type on these valid trials.

Discussion

The results demonstrate that both abrupt appearances and abrupt disappearances capture auditory attention. This is shown by the fact that there are RT benefits when targets follow the experimental manipulation in the same channel (valid trials). In other words, after the disappearance of an initial sound and the abrupt appearance of a target sound in that channel, or the abrupt appearance of a target sound following an initial period of silence in that channel. There appears to be a greater effect on RT of the appearance cue than of the disappearance cue between invalid and valid trials. However, with overall performance, it was found that disappearance cues produced more speeded responses on both invalid and valid trials. It was hypothesized that, based on previous research in vision, there would be faster responses to targets that appeared abruptly following silence than to those that followed the disappearance of a sound. The results tend to contradict this hypothesis.

It can also be seen that cue type seems to have a stronger effect on invalid trials than on valid trials as can be seen by the difference in mean RTs between appearance and disappearance conditions. There was a 57 ms difference between cue type for invalid trials and 18 ms difference for valid trials. It is not clear why there appears to be an RT advantage for the disappearance cue on invalid trials. Based on the fact that RTs are slightly faster on valid trials in response to a disappearance cue, it would be expected that the disappearance cue on invalid trials would produce greater costs or interference effects on responses made to the target, and therefore act to increase RT. This was obviously not the case. The answer to this question is beyond the scope of this paper. In Experiment 2, the interaction between appearance and disappearance cues and voluntarily focused attention was examined.

EXPERIMENT 2

Research has shown that focused attention can have an effect on attentional capture. Based on the intentionality criterion of automaticity, abrupt onsets should capture attention even if the subjects' attention is focused elsewhere (Yantis & Jonides, 1990). Yantis and Jonides (1990) found that this is not always the case in vision, as discussed earlier. Results from their study indicated that subjects' state of attentional readiness will affect the extent to which abrupt onsets capture attention. In addition, when attention is focused on an alternate area in a display, attentional capture by the abrupt onset of a visual stimulus does not occur (Folk, Remington, & Johnston, 1992; Yantis & Jonides, 1990; Remington, Johnston, & Yantis, 1992). The main question of Experiment 2 was whether focused attention disrupts the effect of abrupt onsets and offsets

The results from Experiment 1 established that attentional capture occurs involuntarily with auditory stimuli. There are two main criteria that must be met for attentional capture to be considered involuntary. The stimuli should produce immediate effects that both override voluntary control of search, and are insensitive to any concurrent memory or cognitive load (Jones, 2001). The purpose of the second experiment was to observe the effects, if any, of focusing attention on a certain location. Will appearances and disappearances produce any effects when they occur in the unattended ear? It was hypothesized, based on research in vision, that focused attention will disrupt any effect abrupt appearance or disappearance of a sound will have on reaction time.

Method

Participants

Fifty-four undergraduate psychology students enrolled in an Introduction to Psychology course at the University of Manitoba participated voluntarily in exchange for course credit. Participants were required to have adequate hearing, with no physical problems that would prevent them from performing the task, and each signed a consent form.

Materials

Computer and Sound System: A Dell Dimension L733r Pentium computer was used to run E-prime (Psychology Software Tools, Inc., 1999), and the sounds were presented through Sony Dynamic Stereo Headphones, model number MDR-V600.

Sounds: The same sounds were used as in Experiment 1.

Procedure

Again, participants were presented with two streams of sound on each trial, one to their right ear and one to their left ear. One group of listeners was instructed to listen to the left channel for the occurrence of a rapid modulation of the amplitude of a sound, and the other group was instructed to listen to the right channel. Listeners were instructed to press the 'H' key on a computer keyboard as quickly as possible when they heard this amplitude modulation. There were two main conditions in the experiment which involved looking at the effects of focused attention on reaction time to sound onset versus sound offset.

Trial types were identical to those of Experiment 1 (see Appendix A). The experiment consisted of 384 experimental trials and 16 practice trials. There were 48 experimental trials for each of the four conditions with the amplitude modulated target, and 96 trials for each of the two conditions in which there was no target. It started with a welcome screen and then a demonstration of the steady and amplitude modulated (AM) sounds. There was a short, 10 trial test to see if each participant could detect amplitude modulated sounds. During this test participants were presented with a single sound on each trial and required to indicate by pressing the 1 key if the sound was amplitude modulated (AM) or the 0 key if it was not. They were allowed to continue with the rest of the experiment only after performing adequately on this test. Most participants completed this test with near perfect performance. Those who performed poorly were run through the test trials again until they could discriminate AM from steady sounds.

On the practice and experimental trials, participants were required to perform a detection task on each trial, similar to that required in Experiment 1, only this time the AM sound was presented in one channel 75% of the time and in the other channel 25% of the time. Participants were informed of this, with one group performing a set of trials in which the AM sound would be presented in the left channel 75% of the time, and a second group performing a set of trials in which the AM sound would be presented in the right channel 75% of the time. However, due to an experimenter error in conducting the experiment, this weighting varied slightly across participants from a low of 68% to a high of 82% sounds in the indicated channel. These percentages were created by presenting 144 trials with the AM sound to the expected channel and 48 AM trials to the unexpected channel. This can be broken down to 36 trials each for the valid appearance and disappearance conditions, and for the invalid appearance and disappearance conditions. There were 12 remaining AM trials for each of the four conditions in the unspecified channel; namely, 12 valid appearance and 12 disappearance trials, and 12 invalid appearance and 12 disappearance trials. In addition to these, there were also 192 no target catch trials to make the total of 384 experimental trials. Listeners were required to push the 'H' key on the keyboard as fast as they could after hearing the presentation of an AM sound. They then pressed the space bar to begin the next trial. On trials without AM sounds the participants pressed the space bar to begin the next trial.

Data analysis

The effect of cue type (appearance and disappearance) and channel (expected and unexpected) on target detection was examined. Trials on which participants anticipated the target or contained outliers were excluded, as were catch trials. The number of responses on catch trials was recorded. The rest of the data was analyzed based on the number of correct responses left after the outliers, catch, and anticipated trials were taken out.

Results

Two separate three-way within-subjects ANOVAs (channel [expected, unexpected] x trial type [invalid, valid] x cue type [appearance, disappearance]) were used to assess reaction time (RT) and errors. An error analysis was performed to make sure that there were no speed-accuracy tradeoffs. Analysis of the catch trials indicated that participants responded, on average, to 3% of appearance and 2% of disappearance catch trials in the 75% left condition, and to 4% of appearance and 4% of disappearance catch trials in the 75% right condition.

Response Times

Analysis of the RT data revealed significant main effects of trial type, F (1, 53) = 159.94, $p < .001$, and cue type, F (1, 53) = 10.62, $p < .01$. The main effect of channel was not significant, F (1, 53) = 2.885, $p = .095$. In addition, there were significant interactions between trial type and cue type, F (1, 53) = 46.02, $p < .001$, and between channel, trial type, and cue type, F (1, 53) = 7.58, $p < .01$. Interactions between channel and trial type, and channel and cue type were not significant with F (1, 53) = 1.85, $p = .180$, and $F < 1$, respectively. Overall, RTs to targets were affected to different degrees by whether the trial was an invalid or valid trial and by whether the cue abruptly appeared or disappeared. Specifically, RTs to targets were speeded immediately following an appearance/disappearance manipulation (valid trials).

Table 2

Mean RT and percent errors (%E) as a function of sound appearance and disappearance cues and trial type for the 75% condition in Experiment 2

Trial type	Cue Type	RT	%E
Invalid	Appearance	689	0.87
	Disappearance	648	0.92
Valid	Appearance	591	0.97
	Disappearance	591	0.96

Table 3

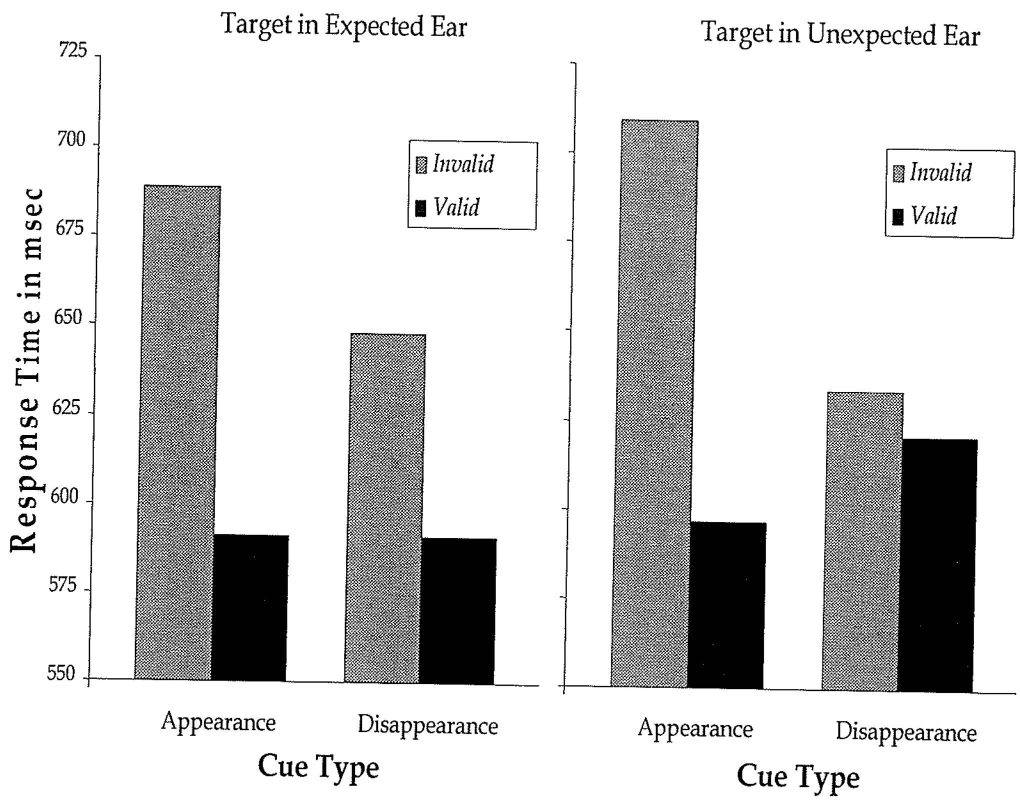
Mean RT and percent errors (%E) as a function of sound appearance and disappearance cues and trial type for the 25% condition in Experiment 2

Trial type	Cue Type	RT	%E
Invalid	Appearance	709	0.87
	Disappearance	634	0.90
Valid	Appearance	597	0.97
	Disappearance	621	0.96

Separate two-way ANOVAs (trial type [invalid, valid] x cue type [appearance, disappearance]) were performed for the expected and unexpected channels to examine the significant three-way interaction. For the expected channel, significant main effects were found for trial type, F (1, 53) = 145.85, p < .001, and cue type, F (1, 53) = 8.46, p < .01, and there was also a significant interaction between the two, F (1, 53) = 12.554, p < .001. Specifically, for the expected channel, RTs were speeded on valid trials compared to invalid trials. There was a 98 ms advantage on valid appearance versus invalid appearance trials, and a 57 ms advantage on valid disappearance versus invalid disappearance trials (p < .001 in both cases). There was a 41 ms advantage for targets following a disappearance cue compared to an appearance cue on invalid trials, F (1, 53) = 15.85, p < .001. However, there was a negligible difference found on valid trials, F < 1.

For the unexpected channel, significant main effects were found for trial type, F (1, 53) = 49.78, p < .001, and cue type, F (1, 53), p < .05, and there was also a significant interaction between the two, F (1, 53) = 32.48, p < .001. There was a 112 ms advantage for valid appearance trials compared to invalid appearance trials, F (1, 53) = 105.85, p < .001, however, the difference was negligible for valid disappearance trials compared to invalid disappearance trials, F < 1. There was a 75 ms advantage for targets following invalid disappearance cues compared to invalid appearance cues, F (1, 53) = 30.33, p < .001, which coincides with Experiment 1. In addition, a 24 ms advantage was found for the valid appearance cue compared to the valid disappearance cue which approached significance, F (1, 53) = 3.79, p = .057, indicating a different result from Experiment 1.

Figure 2. Visual representation of mean response time on invalid and valid trials as a function of cue type and ear in Experiment 2



Errors

Analysis of the error data also indicated significant main effects of trial type, $\underline{F}$ (1, 53) = 28.18, $\underline{p} < .001$, and cue type, $\underline{F}$ (1, 53) = 4.23, $\underline{p} < .05$, indicating that fewer errors were made for targets following an appearance/disappearance manipulation (valid trials) The main effect of channel was not significant, $\underline{F} < 1$, suggesting that differences in errors between expected and unexpected channels was negligible. There was a significant interaction effect between trial type and cue type, $\underline{F}$ (1, 53) = 11.82, $\underline{p} < .01$. Interactions between channel and trial type, channel and cue type, and channel, trial type, and cue type were not significant, with $F < 1$, $F(1, 53) = 1.23$, $p = .272$, and $F < 1$, respectively.

Separate two-way ANOVAs (trial type [invalid, valid] x cue type [appearance, disappearance]) were performed for the expected and unexpected channels to evaluate the trial type x cue type interaction. Analysis of errors in the expected ear condition showed significant main effects for trial type, $F(1, 53) = 21.82$, $p < .001$, and cue type, $F(1, 53) = 6.17$, $p < .05$. There was also a significant trial type x cue type interaction, $F(1, 53) = 16.64$, $p < .001$. Specifically, detection accuracy was .87 for invalid appearance trials compared to .97 for valid appearance trials, $F(1, 53) = 28.66$, $p < .001$, and .92 for invalid disappearance trials compared to .96 for valid disappearance trials, $F(1, 53) = 8.11$, $p < .01$. Detection accuracy was .87 on invalid appearance trials compared to .92 on invalid disappearance trials, $F(1, 53) = 12.05$, $p < .01$. The difference between valid appearance and valid disappearance trials was negligible, $F(1, 53) = 1.38$, $p = .25$.

For the unexpected ear condition, main effects were found for trial type, $F(1, 53) = 20.29$, $p < .001$, but not for cue type, $F(1, 53) = 1.30$, $p = .259$. In addition, a significant interaction was found between trial type and cue type, $F(1, 53) = 4.29$, $p < .05$. Specifically, detection accuracy was .87 for invalid appearance trials compared to .97 for valid appearance trials, $F(1, 53) = 29.8$, $p < .001$, and .90 for invalid disappearance trials compared to .96 for valid disappearance trials, $F(1, 53) = 7.04$, $p < .05$. The difference in errors approached significance for invalid appearance trials compared to invalid disappearance trials, $F(1, 53) = 4.01$, $p = .051$, with detection accuracy at .87 and .90, respectfully. The difference in detection accuracy between valid appearance and disappearance trials was negligible, $F < 1$.

Discussion

As can be seen from the results, focused attention does appear to have some effect on attentional capture by abrupt disappearances. Instructing listeners to focus attention on the 75% channel did not disrupt the effects of abrupt appearances in the 25% channel, however a disruption was found for disappearances. However, it was also found that the overall difference between the two channels was not significant. In this respect, the results seem to satisfy to a certain extent, the first condition for shifting of attention to be considered involuntary; namely, that the stimuli should produce immediate effects that override voluntary intentional control of search (Jones, 2002).

This experiment provides additional support for some of the results found in Experiment 1. Significant RT benefits were again found for the channel in which the target immediately follows the abrupt appearance or disappearance of a sound (valid trials), with costs associated with invalid trials. In contrast with the results of Experiment 1, the abrupt disappearance cue produced faster RTs than the abrupt appearance cue only on invalid trials. Again, a greater effect on RT was found for appearance cues between valid and invalid trials. There was no significant difference in RT for valid appearance versus disappearance trials in the expected channel. In addition, the difference in RT approached significance in the unexpected channel, with slightly better performance for abrupt valid appearance trials compared to valid disappearance trials. Overall, the results provide some evidence for the hypothesis that focused attention will disrupt any effects the abrupt appearance or disappearance of a sound will have on RT. It appears that there may be a certain characteristic of an abrupt event that captures attention regardless of the attentional set of the listener.

GENERAL DISCUSSION

The two experiments described above provide evidence that abrupt appearances and disappearances of sounds capture attention. These results lend support to experiments that have been done in the visual domain. Past research in vision has shown that both appearance and disappearance of a visual object will capture attention (Chastain & Cheal, 1999; Samuel & Weiner, 2001; Yantis, 1988; Yantis & Hillstrom, 1994; Yantis & Jonides, 1984; Yantis & Jonides, 1990). While much research has been conducted in audition, most has dealt primarily with abrupt onset cues, while neglecting offsets. Based on past research in audition, it has been found that a variety of sudden-onset stimuli will capture attention. Experiment 1 was performed to determine if the disappearance of a sound would also capture attention. Based on research that has been done in vision and audition it was hypothesized that there would be faster responses to the abrupt appearance of a sound following silence as opposed to those that followed the disappearance of a sound. The results indicated that this was not the case. It was found that both abrupt appearances and disappearances captured attention, however, RTs were speeded in response to the disappearance cue compared to the appearance cue. It was also found that, although disappearance cues produced the fastest RT, the appearance cues produced the greatest effect on RT between valid and invalid trials. What could account for the discrepancies between visual experiments and the auditory experiments presented in this study? These results will be discussed in further detail along with those of Experiment 2.

Other experiments in vision have looked at state of attentional readiness and whether focused attention will affect the extent to which abrupt onsets capture attention

(Atchley, Kramer, & Hillstrom, 2000; Folk et al., 1992; Yantis & Jonides, 1990). The main goal of the second experiment was to observe any effects of focusing attention on a certain location. It was hypothesized that focused attention would disrupt any effect abrupt appearance or disappearance of a sound might have on RT. Results indicated that this does not appear to be the case. Focused attention does not seem to have an effect on attentional capture by abrupt auditory appearances, however, there is an effect found for disappearances, which satisfies to a certain extent the first condition for shifting of attention to be considered involuntary. In addition, the results of Experiment 2 replicated some of the results in Experiment 1, in that performance was again found to be superior in the channel where the target immediately follows an abrupt sound appearance or disappearance (valid trials). However, in contrast with the first experiment, abrupt disappearances produced faster RT's than abrupt appearances only on invalid trials. On valid trials it was found that difference in RT approached significance in the unexpected channel, with slightly better performance for abrupt appearance trials compared to disappearance trials.

Past research in vision has shown that the abrupt appearance of new objects, differing in texture, motion, or depth will capture attention more quickly than old objects (Yantis & Hillstrom, 1994). It was suggested that, "stimulus-driven visual selection is mediated by an attentional interrupt signal that is generated whenever a new object file is created" (p. 106). Experiments 1 and 2 demonstrated that attention can also be captured by auditory stimuli containing certain characteristics. Specifically, attentional capture was shown to occur for both sound appearance and disappearance.

Samuel and Weiner (2001) compared the effects of appearance and disappearance in vision using true disappearances as opposed to no-onsets. No-onsets are created by removing segments from a block figure eight that was already present, to reveal a letter. They found that there were no facilitative effects at very short SOAs and that, for SOAs greater than 300 ms, slowest responses were made to targets in the same location as the cue. This finding is indicative of Inhibition of Return (briefly described in the introduction). Offset cues followed by onset targets produced inhibition that was constant across all SOAs. Offset cues followed by offset targets produced an inhibitory effect that disappeared within 300 ms. It was suggested that onset cues produce more noticeable effects on the response made to the target. The experimenters concluded that onsets are stronger perceptual events than offsets, and that even though they produce similar results, onsets seem to be more salient.

Both Experiments 1 and 2 in the current study found that appearance cues produced a greater effect on RT between valid and invalid trials. One possible explanation is that the appearances in this study are more salient than the disappearances, or in other words, the appearance cue creates a stronger perceptual event compared to the disappearance cue (i.e. Samuel & Weiner, 2001). However, in terms of overall performance, it was also found in Experiment 1 that disappearance cues generally produced more speeded RTs, which is not consistent with the results of the studies mentioned above (i.e. Yantis & Hillstrom, 1994; Samuel & Weiner, 2001). This effect was much more pronounced in Experiment 1, with significant differences found between appearance and disappearance cues for both invalid and valid trials. Results from Experiment 2 demonstrated a similar effect, however, significant differences between appearance and disappearance cues were found only on invalid trials. An additional finding, which approached significance, was of a slightly greater RT benefit with the appearance cue for valid trials in the unexpected channel, which does not correspond with the findings of Experiment 1.

Spence and Driver (1994) have looked at the effects of abrupt onsets cues in audition. Their experiments were conducted to assess exogenous and endogenous control of auditory attention. The target had an equal chance of being on the same side or different side as the cue. The experimenters suggested that any effect produced by the cue should be under stimulus control or exogenous. Results indicated that responses to the target were made more quickly when it was preceded by a cue on the same side, indicating significant cueing effects despite the cue containing no predictive information. It was concluded that the abrupt onset of a cue acts to facilitate RT when it predicts the correct side the target will be located, which suggests that auditory attention can be captured by exogenous processes. Both Experiments 1 and 2 tend to support the results presented by Spence and Driver (1994). There was a significant cost/benefit pattern for RTs in Experiment 1, with better performance when targets followed appearance and disappearance cues in the same channel (valid trials). Likewise, RTs in Experiment 2 were significantly faster for valid trials compared to invalid trials in the expected channel. The significant cost/benefit difference between invalid and valid appearance cues was also found for the unexpected channel, however, the difference was not significant with the disappearance cue.

Other research has been done to see whether the effects of onsets and offsets can be manipulated due to other experimental conditions. Namely, there have been many experiments done on the effects of focused attention. Yantis and Jonides (1990) hypothesized that abrupt visual onsets capture attention automatically. There are two main criteria that must be satisfied for a process to be automatic. The load-insensitivity criterion states that an automatic process is not hindered when concurrent information load is increased, and the intentionality criterion states that an automatic process is not subject to voluntary control (Yantis & Jonides, 1990). Essentially, results from their experiments showed that abrupt onsets do not capture attention when attention is focused elsewhere. Due to the fact that the intentionality criterion for automaticity was not met, they came to the conclusion that attentional capture in vision may not be completely or strongly automatic. On the other hand, Experiment 2 of the current study found that appearances in audition will capture attention even if attention is focused on another location. Results indicated that there were no significant differences in RT between the channels (expected vs. unexpected). Therefore, it appears that auditory attentional capture satisfies the intentionality criterion for automaticity to a certain extent, whereas visual attentional capture does not. However, future experiments would need to determine whether increasing cognitive load will have an effect. One way to do this would be to add more channels.

As stated earlier, it was hypothesized in Experiment 1 that faster responses would be found to targets that appeared abruptly following silence than to those that followed the disappearance of a sound. However, results indicated that attentional capture occurs for both appearance and disappearance cues. In addition, RTs on trials containing the disappearance cue were slightly faster than RTs on trials containing the appearance cue, in both invalid and valid conditions, which is the opposite of what has been found in visual studies and tends to contradict the hypothesis. Why do both disappearance and appearance cues capture attention? And why would disappearance cues yield slightly better RT performance?

One account of the differing results of Experiments 1 and 2 in the present study with past results in vision may be that the auditory system acts as an advanced or early warning system (Scharf, 1998). It was suggested by Kubovy (1981) that frequency may be used as a cue in audition in the same way as location is used in vision. This would also be evidence that the two attentional systems for audition and vision are separate to a certain extent (Mondor & Amirault, 1998). This would make sense in terms of an early warning system in that the first step would be to determine if a threat is present. If attention is captured by a particular sound characteristic, then the system is put on alert and the next logical step would be to locate where the sound is coming from. After the sound has been localized, a fight or flight response can be initiated. Whereas in vision, location has a much larger effect on attentional capture (i.e. Eriksen & Webb, 1989; Eriksen & Yeh, 1985), thus demonstrating subtle differences in the processing mechanisms of audition and vision.

The auditory system may act as an early warning system due to the fact that it may be more sensitive to changes in the environment than the visual system. Essentially, auditory attention may be drawn to the presence of any new sound, be it the characteristic of frequency (amplitude modulation) or location (channel). In addition, a study by Yantis and Hillstrom (1994) suggested that visual attentional capture may be affected by the generation of 'new object files'. It may be that the auditory system has the capability of creating many more 'new object files' if it does in fact have increased sensitivity, and if so, then there are many more 'files' which are able to capture attention. For example, when walking down a busy street with many different sounds, a sudden scream or yell serves as a new object and will immediately capture and draw attention to the location of the sound in order to asses a possible threat.

A study by Dalton and Lavie (2004) possibly addresses the issue of better performance for disappearance cues, found with the present experiments. Their experiments observed the effects of a non-target with a unique feature on focused attention. They found that found that RT performance is inhibited when this feature is associated with a non-target and facilitated when it coincides with the target. The valid trials in the present study were set up such that, for the disappearance cue condition, a sound was presented for 1 second, disappeared for 100 ms, then reappeared followed by the target, in the same channel and with the same frequency as the initial sound. Valid appearance trials started with silence in the target channel for 1 second, followed by 100 ms of a steady tone, immediately followed by the target for the remaining 900 ms. In line with results found by Dalton and Lavie (2004), perhaps the initial sound in the target channel of the disappearance cue condition serves as a non-target with the same frequency and location features as the target. As these features coincide with those of the target, perhaps they are serving to facilitate RT in the disappearance cue condition. Another possible suggestion for the RT advantage with disappearance cues may be based on another aspect of trial structure. Disappearance trials contain two abrupt events, the abrupt disappearance of a sound and the abrupt reappearance of a sound immediately followed by the target. Perhaps this additional abrupt event is triggering the distribution of additional attentional resources to that location and therefore enabling a speeded response to the appearance of the target. Future experiments could possibly address this issue by using gradual appearances and disappearances, which could be achieved by altering rise time as demonstrated in a study by Mondor and Breau (1999).

Experiment 2 was performed to determine whether appearances and disappearances produce any effects when they occur in the unattended ear. It was hypothesized that focused attention will disrupt any effect abrupt appearance or disappearance of a sound will have on reaction time. Results indicated that this was not the case. Focused attention had no effect on attentional capture by appearance cues, however, an effect was found for disappearance cues. Why would focusing attention on one channel have little effect on attentional capture by these cues?

Automaticity may offer a possible account of these results. As was mentioned in a study by Yantis and Jonides (1990) discussed earlier, there are two main criteria that must be satisfied for a process to be automatic; namely, the load-insensitivity criterion, which states that an automatic process is not hindered when concurrent information load is increased, and the intentionality criterion, which states that an automatic process is not subject to voluntary control. As they demonstrated, attentional capture in vision may not be completely or strongly automatic. Experiment 2 of the current study found that appearances in audition will capture attention even if attention is focused on another location. This shows that auditory attention differs from visual attention in that it may be more strongly automatic. However, additional experiments would need to confirm whether the load-insensitivity criterion is satisfied as well. One possible way of doing this would be to include additional sounds and channels. Instead of using headphones, which provide two channels, a series of speakers could be positioned at varying distances around the participant, and different frequency steady sounds could be presented from each speaker, essentially increasing the information load. In addition, future studies could change the ratio of targets in the expected channel so that a greater number of targets are presented at that location. If attention is still captured in spite of this manipulation, then this would provide further support for the suggestion that auditory attention is a completely automatic process. This being the case, any change in the auditory display, frequency (amplitude modulation), appearance or disappearance of a sound, or location will constitute a new object, and should therefore possess the ability to capture attention.

Another possible explanation is that the auditory system may filter out a specific frequency region (Scharf, Quigley, Aoki, Peachey, & Reeves, 1987). Scharf et al. (1987) proposed that participants are able to use a filter based on certain criteria formulated when the participant focuses on a particular frequency range. This filter serves to facilitate responses to a stimulus specified by the criteria. In the present study, amplitude modulation, introduced prior to starting trials, is the stimulus characteristic participants are required to focus on for both experiments. It may be that participants are creating a filter for this particular characteristic and are focusing in on that particular quality while disregarding other characteristics of the auditory display, such as location, even after being told that the majority of targets would be presented at that location. Likewise, a similar suggestion is that of an attentional template (Mondor & Amirault, 1998; Mondor, Zatorre, and Terrio, 1998). After presentation of the target at the beginning of the experiment, participants may construct an attentional template composed of specific information regarding the target. The template is then used alongside sounds presented on each experimental trial as a basis of comparison. When the sounds match the template, a speeded response can be made. Future studies could possibly use random targets that the participant is not exposed to beforehand. Targets would have to be different on successive trials so as to prevent the formation of a template during the experiment.

As was described in the introduction, there are two well-known models of visual attention, namely the spotlight or zoom-lens and gradient models. The spotlight model suggests that only stimuli that are located in the spotlight beam of attention are attended. This beam can be distributed over a large area with less resolution, or focused in on a narrower area with more resolution (Anderson & Kramer, 1993). The gradient model suggests that processing efficiency varies over a perceptual field, with the density of attentional resources becoming more reduced as distance from the center of the attended area increases (Anderson & Kramer, 1993; Henderson & Marquistan, 1993; Mondor & Zatorre, 1995; Tsal, 1983). Both of these models are based on the idea that attentional resources are finite.

Several frequency sensitivity studies have reported findings that indicate that auditory attention appears to be based on a gradient model (Mondor & Bregman, 1994; Mondor & Zatorre, 1995). In terms of frequency, the gradient model suggests that most attentional resources are centered at the cued frequency location and they decline gradually as frequency separation from the cue increases. The spotlight model, based on studies in vision (Andersen & Kramer, 1993; Eriksen & Yeh, 1985; Tsal, 1983), suggests that attention may be allocated to a specific range of frequencies which are centered at the frequency of the cue (Mondor & Bregman, 1994). Perhaps, with the auditory display in the present study, the spotlight is focused on the entire event and, in response to an appearance or disappearance cue, the 'spotlight beam' focuses in on that location and a response can be made very quickly because all attentional resources have been drawn to that stimulus. However, this does not explain why a response can still be made to the target when it appears in the invalid trials. If the spotlight is focused in on the appearance/disappearance cue location it would be expected that a target in the other channel would be missed completely. On the other hand, perhaps attention is distributed across the channels in a gradient fashion. For example, in Experiment 2 participants were required to focus on a specific channel, therefore attentional resources may have been centered on this location with decreasing resources in the peripheral areas. However, it was found that RT to targets located at the center of the attentional resources was not significantly different from RT to targets located in the periphery (i.e. other channel). One possible explanation for this is that perhaps there are enough attentional resources to adequately cover two channels. Future studies could test this by adding more channels, so that the target could come from one of a number of speakers instead of headphones, which provide only two possible channels. The gradient model seems to provide a better account of the results with the present experiment, however additional experiments are required to rule out the possibility of other models (i.e. Spotlight).

The results may be useful for future research on warning alarms, video games, or a wide range of other practical applications. One such application could be warning alarms in the hospital setting. Based on knowledge of how auditory attention can be captured, alarms could be tailored so that they produce different responses and RTs when they are sounded. Although there are several issues to be addressed by future research, the results demonstrate both differences and similarities between the visual and auditory modalities with respect to attentional processes. Overall, the present study has provided strong evidence for auditory attentional capture by both the appearance and disappearance of sounds.

REFERENCES

Anderson, G. J., & Kramer, A. F. (1993). Limits of focused attention in three-dimensional space. *Perception & Psychophysics*, 53 (6), 658-667.

Atchley, P., Kramer, A. F., & Hillstrom, A. P. (2000). Contingent capture for onsets and offsets: Attentional set for perceptual transients. *Journal of Experimental Psychology: Human Perception and Performance*, 26 (2), 594-606.

Chastain, G., & Cheal, M. (1999). Time course of attention effects with abrupt-onset and offset single- and multiple- element precues. *American Journal of Psychology*, 112 (3), 411.

Christ, S. E., McCrae, C. S., & Abrams, R. A. (2002). Inhibition of return in static and dynamic displays. *Psychonomic Bulletin & Review*. 9 (1), 80-85.

Colcombe, A. M., Kramer, A. F., Irwin, D. E., Petersen, M. S., Colcombe, S., & Hahn, S. (2003). Age-related effects of attentional capture and oculomotor capture by onsets and color singletons as a function of experience. *Acta Psychologica*, 113, 205-225.

Colegate, R., Hoffman, J. E., & Eriksen, C. W. (1973). Selective encoding from multielement visual displays. *Perception & Psychophysics*, 14, 217-224.

Dalton, P., Lavie, N. (2004). Auditory Attentional Capture: Effects of singleton distractor sounds. *Journal of Experimental Psychology: Human Perception and Performance*, 30 (1), 180-193.

Eriksen, C. W., & St. James, J. D. (1986). Visual attention within and around the field of focal attention: A zoom lens model. *Perception & Psychophysics*, 40 (4), 225-240.

Eriksen, C. W., & Webb, J. M. (1989). Shifting of attentional focus within and about a visual display. *Perception & Psychophysics,* 45 (2), 175-183.

Eriksen, C. W., & Yeh, Y. (1985). Allocation of attention in the visual field. *Journal of Experimental Psychology: Human Perception and Performance,* 11, 583-589.

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary Covert Orienting Is Contingent on Attentional Control Settings. *Journal of Experimental Psychology: Human Perception and Performance*, 18 (4), 1030-1044.

Greenberg, G. Z., & Larkin, W. D. (1968). Frequency-response characteristic of auditory observers detecting signals of a single frequency in noise: The probe-signal method. *The Journal of the Acoustical Society of America*, 44 (6), 1513-1523.

Henderson, J. M., & Macquistan, A. D. (1993). The spatial distribution of attention following an exogenous cue. *Perception & Psychophysics*, 53 (2), 221-230.

Jones, M. R. (2001). Temporal expectancies, capture, and timing in auditory sequences. In C. L. Folk and B. S. Gibson (Eds.), *Attraction, Distraction and Action: Multiple Perspectives on Attentional Capture. Advances in Psychology, 133.* (pp. 191-229). New York, NY: Elsevier Science.

Jonides, J., & Yantis, S. (1988). Uniqueness of abrupt visual onset in capturing attention. *Perception & Psychophysics*, 43, 346-354.

Jordan, H., Tipper, S. P. (1998). Object-based inhibition of return in static displays. *Psychonomic Bulletin & Review.* 5 (3), 504-509.

Martin-Emerson, R., & Kramer, A. F. (1997). Offset transients modulate attentional capture by sudden onsets. *Perception & Psychophysics*, 59 (5), 739-751.

Miller, J. (1989). The control of attention by abrupt visual onsets and nononsets. *Perception & Psychophysics*, 45, 567-571.

Mondor, T. A., & Amirault, K. J. (1998). Effect of Same- and different-modality spatial cues on auditory and visual target identification. *Journal of Experimental Psychology: Human Perception and Performance.* 24 (3), 745-755.

Mondor, T. A., & Breau, L. M. (1999). Facilitative and inhibitory effects of location and frequency cues: Evidence of a modulation in perceptual sensitivity. *Perception & Psychophysics*, 61 (3), 438-444.

Mondor, T. A., & Bregman, A. S. (1994). Allocating attention to frequency regions. *Perception & Psychophysics*, 56 (3), 268-276.

Mondor, T. A., & Lacey, T. E. (2001). Facilitative and inhibitory effects of cuing sound duration, intensity, and timbre. *Perception & Psychophysics*, 63 (4), 726-736.

Mondor, T. A., & Zatorre, R. J. (1995). Shifting and focusing auditory spatial attention. *Perception & Psychophysics*, 21 (2), 387-409.

Mondor, T. A., Zatorre, R. J., & Terrio, N. A. (1998). Constraints on the selection of auditory attention. *Journal of Experimental Psychology: Human Perception and Performance,* 24 (1), 66-79.

Psychology Software Tools, Inc. (1999). *E-Prime Software System*. Pittsburgh, PA.

Remington, R. W., Johnston, J. C., & Yantis, S. (1992). Involuntary attentional capture by abrupt onsets. *Perception & Psychophysics*, 51 (3), 279-290.

Samuel, A. G., & Weiner, S. K. (2001). Attentional consequences of object appearance and disappearance. *Journal of Experimental Psychology: Human Perception and Performance*, 27 (6), 1433-1451.

Scharf, B., Quigley, S., Aoki, C., Peachey, N., & Reeves, A. (1987). Focused auditory attention and frequency selectivity. *Perception & Psychophysics*, 42 (3), 215-223.

Spence, C. J., & Driver, J. (1994). Covert spatial orienting in audition: Exogenous and endogenous mechanisms. *Journal of Experimental Psychology: Human Perception and Performance*, 20 (3), 555-574.

Syntrillium Software Corporation. (1996). *Cool Edit Software System*. Scottsdale, AZ.

Tsal, Y. (1983). Movements of attention across the visual field. *Journal of Experimental Psychology: Human Perception and Performance*, 9 (4), 523-530.

Yantis, S. (1993). Stimulus-Driven Attentional Capture and Attentional Control Settings. *Journal of Experimental Psychology: Human Perception and Performance*, 19 (3), 676-681.

Yantis, S., & Hillstrom, A. P. (1994). Stimulus-Driven Attentional Capture: Evidence From Equiluminant Visual Objects. *Journal of Experimental Psychology: Human Perception and Performance*, 20 (1), 95-107.

Yantis, S., Jonides, J. (1984). Abrupt visual onsets and selective attention: Evidence from visual search. *Journal of Experimental Psychology: Human Perception and Performance*, 10 (5), 601-621.

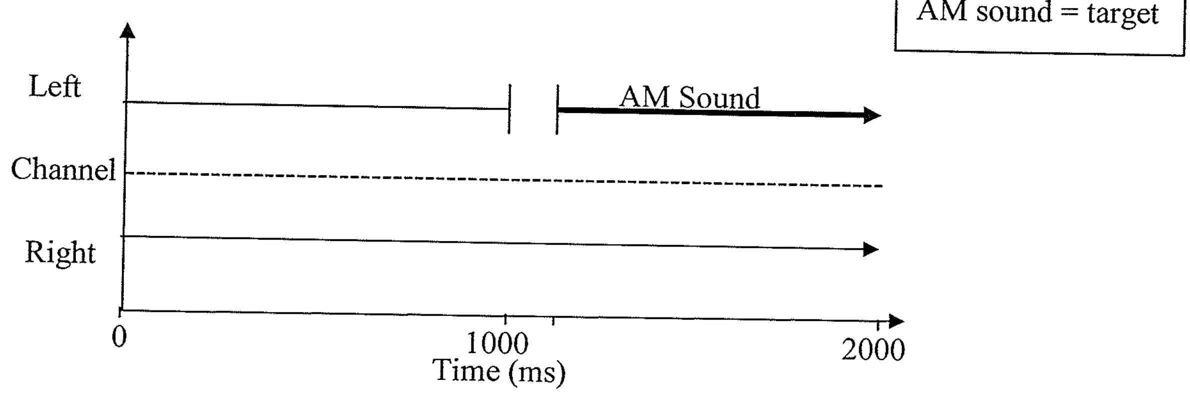
Yantis, S., & Jonides, J. (1990). Abrupt visual onsets and selective attention: Voluntary versus automatic allocation. *Journal of Experimental Psychology: Human Perception and Performance*, 16 (1), 121-134.

Appendix A:

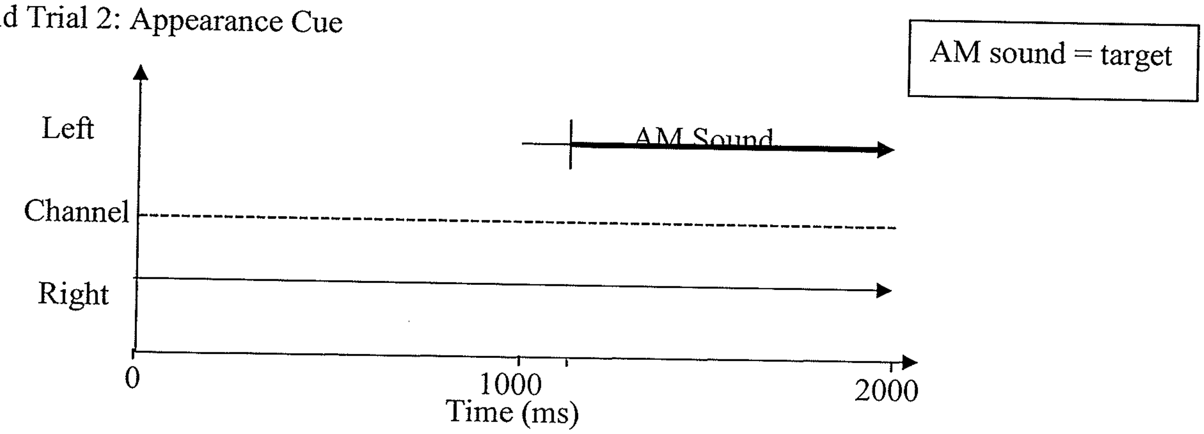
Visual representation of the six different types of trials used in the study.

APPENDIX A:

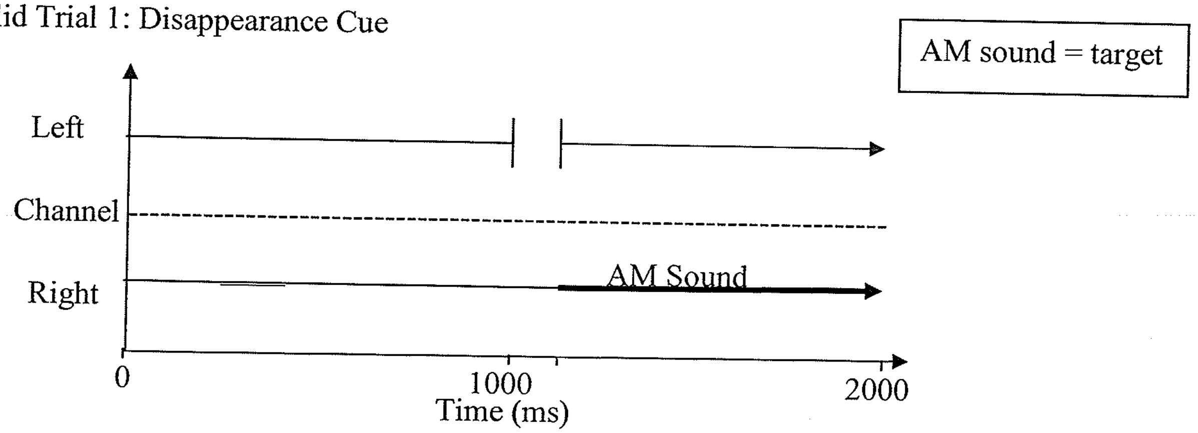
Valid Trial 1: Disappearance Cue



Valid Trial 2: Appearance Cue



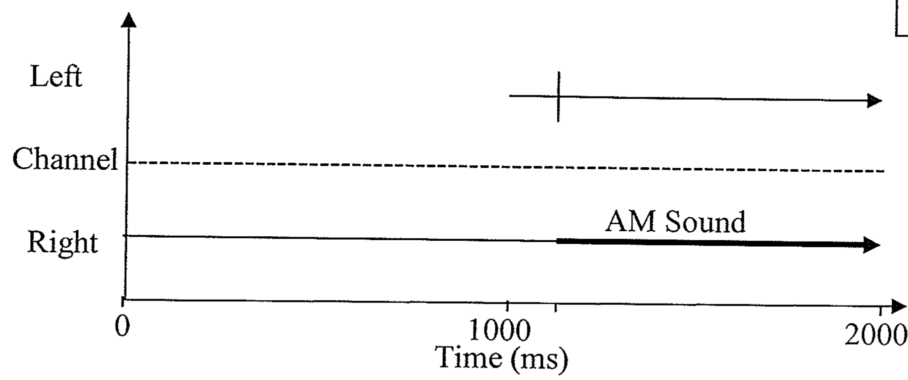
Invalid Trial 1: Disappearance Cue



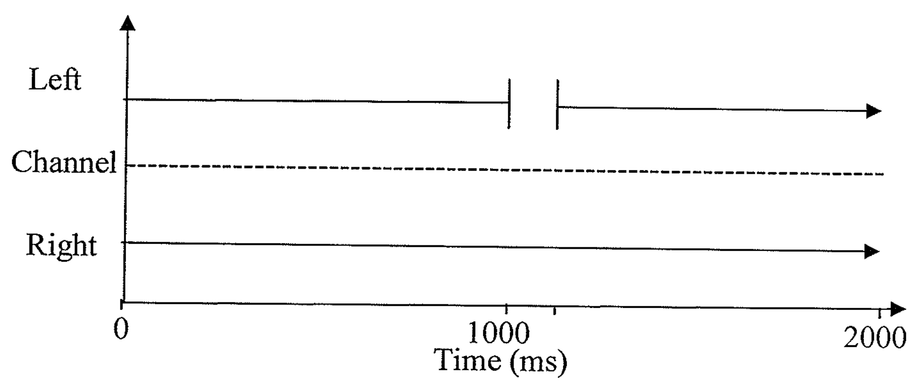
APPENDIX A (CONTINUED):

Invalid Trial 2: Appearance Cue

AM sound = target



Catch Trial 1: Disappearance Cue



Catch Trial 2: Appearance Cue