Attentional Capture by Sound Disappearance

By

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Abstract

In the current study, I investigated whether the abrupt disappearance of an auditory stimulus can capture attention. Previous research has shown that abrupt onsets can capture attention and evidence has also accumulated, indicating that the disappearance of a visual object can also capture attention. The possibility that the disappearance of a sound similarly captures attention has not yet been examined. The present study was designed to address this unresolved issue. In Experiment 1, participants were presented with a context sound from either the right or left channel that abruptly terminated 100 or 200 ms before the presentation of the target (also presented from either the right or left channel). Under these conditions, participants responded more quickly when the target was presented in the same channel as the context sound for the 100 ms condition but not the 200 ms condition. In Experiment 2, two context sounds were presented dichotically. The first could terminate either 100 or 200 ms prior to the target, while the second always terminated 25 ms prior to the target presentation. Similar to the results of Experiment 1, participants responded more quickly when the target was presented in the same channel as the context sound that terminated first in the 100 ms condition, but not the 200 ms condition. Experiment 3 was identical to Experiment 2, with the addition of conditions where the target was presented further from both context sounds to investigate whether the attention capture would persist with a longer interstimulus interval. Experiment 3 successfully replicated the results of Experiments 1 and 2. Furthermore, this effect persisted with later target placement; participants responded more quickly when the target was presented in the same channel as the context sound that terminated first even when the target is presented much later.

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Given our dynamic, perceptually rich environment, it seems intuitively reasonable that an abrupt change, such as the sudden appearance or disappearance of an object, might cause a reflexive allocation of attention towards that change. Such a shift in attention would permit an appropriate and timely response. Not surprisingly, current research suggests that our perceptual and attentional processes responsible for keeping track of the continuous flow of information about objects and events have adapted in a way that allows a constant updating of our perceptual representations to reflect any relevant change in our environment (Pratt & Hirshhorn, 2003; Samuel & Weiner, 2001).

There is a growing body of evidence suggesting that salient stimuli can attain attentional priority irrespective of our goals and beliefs (Egeth & Yantis, 1997; Eriksen & Hoffman, 1972; Franconeri & Simons, 2003; Theeuwes, 1991; Yantis & Hillstrom, 1994; Yantis & Johnson, 1990; Yantis & Jonides, 1984, 1990). Such stimuli (or cues), placed near a target stimulus (Mondor & Bryden, 1992; Posner, 1980, 1984), or which contain similar properties to the target (Mondor & Breau, 1999; Mondor & Lacey, 2001), have been shown to produce facilitative effects in target discrimination paradigms. Researchers generally agree that these cues automatically draw attention to a particular location or property even if they provide no predictive information regarding the target and do not share any features with the upcoming target. This involuntary allocation of attention is commonly referred to as *attention capture* (Mulckhuyse & Theeuwes, 2010; Wright & Ward, 2008b).

In contrast, when attention is purposefully allocated to locations relevant to performing some task, attention is said to be directed voluntarily (Bacon & Egeth, 1994;

Folk, Remington, & Johnston, 1992; Klein, 2009). Symbolic cues, for example, can provide target location information, and when these cues accurately predict the location of a target, the observer may purposefully direct attention in order to facilitate task completion. This dichotomy in the attention literature is often referred to as “voluntary versus involuntary” (Jonides, 1981; Müller & Rabbitt, 1989), “endogenous versus exogenous” (Posner, 1980, 1984), “overt versus covert” orienting (Spence & Driver, 1994, 1996, 1997) or “top-down versus bottom-up” attentional control (Eriksen & Hoffman, 1972; Theeuwes, 1991; Yantis & Jonides, 1984).

Attentional Capture by Object Appearance

The sudden appearance of a new object could signify important changes in our immediate environment that may or may not threaten our safety. In fact, it is not difficult to think of common examples where the inability to quickly and reflexively allocate attention to the sudden appearance of an object can have severe consequences. Consider something as mundane as crossing the street and having an approaching car suddenly appear. Having the ability to attend to the new object in a timely manner can give important information such as the car’s trajectory and speed, which would allow a timely and appropriate response. There is, in fact, an abundance of visual attention literature dating back to Eriksen and Hoffman (1972), Posner (1980) and Jonides (1981) suggesting that a sudden appearance or abrupt onset of an object may capture attention.

Abrupt visual onsets. Many of the first methodical studies of visual attention capture were performed by Posner and colleagues (Posner, Snyder, & Davidson, 1980; Posner, 1980, 1984), who developed a cue-location paradigm where a peripheral onset cue is presented prior to a peripheral target. They examined the effects of varying the location of the onset cue in relation to the subsequent target, as well as the time interval between the onset of the cue and the target; referred to as the *stimulus-onset asynchrony* (SOA). In a significant study by Posner and Cohen (1984), the authors presented an onset cue (the brightening of one of two placeholder boxes placed on either side of a centered box) for 150 ms. The target subsequently appeared in one of the three locations after a variable delay (0, 50, 100, 200, 300 or 500 ms), requiring a detection response from the participant. Posner observed that the target detection response time was faster when the onset cue and target appeared in the same peripheral location rather than when the locations differed, despite the fact that the cue provided no predictive information about target location. This facilitation effect only occurred when the cue-target SOA was less than 200 ms. When the SOA was greater than 300 ms responses tended to be slower if the cue and target appeared in the same location. Since the onset cue did not reliably predict the location of the target, they concluded that the abrupt onset captured attention, automatically drawing attention to the cued location. The facilitative effect is referred to as the "attentional cue effect", while the later inhibition effect has come to be referred to as "inhibition of return" (IOR; Posner, 1980, 1984).

Since the creation of the cue paradigm, many researchers have examined the effects of abrupt onsets on attention and have evaluated possible causal mechanisms. Some have argued that the attentional capture effects elicited by abrupt onsets is due to the specific properties of the onset, such as the changes in luminance (Jonides & Yantis, 1988; Theeuwes, 1994; Yantis & Jonides, 1984), the abrupt sensory transients (Franconeri & Simons, 2003; Hollingworth, Simons, & Franconeri, 2010) or simply the appearance of a new object in the visual field (Yantis & Hillstrom, 1994; Yantis &

Johnson, 1990). Regardless of the underlying mechanisms, there is near unanimous agreement that abrupt onsets do hold some special status in attention, and while it should be noted that there are some reports where peripheral cues do not produce significant facilitative effects (Berlucchi, Tassinari, Marzi, & Stefano, 1989; Tassinari, Aglioti, Chelazzi, Peru, & Berlucchi, 1994), there is a large, ever-growing body of evidence that abrupt onsets can capture attention (e.g., see Brockmole & Henderson, 2005; Cole & Kuhn, 2009, 2010; Enns, Austen, Lollo, Rauschenberger, & Yantis, 2001; Koelewijn, Bronkhorst, & Theeuwes, 2009; Pratt & McAuliffe, 2001; Pratt & Trottier, 2005; Remington et al., 1992; Schreij, Owens, & Theeuwes, 2008).

In the visual literature there are two competing hypotheses that attempt to account for the attentional capture effects of abrupt onsets. The first is called the *new-object hypothesis*, which claims that the only event that can produce attentional capture effects reliably is the appearance of a new object in the visual field (e.g., Yantis & Egeth, 1999; Yantis & Hillstrom, 1994; Yantis & Johnston, 1990; Yantis, 1996). According to this account, when an observer first views a scene, objects are indexed. The sudden onset of a new object requires a new object index (the creation of a new object representation), triggering an attentional interrupt, followed by an attentional shift to the new object and immediate update of visual short-term memory (Kahneman, Treisman, & Gibbs, 1992). Thus, the new object is given attentional priority and attention is effectively “captured”. A critical implication of the of the new-object hypothesis is that attentional capture of new objects does not require a sensory transient and, more importantly, a sensory transient is not *sufficient* for attentional capture (Chua, 2013; Franconeri, Hollingworth, & Simons, 2005; Ruz & Lupiáñez, 2002).

Unfortunately, the presence of a sensory transient is easily confounded with the presentation of a new object. To extricate these variables, Yantis and Jonides (1984) presented participants with a visual search task where letters could be formed by offsetting segments of a figure-eight or by appearing where there was no letter previously; thereby creating new objects (through an abrupt onset) and old objects (through the transformation of the figure-eight) accompanied by equal sensory transients. The target letter could appear with equal probability at each location, and as an old or new object. As with other visual search tasks, if attention is automatically captured by the new object than the detection time should be independent of the search display size. The authors found that search times were independent of set size when the target appeared as a new object, but increased as a function of set size when the target appeared as an old object. Since luminance for the new and old objects were controlled so transients occurred for both the old and new items, the authors concluded that new objects could direct attention regardless of the sensory transients that accompany them.

Jonides and Yantis (1988) extended this paradigm by comparing singletons unique in the display because they were created through an onset (a new object) and singletons unique in colour and luminance. As with their previous study, participants were presented with an array of figure eights (various set sizes), and in the onset condition the target letter could abruptly appear in a location previously empty or be formed through the transformation of one of the figure-eights. In the luminance and colour conditions, however, all the display items appeared abruptly, with one item being the unique luminance or colour singleton. In all experiments, the singleton could appear as the target letter or a non-target letter and at any of the locations with equal probability.

As with the previous study, when the target letter was formed from an abrupt onset search times were independent of set size. However, when the target letter was a luminance or colour singleton search times increased as a function of set size. Jonides and Yantis concluded that attentional capture is a unique property of new objects that does not extend to other stimulus properties such as luminance and colour. Similar studies using this irrelevant feature search task have lent support to the new-object hypothesis, demonstrating that other salient features such as form and motion could not direct attention (Folk & Annett, 1994; Hillstrom & Yantis, 1994; Yantis & Hillstrom, 1994; Yantis, 1993). Though it may be the case that salient features such as luminance and colour can guide attention, it does not appear to capture attention in a bottom-up fashion, according to this view (Jonides & Yantis, 1988; Yantis & Egeth, 1999).

The alternative view, dubbed the *transient hypothesis*, proposes that some types of sensory transients such as luminance and motion capture attention regardless of whether they are associated with a new object or not (e.g., Franconeri & Simons, 2003; Hollingworth et al., 2010; Jonides & Yantis, 1988; Yantis & Jonides, 1984). Accordingly, new objects capture attention because of the sensory transients that accompany them. Early studies found that attention capture effects could be mitigated by manipulating the ratio of luminance changes between the target and distractors (Martin-Emerson & Kramer, 1997; Miller, 1989). For example, Miller (1989) replicated and extended the paradigm used by Yantis and Jonides (1984), altering the number of offsetting line-segments. Miller argued that the overall change in luminance (the number of offsetting line-segments plus the number of onsetting line-segments) was greater for the onset than for the offset letters. The abrupt onset may have captured attention because of this overall change in display luminance and not because it was the only onset. By increasing the number of offsetting line-segments, Miller found that the onset target no longer captured attention, suggesting that luminance changes were able to draw attention away from the new object.

Similarly, Franconeri, Hollingworth and Simons (2005) attempted to mask the sensory transients that accompany the new object in order to mitigate the attentional capture effects. Using a visual search task similar to those used by Yantis and Jonides (1984), participants were presented with a set of figure-eight placeholders surrounded by a ring. This ring would shrink, briefly occluding the placeholders. At the maximal point of occlusion the figure-eight placeholders would transform into letters (through the offsetting of line-segments) and a target letter could either appear as one of the transformed placeholders or abruptly appear in a previously empty location. Franconeri and colleagues argued that if the new object captured attention then the letter that appeared in a previously empty location would receive search priority. If, on the other hand, luminance transients capture attention then the new letter will not be given priority, since the brief occlusion of the search display will cause all the letters to appear with equal luminance transients. Consistent with the transient hypothesis, when the luminance transients were concealed new objects were not given priority and search times increased as a function of set size. While there are other studies that support the notion that new objects are not sufficient for attention capture (Brockmole & Henderson, 2005a, 2005b; Chua, 2011), it should be noted that other recent studies applying the same general logic as Franconeri and colleagues (2005) found contradictory results with new objects capturing attention despite concealed sensory transients (e.g., Cole, Kuhn, & Skarratt, 2011; Davoli, Suszko, & Abrams, 2007).

Abrupt auditory onsets. Interestingly, analogous research in the auditory literature was not intended to investigate the role of attention, but instead investigated filtering mechanisms and only linked these effects to attention in retrospect. More specifically, these studies examined the effects of selective listening on the perception of nonverbal sounds. By varying the frequency relation between the target and the cue, these studies examined attention to particular frequency regions and their effect on target perception; a phenomenon referred to as the “frequency selectivity effect” (e.g., Creelman, 1960; Green, McKey, & Licklider, 1959; Green, 1961; Greenberg & Larkin, 1968; Hafter, Schlauch, & Tang, 1993; Hübner & Hafter, 1995; Mondor, Hurlburt, & Gammell, 2003). Typically in these experiments two noise-filled intervals are presented following a pure tone cue and participants are required to either indicate the presence of a pure tone target (e.g., Larkin & Greenberg, 1970) or to indicate which of the two intervals contained the target (e.g., Greenberg & Larkin, 1968). The results revealed that accurate target perception drops as the frequency difference between the cue and target increases and often diminished target perception is apparent when the frequency between the target and cue differ by just 10% (Green, 1961; Hübner & Hafter, 1995; Mondor et al., 2003).

Further research using similar cue paradigms have established evidence that auditory attention can be automatically allocated in response to auditory location cues (Mondor, Breau, & Milliken, 1998; Mondor & Bryden, 1992; Mondor & Zatorre, 1995; Spence & Driver, 1994, 1996, 1998), as well as frequency cues (Green & McKeown, 2001; Mondor & Breau, 1999; Mondor & Bregman, 1994; Scharf, Quigley, & Aoki, 1987; Woods, Alain, Diaz, Rhodes, & Ogawa, 2001) and other perceptual qualities such as duration, intensity and timbre (Mondor & Lacey, 2001).

Some of the earliest examples of the attentional cuing effect in auditory attention include a series of studies by Mondor and Bryden (1991, 1992). A common finding in dichotic listening tasks is a right-ear advantage for verbal stimuli. Mondor and Bryden investigated the role attention may have on this phenomenon. The first study used a pre-cue paradigm to direct attention in a dichotic listening task. A tone (cue) presented to either to the left or right ear was followed by two simultaneously presented consonant-vowel syllables presented dichotically. The SOA between the cue and targets was varied to manipulate the amount of time the participant had to orient attention to the cued channel (150, 450 and 750 ms). Participants were required to report only the syllable presented to the cued ear. The results of this study showed the right-ear advantage only occurred at the earliest SOA of 150 ms and, while performance improved for the left ear trials as the SOA increased, performance for the right-ear trials remained static across SOA conditions. This led the authors to conclude that attention was playing a significant role in the right-ear advantage; the longer SOA conditions allowed the participant more time to correct for the right ear bias (Mondor & Bryden, 1991).

The second study by Mondor and Bryden (1992) examined whether the cue from the above experiments was in fact orienting attention to the cued location or simply alerting the participant of the upcoming trial. Mondor and Bryden altered their earlier paradigm to be more similar to the classic cue-paradigms used by Posner (1984). The consonant-syllables were now spoken by two different female voices, and participants were assigned a target voice and required to report the consonant-syllable from that voice only (regardless of location). The tone cue could sound either in the same ear as the target voice (Valid trials) or in the ear as the distractor voice (Invalid trials) with an SOA of 150, 450 or 750 ms. For Experiment 1, the cue accurately predicted the target voice's location for 90% of the trials. The authors reasoned that if the cue orients attention, then performance will be facilitated by the Valid cues but impaired by the Invalid cues. On the other hand, if the cue is simply alerting the participant of the upcoming trial, performance will be facilitated by both the Valid and Invalid cues. Using a cost plus benefits analysis (Posner, 1980), the results from the first experiment revealed a strong effect on the left-ear trials (performance was facilitated by Valid cues and longer SOA's) and a similar but weaker effect on the right-ear trials. Concerned about a possible ceiling effect in the right-ear trials (average of 6% error rates), Experiment 2 replicated Experiment 1 while increasing the difficulty of the task by inserting a 2400 ms noise mask immediately following each trial. The results of Experiment 2 showed the opposite results as Experiment 1: a strong effect in the right-ear trials but a weak effect for the left-ear trials.

A likely explanation for the asymmetry in results, as noted by Mondor and Bryden (1992), was that the design of the experiment allowed subjects to employ different performance strategies. Therefore, Experiment 3 was designed to limit the possible strategies in an effort to produce more consistent results. Unlike Experiments 1 and 2, Experiment 3 used only the 450 ms SOA (this SOA produced the largest facilitating effect in previous experiments) and, instead of location cues, the authors used frequency cues presented in either the right or left ear. A high (1500 Hz) and low-pitched tone (600 Hz) indicated the ear subjects were to attend to and report from. The high pitch indicated that subjects should attend to the left ear and the low pitch indicated the right ear. On 80% of trials the low-pitch tone sounded in the right ear and the high-pitch tone sounded in the left ear, and on 20% of trials the low-pitch tone sounded in the left ear and the high-pitch tone sounded in the right ear. Therefore, on 80% of trials the location of cue tone and the location information provided by the pitch were consistent (Valid trials), and on the remaining 20% of trials the location of the cue tone and the location information provided by the pitch were inconsistent (Invalid trials). The results revealed significantly lower error rates for Valid trials in both the right and left ear conditions than the Invalid trials. Taken together, these three experiments have shown evidence that the lateralized tone cue orients attention to the ear in which it is located (Mondor & Bryden, 1992).

The early data from Mondor and Bryden (1991, 1992) demonstrating attentional cuing in auditory attention was further replicated by Spence and Driver (1994) using uninformative location cues. They used an orthogonal location-cue paradigm where participants were instructed to ignore an uninformative cue and judge whether a subsequently presented target was in front or behind them (regardless of target lateralization). Using an array of six speakers (three speakers on either side of the participant), both targets and cues were presented on the left or right of the participants midline. Using a variable SOA (100, 400 and 1000 ms), the results of this study revealed that participants were faster to localize the target as being in front or behind them when it was preceded by the cue on the same side at 100 ms SOA. These results were further substantiated in a second experiment where the target localization was an up or down judgement rather than in front or behind judgement, and further replicated in later studies (Spence & Driver, 1997, 1998).

Likewise, Mondor, Breau and Milliken (1998) investigated the effects of location and frequency cues using a similar paradigm as Mondor and Bryden (1991, 1992). In the location condition the cue and target (two noise bursts) could either be presented in the same location or from different locations. In the second condition the cue and target (two pure tones) were presented from the same location but were either the same frequency or different frequencies. There was no predictive relation between the target and cue in either condition and the target was presented with a variable SOA of 150, 450 or 750 ms. Different groups of participants were required to make either a target-discrimination or a target-detection response. For both the discrimination and detection tasks a response time advantage was found at the earliest SOA (150 ms) when the cue and target were presented from the same location and when the cue and target were the same frequency. Furthermore, the results of this study mirrored visual attention literature that has found reversed effects at later SOAs (750 ms). In other words, there was a response time advantage for the trials where the cue and target were presented in different locations or with different frequencies. This phenomena has been referred to in the visual literature as inhibition of return (IOR) (Birmingham & Pratt, 2005; Lupianez, Klein, & Bartolomeo, 2006; Pratt & McAuliffe, 2001; Riggio, Bello, & Umiltà, 1998). This study was replicated using various sound qualities such as duration, intensity and timbre by Mondor and Lacey (2001) and, as in the visual literature, there is a general consensus that abrupt onsets can capture auditory attention at SOAs less than 200 ms and produce inhibitory effects at SOAs around 750 ms (Kanai, Ikeda, & Tayama, 2007; McDonald & Ward, 1999; Mondor & Breau, 1999; Mondor & Lacey, 2001; Prime, Visser, & Ward, 2006; Prime & Ward, 2002; Reuter-Lorenz, Jha, & Rosenquist, 1996; Roggeveen, Prime, & Ward, 2005; Spence & Driver, 1998).

Attentional Capture by Object Disappearance

Abrupt visual offsets. It is possible that any major change in our perceptual environment may cause the automatic allocation of attention and, in fact, some of the early work in the visual literature that investigated the effects of object appearance also investigated the effects of object disappearance (Miller, 1989; Watson & Humphreys, 1995). Yantis and colleagues (1984), for example, used a paradigm which required the detection of a target letter among distractors in what is now a common visual search task. The search display under this paradigm is preceded by a placeholder display made up of figure-eight's arranged in a circular pattern. After a short period (500 ms, for example), the figure-eight's would either disappear or transform into letters through the removal of line segments, and at the same time another letter would appear in a previously unoccupied location. Participants were instructed to locate a specific letter which could have been formed from the sudden appearance of a new stimulus (abrupt-onset targets), the gradual appearance of a new stimulus (gradual-onset targets) or created through the removal of camouflaging line segments (offset targets). Therefore, offset targets would first appear as a figure-eight and, through the removal of line segments, be transformed into the target letter. When the target was formed by an abrupt onset the response time to detect the target was independent of the number of items in the display and abrupt-onset targets were detected faster than gradual-onset targets and offset targets. They concluded that the abrupt onset of the target automatically captured attention and, therefore, onset items were processed first before resorting to serial search strategies (Yantis & Jonides, 1984; Yantis, 1996).

Theeuwes (1991) investigated the effect of peripheral offset cues using a paradigm that makes use of both the visual search and cue paradigms. Participants in this study searched for a target letter among three distractor letters arranged in a circular pattern. With these experiments, Theeweus used a placeholder display containing four figure-eight's that would transform into letters through the removal of line segments. In his first experiment Theeuwes demonstrated that the onset of an uninformative cue (a black rectangle) could facilitate search response time when it appeared suddenly near the target letter after 80 or 160 ms SOA. In the second experiment the placeholder display began with a black rectangle placed near each figure-eight and demonstrated that when one of the peripheral cues disappeared near the target letter target localization was facilitated, similar to Experiment 1. This study shows early evidence that the disappearance of a peripheral cue may capture attention in a similar fashion as the appearance of peripheral cue.

Similarly, Pratt and McAuliffe (2001) used a paradigm more akin to the location-cue paradigms developed by Posner and Cohen (1984) to investigate the effects of object disappearance and replicated the results of Theeuwes (1991). Pratt and McAuliffe presented participants with two place holder boxes to the left and right of a fixation point. A dot could either appear in one of the boxes (onset cue) or the display would begin with the cue and disappear (offset cue) prior to target presentation. Similar to previous results, early SOAs (100 ms) produced facilitative results while later SOAs (900 ms) produced inhibitory results. It should be noted that these results are in contrast to a study by Riggio, Bello and Umiltà (1998), who used a nearly identical cue paradigm as Pratt and McAuliffe (2001) with a target detection task. Riggio et al.'s paradigm consisted of a central fixation point and two peripheral placeholder boxes placed on either side of the fixation point. The cue was an arrow that could either suddenly appear (onset) or disappear (offset) directly below one of the boxes. Three experiments were performed with varying results: The first found facilitative effects of both onset and offset cues at the 50 ms SOA, while experiments 2 and 3 failed to produce significant facilitative results at either the 50 or 150 ms SOA for both onset and offset cues. Pratt and McAuliffe (2001) addressed this discrepancy and replicated this study with the detection task, which produced facilitative effects of onsets and offsets at the 100 ms SOA.

While there is a significant body of evidence in the visual attention literature that suggests object disappearance can receive attentional priority (e.g., see Atchley, Kramer, & Hillstrom, 2000; Birmingham & Pratt, 2005; Brockmole & Henderson, 2005; Cole & Kuhn, 2010; Gawryszewski, Thomaz, W., & Sant'Anna, 1994; Miller, 1989; Pratt & McAuliffe, 2001; Pratt, Theeuwes, & Donk, 2007; Riggio et al., 1998; Samuel & Weiner, 2001; Theeuwes, 1991; Watson & Humphreys, 1995), there are some studies that do not show any effects or only produce effects at specific SOAs. Gawryszewski, Thomaz, Machado-Pinheiro, and Sant'Anna (1994), for example, found that offset cues did not produce facilitative effects but produced inhibitory responses at both short (100 ms) and long (800 ms) SOAs. Riggio et al. (1998) found inconsistent facilitation effects at early SOAs (50 and 150 ms) but strong inhibitory effects at late SOAs (500 and 1000 ms). Pratt and Hirshhorn (2003) found only inhibitory responses for all the SOAs in their paradigm (250, 750 and 1000 ms) and, in contrast, Spence and Driver (1997) found only facilitative effects at all their SOAs (100, 200 and 700 ms).

Overall, however, there seems to be considerable evidence that object disappearance can, at least under some circumstances, capture visual attention (even if the mechanisms are not readily understood). This evidence spans a wide range of different paradigms and phenomena. As noted above, visual search tasks (e.g., Jonides, 1981; Yantis & Jonides, 1984, 1990), location-cue paradigms (e.g., Birmingham & Pratt, 2005; Koelewijn et al., 2009; Pratt & McAuliffe, 2001; Theeuwes, 1991) and cross-modal paradigms (Spence & Driver, 1997) have been employed to investigate object disappearance. However, significant effects of object disappearance were also found investigating other phenomena such as the attentional repulsion effect (Pratt & Arnott, 2008), the Simon effect (Wühr & Kunde, 2006), change detection (G.G. Cole, Kentridge, Gellatly, & Heywood, 2003), spatial Stroop (Luo, Lupiáñez, Fu, & Weng, 2010), and prepotent responses (Pratt & Trottier, 2005). Given that object disappearance has been found to direct visual attention in such a wide variety of paradigms and phenomena, it seems highly likely that object disappearance does receive attentional priority in some capacity.

This evidence is critical in evaluating the validity of the new-object hypothesis and the transient hypothesis. One implication of the new-object hypothesis is that object disappearance should not be able to direct attention in an automatic fashion. The disappearance of an object brings no new information to the display; therefore there is no need to create a new object representation or update the object index, and attention should not be directed to the offset site. According to the transient hypothesis, on the other hand, an object captures attention because of its unique sensory transients. Therefore, regardless of whether the abrupt luminance change is an increase (onset) or decrease (offset), the sudden change should still capture attention (Chua, 2011, 2013; Hollingworth et al., 2010). Therefore, evidence that offsets can direct attention is contradictory to the new-object hypothesis and lends support for the transient hypothesis.

Abrupt auditory offsets. Given the amount of empirical investigation into object disappearance in visual attention, it is surprising that there are no analogous studies in auditory attention using the traditional cue paradigm. In early studies of a phenomenon known as the “Simon effect” however researchers have investigated effects of offset auditory cues. The Simon effect refers to the finding that response times are facilitated when the target stimulus and the response occur in the same location or when the response refers to the same location as the target, even when the location of the target is irrelevant to the task. For example, a task could consist of responding to the colour of a stimulus, with the left response key assigned to one colour and the right response key to the other. Typically, responses to this non-spatial property (in this case colour) are faster and more accurate when the key required corresponds to the target location (Nishimura & Yokosawa, 2010; Simon, Craft, & Webster, 1971; Simon & Rudell, 1967; Wühr & Kunde, 2006).

Simon, Craft and Webster (1971), for example, investigated the effects of stimulus offsets using both visual and auditory Simon tasks. In Experiment 1 participants responded to a visual offset. At the beginning of each trial two response buttons were illuminated and, after a short duration, one of the buttons was extinguished. In one block of trials participants were required to respond by pressing the button that had turned off, and in another block they were required to respond by pressing the button that remained illuminated. The results revealed that participants were faster at responding to the button that had turned off rather than the button that remained lit. In Experiment 2 the procedure was replicated using auditory stimuli. These trials began with two identical pure tones being presented to the left and right ears, one of which was subsequently extinguished. Participants were required to press either the left or right key with their corresponding index fingers in response to the tone that persisted (first block of trials) or the tone that had ended (second block of trials). In contrast to the first experiment, performance was better when the key press corresponded to the tone that persisted. As noted by Simon et al. (1971), these differential effects may have been due to the fact that a binaural tone shifting to a monaural tone can lead to the perception of a single tone being presented in the channel where the tone persisted rather than an offset in the opposite channel.

Similar results have been found using a task irrelevant peripheral cue whose location coincides with the response location. This visual or auditory peripheral cue has been dubbed the “accessory stimulus” and the effect, not surprisingly, has been termed the “accessory Simon effect” (e.g., see Moore, Lleras, Grosjean, & Marrara, 2004; Nishimura & Yokosawa, 2010; Proctor, Pick, Vu, & Anderson, 2005; J R Simon & Pouraghabagher, 1978; Wühr & Kunde, 2006). A recent study by Nishimura and Yokosawa (2010) investigated the effects of auditory accessory stimulus onsets and offsets on the Simon effect. Participants in this study responded to a centrally presented visual target with either a right or left keypress and the accessory stimuli were presented binaurally through headphones. The accessory stimuli consisted of a 300 Hz pure tone and white noise. In the onset condition, a central fixation point was presented for 2000 ms followed by the target stimulus and one of the accessory stimuli (presented monaurally to the left or right ear) presented simultaneously. In the offset condition, the pure tone and white noise were presented dichotically with the central fixation cross for 2000 ms, at which point one of the two sounds would offset simultaneously with presentation of the target stimulus. The results of this study showed response time facilitation when the keypress corresponded with the location of the accessory stimulus in the onset condition. In the offset condition, responses were significantly quicker when the keypress corresponded with the auditory channel that persisted rather than the offsetting channel.

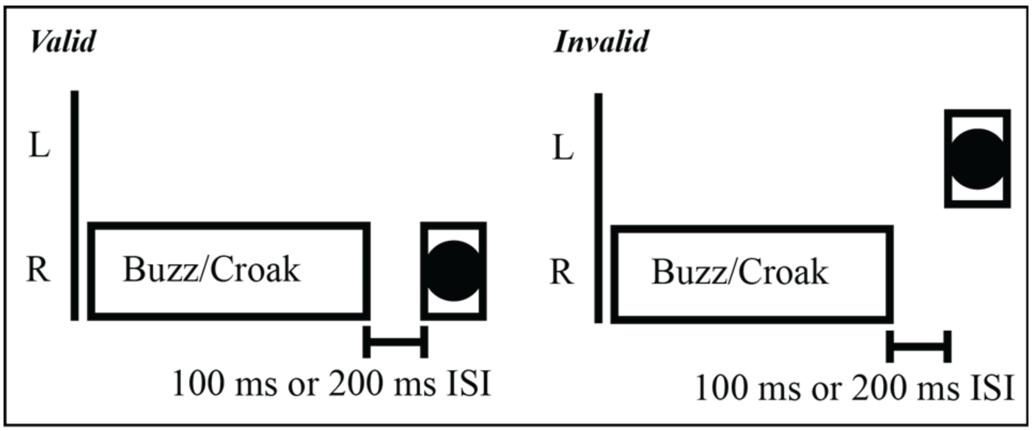
There are, however, some important differences between these studies on the Simon effect and traditional cue paradigms. First, Nishimura and Yokosawa's (2010) study utilizes a crossmodal paradigm where the target is visual and the cues are auditory. Considering the results in visual offset studies vary greatly, and some differential effects are found in crossmodal attention capture studies (Spence & Driver, 1994, 1996; Wright & Ward, 2008a), it is unclear how the crossmodal offset results would correspond to a unimodal paradigm. Secondly, in a typical Simon effect experiment the cue and target are presented simultaneously, while in typical cue paradigm facilitative effects are found when the cue precedes the target by 50 to 200 ms (Mondor & Breau, 1999; Mondor & Lacey, 2001; Posner, 1984; Spence & Driver, 1994). Lastly, and perhaps most importantly, the accessory Simon task does not involve target localization. While in the typical cue paradigm target location is irrelevant to the discrimination or detection task, the target can appear in multiple locations. In contrast, the accessory Simon task consistently presents the target in the center of the display. From these results, it is unclear whether an auditory offset can cause a reflexive allocation of attention to the corresponding location.

While there is considerable auditory research showing object appearance can direct attention, there is little to no evidence showing the effects of object disappearance. The present study has been designed to investigate whether similar effects of object disappearance in visual attention will be found in auditory attention. All three experiments were designed in a similar fashion as the location-cue paradigms used by Posner and Cohen (1984), Pratt and MacAuliffe (2001) and Mondor and colleagues (Mondor & Breau, 1999; Mondor & Lacey, 2001). Given the inconsistent results in the visual attention literature, it is unclear whether early or late target presentation will produce facilitative, inhibitory or null effects.

Experiment 1

In Experiment 1 participants were presented with a context sound followed by a target sound, each of which could be presented from the right or left speakers (see Figure 1). The targets were presented with an interstimulus interval (ISI) of either 100 or 200 ms. For all trials, participants performed a target discrimination task, judging the pitch of the target (high or low). In order to learn how to discriminate between the high and low tones that were to be presented, participants were required to complete a training session before completing the 96 experimental trials. While similar to a traditional cuing paradigm, previous research studying abrupt onsets used short cue durations (50 ms) with varied stimulus-onset asynchronies (50 to 750 ms) between the cue and target. To avoid possible onset effects, the context sound in the current study was 1000 ms in duration with a varied interstimulus interval (100 or 200 ms). Given that this design employs a task independent of lateralization, evidence of attention capture will be apparent if responses on Valid trials (those trials where the cue offset and target are located in the same channel) are executed more quickly than Invalid trials (trials where the target and cue are presented in different channels) as per other classic location-cue studies (Mondor & Bryden, 1991, 1992; Posner, 1984; Pratt & McAuliffe, 2001; Spence & Driver, 1994)

Figure 1. *Schematic illustration of the stimuli used in Experiment 1.*



Methods

Participants. Twelve undergraduate students attending the University of Manitoba participated in exchange for course credit. None of the participants reported any corrected or uncorrected hearing impairments.

Materials.

Computer and sound system. The experiments were controlled by a Dell Pentium computer operating at 800 MHZ running the E-Prime programming software (Psychology Software Tools, Inc., 2003). Sounds were presented over Altec Lansing speakers (model #VS2620) at a 45° angle from the listener and at an intensity of approximately 70 dB.

Sounds. Sounds were synthesized using Adobe Audition 1.5 (Adobe, 2004) at a sampling rate of 44100 Hz. Two target sounds were created. Both of these were pure tones, one at 262 Hz and the other at 330 Hz, and both were 100 ms in duration, including 5 ms onset and offset amplitude ramps used to eliminate clicks associated with abrupt intensity changes. In addition, two context sounds, a 'buzz' and a 'croak', were also synthesized (these were identical to sounds with the same names created and used by Leboe & Mondor (2007)). The *buzz* context sound was created using a square wave and included a fundamental frequency of 200 Hz plus the first (400 Hz), second (600 Hz), third (800 Hz), and fourth (1000 Hz) harmonics. In relation to the intensity of the fundamental frequency, the harmonics were presented at 40%, 30%, 20%, and 10%, respectively. The *croak* context sound was created using a sine wave with a fundamental frequency of 500 Hz that was modulated randomly between 450 and 550 Hz at a rate of 40 times per second. The *buzz* and *croak* sounds were each 1000 ms in duration, including 5 ms onset and offset amplitude ramps.

Procedure. The experiment consisted of a training session, two practice sessions and an experimental session. During the training session participants were instructed to listen to the target tones until the distinction between them is clear (verbal confirmation). Following the training session, which consisted of 10 trials, the first practice session began. During each trial, one of the target tones (100 ms in duration) was presented in isolation following 500 ms of silence. The participants were instructed to indicate whether the tone presented was the high- or low-pitched using the keyboard in front of them ('1' for high-pitched and '2' for low-pitched response keys). Participants received accuracy feedback (presented on the computer screen: correct or incorrect) following each response and were instructed to initiate the next trial when they were ready by pressing the space-bar on the keyboard. Each participant was required to achieve 70% accuracy to move on to the second practice session. If a participant did not meet this criterion they were required to go through the training session again and complete another block of practice trials. The second practice session consisted of 16 trials and was identical to the experimental trials, except that participants received accuracy feedback following each response. Participants were required to achieve 70% accuracy on the second practice session before moving on to the experimental trials. If a participant does not meet this criterion after the first block they repeated one or more blocks of 16 practice trials until they had.

For the experimental session, participants were presented with either the buzz or croak context sound in either the left or right channel followed by one of the two target tones presented in either the left or right channel. The time period between the end of the context sound and the beginning of the target sound (Inter-Stimulus Interval or ISI) could be either 100 ms or 200 ms. On half of the 96 trials the target sound was presented in the same location as the preceding context sound (these will be referred to as ‘Valid trials’), and on the other half of the trials the target sound was presented from the channel opposite the context sound (these will be referred to as ‘Invalid trials’). Across trials, the high- and low-pitched sounds was presented equally often and each of these was preceded equally often by the buzz and croak context sounds.

Results and Discussion

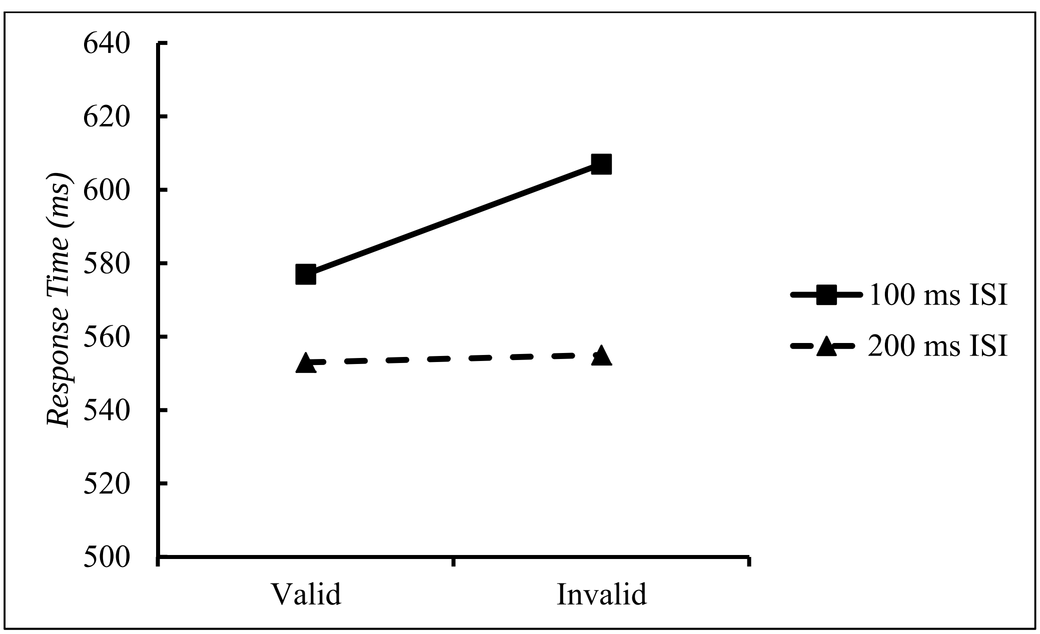
In each condition, outlying response times (as defined as those more than 2.5 standard deviations above or below the mean) were excluded from the data analysis, resulting in the removal of 3.42% of trials. Mean correct RTs and error rate as a function of Trial Type and ISI are described in Table 1 and Figure 2. Both RT and error rates were submitted to a two-way within-subjects analysis of variance (ANOVA; Trial Type [Valid, Invalid] X ISI [100, 200]). The RT analysis revealed significant main effects of Trial Type, $F(1,11) = 6.55$, $p < .05$, and ISI, $F(1,11) = 25.10$, $p < .001$, and a significant interaction between ISI and Trial Type, $F(1,11) = 8.78$, $p < .05$. The analysis of error rates produced no significant results in all cases ($p > .05$).

Table 1. *Mean response times and percentage errors from Experiment 1.*

		Valid	Invalid
100 ms ISI	RT (ms)	577 (31.94)	607 (31.55)
	PE	5.03 (1.18)	6.08 (1.61)
200 ms ISI	RT (ms)	553 (31.54)	555 (29.70)
	PE	5.90 (2.12)	6.95(1.32)

Note: Mean response times (RT) and percentage errors (PE) with standard errors (in parentheses) are displayed as a function of Trial Type and ISI.

Figure 2. *Mean response times from Experiment 1.*



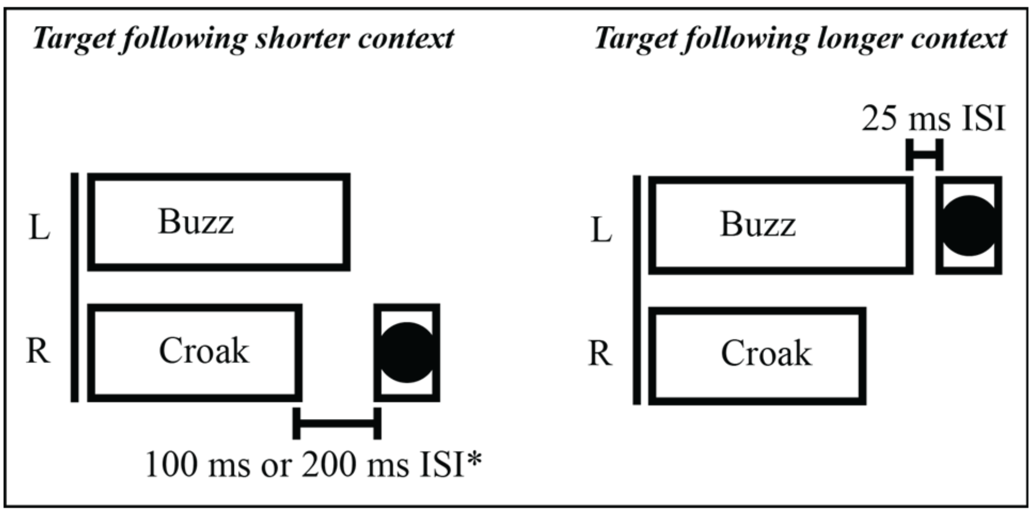
To explore the significant effects on RT, performance was examined separately for the 100 ms and 200 ms ISI conditions. At 100 ms ISI, RT varied significantly as a function of trial type, $F(1,11) = 10.19$, $p < .01$, as participants responded significantly more quickly on Valid trials (M = 577 ms) than on Invalid trials (M = 607 ms). At 200 ms ISI, however, performance on the Valid trials (M = 553 ms) and on Invalid trials (M = 555 ms) did not differ significantly ($p > .05$).

Given that the response times were faster when the target followed the disappearance of the context sound at the early ISI of 100 ms, these results can be taken as preliminary evidence that object disappearance can capture attention. However, it is possible that the presence of a sound in only one channel was in fact directing attention as opposed to the sound offset. Another possibility is that the onset of the cue produced a facilitative effect. Experiment 2 was designed to address these issues by adding a second, competing context sound, while maintaining the paradigm from Experiment 1. While the original context sound will still offset either 100 or 200 ms prior to the target, the second context sound will always offset 25 ms prior to the target sound with the assumption that 25 ms is not sufficient time to direct attention (e.g., Lamy & Egeth, 2003; Logan, 2005; Moore, Egeth, Berglan, & Luck, 1996; Theeuwes, Godijn, & Pratt, 2004). If it was in fact the offset of the context sound directing attention in Experiment 1, then the results should be replicated Experiment 2 despite the added context sound.

Experiment 2

The results of Experiment 1 are consistent with the possibility that the disappearance of an auditory object can capture attention at short ISIs (100 ms). In Experiment 2, we sought to determine whether this result would be replicated when two context sounds were presented simultaneously, one ending before the other. One context sound will offset either 100 or 200 ms prior to the presentation of the target, while the second context sound will always end 25 ms prior to the target (see Figure 3). There is a large body of evidence that suggests that at least 50 ms is required to disengage attention and shift to a new object (e.g., Lamy & Egeth, 2003; Logan, 2005; Mondor, Leboe, & Leboe, 2005; Moore, Egeth, Berglan, & Luck, 1996; Theeuwes, Godijn, & Pratt, 2004). Therefore, 25 ms will most likely be an insufficient amount of time to redeploy attention to the other channel prior to the target onset

Figure 3. *Schematic illustration of the stimuli used in Experiments 2 and 3 (Brief ISI).*



**ISI was 100 ms in the 'Small-Context-Difference' condition and 200 ms in the Large-Context-Difference condition*

Attention capture will be apparent if responses are executed more quickly when the target is presented in the same channel as the earlier offsetting context sound. This also eliminates a possible confound in Experiment 1, that the valid trials were facilitated by the presentation of a single context sound in only one channel. I have included a condition in which the target occurred 200 ms following the first-ending context sound to determine, again assuming that an offset captures attention, whether attention would persist in the location of the offset for this period of time.

Methods

Participants. Thirty undergraduate students attending the University of Manitoba participated in exchange for course credit. None of the participants reported any corrected or uncorrected hearing impairments.

Materials. The computer, sound system and sounds used in Experiment 2 were identical to those used in Experiment 1. The experimental paradigm was similar to the first experiment except that different context sounds were presented concurrently from different locations (one from the left channel and one from the right channel). In addition, whereas one of the context sounds terminated either 100 or 200 ms prior to the onset of a target, the other terminated 25 ms prior to the target. The target sound was presented either in the same location as the longer context sound (25 ms ISI) or in the location of the shorter context sound (100 or 200 ms ISI). Therefore, the two context sounds began at the same time but one ended either 75 ms or 175 ms before the other. Several different durations of the context sounds were used so that listeners were unable to anticipate precisely when they might end. Specifically, the shorter / longer durations (in ms) of the pair of context sounds that will be used on a particular trial could be 1000 / 1075, 1450 / 1525, 1950 / 2025, 900 / 1075, 1350 / 1525, and 1850 / 2025. Target sounds were randomly presented to either the left or right channel and occurred either 25 ms after the context sound that ended last or 100 ms or 200 ms after the context sound that ended first.

Procedure. The procedure for Experiment 2 was similar to that used in Experiment 1. However, as noted above, two context sounds were presented dichotically on each trial. One of these ended 75 ms or 175 ms before the other and the single target sound presented on each trial could occur either in the same channel as the context sound that ended first (ISI in this case was either 100 ms or 200 ms) or in the same channel as the context sound that ended last (ISI in this case was 25 ms). The target sound was always presented after both context sounds had ended.

I thought it possible that the overall context in which targets were presented may have an impact on performance. For this reason I designed the experiment so that participants completed an equal number of trials for when the context sounds differed in duration by 75 ms (I will refer to this as the 'small-context-difference' condition) and when they differed by 175 ms (I will refer to this as the 'large-context-difference' condition) as separate conditions. Within each of these conditions, participants completed an equal number of trials when the target was presented in the same channel as the context sound ending first and when the target was presented in the same channel as the context sound ending second. I preserved this distinction in the analysis and evaluated performance for the small-context-difference and large-context-difference conditions separately.

Participants completed a total 196 experimental trials. All other methodological details were the same as for Experiment 1.

Results and Discussion

In each condition, outlying response times (as defined as those more than 2.5 standard deviations above or below the mean) were excluded from the data analysis, resulting in the removal 3.30% of trials. Mean correct RTs and error rates as a function of Channel and Context are displayed in Table 2 and Figure 4. As in Experiment 1, a two-way within-subjects analysis of variance (Channel [Target following longer context sound, Target following shorter context sound] x Context [Small-Context-Difference, Long-Context Difference]) was conducted with RT and error rates as the dependent measures. The RT analysis showed a significant main effect of Context, $F(1,29) = 9.97$, $p < .05$, and a significant interaction between Context and Channel, $F(1,29) = 5.33$, $p < .05$. The main effect of Channel was not significant, F (1, 29) = 1.03, p = .32.

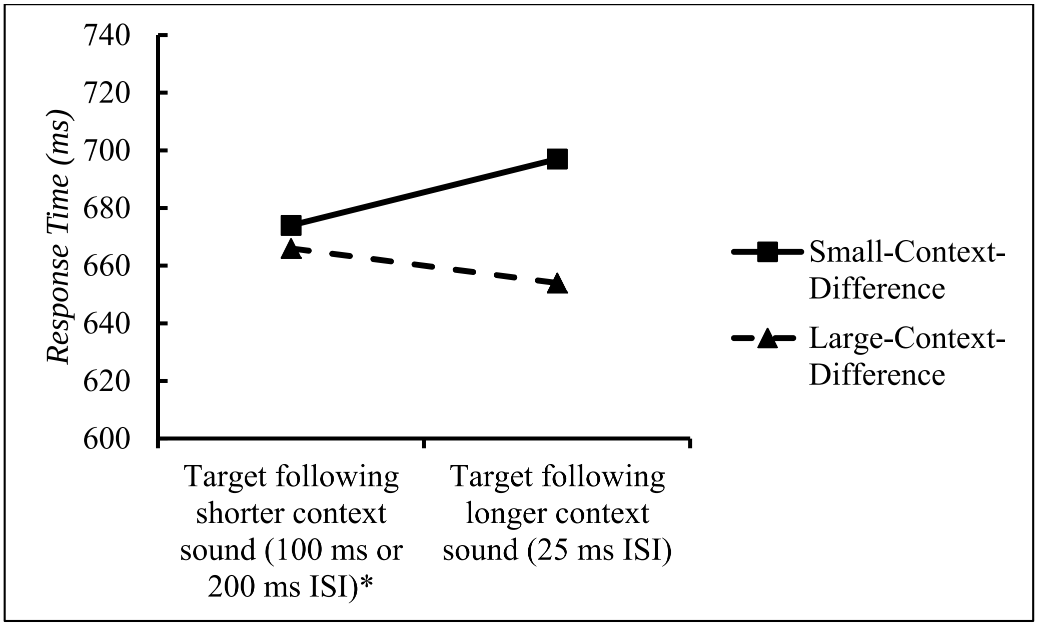
Table 2. *Mean response times and percentage errors from Experiment 2.*

		Target following shorter context sound (100 ms or 200 ms ISI)*	Target following longer context sound (25 ms ISI)
Small-Context-Difference	RT (ms)	674 (29.43)	697 (32.48)
	PE	6.28 (1.44)	7.74 (1.33)
Large-Context-Difference	RT (ms)	666 (28.53)	654 (29.43)
	PE	6.98 (1.73)	6.04 (1.33)

**ISI was 100 ms in the 'Small-Context-Difference' condition and 200 ms in the Large-Context-Difference condition*

Note: Mean response times (RT) and percentage errors (PE) with standard errors (in parentheses) are displayed as a function of Context and Channel.

Figure 4. *Mean response times from Experiment 2.*



To explore the significant main effect of Channel, a separate analysis of the Small-Context-Difference and Large-Context-Difference conditions was performed. The analysis of the Small-Context Difference revealed that RT varied significantly as a function of Channel, $F(1,29) = 5.05$, $p < .05$; participants responded significantly more quickly when the target followed the shorter context sound ($M = 674$ ms) than the longer context sound ($M = 697$ ms). However, in the Large-Context-Difference condition there was no significant difference in response times. $F(1,29) = 1.93$, $p = .176$.

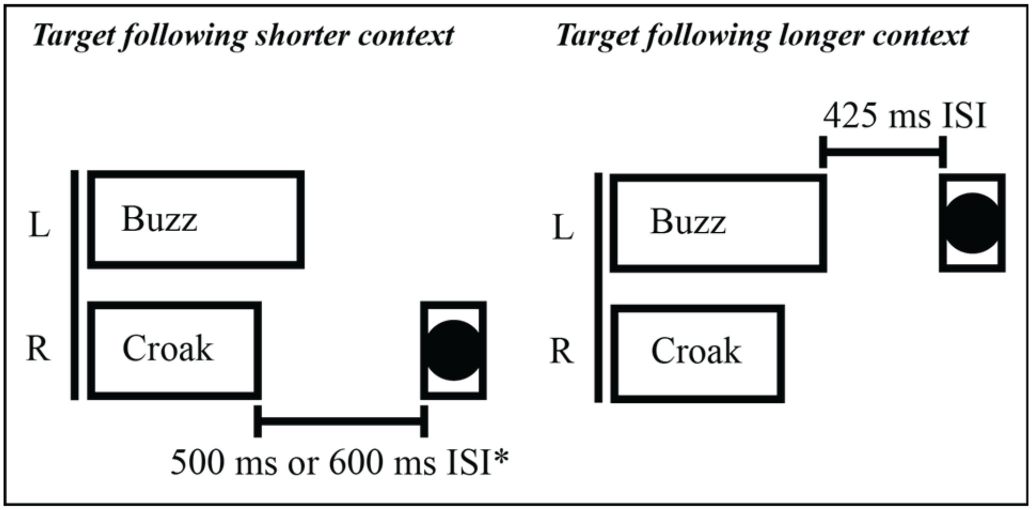
The analysis of error rates produced no significant main effects of Context or Channel ($p > .05$). There was a significant interaction effect, however, between Context and Channel, $F\ (1, 29) = 6.07$, $p < .05$. This suggests that, in the Small-Context-Difference condition, participants made less errors when the target followed the shorter context sound ($M = 6.28\%$) as compared to when the target followed the longer context sound ($M = 7.74\%$), while in the Large-Context-Difference trials participants made more errors when the target followed the shorter context sound ($M = 6.98\%$) as compared to when the target followed the longer context sound (*M* = 6.04%). However, further analysis of the Small-Context-Difference and Large-Context-Difference conditions revealed no significant differences between error rates ($p > .05$).

Participants responded more quickly to the target when it followed the shorter context sound but, as with Experiment 1, this effect occurred only when the target followed with 100 ms ISI and not when it followed with a 200 ms ISI. These results again suggest that the sudden disappearance of sound can direct attention.

Experiment 3

Experiment 3 was designed to replicate the findings of Experiment 2 while extending the paradigm to examine the effects of an early target (Brief ISI; see Figure 3) and late target (Long ISI; see Figure 5) presentation. As noted above, there is little agreement in the visual attention literature about how long the effect would persist following attentional capture, therefore it was unclear what the effects of the longer ISI would be. To replicate the results of Experiments 1 and 2, the original conditions were still present and adapted to include trials where the target was presented with longer ISIs (425 ms and 500 or 600 ms).

Figure 5. *Schematic illustration of the stimuli used in Experiment 3 (Long ISI).*



Methods

Participants. Sixteen undergraduate students attending the University of Manitoba participated in exchange for course credit. None of the participants reported any corrected or uncorrected hearing impairments.

Materials. The computer, sound system and sounds used in Experiment 3 was identical to those used in Experiment 2.

Procedure. The procedure for Experiment 3 was identical to Experiment 2 except that target sounds could be presented either 25 ms following the last-ending context sound and 100 or 200ms following the first-ending context sound (Brief ISI condition; see Figure 3) or either 425 ms following the last-ending context sound and 500 or 600 ms following the first-ending context sound (Long ISI condition; see Figure 5). These additional ISIs were incorporated to assess the time-course of orienting in response to abrupt offsets.

In keeping with the reasoning I elaborated in Experiment 2, the experiment was designed so that performance could be evaluated separately for each combination of the relative durations of the context sounds. Thus, I analyzed the data as a three-way factorial design (ISI Category [Brief, Long] X Channel [Target following longer context sound, Target following shorter context sound] X Context (Small-Context-Difference, Large-Context-Difference).

Experiment 3 was the same as Experiment 2 in all other respects.

Results and Discussion

In each condition, outlying response times (as defined as those more than 2.5 standard deviations above or below the mean) were excluded from the data analysis, resulting in the removal 3.58% of trials. Mean correct RTs and error rate as a function of Context, Channel and ISI Category are described in Table 3 and Figure 6. A three-way within-subjects analysis of variance (ANOVA; ISI Category [Brief, Long] X Channel [Target following longer context sound, Target following shorter context sound] X Context (Small-Context-Difference, Large-Context-Difference) was conducted for the RT and error rates. The analysis of error rates yielded no significant effects in all cases ($p > .05$). The RT analysis of correct responses revealed a significant main effect of ISI Category, $F(1,15) = 60.95$, $p < .001$, and a significant interaction effect between Context and Channel, $F(1,15) = 8.77$, $p = .01$.

Table 3. *Mean response times and percentage errors from Experiment 3.*

		Small-Context-Difference	
		Target following shorter context sound (100 ms or 500 ms ISI)*	Target following longer context sound (25 or 425 ms ISI)**
Brief ISI	RT (ms)	601 (20.28)	624 (21.50)
	PE	3.62 (0.91)	4.56 (1.14)
Long ISI	RT (ms)	536 (16.20)	553 (18.06)
	PE	4.25 (1.06)	4.44 (1.11)

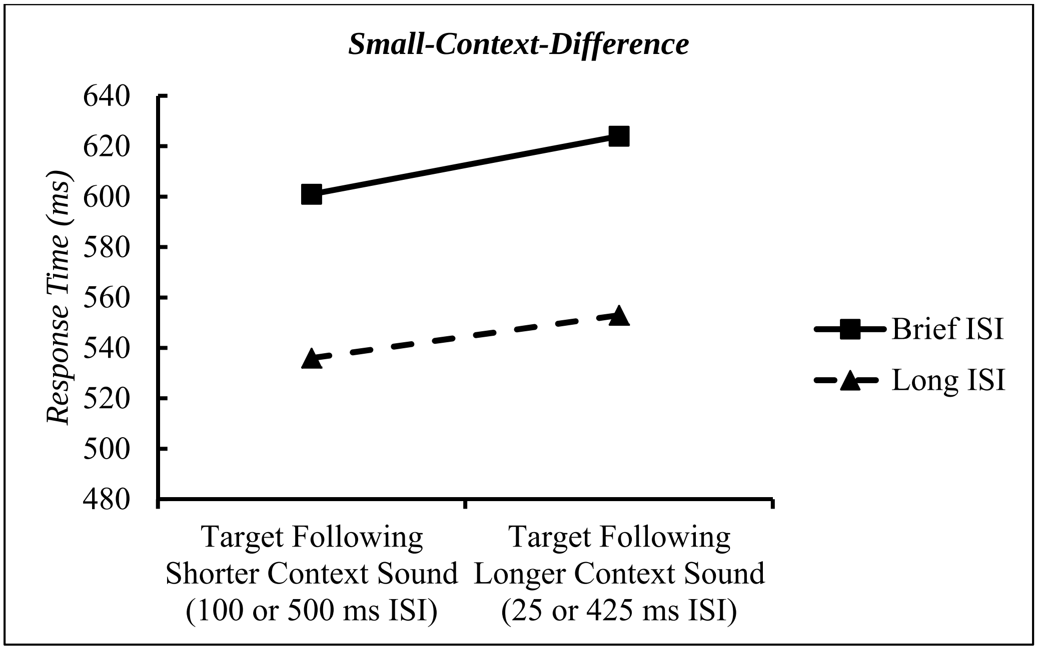
**ISI was 100 ms in the 'Brief ISI' condition and 500 ms in the 'Long ISI' condition*
***ISI was 25 ms in the 'Brief ISI' condition and 425 ms in the 'Long ISI' condition*

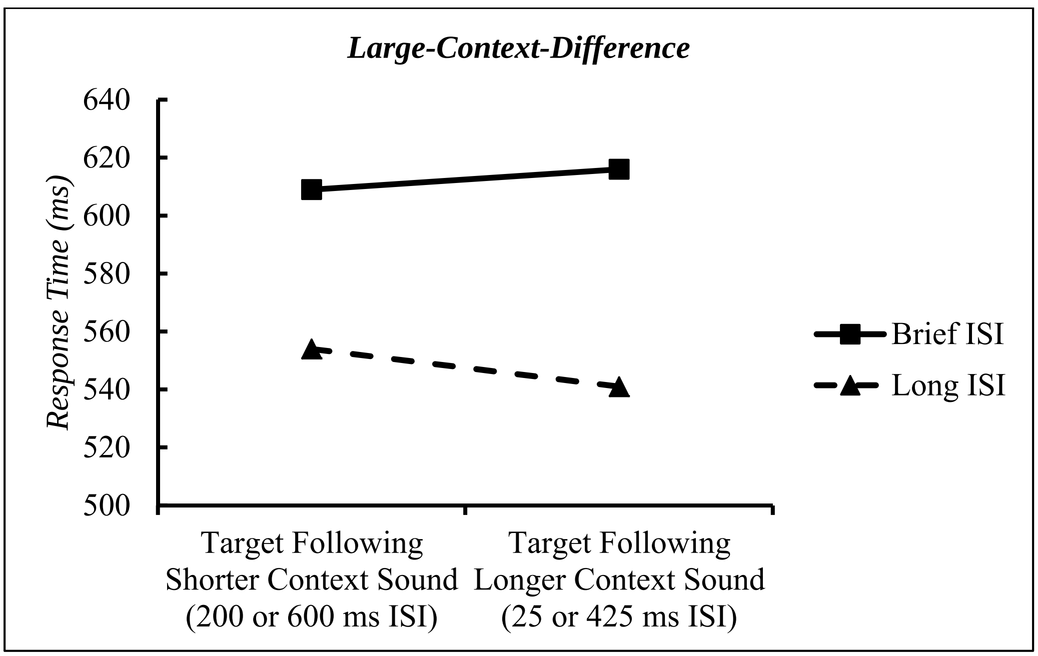
		Large-Context-Difference	
		Target following shorter context sound (200 ms or 600 ms ISI)*	Target following longer context sound (25 or 425 ms ISI)**
Brief ISI	RT (ms)	609 (22.08)	616 (30.70)
	PE	4.00 (1.00)	2.81 (0.70)
Long ISI	RT (ms)	554 (20.01)	541 (15.60)
	PE	3.25 (0.81)	4.31 (1.08)

**ISI was 200 ms in the 'Brief ISI' condition and 600 ms in the 'Long ISI' condition*
***ISI was 25 ms in the 'Brief ISI' condition and 425 ms in the 'Long ISI' condition*

Note: Mean response times (RT) and percentage errors (PE) with standard errors (in parentheses) are displayed as a function of ISI Category, Context, and Channel.

Figure 6. *Mean response times from Experiment 3.*





To remain consistent with earlier RT analyses, each of the Context conditions were analyzed separately. The RT analysis of the Small-Context-Difference condition revealed a main effect of ISI Category, $F(1,15) = 51.99$, $p < .001$, and Channel, $F(1,15) =$

11.35, $p < .05$. Overall, participants responded more quickly when the target followed the shorter context sound (M = 568 ms) than when it followed the longer context sound (M = 589 ms), and response times in the Long ISI condition (M = 554 ms) were significantly faster than the Brief ISI condition (M = 612 ms).

Further analysis of the Brief ISI condition revealed that participants responded significantly more quickly when the target followed the shorter context sound (M = 601 ms) than the longer context sound (M = 624 ms), $F(1, 15) = 6.35$, $p < .05$. Likewise, in the Long ISI condition, participants also responded significantly faster when the target followed the shorter context sound (M = 536 ms) rather than the longer context sound (M = 553 ms), $F(1,15) = 5.28$, $p < .05$.

The analysis of the Large-Context-Difference condition revealed a significant effect of ISI Category, $F(1,15) = 31.39$, $p < .001$, though no significant effect of Channel, $F(1,15) = .199$, $p = .662$, and no interaction effect, $F(1, 15) = 1.12$, $p = .307$. Further analyses of the Brief and Long ISI categories produced non-significant results; RT did not significantly vary as function of Channel placement in both Brief ISI, $F(1,15) = .227$, $p = .606$ and Long ISI conditions, $F(1,15) = 1.5$, $p = .240$.

The results of the Brief ISI condition replicated the findings of Experiment 2, in that participants responded more quickly when the target followed the shorter context sound in the 100 ms ISI trials, but not the 200 ms ISI trials. Likewise, in the Long ISI condition, participants responded more quickly when the target followed the shorter context sound in the 500 ms ISI trials, but not the 600 ms ISI trials. Therefore, there was a significant attentional capture effect when there was a small difference between the offsets (75 ms), but not when there is a large difference (175 ms). Furthermore, the effect persisted with a much later target presentation. This last result is somewhat surprising given that the literature on abrupt onset capture has generally found that attentional capture effects only last up to 300 ms after the onset of the cue (i.e., Mondor & Bryden, 1992; Mondor & Lacey, 2001; Posner, 1984; Spence & Driver, 1997; Theeuwes, 1991).

General Discussion

The three experiments described above provide evidence that the sudden disappearance of a sound can capture attention. These results are consistent with the visual literature which has also found attentional capture effects with offset cues (Pratt & McAuliffe, 2001; Theeuwes, 1991). Furthermore, this evidence contradicts the new-object hypothesis and suggests that it may be appropriate to extend the transient hypothesis to include the auditory domain (e.g., Hollingworth et al., 2010; Jonides & Yantis, 1988). According to the new-object hypothesis, the abrupt onset triggers an attentional interrupt and an attentional shift *because* a new object representation needs to be created (i.e., an object file) and the object index needs to be updated. Since the disappearance of an object does not require the creation of a new object representation, it should not capture attention (Chua, 2011; Kahneman et al., 1992; Yantis, 1993). In contrast, the transient hypothesis claims that the abrupt onset captures attention because of the perceptual transients that accompany the onset (change in luminance, for example). Therefore, according to this view, an offset will be accompanied by the same perceptual transients as an onset and should capture attention (Franconeri et al., 2005; Hollingworth et al., 2010; Jonides & Yantis, 1988; Yantis & Jonides, 1984).

While there is a large amount of research in audition examining attentional capture, most have focused on the sudden onset of a cue. Previous studies have shown that a variety of auditory cues can capture attention, and the auditory literature is generally in agreement that the sudden appearance of a stimulus can capture attention (e.g, Mondor et al., 1998; Mondor & Bryden, 1992; Mondor & Lacey, 2001; Spence & Driver, 1994, 1997).

The paradigm used in all three experiments was based on the cueing paradigm developed by Posner (1980, 1984). This paradigm has been adopted by much of the auditory research to study attentional capture effects of onset cues (e.g., Mondor & Breau, 1999; Mondor & Lacey, 2001; Spence & Driver, 1994) and has been used to examine offset cues in the visual literature (e.g., Pratt & McAuliffe, 2001; Theeuwes, 1991). Experiment 1 was designed to assess whether the abrupt offset of a stimulus can evoke attentional capture effects and, more specifically, replicate the study by Pratt and McAuliffe (2001), who found visual offset cue effects. Therefore, Experiment 1 used a single offset cue (referred to as a context sound) which would offset prior to the presentation of the target. The target and cue could appear in one of two locations with equal probability, and, therefore, the cue provided no predictive information about the location of the target. Previous auditory research has found cue effects with stimulus onset asynchronies of 100 ms but null effects with SOAs as late as 450 ms (Mondor & Breau, 1999; Mondor & Lacey, 2001; Spence & Driver, 1994). Therefore, 100 and 200 ms inter-stimulus intervals (ISI) were used to examine the time-course of the attentional capture effects. However, there is little agreement in the visual attention studies about the timecourse of offset attentional capture effects. Therefore, it was hypothesized that response times would be shorter when the target appeared in the same location as the offset cue for the 100 ms ISI condition, but it was unclear whether these effects would persist with a 200 ms ISI. The results indicated that response times were shorter when the target appeared in the same location as the offset cue, however, only when the target followed the cue by 100 ms and not 200 ms. This result is consistent with the studies of auditory onset cues (Mondor & Breau, 1999; Mondor & Lacey, 2001; Spence & Driver, 1994) that have found facilitative effects of onset cues at early 100 ms SOA but not later SOAs (450 to 1000 ms). This is also consistent with the study of visual offset cues by Pratt and McAuliffe (2001), who found facilitative effects at 100 ms SOA.

While the results of Experiment 1 provide evidence that the disappearance of a sound can capture attention, there are other possible explanations for the results. First, it may be the case that the persistence of sound in one channel and absence of sound in the other caused participants to direct their attention to the offset cue channel for the entire duration of the trial. The second possibility is that the onset of the cue, which occurs only in one channel, caused participants to direct their attention to the cue channel and not the offset. Although the cue duration of 1000 ms was chosen because onset cue effects tend to dissipate by 300 to 450 ms, there is still the possibility that the effect was prolonged because of the cue stimulus persistence. Furthermore, the study by Nishimura and Yokosawa (2010) found that the accessory Simon effect could not be produced when using auditory offset cues. A critical difference between their study and the visual cue studies is the use of two dichotically presented cues. Therefore, it is possible that the overall context (one versus two context sounds) may cause differential effects. Experiment 2 was designed to address these issues by adding a second competing context sound. As stated above, offset attentional capture experiments in the visual literature have used a single offset cue and found significant offset cueing effects (Pratt & McAuliffe, 2001; Theeuwes, 1991), while the study by Nishimura and Yokosawa (2010) used two dichotically presented auditory cues and were not able to produce reliable Simon effects. Therefore, the purpose of Experiment 2 was to replicate the results of Experiment 1 with two dichotically presented context sounds. The paradigm retained the 100 and 200 ms ISI used in Experiment 1, however, the second context sound always offset 25 ms prior to the presentation of the target. Based on the results of Experiment 1, it was hypothesized that response times would be faster when the target was presented in the same channel as the context sound that offset 100 ms prior to the target, but not when the ISI was 200 ms. Results indicated that this was indeed the case, and the results of Experiment 1 were replicated.

While these results are consistent with Experiment 1 and the existing visual literature, it is inconsistent with the findings of Nishimura and Yokosawa (2010). There a number of differences between the paradigms they used and the ones adopted for the current study that may account for this disparity. One difference is that Nishimura and Yokasawa used auditory cues with visual targets. Historically, crossmodal cue-target studies have not always produced similar results as their unimodal counterparts and, furthermore, results have often been varied and inconsistent (Wright & Ward, 2008a). For example, Ward (1994) reported two experiments that examined crossmodal cueing effects. In their first experiment, subjects had to indicate whether an auditory target was presented from the left or right speaker, and in the second experiment they had to indicate whether a visual target was presented from a left or right placeholder box. In both experiments, targets could be preceded by a visual cue, an auditory cue, both, or neither. The results of this study indicated that visual cues facilitated response times for both visual and auditory targets, while auditory cues only facilitated response times for auditory targets. These results are in contrast to a pair of studies by Spence and Driver (1994, 1997), who found the opposite results. In their experiments, auditory and visual targets could appear in four different locations: two to the left and two to the right of the participant. Each lateralized pair was arranged vertically and participants were required to indicate whether the target came from the top or bottom, ignoring its lateralized position. Prior to the target presentation an auditory or visual cue could appear, again to the left or right of the participant, but from a location centered vertically between each pair of target locations. From a series of experiments using this paradigm, it was found that auditory cues facilitated both auditory and visual target identification, while visual cues only facilitated visual target identification. Given the inconsistency in results, it is unclear whether one should expect crossmodal offsest cuing effects to be similar to unimodal effects.

There is also a difference in how the cue and targets are presented: Nishimura and Yokasawa (2010) presented the cue and target simultaneously. While simultaneous presentation is typical for experiments examining the Simon effect, in a typical cueing paradigm the cue precedes the target by at least 50 to 150 ms (e.g., Mondor & Bryden, 1991, 1992; Mondor & Lacey, 2001; Posner, 1980; Pratt & McAuliffe, 2001; Spence & Driver, 1994). Since the offset of the auditory cue and the onset of the visual target occur simultaneously, they are in effect put in competition. Previous studies have shown that simultaneous presentation auditory and visual peripheral cues do not diminish the attentional capture effects of either of the cues (Koelewijn, Bronkhorst, & Theeuwes, 2009b; Spence & Driver, 1997). However, there have been studies in the visual literature that have found differential effects of simultaneous onset and offset cues (e.g., Pratt & Hirshhorn, 2003; Pratt & McAuliffe, 2001). Pratt and McAuliffe (2001), for example, included trials with simultaneous offset and onset cues. In their experiment, the initial display consisted of two placeholder boxes located to either side of a central fixation point. The target was the enlargement of one of the boxes and the cues could appear in either of the placeholder boxes. In one of the conditions, a cue would offset in one of the placeholder boxes while another would simultaneously onset in the other placeholder box. For this condition, it was found that response times were faster when the target occurred in the onset-cued location than the offset-cued location, suggesting that the onset cue was given priority over the offset cue. Therefore, it may be the case that the onset of the target received attentional priority over the auditory offset cue.

In addition, the accessory Simon paradigm does not involve target localization. In the typical accessory Simon paradigm, the display begins with a central fixation point followed by the target which is always presented in the center of the display. In other words, the target is endogenously cued to the center of the display with 100% validity. The literature is mixed about whether endogenously focused visual attention can be interrupted by auditory peripheral cues. While there are studies that show that endogenously focused visual attention can be interrupted and has no effect on the attentional capture effects of an auditory cue (e.g., Koelewijn et al., 2009a; Mazza, Turatto, Rossi, & Umiltà, 2007; van der Lubbe & Postma, 2005), there is also recent evidence that shows that when visual attention is focused via an additional task, (Santangelo & Spence, 2007) or when a predictive visual cue is presented at the same time (Koelewijn et al., 2009b), auditory cues fail to capture attention. Again, the evidence is mixed, so it is unclear whether focused visual attention could mitigate the attentional capture effects of the auditory offset.

Finally, in Nishimura and Yokasawa's (2010) experiment, one auditory cue would terminate while the other would persist for additional 2000 ms, while in Experiment 2 of the current study, both sounds terminated before the presentation of the target. Since both the target and cues were auditory stimuli in the current study, the target needed to be presented in isolation to prevent possible masking effects of the remaining context sound. It is possible that the persistence of sound in Nishimura and Yokasawa's experiment caused a shift in attention, while presenting the target in isolation in the current study allowed for more robust attentional capture effects.

Experiment 3 was designed to examine the effects of later target placement and to replicate the findings from Experiments 1 and 2. Experiment 3 was identical to Experiment 2, with the addition of conditions where the target is presented further from both context sounds. From the previous literature it was unclear whether the effect should persist, or, perhaps with a longer gap between the second context sound and the target, if it was possible that the second offset would capture attention. The results of Experiment 3 successfully replicated the findings from Experiments 1 and 2, and attentional capture effects were found when the target followed the early context sound by 100 ms, but not 200 ms. When the target was presented further from both context sounds it was found that the original effect persisted: target identification was facilitated when the target was presented in the same channel as the short context sound. The target facilitation at 500 ms ISI is surprising given that a number of previous auditory attentional capture studies have found null effects at 400 to 450 ms SOA (e.g., Mondor & Breau, 1999; Mondor & Lacey, 2001; Spence & Driver, 1994). However, there are some studies that show attentional capture effects at later SOAs. For example, Mondor and Bryden (1992) did find location cue effects with a 450 ms SOA, and Spence and Driver (1994) noted that, while the attentional capture effects were not significant for the 400 ms SOA condition, 14 of the 30 subjects responded faster when the target followed the cue in the 400 ms SOA condition.

The results of Experiment 3 also suggest that the 75 ms difference between the offsets in the small-context-difference condition was insufficient for participants to disengage attention from the first offset and reorient to the second offset. These results are consistent with recent estimates of attentional dwell time. Logan (2005), for example, modelled the time needed to encode and switch between cues using a typical visual cue paradigm (see Eriksen & Hoffman, 1972). Through model fitting, Logan estimated that cue encoding takes 67 to 74 ms and attention switching takes 76 to 101 ms; therefore, 75 ms would be insufficient to both encode the first offset cue and switch to the second offset.

Experiment 3 also showed non-significant results for the large-context-difference condition in both the Brief and Long ISI trials. As with Experiment 2, there were no attentional capture effects when the target was presented 200 ms after the offset cue, suggesting that the attentional capture effects of the offset dissipates within 100 to 200 ms when there is a competing context sound in the opposite channel. An interesting, but surprising, result was that the attentional capture effect persisted from 100 to 500 ms after the offset cue when there was a small difference between the offset cues (75 ms), but did not produce any attentional capture effects at 200 or 600 ms ISI when there was a large difference between the offset cues (175 ms). This signifies the importance of the overall context on the attentional capture effects of sound disappearance and suggests that the effect of multiple context objects should be explored in both the auditory and visual modality.

Lastly, when the target was presented further from both context sounds in the large-context-difference trials, both offset cues failed to capture attention. It may have been the case that the 175 ms difference represents a middle ground, where the attentional capture effects of the first offset have dissipated but are still interfering with the ability of the second offset to orient attention. This interpretation is consistent with the model presented by Logan (2005), which suggested that 175 ms is at the extreme end of the estimated time to encode and switch attention between cues. Therefore, it may be sufficient time for some participants and not for others.

Taken together, the results of the three experiments suggest that, under some conditions, the sudden disappearance of a sound can capture attention. Furthermore, these results suggest that, under most conditions, the attentional capture effect generally dissipates quickly (100-200 ms), which is consistent with the previous literature. The results of Experiment 3, however, reflect the importance of overall context. By introducing a second context sound and placing the target further away from both context sounds, the attentional capture effects persisted for 500 ms.

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