THE INFLUENCE OF OBJECT FILE CONTINUITY ON THE AUDITORY ATTENTIONAL BLINK

BY

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ABSTRACT

The three experiments were designed to investigate the auditory attentional blink (AB). On each trial, listeners were required to detect a target and a probe sound presented in a rapid series of distractor sounds. Across experiments, the target and the probe could differ from the distractors at the feature level or at the object level. Experiment 1 indicated that there was a larger auditory AB when the target differed from the distractors at the object level than when it differed from the distractors at the feature level. Experiment 2 showed that, when the distractors were pure tones, small auditory AB deficits were apparent when the target and the probe both differed from the distractors at the object level and when they both differed from the distractors at the feature level. In contrast, when the distractors were pulse sounds, a large auditory AB deficit was apparent when both the target and the probe both differed from the distractors at the feature level but not when they differed from the distractors at the object level. Experiment 3 provided converging evidences that the auditory AB is influenced by both the requirement of creating and consolidating a new object file for the target and the overwriting of the probe by the distractors following it. These results can be explained by a revised version of the two-stage model (Chun & Potter, 1995; Giesbrecht & Di Lollo, 1998; Jolicoeur, 1998) which incorporates the thoughts of the object file continuity theory (Raymond, 2003).

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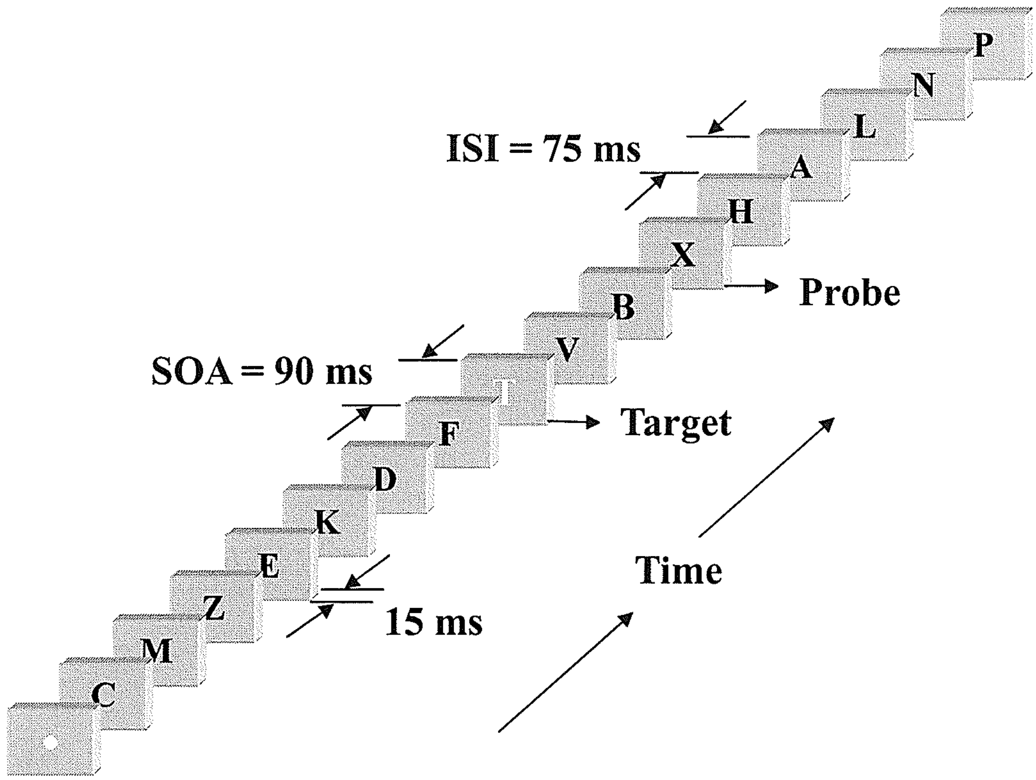
INTRODUCTION

It has been established that if two targets are to be identified among distractors in a rapid serial visual or auditory presentation (RSVP or RSAP) stream (an example of a visual stream is shown in Figure 1), correct identification of the first target may produce a deficit in processing the second target lasting several hundred ms (e.g., Broadbent & Broadbent, 1987; Chun & Potter, 1995; Duncan, Ward, & Shapiro, 1994; Jolicoeur, 1998; Kellie Shapiro, 2004; Raymond, Shapiro, & Arnell, 1992; Shapiro, Raymond, & Arnell, 1994; Shen & Mondor, 2006). This processing deficit has been labelled the attentional blink (AB) by Raymond et al. (1992), and it provides important information about the deployment of attention in the temporal domain.

Visual AB Studies

Two procedures have been used to study the visual AB. One is the RSVP procedure, and the other is the critical-items procedure. In most studies of the visual AB, the RSVP procedure has been employed. In the RSVP procedure, the two targets (hereinafter the first of these will be referred to as the 'target' and the second will be referred to as the 'probe') are presented in a rapid serial visual presentation stream. Distractor items are presented prior to the target, between the target and the probe, and following the probe. Normally, the stimulus onset asynchrony (SOA) is about 100 ms between successive items. However, in a few studies the SOA was much shorter (e.g., 13 ms and 40 ms in Potter, Staub, & O'Connor, 2002) or much longer (e.g., 250 ms in Duncan, Martens, & Ward, 1997). In general, the number of the items in one stream varies from 12 (e.g., Broadbent & Broadbent, 1987) to 25 (e.g., Kawahara, Di Lollo, & Enns, 2001). In contrast, in the critical-items procedure (Duncan, Ward, & Shapiro, 1994), only four items are presented in a sequence; namely, the target, the mask following

Figure 1. An example of the visual AB presentation procedure based on Experiment 2 of the study of Raymond, Shapiro, and Arnell (1992)



the target, the probe, and the mask following the probe.

Whether the RSVP or the critical-items procedure is used, performance in an experimental condition is compared with that in a control condition. In the experimental condition, participants are required to identify or detect both the target and the probe. Two different types of control conditions have been used. The probe is to be detected or identified in both of these conditions. In one type of control condition, participants are instructed to ignore the target, although it is presented. In the other type of control condition, participants are instructed to detect the target, but it is absent. The advantage of the former approach is that it can help evaluate the effect of sensory masking; the advantage of the latter approach is that it can help assess the effect of involuntary attentional capture. Typically, the accuracy of probe detetcion is higher in the control condition than in the experimental condition, and this difference decreases as the time between the target and the probe increases. This 'attentional blink' persists for approximately 400 - 500 ms (e.g., Broadbent & Broadbent, 1987).

Quite a large number of studies have been conducted to examine the visual AB phenomenon using various kinds of materials, such as letters (e.g., Isaak, Shapiro, & Martin, 1999; Jiang & Chun, 2001; Jolicoeur, 1998, 1999; Jolicoeur & Dell'Acqua, 1998; Raymond et al, 1992, 1995; Seiffert & Di Lollo, 1997; Shapiro et al., 1994), letters and digits (e.g., Brehaut, Enns, & Di Lollo, 1999; Chun & Potter, 1995; Giesbrecht & Di Lollo, 1998; Kawahara, Di Lollo, & Enns, 2001; Kawahara, Zuvic, Enns, & Di Lollo, 2003), words (e.g., Broadbent & Broadbent, 1987; Olson, Chun, & Anderson, 2001; Potter, Staub, & O'Connor, 2002), syllables (e.g., Olson et al., 2001), dot patterns (e.g., Giesbrecht & Di Lollo, 1998) , keyboard symbols (e.g., Chun & Potter, 1995; Potter et al., 2002), line segments (e.g., Kawahara et al., 2001; Kawahara et al., 2003), geometric figures (e.g., Raymond, 2003), object images (e.g., Kellie & Shapiro, 2004), and so on.

The visual AB has been shown to be influenced by a variety of factors including; attention task (e.g., selective set vs. selective filtering, Broadbent & Broadbent, 1987), association between the target and the probe (e.g., table and chair, Broadbent & Broadbent, 1987), similarity between the target and the probe (e.g., Shapiro et al., 1994), similarity between the item immediately following the target and the other items (e.g., Chun & Potter, 1995; Raymond et al., 1992; Raymond, Shapiro, & Arnell, 1995; Seiffert & Di Lollo, 1997), similarity between the item immediately following the probe and the other items (e.g., Chun & Potter, 1995), the number of items in stream (e.g., Isaak, Shapiro, & Martin,1999), the type of target (e.g., a new object or new feature; Raymond, 2003), the arrangement of the stream items (e.g., object file continuity; Kellie & Shapiro, 2004), the global discriminability of the distractors (e.g., Chun & Potter, 1995), target processing difficulty (e.g., Chun & Potter, 1995; Jolicoeur, 1998, 1999; Olson et al., 2001), the overwriting (object-substitution) of the Probe (e.g., Giesbrecht & Di Lollo, 1998; Karawahara et al., 2003), luminance level of masking for the target and the probe (e.g., Brehaut et al., 1999), and SOA between the target and the probe and the items immediately following them (e.g., Brehaut et al., 1999).

Theoretical Accounts of Visual AB

A variety of different theories have been proposed to explain the visual AB on the basis of evidence obtained in these studies. These theories include the 'two-stage detect-then-identify model' (Broadbent & Broadbent, 1987), the attentional gate model (Raymond et al., 1992), the competition hypothesis (Shapiro et al., 1994), the dwell time theory (Duncan, Ward, & Shapiro, 1994), the two-stage model (Chun and Potter, 1995), the central interference theory (Jolicoeur, 1998), the object-substitution account

(Giesbrecht & Di Lollo, 1998), the two-stage competition model (Potter, Staub, & O'Connor, 2002), and the object file continuity theory (Raymond, 2003; Kellie & Shapiro, 2004). Each of these theories is summarized below.

Two-Stage Detect-Then-Identify Model. The first model proposed to explain the AB was the 'two-stage detect-then-identify model' (Broadbent & Broadbent, 1987). This model consists of two stages. In the first stage, the physical features of every item in an RSVP sequence are encoded in parallel. The second, capacity-limited, stage of processing will begin only when enough features of a potential target have been encoded. The target items (target and probe) are identified in this capacity-limited stage that is "based on computation of the conjunction of features" (p. 112). Thus, the AB arises because ongoing processes involved in the identification of one target occupy the limited resources available so that insufficient resources are available to identify a second target.

This model makes several predictions. First, because the second stage is capacity-limited, the successful identification of one critical item (i.e., the target or the probe) will decrease the possibility of identification of the other critical item. In the Experiment 1 of Broadbent and Broadbent's (1987) study, this prediction was supported. Subjects were presented with RSVP streams consisting of 12 five-letter words (nouns). The two targets (target and probe) were presented as capital letters or animal names. The distractors were lower case nouns (excluding animal names). The target could be presented at one of the first eight temporal positions, and the probe could be presented in one of first four positions following the target (i.e., +1, +2, +3, or +4 position). Note that the first and the last three words could never be the target or the probe. SOA between successive items was 80 ms, and inter-stimulus interval (ISI) was 0. The subjects were required to write down the target and probe at the end of each trial. The results revealed that subjects correctly identified either the target or the probe but not both when the probe was in the +1 position. Thus, it seems that the identification of one critical item reduced the possibility of identification of the other.

A second prediction of the model is that the AB should be reduced when interference is reduced. In Experiment 2 of Broadbent and Broadbent's (1987) study, two conditions were used; associated target and probe (e.g., table and chair), and non-associated target and probe. The authors reasoned that when the target and the probe were associated, the identification of one would assist in the identification of the other. The results revealed that the correct identification of one critical item still impaired the identification of the other even in the associated condition. However, at the +1 position the probe processing deficit was smaller in the associated condition, suggesting that a semantic association did reduce interference.

In brief, these experiments demonstrated that the interference between the identification of the target and the identification of the probe did affect the AB, and thus supported the two-stage detect-then-identify model. This model was the first offered to explain the AB, and it has produced a tremendous influence on development of theoretical accounts of the AB. However, it ignores the effect of distractors on the AB that is addressed by most of the more recent models.

Attentional Gate Model. According to the attentional gate model (Raymond et al., 1992), target identification (one episode) is thought to require two stages. In the first stage, a key feature is detected (this may be, for example, colour with participants instructed to 'look for a red letter'). In the second stage, the key feature is linked with the appropriate response in a process that produces conscious identification. An attentional gate is shut and locked following detection of the critical target feature to protect the identification process if a new stimulus (the item immediately following the target) is presented, and this 'locking' results in an active inhibition against processing new items. This inhibition lasts for about 400 ms during which time the probe is unlikely to be detected. This model is then similar to the 'two-stage detect-then-identify model' (Broadbent & Broadbent, 1987) but addresses the effect of inhibition rather than the effect of the interference.

This model predicts that both identification and detection tasks can produce an AB (Broadbent and Broadbent, 1987, argued that the AB is caused by interference between the identification of the target and the identification of the probe) and states that the AB is attentional in nature rather than caused by low-level sensory masking. In Experiment 2 of Raymond et al. (1992), probe detection rather than identification was required and, in the control condition, participants were instructed to ignore the target. This control condition was used to rule out the possibility that the AB might be caused by sensory masking of the probe by the target. The number of distractors prior to the target varied from 7 to 15. SOA was 90 ms, and ISI was 75 ms. Eight letters always followed the target. In the experimental condition, the subjects were required to identify any white letter presented (target) and to detect the letter 'X' (probe) which could be embedded in sequences of black distractor letters. In the control condition, the subjects were instructed to ignore the target, and only to detect the probe. The probe could be presented in temporal positions 0 through + 8 positions. At the '0' position, the target and the probe were presented simultaneously as a white 'X'. The results revealed a robust AB, thus demonstrating that a detection task can produce an AB deficit. In addition, it appears that the AB deficit was attentional in nature rather than the product of sensory masking because there was still a robust AB when the target-ignored condition was used as the control condition.

A second prediction of the attentional gate model is that the AB is ballistic (the item immediately following the target triggers the AB) and time-dependent. Raymond et al. (1992) conducted two experiments to examine whether the probe deficit was ballistic or not, and to examine whether it was time-dependent or event-related. In Experiment 3, blank periods of 0, 90, 180, or 270 ms could follow the target. In different conditions, subjects were instructed to either attend to, or ignore, the target. The results revealed a probe processing deficit only when a 0 ms blank period followed the target (full stream). This suggests that the AB is ballistic because it was eliminated when presentation of the item immediately following the target was deleted. In Experiment 4, blank periods of 0, 90, and 180 ms could follow the +1 item and probe processing deficits were apparent for all of these. This result suggests that the AB can be caused when an item immediately follows the target (+1 item) regardless of whether or not there was an item following the +1 item. Thus, the AB appears to be ballistic and time-dependent rather than event-dependent.

In brief, these experiments suggest that the AB is triggered by the item immediately following the target (of course, this is just a possibility about how the +1 item affect the AB), and that the AB is time-dependent. These results support the attentional gate model (Raymond et al., 1992). In addition, it is clear that a detection task may also cause the AB, and this result does not support the model of Broadbent and Broadbent (1987) which states that the AB is caused by the interference between the identification of the target and that of the probe (Broadbent & Broadbent, 1987). However, as some researchers (e.g., Chun & Potter, 1995) have pointed out, the use of a detection task does not completely rule out the possibility of identification. In addition, the attentional gate model only concerns itself with the effect of the +1 item, but does not take into account any effect of the other distractors on the AB.

Competition Hypothesis. The competition hypothesis (Shapiro et al., 1994) is a late-selection model based on the idea that an internal representation that includes both perceptual and conceptual characteristics is created for each item in an RSVP stream. Each representation is compared with an internal template defined by the instructions given to participants. When an item matches the template, it enters into visual short-term memory (VSTM), and will then be processed for about 500 ms during which time the perceptual and conceptual characteristics of the item are integrated to form a unitary representation. Only items that enter VSTM can become a response item. Both the target and the probe are admitted to VSTM. However, the model asserts that the distractors immediately following the target and probe are likely to enter into VSTM because they are presented in a similar temporal position to the targets. Raymond et al. (1992, p. 61) wrote that "depending on the goodness of the match, representations are assigned a weighting in VSTM". Moreover, "the total assignable weighting is limited, and weightings may degrade with the passage of time. The likelihood that a representation will be selected out of VSTM and passed on to a report stage may depend on its weighting assignment, the number of other items in VSTM, the similarity of items in VSTM, or a combination of these factors" (Raymond et al., 1995, p. 661). According to this theory, the AB is caused by competition for limited perceptual and semantic processing resources between the target, the probe, and any distractors admitted to VSTM. This competition is greatest when the probe immediately follows the target because these items will have the longest common processing time in this situation. Competition decreases as the time between the target and probe increases. Thus, the probe processing deficit is larger at shorter SOAs than at longer SOAs.

The theory predicts that there is a relationship between the similarity of the target and the probe and the magnitude of the AB because a high degree of similarity can make them difficult to select out of VSTM. In Experiment 5A of Shapiro et al.'s (1994) study, they required subjects to detect a temporal gap (165 ms) in a sequence of black letters as the target task. Detecting an 'X' was the probe task. The results revealed no significant AB. In Experiment 5B, they required subjects to identify a short (165 ms) or long (255 ms) gap as the target task to examine whether identification can cause the AB. Again, no AB was apparent. Thus, the results of these experiments suggested that there was no significant AB when the target (gap) and the probe (letter) were very dissimilar. Of course, as the authors themselves mentioned, these results may also indicate that the target must consist of pattern information to cause AB.

A second prediction of the competition model is that the similarity of the target and probe to the distractors can influence the AB because a high degree of similarity can make the probe difficult to select out of VSTM. Raymond et al. (1995) examined this possibility by adjusting the similarity between the target and probe and +1 item (they manipulated categorical dissimilarity in Experiment 1, feature dissimilarity in Experiment 2, and spatial dissimilarity in Experiment 3). The procedure was similar to that used in Raymond et al.'s (1992) study in that each item was presented for 15 ms, and ISI was 75 ms. In Experiment 1, the +1 item was a number (from 2 to 9) for both conditions. In the experimental condition, the subjects were required to name a white letter (target) and to detect a black 'X' (probe) in a sequence of black letters. In the control condition, the subjects were instructed to ignore the white letter and to detect the black letter 'X'. The results revealed a significant AB. In comparing these results with those obtained in

Experiment 2 of Raymond et al. (1992) in which all items in the sequences were letters, they found that categorical dissimilarity did not reduce the magnitude of the AB. The influence on the AB of featural similarity of the target and the probe to the +1 item was tested in Experiment 2. In one condition, the + 1 item was a black random-dot pattern (the 'dots' condition). In a second condition, the +1 item was a black letter 'S' (the 'same-letter' condition). The results revealed a significant AB for both conditions; however, there was a smaller magnitude of AB in the dots condition. Thus, featural similarity did affect the magnitude of the AB. In Experiment 3, the influence of spatial similarity of the target and probe to the +1 item was tested. The +1 item was always a black letter 'S'. In the displaced condition, it was presented in a different spatial position (right of the fixation spot) from other items (left of the fixation spot). In the non-displaced condition, the +1 item was presented in the same position as other items. The results revealed a significant AB for both conditions; however, a smaller AB was observed in the displaced condition. Thus, spatial similarity affected the magnitude of the AB. In brief, the featural and spatial similarity of the target and probe to the +1 item did affect the magnitude of the AB.

A third prediction of the competition hypothesis is that the magnitude of the AB should increase with the number of items in VSTM. Evidence supporting this prediction was reported in Experiment 3 of Isaak et al. (1999). On each trial in their study a sequence consisted of a target (N or Z), a +1 item ('M' or a pattern mask), a +2 item ('A' or a pattern mask), a probe ('K' or 'Y'), and an item immediately following the probe ('W' or a pattern mask). Thus, whereas 5 items were presented on every trial, the number of letters varied from 2 to 5. The authors assumed that only letters would compete for processing with the target and probe. The subjects were required to identify the target and to detect the probe. The results revealed that the magnitude of the AB was increased with the number of letters presented in the sequence. Thus, it appears that the number of items in VSTM does affect the magnitude of the visual AB.

The fourth prediction of the competition hypothesis is that there should be no relationship between target processing difficulty and the magnitude of the AB because this does not affect competition for processing in VSTM. In Experiment 1 of the study of Shapiro et al. (1994), the number of potential target items was reduced from 25 (Raymond et al., 1992) to 3. However, a significant AB remained and its magnitude was not reduced. It appears, then, that target processing difficulty does not affect the magnitude of the AB.

In summary, the experiments described above indicate that the similarity between the target and the probe, the similarity of the target and probe to the distractors, and the number of items in VSTM all affect the magnitude of the AB. All of these results support the competition hypothesis (Shapiro et al., 1994). However, although this model addresses the effect of the distractors, it does not distinguish the effects of distractors in different temporal positions in the sequence. In fact, it attributes the effects of all distractors to competition in VSTM. It is so rigid that some patterns of performance cannot be directly explained by it. For example, the competition hypothesis cannot explain results reported by Shen & Mondor (2006) who found that the item following the probe, but not the +1 item, affected the magnitude of the auditory AB (see also Mondor, 1998).

Dwell-Time Theory. The dwell-time theory (Duncan, Ward, & Shapiro, 1994) states that, “visual attention is not a high – speed switching mechanism, but a sustained state during which relevant objects become available to influence behavior. Attention can be divided between several objects at once, but with increasing cost as the number of attended objects increases." (p. 313). According to Duncan et al. (1994), it is this cost of dividing attention that causes the AB.

This model states that the critical-items procedure (target, pattern mask, probe, and pattern mask) may cause the AB deficit because of a limitation in dividing attention between the target and the probe. Duncan et al. (1994) used the critical-items procedure to test this theory. One target was a green digit (either 2 or 5) presented at one of two horizontal locations (either left or right frame). Another target was a red letter (either L or D) presented at one of two vertical locations (either top or bottom frame). Both items were presented for 45 – 60 ms. The SOA between the two targets was 0 – 900 ms (0 ms SOA means that the two targets were presented simultaneously). If a red letter was presented as the target, then a green digit would be presented as the probe, and if a green digit was presented as the target, then a red letter would be presented as the probe. The target and the probe were both followed by a 250 ms pattern mask. In different conditions, the subjects were required to identify only the red letter, only the green digit, or both (the single task was used as the control condition, and the double task was used as the experimental condition). The results revealed a significant AB deficit that lasted for several hundred ms when both letters were to be detected. This result is consistent with the idea that dividing attention between two items results in the probe-processing deficit.

A second prediction of the dwell-time model is that even when the target is absent, a non-target or distractor item also can impair perception of the probe because the distractor also can draw some attention away from the probe. In Experiment 2 of the study reported by Duncan et al. (1994), on each trial a pattern mask was presented followed by two items, both of which were the letter L. Subjects were required to detect the upright letter L, which could be the target (first item) or the probe (second item). The target and probe were defined as an upright L. Distractor items were defined as the letter L rotated 90° clockwise or counter-clockwise. The results revealed that detection of the upright L presented in the probe position was impaired by a preceding nontarget item. Thus, it seems that a non-target item also can draw some attention away from the probe.

A third prediction of the dwell-time model is that the AB deficit is caused by a limitation of visual attention rather than by a limitation in response selection (i.e., the psychological refractory period; e.g., Pashler, 1989). Ward, Duncan, and Shapiro (1996) studied this issue. In Experiment 2 of their study, they manipulated the number of potential target objects and the number of object attributes that had to be monitored. If the visual attention limitation hypothesis is correct, then only the number of potential target objects should affect perception of the probe. On the other hand, if the response selection limitation hypothesis is correct, then the number of the independent responses should affect the perception of the probe. In this experiment the target was a digit (either 2 or 5), and the probe was a letter (either L or T). The SOA between the target and the probe was 0, 100, 200, 300, 450, 600, or 900 ms. The target could be larger or smaller than the other items. There were 4 conditions in the experiment. In one condition the target was to be ignored and the probe was to be identified. In a second condition, the target and probe were both to be identified and the required responses were independent of one another. In a third condition, target size was to be judged and the probe was to be identified and the responses were independent of one another. In the fourth condition, the size of the target was to be judged and the identity of both the target and probe were to be determined, and all three of these responses were independent of one another. Results showed that the accuracy with which the probe was identified was higher when the target was ignored than when it was to be judged, and there was no difference in probe accuracy in the three conditions in which both the target and probe were judged. Thus, it appears that the number of potential target objects rather than the number of the independent responses affected probe perception. In another experiment, Ward et al. (1996) manipulated the number of the target objects (one or two digits). The probe was still a single red letter (L or T). The results revealed that probe performance was better in the one-object target condition than in the two-object target condition. Thus, once again, the number of potential target objects affected perception of the probe. These results suggest that the AB deficit is caused by a limitation of visual attention rather than by a limitation in response selection.

A fourth prediction of the dwell-time model is that there is no relationship between the similarity of the target and the probe and the magnitude of the AB because this model suggests that it is the number of relevant objects that must be attended that determines the magnitude of the AB. Ward, Duncan, and Shapiro (1997) conducted several experiments to examine this prediction. In Experiment 1, the target could be either the letter X or an outline box shape and could be either large or small. The probe was always the letter X. (Note that, in contrast with their previous studies, in this study the target and the probe were presented at the same location in order to eliminate the effect of location switching.) The target was presented in white and the probe was presented in black, and each was followed by a mask of the same colour. Target and probe were each presented for 15 ms. SOA between target and mask was always 90 ms. Target – probe SOA ranged from 180 to 810 ms. The subjects were required to judge the size of the target, and to detect the probe. The results revealed a significant probe processing deficit, but no effect of similarity of the target and the probe because there were no differences in the magnitude of the AB in the letter target and outline box target conditions. Thus, there appears to be no relation between similarity of the target to the probe and the magnitude of the AB.

In Experiment 2, an RSVP procedure was used. The target was white, the probe was black, and all of the distractors were black. There were 7 – 15 distractors prior to the target and 8 distractors following the target. Each item was presented for 15 ms, and SOA was 90 ms. The difficulty of detecting the target was manipulated in two conditions. Whereas, in the 'hard' condition the target was small or medium in size, in the 'easy' condition the target was small or large in size (target size was defined relative to the size of the probe and the distractors). There were also three conditions in which the similarity of the target to the other items was manipulated. In the 'different category' condition the target was an outline box. In the 'same category' condition the target was the letter S. In the 'identical condition' the target was the letter X. The probe was always the black letter X, and the distractors were black nontarget letters. The results revealed probe processing deficits in all conditions. In addition, there was a larger deficit in the identical condition than in the other conditions and the authors argued that this may indicate the effect of repetition blindness. There was, however, no effect of target processing difficulty. Thus, these results suggest that there is no relationship between the similarity of the target to the probe and the magnitude of the AB.

In summary, the experiments described above are consistent with the notion that the AB reflects a limitation of visual attention which arises when attention needs to be divided between different objects. The AB does not appear to be related to a limitation in response selection, or to the degree of similarity between the target and the probe. Thus, these results are consistent with the dwell time theory (Duncan et al., 1994). In fact, this theory is similar to the competition hypothesis (Shapiro et al., 1994). They both assume that the target and the probe can be processed in parallel (in direct contrast with the two-stage model which suggests that the target and the probe are processed sequentially). However, the dwell-time hypothesis emphasizes a limitation in dividing attention, and the competition hypothesis emphasizes the competition for processing resources in VSTM between the target, the probe, and the distractors. The dwell-time model ignores the effect of distractors. Although Duncan et al. (1994) and Ward et al. (1996, 1997) used the critical-items procedure, it is possible that the masks following the target and the probe may also serve as distractors, and thereby play an important role in generating the AB.

Two-Stage Model. The two-stage model (Chun & Potter, 1995) is based on two stages of processing. In an initial stage, each item in the RSVP stream is momentarily identified. However, to successfully report the target and probe, they must be processed in a second limited–capacity stage. In this second stage, the target items are processed in a serial fashion according to the task requirements. Thus, when the participant must report both the target and the probe, there is a delay in processing the probe caused by ongoing processing of the preceding target. The +1 item can be processed together with the target thereby increasing the delay. During this delay the representation in memory of the probe may decay or be interfered with by subsequently presented distractors, and this deterioration in the representation of the probe is responsible for the probe processing deficit. Because the probe processing delay is greatest when the probe is presented immediately following the target, the impairment in probe processing declines as the time between the target and probe increases.

This model makes several predictions. First, each successive target can produce an AB deficit. In their Experiment 2, Chun and Potter (1995) examined whether an AB deficit can occur following the probe as well as following the target. The sequence presented on each trial consisted of 3 targets (letters) and 14 distractors (digits). The first target was presented in position 2, 3, or 4, a second target was presented in one of the first 6 positions following the first target, and the third target was presented in one of the first 6 positions following the second target. The subjects were required to identify all three targets. The results revealed that AB deficit occurred after the probe as well as after the target.

A second prediction of the model is that there are local effects of the item immediately following the target and of the item immediately following the probe. The item following the target can be processed together with the target thereby increasing target processing difficulty (and duration). The item following the probe can interfere with probe processing (a precise explanation of this was not given in their paper). In Experiment 3 of Chun and Potter (1995), there were three conditions. One was a full – stream condition, in which there were 16 items in the sequences. Each item was presented for 100 ms with 0 ms ISI. The target and the probe were letters, and the distractors were digits. The target was presented in position 3, 4, 5, 6, or 7, and the probe was presented in positions +1 though +8 following the target. The subjects were required to identify the target and the probe. In the other two conditions either the +1 item or the +2 item was replaced by a blank. The results revealed a reduced AB when the +1 item was replaced by a blank but not when the +2 item was replaced by a blank.

In Experiment 4, the sequence presented on each trial consisted of 13 items. The target and the probe were letters and the distractors were digits. The target was presented in positions 3, 4, or 5, and the probe was presented in positions +1 to + 6 following the target. The item immediately following the target or the probe could be a digit (2 through

9) or a symbol (<, >, =, #, %, ?, /, and *). The results revealed a significant AB for all conditions (digit – digit, digit – symbol, symbol – digit, and symbol – symbol). However, the magnitude of AB was as follows: digit – digit > symbol – digit > digit – symbol > symbol – symbol. Thus, it appears that the items immediately following the target and the probe do appear to have significant influences on the AB.

Seiffert and Di Lollo (1997) also examined this issue by using the procedure of Raymond et al. (1992) except that all items were white, and the target was brighter than other items. The results of their first experiment revealed that a larger AB was apparent when full stream sequences were presented than when the +1 item was replaced by a blank. In Experiment 4, there were two conditions. In the ‘simultaneous’ condition the target was presented with a distractor simultaneously at different locations and the +1 position was always blank. In the ‘delayed’ condition the target was presented alone and there was a distractor at the +1 position. The results revealed a larger AB in the delayed condition. Overall, the results suggest that the +1 item affects target processing difficulty, and thus affects the magnitude of the AB.

A third prediction of the two-stage model is that there is a global discriminability effect of all distractors on the AB. Chun and Potter (1995) examined this prediction. Target-distractor similarity was varied in two conditions; namely, a ‘low discriminability’ (digit) condition, and a ‘high discriminability’ (symbol) condition. The target and the probe were always letters. Whereas, in the low discriminability (digit) condition there was a significant AB, in the high-discriminability (symbol) condition there was only a small AB. In general, then the AB was attenuated in the high-discriminability (symbol) condition. Chun and Potter (1995) argued that there was a global effect of the distractors on the discriminability of the target and probe. Overall discriminability affected target processing difficulty, and thereby determined the delay in processing the probe which is related to the likelihood of the probe representation passively decaying or being interfered with by the distractors. In addition, the discriminability of probe also would directly affect the possibility of its passive decay and of its being interfered with by the distractors. Thus, the overall discriminability affects the magnitude of the AB.

A fourth prediction of the two-stage model is that target processing difficulty affects the magnitude of the AB. Olson, Chun, and Anderson (2001) examined whether target processing difficulty affects the magnitude of the AB. Following the view of Jolicoeur (1998), they proposed that the short-term consolidation of the target rather than its initial sensory registration affects the magnitude of the AB. Short-term consolidation refers to "the process of encoding information into short-term memory" (Jolicoeur, 1998, p. 1028). Olson et al. (2001) manipulated the phonological word length (the number of syllables) of the items. In Experiment 1 pronounceable pseudowords were used for targets, and real words were used for probes. Distractors were five-syllable pseudowords. The visual length and phonological length of words and pseudowords were manipulated (visually short, phonologically short, visually long, and phonologically long). There were 15 items in each sequence. Each item was presented for 147 ms and ISI was 0 ms. The target was a one-syllable or four-syllable pseudoword (half were visually short and half were visually long). The probe was always a two-syllable real word. Whereas the target was green, the probe was blue, and the distractors were black. The target could be presented in positions 2 through 5, and the probe could be presented in the +2, +4, or +8 positions following the target. The results revealed that there was a larger AB for phonologically long pseudowords than for phonologically short pseudowords, and thus the phonological length of the target affected the magnitude of AB, but the visual length of the target did not affect the AB even though it did affect target performance. In Experiment 2 of their study, Olson et al. (2001) used real words for the target and obtained results that also verified that phonological word length influences the magnitude of the AB in that there was a larger AB for phonologically long words than for phonologically short words. Thus, it appears that short-term consolidation of the target rather than its initial sensory registration is of primary importance in determining the magnitude of the AB.

In brief, the experiments described by Chun and Potter (1995), Olson et al. (2001), and Seiffert & DiLollo (1997) demonstrate the importance of the distractors immediately following the target and the probe, the global effect of all distractors, and target processing difficulty on the AB, and thus support the two-stage model. The most important contribution of this model is that it separates the effect of the + 1 item from that of the item immediately following the probe (i.e., whereas the former can increase the difficulty of target processing, the latter can interfere with probe processing). This makes the model more flexible than many of the other models. In addition, it also addresses the global effect of all distractors on the AB. However, this original two-stage model does not give details about the capacity-limited stage and how the item immediately following the probe interferes with probe processing. Later, revised two-stage models were offered which included such details (i.e., the central interference theory and the object-substitution account).

Central Interference Model. Jolicoeur (1998) developed a central interference theory based on the two stage model described by Chun & Potter (1995). In this model the capacity-limited second stage is explicitly identified as short-term consolidation (STC). Furthermore, many cognitive operations that require central, capacity-limited processing can interfere with STC of the probe, such as response selection, STC of the target (two-stage model; Chun & Potter, 1995), mental rotation, retrieval from long-term memory, and task-switching.

This model makes several predictions. First, when the target task requires a speeded response, a larger AB will be apparent because this model assumes that response selection also can affect the AB. In the conventional AB paradigm, the target and probe tasks are all unspeeded. In the study of Jolicoeur (1998), the target task was speeded (i.e., performed on-line) in order to study whether this change would affect the AB and to study the relationship between response time and the AB effect. He reasoned that if this change affects the AB, then this suggests that the AB is influenced by response selection because there is temporal overlap between the target response and probe perceptual processing.

In Experiment 1 of Jolicoeur's study, most of the stimuli were white uppercase letters, the target was a red letter H or S, and the probe was a white letter X or Y. There were 6 – 9 letters prior to the target, 9 – 12 letters following the target, and the probe could be presented at any of the first eight positions following the target. In this experiment, the target task was unspeeded. The results showed a robust AB. In Experiment 2, the target task was speeded (on line), and results revealed a larger AB than was apparent in Experiment 1. The third experiment combined Experiments 1 and 2 into one experiment using a within-subjects design. These results also showed that there was a larger AB in the speeded condition than in the unspeeded condition. Further, probe performance depended on the response time to the target (see also in Experiment 2). Thus, these results suggest that response selection processes also affect the AB.

A second prediction of the central interference theory is that when the target task is speeded, the number of response alternatives (simple RT, two-alternative discrimination [2AD], or four-alternative discrimination [4AD]) should affect the magnitude of the AB. In Experiment 1 of the study reported by Jolicoeur (1999), the distractor stimuli were white uppercase letters, the target was a red letter (red H or S and larger or smaller size), and the probe was a white X or Y. There were 6-9 letters prior to the target, 9-12 letters following the target, and the probe could be presented in any one of the first eight positions following the target. In this experiment, the target task was unspeeded. There were three kinds of target task: two types of 2AD tasks, one based on letter identity (H or S) and one based on size (large or small), and one type of 4 AD task based on a combination of letter identity and size (large H, large S, small H, or small S). A 2 AD task (X or Y) was used for the Probe. The results revealed that the number of response alternatives in the target task (2AD or 4AD) did not affect the magnitude of the AB obtained. In Experiment 2, the target task was speeded and performed on-line. The results revealed a larger AB for the 4 AD condition than that for either of the 2AD tasks. In Experiment 3, Jolicoeur used a speeded or unspeeded 2AD target task. The results revealed that a larger AB effect was apparent when the target task was speeded than when it was unspeeded.

Overall, then, the results reported by Jolicoeur (1998, 1999) demonstrate that the AB is affected by the number of response alternatives in the target task, by whether the target task is speeded, and by the response time to the target. Thus, it appears that the AB is also influenced by response selection because there is temporal overlap between the target response and probe perceptual processing. These results supported the central interference theory (Jolicoeur, 1998). However, the use of a speeded target task is not a conventional AB procedure. Thus, there is a question as to whether or not the AB is also affected by response selection in the traditional unspeeded AB procedure.

Object-Substitution Model. The object-substitution account (Giesbrecht & Di Lollo, 1998) was also developed from the two-stage model (Chun & Potter, 1995). The most important contribution of this model is that it gives a clear explanation about how the item immediately following the probe may interfere with probe processing. "The revision introduces an intermediate stage that could be regarded as a holding buffer where the output of Stage 1 can be stored if Stage 2 is busy" (p. 1465). According to Giesbrecht & Di Lollo (1998), "The encoded representation is then transferred to the holding buffer where it replaces the previous contents." (p.1465). "In this fashion, a trailing mask can erase the representation of the second target in the holding buffer, but need not interfere with the residual activity of Stage-1 mechanisms that had been triggered while the second target was being processed at that level" (p. 1465).

The model makes several predictions. First, delayed masking of the probe is necessary to produce the AB because this causes substitution in the buffer in which the probe is held by the distractor immediately following it. Giesbrecht & Di Lollo (1998) examined this issue. They distinguished between two types of masking. Integration (simultaneous) masking occurs when a mask is presented at the same time as an item and this interferes with the item's earliest representation. Interruption (delayed) masking occurs when a mask is presented following the offset of an item and this can act to replace the item in the holding buffer. In Experiment 1 of that study, there were four conditions determined by the relation between the probe and the mask: no masking, simultaneous masking, delayed masking, and stream mask (1-7 distractor items following the probe). The target and the probe were English letters, and the mask and the distractors were digits (0-9). Each item was presented for 10 ms, and ISI was 90 ms. The number of distractors prior to the target varied from 7 to 15, and the probe was presented in the +1 to +7 positions. Subjects were required to identify the target and the probe. The results revealed that the two delayed masking conditions produced significant AB deficits. In contrast, whereas the simultaneous masking condition produced an overall impairment, no AB was produced in the no-mask condition. In Experiment 2, three masking conditions were studied. In the simultaneous masking condition a patch of 100 dots was used as the mask. In the delayed masking condition a digit was used as the mask. In the combined masking condition, a patch of 100 dots was used as a simultaneous mask and a digit was used as a delayed mask. The results revealed that the two delayed masking conditions produced significant AB deficits. Simultaneous masking of the probe did not generate an AB regardless of whether it was meaningful (a digit) or meaningless (a patch of 100 dots). In Experiment 3, a patch of 100 dots was used as either a simultaneous or delayed mask. SOA between the probe and the mask was 0, 50, 100, or 200 ms. The results revealed no AB in the simultaneous masking condition (0 ms SOA), but a significant AB was apparent for all other SOA conditions. Thus, delayed masking of the probe was necessary to produce the AB, but the mask did not need to be meaningful.

The second prediction of the object-substitution account is similar to one of the two-stage model predictions (Chun & Potter, 1995). Specifically, the model suggests that the AB is influenced by local effects of both the distractor following the target (it can be processed together with the target thereby acting to increase target processing difficulty) and of the distractor following probe (it can replace the probe in the holding buffer). In Experiment 2 of the study by Brehaut et al. (1999) three different luminance levels (bright, medium, and dim) of masking of the target and the probe were used in a critical-item procedure. The results indicated that the accuracy of target and probe judgments were reduced as luminance of the mask increased. In Experiment 3, they manipulated the SOA between the target and the probe and the masks at 0 (integration), 60, and 90 ms. The results revealed a larger AB in the 60 ms SOA condition than in the 90 ms SOA condition, and no AB in the 0 ms SOA condition. Thus, the item following the target and the one following the probe both have an important influence on the AB. The +1 item can be processed together with the target and this increases target processing difficulty and the consequent delay in processing the probe, and the item following the probe can overwrite the probe. The larger AB in the 60 ms SOA condition than in 90 ms SOA condition is consistent with this view because the shorter SOA can increase the likelihood that the +1 item is processed together with the target. The shorter SOA can also increase the likelihood that the item following the probe will overwrite it. The absence of an AB in the 0 ms condition shows that delayed masking of the probe is necessary to produce the AB.

These experiments demonstrated that there are local effects of both the item following the target and of the item following the probe on the AB. Thus, these results support the object-substitution account (Giesbrecht & Di Lollo, 1998) because it is based on the idea that the AB is caused by the substitution of the probe by the distractor immediately following it in the holding buffer. However, this model may overemphasize the effect of the substitution of the probe by the distractor following it, in that the possibility of passive decay of the probe is not considered. Although there was no AB when no distractor followed the probe in the study of Giesbrecht and Di Lollo (1998), it is possible that an AB might be apparent if the discriminability of the sequence were reduced (e.g., shorter SOA or lower luminance) both because increased target processing difficulty would increase the delay in processing the probe and because of reduced discriminability of the probe. Results consistent with this idea were recently reported by Shen and Mondor (2006) who found that a small but significant auditory AB remained even when all the distractors following the probe were deleted. They also found that the accuracy of probe processing was reduced when the SOA between items was 80 ms than when it was 95 ms. Following the view of Chun and Potter (1995) who suggested that a global effect of distractors has an influence on the magnitude of the visual AB, Shen and Mondor argued that the presence of distractors reduces discriminability of the target and the probe. As a result, the time required to process the target is increased when distractors are present relative to when the target is presented in isolation. If processing of the probe is delayed until target processing is complete, then this could indirectly generate an AB because of an increase in the probability of the probe representation decaying. There might also be an effect of the distractors on the discriminability of the probe such that the quality of the memorial representation of the probe is reduced when it is presented in the context of other distractor sounds. This explanation is consistent with the results obtained when SOA was extended to 95 ms. It may be that in this situation little evidence of an AB was obtained because the longer SOA served to improve discriminability of the target and the probe relative to the 80 ms SOA condition.

Two-Stage Competition Model. Potter et al. (2002) proposed a two-stage competition model that they developed from Chun and Potter's (1995) original two-stage model and which includes some aspects from the competition hypothesis (Shapiro et al., 1994). The main idea on which this model is based is that there is competition for processing resources at the first stage and that either the target or the probe could win the competition and enter into the second stage to be processed first. In the first stage, all items in the sequence must be identified. If a stimulus is interpreted as a possible target, then it will attract more resources. If the probe is presented before the completion of target processing, then it will compete with the target for resources in the first stage. However, Potter et al. (2002) claim that if the SOA between the target and the probe is very short, then the probe can benefit from target detection, and thus could be identified first (the process by which this might occur is not described in detail). The first critical item (target or probe) that is identified will enter stage 2 (a capacity-limited central bottleneck) for short-term consolidation and reporting. The second critical item (target or probe) must wait in the first stage for completion of second stage processing of the first item, and its representation will passively decay or be overwritten by the distractors following it. Similar to the original two-stage model (Chun & Potter, 1995), this model also addresses two kinds of distractor effects; a local effect of the distractors immediately following the target and the probe, and a global effect of all distractors.

This model makes the counter-intuitive prediction that probe accuracy could be higher than target accuracy when the SOA between the target and the probe is less than 100 ms because it is possible that the probe will be processed before the target. In this situation, target processing would be delayed until processing of the probe in the second stage is completed. In Experiment 1 of Potter et al.'s (2002) study, each item was presented for 53 ms, with no ISI. The target was presented in the fourth or fifth position, SOA between the target and the probe was 53, 107, or 213 ms, and distractors following the probe continued for 267 ms (+ 5). The target and the probe were four- or five-letter lowercase nouns. The distractors were rows of percentage signs (%%%%) or rows of ampersands (&&&&). The critical items (target and the probe) and the distractors were all black. The distractor immediately following the target and the probe was always comprised of rows of ampersands. The subjects were required to type the two words at the end of the trial. The results revealed that the largest probe-processing deficit was at 213 ms SOA, and a smaller probe-processing deficit at 107 ms SOA (lag 1 sparing). At 53 ms SOA a smaller probe-processing deficit was apparent but the accuracy of the probe identification actually exceeded that for the target. Experiment 2 was designed to rule out the possibility that low target accuracy at 53 ms SOA was caused by sensory masking. Two streams were used in this experiment with the target presented in one stream, and the probe presented in the other stream. The SOA between the target and the probe could be 40, 107, or 213 ms. The results revealed a similar pattern to that apparent in Experiment 1. Specifically, the largest probe-processing deficit was apparent at 213 ms SOA, and the smallest deficit was apparent at 107 ms SOA (lag 1 sparing). At 40 ms SOA a small probe – processing deficit was apparent but the probe was identified more accurately than the target. Finally, these results appear not to have been caused by sensory masking because the target and the probe were presented in different streams. In Experiment 3, the SOA between the target and the probe could be 13, 27, or 40 ms (the target and the probe partly overlapped in time). Other experimental arrangements were the same as those in Experiment 2 except that "no further stream of distractors followed the ampersand mask" (p. 1155). In other words, only one distractor followed the target and only one followed the probe. The results were similar to those obtained in Experiments 1 and 2. For all three SOAs a probe-processing deficit was apparent and the accuracy of probe processing was higher than that of target processing. These results provide evidence that the accuracy of probe processing can be higher than that of target processing when the SOA between the target and the probe is very short and this provides some support for the two-stage competition model.

A second prediction of the two-stage competition model is that the accuracy in judging a single critical item (target or probe) will always be better than when both critical items must be judged. In Experiment 4 of the Potter et al. (2002) study, one third of the sequences included the target, one third included the probe, and one third included both. The SOA between the target and the probe was 0, 40, 107, or 213 ms. The results revealed that when both the target and probe were presented, there was higher probe accuracy at 0 and 40 ms SOA and higher target accuracy at 107 ms and 213 ms SOA. In addition, as the model predicted, the accuracy in the one-target conditions was always better than in two-target condition.

In summary, these experiments demonstrated that probe accuracy may be higher than target accuracy when the SOA between the target and the probe is very brief, and that performance when only one critical item must be judged is better than when two critical items must be judged. Thus, these results support the two-stage competition model. However, this model assumes that the first critical item that enters into the second processing stage will be judged more accurately than the second item. This view ignores the fact that performance also depends on processing difficulty. If the target task is more difficult than the probe task, then target accuracy could be lower than probe accuracy even though the target is processed first. Thus, the logic of this model is not powerful.

Object File Continuity Theory. The object file continuity theory (Raymond, 2003) is based on the idea that the AB reflects a break in object file continuity. Raymond (2003) has argued that an object file is created when the first item in a sequence is presented, and this file will be continuously updated as subsequent items are presented. If the target is not perceived as a new object, then updating will be easy and the old object file will be maintained. In contrast, if the target is perceived as a new object, then updating will be difficult and the old object file may be discarded in favour of a new one. Establishing a new object file draws on capacity-limited attentional resources. Therefore, if, during this processing, the probe is presented, then its processing will be impaired because of a scarcity of resources, and an AB will result.

This theory states that the AB reflects a requirement in creating a new object file for the target rather than a problem of incorporating new stimuli into an existing object file. In Experiment 1 of Raymond (2003), each item was present for 75 ms, and ISI was 15 ms. The distractors were images of tridents in various orientations. The target was a thickened central bar presented as part of an arrowhead (new object) or as part of a trident (new feature). The probe was a trident with a short foot. There were 7 – 15 items prior to the target, and the probe could be presented in the +1, +3, +5, or +7 position. There were always 8 items following the target. Performance was examined in three conditions defined by the type of target presented; no target, trident target, and arrowhead target. The subjects were required to detect the target (thick bar) and to identify the object in which it was presented (trident or arrowhead), and to detect the probe as well. The results revealed a significant AB when the target was embedded in an arrowhead but not when it was embedded in a trident. Experiment 2 was performed to rule out the possibility that the trident-target condition did not show the AB effect because the target and probe were the same kind of objects (recall that the probe was always a trident). Thus, in this experiment there were two conditions, one in which both the target and probe were arrowheads, and a second in which the target was a trident and the probe was an arrowhead. The results revealed that there was an AB in the arrowhead-arrowhead condition but not in the trident-arrowhead condition. These results suggest that the AB was caused by a requirement to create a new object file for the target.

In their first experiment, Kellie and Shapiro (2004) compared two kinds of streams; smooth morph streams in which there were small, ordered changes between successive items (e.g., smoking pipe changing into a saucepan), and scrambled morph streams in which there were large, random changes between successive items. The target was defined as a group of small or large dots, and the probe was defined as a group of small or large squares. There were 24 items in each stream. The target was presented in the 12th position, and the probe could be presented 67, 133, 200, 267, 333, 400, 467, or 534 ms following the target. ISI was 0 ms. The results revealed a significant AB in the scrambled morph condition, but not in the smooth morph condition. In Experiment 2, the distractors were a series of random objects (e.g., apple, clock, and violin). The results revealed a longer-lasting AB in this condition than in the scrambled morph streams used in Experiment 1. Thus, these experiments also provided some evidence that the AB reflects a limitation in processing a 'new object' or in establishing a new object file.

However, in contrast with the view of Raymond (2003) that the distractors prior to the target are critical to generating the AB deficit because the relationship between them and the target determines whether or not a new object file needs to be created for the target, Kellie & Shapiro (2004) argued that the object file continuity between the target and the probe is responsible for the AB deficit because the target and the probe cannot share the same object file if continuity between them is broken. In that situation, creating a new file for the probe draws processing resource, and thus an AB occurs.

In Experiment 3 of Kellie & Shapiro (2004) the critical items procedure was used for the smooth, ordered morph streams used in Experiment 1, and the probe could be presented in the +2 to + 8 positions. The results revealed no significant AB. In Experiment 4, random objects were presented between the target and the probe. The results revealed a significant AB. In Experiment 5, the procedure was the same as in

Experiment 4 except that each trial consisted of 11 items prior to the target, the +1 item, a silent period, the probe, and the item immediately following the probe. The results did not reveal a significant AB. Overall, then, this study suggested that the items between the target and the probe are important in determining whether a single object file may be maintained and thereby may modulate the AB.

In brief, these experiments suggest that the AB reflects a requirement to create a new object file rather than a problem of incorporating a new feature into an existing object file. Whereas Raymond (2003) suggested that the critical locus of object file continuity is in the pre-target stream, Kellie and Shapiro (2004) found that the items between the target and probe were most important in maintaining object file continuity and in generating the AB. It is possible that both loci are important in producing the AB but under different conditions. Additional empirical evidence is required to determine whether this is the case. In addition, this theory itself cannot directly explain the effect of the +1 item on the AB. According to the argument of Raymond (2003), the items prior to the target play a very important role in generating the AB because they affect the updating of the object file which may be used for the target. Thus, it seems the +1 item should not play an important role in generating the AB. According to Kellie and Shapiro (2004), the items between the target and the probe are critical to the object file continuity, and that deleting the +1 item should break the continuity. Thus, the magnitude of the AB should be increased rather than decreased in this situation. However, the empirical evidence has shown that this is not the case (e.g., Chun & Potter, 1995; Raymond et al., 1992; Shapiro et al., 1994). This theory also cannot explain the fact that the AB is reduced when the item immediately following the probe is deleted (e.g., Giesbrecht & Di Lollo, 1998).

Summary for the Theoretical Accounts of Visual AB

Since the 1950s the locus of attention has become a significant focus of psychological study. Some researchers (e.g., Broadbent, 1958; Treisman, 1960) have argued that the locus of attention precedes stimulus identification (early selection). In contrast, other researchers (e.g., Deutsch & Deutsch, 1963; Norman, 1968) proposed that the locus is after stimulus identification (late selection). This controversy has penetrated every area of attention research. In fact, the accounts of the AB discussed above also can be divided into two types according to the assumption each makes regarding the locus of attention.

The two-stage detect-then-identify model (Broadbent & Broadbent, 1987), the attentional gate model (Raymond et al, 1992), and the object file continuity theory (Kellie & Shapiro, 2004; Raymond, 2003) all assume that selection occurs prior to stimulus identification. Recall that the two-stage detect-then-identify model assumes that interference between the identification of the target and the identification of the probe in the capacity-limited second stage causes the AB. However, this model does not address the effect of the distractors. For example, it cannot explain why deleting the +1 item (e.g., Chun & Potter, 1995; Shapiro et al., 1994, Raymond et al., 1992) and the item immediately following the probe (e.g., Giesbrecht & Di Lollo, 1998) can reduce the visual AB, or why there is a global effect of all distractors on the magnitude of the AB (e.g., Chun & Potter, 1995). In contrast, the attentional gate model assumes that in order to protect the identification of the target, the item immediately following the target initiates an active inhibition against processing additional items lasting several hundred milliseconds. If the probe is presented during this period, then it will be inhibited, and an AB will result. This model can explain why deleting the +1 item can reduce the visual

AB because this item is thought to initiate the inhibitory process. However, it cannot explain why deleting the item immediately following the probe can act to reduce the AB, nor does it address the global effect of all distractors on the AB. Finally, the object file continuity theory assumes that the AB reflects a break in object file continuity. This theory itself cannot directly explain the effect of the +1 item on the AB. According to the argument of Raymond (2003), the items prior to the target play a very important role on the AB because they affect the updating of the target's object file. Thus, it seems the +1 item should not play an important role on the AB. According to the Kellie and Shapiro (2004), the items between the target and the probe are critical to the object file continuity. Thus, deleting the +1 item should break the continuity, and the magnitude of the AB should be increased rather than be decreased. This theory also cannot explain the fact that the AB is reduced when the item immediately following the probe is deleted (e.g., Giesbrecht & Di Lollo, 1998).

Other accounts of the AB, such as the competition hypothesis (Shapiro et al., 1994), the dwell-time theory (Duncan, Ward, & Shapiro, 1994), the two-stage model (Chun and Potter, 1995), the central interference theory (Jolicoeur, 1998), the object-substitution account (Giesbrecht & Di Lollo, 1998), and the two-stage competition model (Potter, Staub, & O'Connor, 2002) are based on the assumption that selection follows stimulus identification. These accounts can be further divided on the basis of whether or not the probe can be processed during ongoing processing of the target. Both the competition hypothesis (Shapiro et al., 1994) and the dwell-time theory (Duncan et al., 1994) suggest that the target and the probe can be processed in parallel in the capacity-limited stage, and that competition and interference between them cause the AB. Whereas the competition hypothesis stresses the competition between the target, the probe, and the distractors in VSTM, the dwell time theory stresses the limitation in dividing attention between the target and the probe. In addition, the competition hypothesis does not distinguish the different effects of the +1 item and the item immediately following the probe and other distractors in sequences on the AB and thus cannot explain some results (e.g., Shen & Mondor, 2006). The dwell time theory is silent with respect to any effect of the distractors.

In contrast with these theories, the two-stage model (Chun and Potter, 1995), the central interference theory (Jolicoeur, 1998), the object-substitution account (Giesbrecht & Di Lollo, 1998), and the two-stage competition model (Potter, Staub, & O'Connor, 2002) are all based on the idea that there is a delay in processing the probe caused by ongoing processing of the target. During this delay, the memorial representation of the probe can passively decay or be overwritten by the item following it, and this results in the AB. Whereas the two-stage competition model suggests that either the target or the probe may be processed first (at brief SOAs between them), the others suggest that the target is always processed first in the capacity-limited stage, and that probe processing is delayed.

Chun and Potter (2001) developed a model that combines elements of the two-stage model, the object-substitution account, and the central interference theory. They proposed that in an initial rapid-detection stage, each item in the RSVP stream is momentarily identified. However, to successfully identify the target and probe, their perceptual representations must be consolidated in a second limited-capacity stage (i.e., short-term consolidation). In this second stage, the target items are encoded into STM in a serial fashion according to the task requirements. Thus, when the participant must identify both the target and the probe, there is a delay in processing the probe caused by ongoing consolidation of the preceding target. During this delay the representation in memory of the probe may decay or be overwritten by subsequently presented distractors, and a probe processing deficit occurs. The probe processing delay is greatest when the probe is presented immediately following the target. Thus, the impairment in probe processing declines as the time between the target and probe increases.

Currently, the most dominant account of the AB is the two-stage model (Chun & Potter, 1995; Giesbrecht & Di Lollo, 1998; Jolicoeur, 1998). The two-stage model appears to be very powerful because it differentiates the effect of the +1 tem and the effect of the item immediately following the probe. Whereas the +1 item can be processed together with the target thereby increasing target processing difficulty; the item immediately following the probe can overwrite the probe and thus impair perception. This separation makes the model very flexible. It also addresses the global effect of all distractors on the AB. To date, no empirical evidence has been reported that falsifies it. Chun (1997) and Raymond (2003) claimed the model can even explain the result that the AB reflects a requirement of creating an object file (e.g., Raymond, 2003). For example, they claimed it could be that the second stage processing will be initiated only when the target is a new object. However, they did not give details about this explanation.

Auditory AB Studies

Although a great deal of empirical and theoretical analysis of the visual AB has taken place, there have been only a few investigations of the auditory AB (e.g., Arnell & Jenkins, 2004; Arnell & Jolicoeur, 1999; Arnell & Larson, 2002; Duncan, Martens, & Ward, 1997; Mondor, 1998; Shen & Mondor, 2006; Soto-Faraco & Spence, 2002; Tremblay, Vachon, & Jones, 2005).

So far, an RSAP (rapid serial auditory presentation) procedure has been employed in all auditory AB studies. These investigations have used three kinds of materials; namely, spoken syllables (e.g., Ducan et al., 1997; Tremblay et al., 2005), spoken letters and digits (e.g., Arnell & Jenkins, 2004; Arnell & Jolicoeur, 1999; Arnell & Larson, 2002; Soto-Faraco & Spence, 2002), and tones (e.g., Mondor, 1998; Shen & Mondor, 2006).

In Duncan et al.'s (1997) experiments, participants were presented with two concurrent, auditory streams. One stream was presented in a low-pitched voice and another one was presented in high-pitched voice, and the target and probe were always presented in different streams. Participants were to listen for the target words 'nap' or 'nab' in the low-pitched stream and 'cot' or 'cod' in the high-pitched stream. The spoken syllable 'guh' was used as a distractor. SOA was 250 ms in duration, and the ISI was 100 ms. One stream, chosen at random on each trial, began 125 ms before the other to increase the likelihood that participants would perceive two separate channels. The results revealed that there was a deficit in identifying the probe when the target was attended, and that the magnitude of the deficit decreased as the time between the target and probe increased. However, no deficit in processing the probe was apparent when the target was not attended. Thus, these results revealed a significant auditory AB for spoken verbal material. Tremblay, Vachon, and Jones (2005) used materials similar to those of Duncan et al. (1997) and also observed an auditory AB.

In the experiments performed by Arnell and Jolicoeur (1999), participants were presented with a single stream of spoken digits and letters. The target was a specific spoken digit (1, 2, 3, or 4), the probe was the spoken letter X, and the distractors were other spoken letters. When participants were to identify the target and detect the probe, they found a deficit in detecting the probe when the target was attended. In the experiments of Arnell and Larson (2002), the auditory stimuli were spoken letters presented in compressed speech. SOA was 83.5 ms, and ISI was 3.5 ms. Each letter was presented to the right ear. A tone was presented to the left ear at the same time as the target and probe letters, and participants were required to identify the letter presented simultaneously with the tone. The results revealed that identification of the probe letter was impaired when it was presented immediately following the target letter. Soto-Faraco and Spence (2002) used digits as the target and the probe, and letters as the distractors. SOA was 108 ms, and ISI was 23 ms. Participants were required to identify the two targets. The results also showed a robust auditory attentional blink.

In a study using non-verbal materials, Mondor (1998) used 26 pure tones as distractors. The target was a tone of a specific, especially high, frequency and the probe was a complex sound comprised of multiple frequency components. SOA was 90 ms, and ISI was 60 ms. Mondor reported a robust auditory AB when both the target and the probe were to be detected. Shen and Mondor (2006) also obtained a robust auditory AB by using tones.

In addition to demonstrating the existence of an auditory AB, these studies have provided evidence that several factors influence the auditory AB. Arnell and Jolicoeur (1999) found that the magnitude of this auditory AB depended on the rate of the sequence. Specifically, with a consistent ISI of 15 ms an AB occurred for the two faster rates used (105 ms & 120 ms SOA), but not for the two slower rates used (135 ms & 150 ms SOA). Tremblay, Vachon, and Jones (2005) found that the magnitude of the auditory AB increased as the heterogeneity of the distractors increased. Both Mondor (1998) and Shen and Mondor (2006) found that the magnitude of the auditory AB was unchanged when the item immediately following the target was replaced by a silent period. Shen and

Mondor (2006) also found that the overwriting of the probe by the distractors following it is a major factor in generating the auditory AB, and that the presence of the distractors and the rate of the sequences influenced target and probe processing difficulty by affecting the discriminability of the sequences.

Evidence of an auditory AB has, then, been reported several times. However, a great deal of additional research is required to discover the mechanism(s) responsible for the effect. The study reported by Shen and Mondor (2006) was conducted to examine the role that distractors play in producing the auditory AB as a means of moving toward a theoretical account of it. As discussed above, distractors play a very important role in some theories of the visual AB. For example, the two-stage model (Chun & Potter, 1995; Giesbrecht & Di Lollo, 1998; Jolicoeur, 1998) states that a delay in probe processing arises because the target and the distractor immediately following it are processed together. While the target is being processed, the representation of the probe may be subject to passive decay or overwriting by the distractors following it, and this causes the visual AB. The competition hypothesis (Shapiro et al., 1994) suggests that the competition for resources between the target, the probe, and the distractors immediately following each of them causes the visual AB. Finally, the attentional gate model (Raymond et al., 1992) suggests that the distractor immediately following the target initiates an inhibition mechanism, and this produces the visual AB. Clearly, all of these theoretical accounts of the visual AB recognize the importance of distractors.

Four experiments were conducted in Shen and Mondor's (2006) study. In Experiment 1, subjects were presented with RSAP streams that consisted of either 16 tones (full stream) or two tones (no stream). Each tone was presented for 30 ms, and ISI was 50 ms. Twenty-one pure tones were used as distractors. The frequencies of these tones were log-related ranging from 529 Hz to 1330 Hz. The target was composed of six, 5 ms pulses, and could be any of the same 21 frequencies as the distractors. The probe was a glide that changed smoothly in frequency from 636 to 1006 Hz. In full-stream trials, the target could occur following either five or seven distractor sounds and the probe could occur in any of the first eight temporal positions following the target. In no-stream trials, only two sounds were presented on each trial. The target was presented after either 400 or 560 ms of silence (this is equivalent to the time period prior to the target presentation when a full-stream sequence was presented), and the probe could occur 80, 160, 240, 320, 400, 480, 560, or 640 ms following the target (again these delays are equivalent to those of the full-stream trials). For both types of trials, participants were instructed to detect both the target and the probe in one block of trials, and to detect only the probe in another block of trials. The results revealed a robust AB deficit when the target and the probe were embedded in a sequence of distractors than when they were presented in isolation. In addition, for the full-stream sequences a significantly larger attentional blink was apparent when the target was attended than when the target was ignored. These results indicate that the presence of the distractors is necessary to the emergence of the auditory AB, and that the auditory AB is attentional in nature rather than the result of sensory masking.

In their second experiment, Shen and Mondor found the auditory AB was reduced when the distractor immediately following the probe was deleted, and not when the distractor immediately preceding or following the target, or preceding the probe was deleted. In Experiment 3, the stimulus onset asynchrony (SOA) was increased from 80 to 95 ms, and the pattern of results was similar to that apparent in Experiment 2.

Shen and Mondor (2006) suggested that a modified version of the two-stage model may be able to explain the results because it is based on the notion that the items immediately following the target and the probe have different effects. According to the two-stage model, whereas the +1 item can be processed together with the target and thereby increase the difficulty of target processing during short-term consolidation, the item immediately following the probe can overwrite or replace the probe and thereby cause a large AB deficit. In audition, it seems quite likely that there is no substantive effect of inserting a silent period following the target because the +1 item is not processed along with the target, and so does not affect its consolidation in short-term memory. Thus, although Shen and Mondor did find that deleting the +1 item reduced the difficulty of target processing, this may well be because of a reduction in the backward masking of the target that influences the sensory registration of the target but not its short-term consolidation. According to the two-stage model, the AB is only affected when the duration of consolidation of the target in short-term memory is affected (Jolicoeur, 1998; Olson, Chun, & Anderson, 2001).

Shen and Mondor (2006) conducted a fourth experiment to examine whether the AB effect might be fully eliminated when all of the items following the probe were replaced by silence. The magnitude of the probe processing deficit was reduced substantially relative to that apparent when the single item immediately following the probe was replaced by silence (Experiments 2 & 3) for both 80 ms and 95 ms sequences. However, a small but significant AB effect remained even in this situation. Given that in Experiment 1 of their study there was no significant AB for the no-stream sequences, it appears that the distractors prior to the target and between the target and probe may also play a small role in causing the auditory AB. It may be, as Chun and Potter (1995) have suggested, that a global effect of distractors influences the magnitude of the visual AB.

According to this view, the presence of distractors reduces discriminability of the target and the probe. As a result, the time required to process the target would be increased when distractors are present relative to what the target is presented in isolation. If processing of the probe is delayed until target processing is complete, then this could indirectly generate an AB because of an increase in the probability of the probe representation decaying. There might also be an effect of the distractors on the discriminability of the probe such that the quality of the memorial representation of the probe is reduced when it is presented in the context of other distractor sounds. Such a view is consistent with the finding that the accuracy of probe detection was higher in the 95 ms SOA sequences than in the 80 ms SOA sequences. It may be that the lengthened SOA (95 ms) improved discriminability of the target and the probe relative to the 80 ms SOA condition.

In summary, the results reported by Shen and Mondor (2006) suggest that the auditory AB is caused by both a local effect of the distractors following the probe and by a global effect of any distractors presented in the sequence, and, for these reasons, it may be explained by the revised two-stage model.

Auditory AB and Lag-1 Sparing

The auditory probe-processing deficit could be caused by a variety of different mechanisms. For example, switching from listening for a target to listening for a probe could, in and of itself, create impairment in detecting a probe presented before this 'task-switching' is completed. Chun and Potter (2001; see also Potter, Chun, Banks, & Muckenhoupt, 1998) proposed that 'lag-1 sparing' may be a good indicator of whether performance is due to such task-switching deficit or to a 'true' AB. Lag-1 sparing occurs when the probe processing deficit at the +1 position is smaller than the maximum deficit.

In other words, according to Chun and Potter, a true AB should be characterized by a U-shaped function relating probe detection to probe position rather than by a linear function. Chun and Potter suggested that if the probe processing deficit is attentional in nature, then a probe presented in the +1 position should be processed together with the target so its processing would not be delayed and only a minimal deficit would be apparent. Because Chun and Potter (2001; see also Potter et al., 1998) found no evidence that the auditory AB was consistent with this performance criteria, they argued that it resulted from task-switching. It is true that the experimental results reported by Shen and Mondor (2006) and the results of most other auditory studies (Arnell & Jenkins, 2004; Arnell & Jolicoeur, 1999; Arnell & Larson, 2002; Duncan et al., 1997; Mondor, 1998; but see Soto-Faraco & Spence, 2002, for evidence of a U-shaped function) showed a generally linear probe processing deficit. However, this pattern does not necessarily indicate that the auditory probe processing deficit is caused by task-switching. Rather, the difference between a linear and a U-shaped curve may simply provide an indication as to whether the item immediately following the target is processed together with the target. The finding that replacement of the +1 distractor with a silent period has no effect on the auditory AB (Mondor, 1998; Shen & Mondor, 2006) suggests that the +1 item is not processed together with the target, and this may be because the auditory system generally has better temporal resolution and poorer spatial resolution than does the visual system (e.g., Neath, 1998, p. 47). Accordingly, when the probe is presented in the +1 position, the auditory system may be more likely to process the target and the probe sequentially than the visual system. Moreover, although it is true that a U-shaped probe processing deficit is more frequently reported in studies of the visual AB than in studies of the auditory AB, only about half of the studies of the visual AB have reported such a pattern

(Visser, Bischof, & Di Lollo, 1999). In brief, even in visual processing the U-shaped pattern is not a diagnostic of an AB.

The Present Study

In the studies of Mondor (1998) and Shen and Mondor (2006), deleting the + 1 item was found not to reduce the magnitude of the auditory AB. Further, Shen and Mondor (2006) showed that the major cause of the auditory AB is the overwriting of the probe by the distractors following it, and that the discriminability of the target which is affected by the presence of distractors and the rate of the stream can affect target processing difficulty, and thus affect the magnitude of the auditory AB. These results support a revised vision of the two-stage model (Chun & Potter, 1995; Giesbrecht & Di Lollo, 1998; Jolicoeur, 1998).

One focus of investigation in visual attention studies has been on 'object file continuity' (e.g., Kahneman, Treisman, and Gibbs, 1992; Rauschenberger, 2003; Yantis, 1995; Yantis & Gibson; 1994) which is based on the notion that object is the basic unit of perceptual processing (e.g., Kahneman et al, 1992). Kahneman et al. (1992) defined "an object file as a temporary episodic representation, within which successive states of an object are linked and integrated." (p175). They argued that successive stimuli may be represented by the same object file so long as they do not differ markedly. In contrast, successive stimuli that do differ substantially must be represented by separate object files.

Recently, the 'object file continuity' issue has also been addressed in AB studies. Raymond (2003) suggested that the visual AB reflects a requirement to create a new object file for the target rather than a problem of incorporating a new feature into an existing object file. According to this account, at the beginning of each RSVP sequence, an object file is created and this file is continually updated as each, similar object is presented. Presentation of a target that differs substantially from the preceding distractors at object level is presented requires creation of a new object file and this draws on capacity-limited attentional resources. If, the probe is presented while an object file is being created for the target, then its processing will be impaired because of a scarcity of resources, and an AB will result.

The present study was specifically designed to examine whether a requirement to create a new object file for the target has an influence on the auditory AB. The relationship between the target and the distractors was manipulated. In one condition, the target was different from the distractors at object level (object-target). In another condition, the target was different form the distractors at the feature level (feature-target). According to Treisman's feature integration theory, a feature is:

> A value on a dimension if (a) that dimension appears to be perceptually coded as a distinct and separable entity and (b) the value on that dimension is coded independently of any other values on the same dimension that are also present in the field. (Treisman & Gormican, 1988, p. 16)

This definition suggests that such visual attributes as brightness, colour, orientation, size, and spatial frequency, can be considered as independent dimensions, and specific values on these dimensions as features. This is consistent with previous studies of auditory perception in which frequency, intensity, duration, and location have all been considered as dimensions of a sound and specific values on these dimensions as features (e.g., Hall, Pastore, Acker, & Huang, 2000; Jamieson, Thompson, Cuddy, & Mewhort, 2003; Thompson, Hall, & Pressing, 2001; Thompson & Sinclair, 1993).

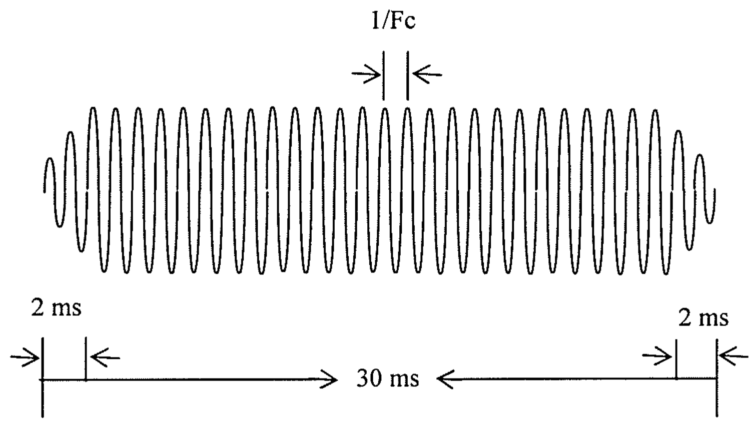
In the present study, a feature difference was defined as a frequency difference and different objects were defined as different type of sounds; namely, pure tones vs. pulse tones (shown in Figure 2). If an AB is apparent in the object-target condition but not in the feature-target condition, then this will mean that the auditory AB also reflects a requirement to create a new object file rather than a process of incorporating a new feature into an existing object file.

As I mentioned above, frequency is normally considered as a unidimentional, and different frequencies can be seen as different features (e.g., 400 Hz vs. 500 Hz). In the studies of visual object perception (e.g., Hillstrom & Yantis, 1994; Rauschenberger, 2003), researchers have found that the distinguishing between an object and a feature is not absolute. When the difference between two features is salient enough, object file continuity can be also broken. For example, Rauschenberger (2003) demonstrated that a large luminance change can break object file continuity. Accordingly, if a frequency change is salient enough, a new object file may also need to be created. In general, an auditory object is closely related to sound sources (e.g., Bregman, 1990; Moore, 2003). Bregman (1990) demonstrated that when the difference between the frequencies of two rapidly alternating tones is over one octave (doubling frequency), streaming will occur (sounds are identified as coming from different sources). In order to minimize the likelihood that a change in frequency may be perceived as an object change, all frequency changes were kept below one octave in the present study. With regard to the definition of an object, Kahneman et al. (1992) mentioned:

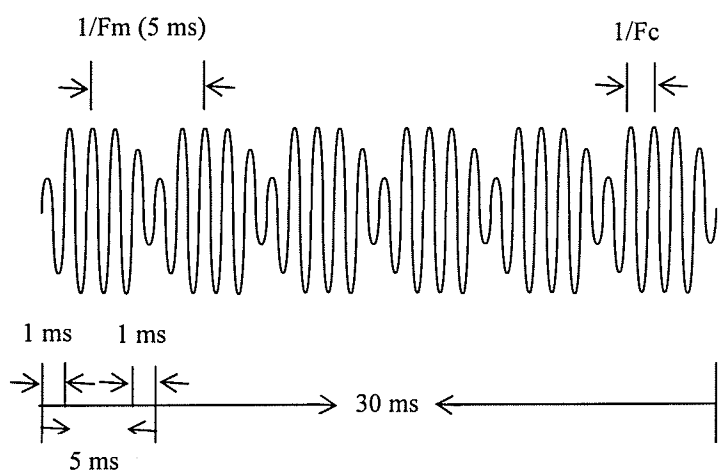
> Visual objects are hierarchically organized; a group of dancers can be a visual object, as can an individual dancer, or her right hand. At any instant one of these levels may be dominant in the parsing of the scene. Tentatively, we assume that object files are set up at the preferred level, which is determined by the controlled

Figure 2. Top: A 30 ms pure tone is shown with only a carrier frequency (Fc). It includes 2 ms linear onset/offset amplitude ramps. Bottom: Six, 5 ms pulses with a carrier frequency (Fc) and a modulation frequency (Fm) is shown. There are 1 ms linear onset/offset amplitude ramps for each 5 ms pulse.

Pure Tone



Six, 5 ms Pulses



allocation of attention (LaBerge, 1983; Navon, 1977) or by the automatic effect of bottom-up constraints and grouping factors. (p.178)

For example, in Kahneman et al. (1992), different English letters were regarded as different objects. In the study of Raymond (2003), tridents and arrowheads were regarded as different objects. In the present study, pure tones and pulses were defined as different objects. In auditory perception, timbre often differentiates sounds that arise from different sources. Timbre is multi-dimensional (such as distribution of spectral energy, time-varying pattern, and so on). It is a very important attribute used to define an auditory object (e.g., Bregman, 1990; Moore, 2001; Neuhoff, 2003). In general, pure tones and pulses are usually seen as sounds with different timbres, and thus pure tones and pulses were defined as different objects in the present study.

EXPERIMENT 1

The present experiment was conducted to examine whether the auditory AB reflects a requirement to create a new object file for the target rather than the processing required to incorporate a new feature into an existing object file of the target. Two types of sequences were employed. In one type, the target was always different from the distractors at the object level. In the other type, the target was always different from the distractors at the feature level. If a larger AB is apparent for the former type of sequence than for the latter, then this would suggest that the auditory AB is caused, at least in part, by the necessity of creating of a new object file for the target.

According to Chun and Potter (2001), if the target and probe differ categorically, then a task-switching deficit could result. To examine whether the auditory AB is caused by task-switching, the target and the probe were exchanged in the two types of sequences.

In the object-feature sequences the target was different from the distractors at the object level and the probe was different from the distractors at the feature level. In contrast, in the feature-object sequences the target was different from the distractors at the feature level and the probe was different from the distractors at the object level. If the AB deficit is caused by task-switching, then there should be an equal auditory AB for the object-feature (similar to a condition in Experiment 1 of Raymond, 2003, study) and the feature-object sequences (similar to a condition in Experiment 2 of Raymond (2003) study). In contrast, at minimum, if a larger AB is apparent in the object-feature sequences than in the feature-object sequences, then this will suggest that the requirement of creating a new object file does affect the auditory AB.

A condition in which the target was to be ignored (target-ignored condition) was used to address the possibility that low-level masking (target to probe) may contribute to the auditory AB. If there is a larger AB when the target is to be attended (target-attended condition) but not when it is to be ignored (target-ignored condition), then this will provide evidence that the AB deficit is attentional in nature and does not simply reflect the effect of the sensory masking.

Experiment 1 A

Pure tones (1000 Hz) were always used as the distractors. In the sequences that the target was different from the distractors at object level, the target was comprised of six, 5 ms pulses (1500 Hz) and the probe was a pure tone (1500 Hz). In the sequences in which the target was different from the distractors at feature level, the target was a pure tone (1500 Hz) and the probe was a pulse comprised of six, 5 ms pulses (1500 Hz).

Method

Participants

Eighty undergraduate students, enrolled in an Introduction to Psychology course at the University of Manitoba participated in the experiment in exchange for course credit. They all had normal hearing according to self-report.

Materials

Computer and Sound System. The experiment was conducted using a Dell Pentium computer running E-Prime (Psychology Software Tools, Inc, 2001). Sounds were synthesized using Abode Audition 1.5 (Adobe Systems Incorporated, 2004) at a sampling rate of 44,100 Hz. Sounds were presented at a comfortable intensity of about 70 dB SPL from headphones Sony (MDR – V600).

Sounds. All sounds were 30 ms in duration and included 2 ms linear onset/offset amplitude ramps to eliminate onset/offset clicks. Twenty-one pure tones were used as distractors. The frequencies of these tones were all 1000 Hz. For half the subjects, the target was comprised of six, 5 ms pulses at1500 Hz, and the probe was a 1500 Hz pure tone. For the other half of subjects, the target was a 1500 Hz pure tone and the probe was comprised of six, 5 ms pulses at 1500 Hz. The relative intensity of the left and right channels of each tone was varied (the possible intensity pairings of the right and left channels was always 70 dB SPL for one ear; for the other ear, the intensity will be as follows ranged from 63.98 to 73.52 dB SPL (50% – 150% amplification)). These changes resulted in subjective location changes throughout each sequence.

Procedure

In all conditions, the target was presented on 50% of the trials, and the probe was presented on 50% of the trials. This arrangement means that on different trials; the target and the probe were both presented, only the target was presented, only the probe was presented, or neither the target nor the probe was presented. Thus, there were four types of trials each of which occurred equally often. On trials on which the target or probe was not presented, a distractor was presented in its place.

In each sequence the target could occur following either four or six distractor sounds and the probe may occur in any of the first seven temporal positions following the target. Stimulus onset asynchrony (SOA) between successive sounds was 95 ms and inter-stimulus interval (ISI) was 65 ms. Half the participants (40) were instructed to listen for both the target and the probe. The other half participants (40) were instructed to listen only for the probe. For half of the participants in each of these groups, the target was comprised of six, 5 ms pulses at 1500 Hz, and the probe was a 1500 Hz pure tone. For the other half of the participants in each group, the target was a 1500 Hz pure tone, and the probe was six, 5 ms pulse at 1500 Hz. Half of the participants were required to make separate target and probe detection judgments in response to questions that appeared on the computer screen at the end of each sequence. The first question ("Was the target present [press 1] or absent [press 0]"?) appeared immediately after the end of each sequence, and the second question ("Was the probe present [press 1] or absent [press 0]"?) appeared immediately following an acceptable response to the first question. The other participants were only required to listen for, and judge, the probe.

There were four blocks of trials created by the combination of two tasks (detect both the target and the probe, or only the probe) and target and probe pairing (object-target [six, 5 ms pulses] and feature-probe [1500 Hz pure tone], or feature-target [1500 Hz pure tone] and object-probe [six, 5 ms pulses]). For each of these blocks, there were 32 practice trials and 224 experimental trials. Different groups of 20 participants were used for each. Random order was used for the four blocks. With regard to the practice trials, each participant was required to meet a criterion of 80% correct on target and probe judgments before beginning the experimental trials.

Design

A split-plot design was used with two between-subjects factors (Task [listen for both the target and the probe or only the probe], and Target-Probe pair [feature-object, or object-feature]) and two within-subjects factors (Target Presence [present, absent], and Probe Position [+1 to +7]).

Data Analysis

All ANOVAs reported in the paper used the Greenhouse-Geisser adjustment test because it is robust with respect to the sphericity assumption. A significant main effect of Target Presence and a significant interaction between Target Presence and Probe Position on probe processing accuracy were used to indicate the occurrence of an AB (Seiffert & Di Lollo, 1997). If the effects were significant, then simple effects of Target Presence at each probe position would be examined. All tests of simple effects were performed using Bonferroni's adjustment method with $\alpha_{FW} = .05$ (this is an appropriate method to control the α_{FW} level; Maxwell & Delaney, 2004).

Results

Target Detection

Overall, participants found the target quite easy to detect. The probability of a correct response to the target task when the target was attended was 0.965 (*SE* = .006). The probability of a correct response on target-present trials (hit) was 0.961, and the probability of an incorrect response on target-absent trials (false alarms) was 0.033. Thus, average d' was 3.60.

Performance in each condition is described in Table 1 and Table 2. A 2 x 2 (Target [object, feature] x Probe Presence [present, absent]) split-plot analysis of variance (ANOVA) was conducted using the probability of accurate target detection as the dependent variable when the target was present. The analysis revealed a marginally significant main effect of Target, $F(1, 38) = 3.609$, $p = .065$. The accuracy of target detection was slightly higher in the feature-object sequences than in the object-fature sequences. Other effects were all not significant, $p > .15$ in all cases.

Whether performance on the target detection task may have been influenced by the position of the probe was also examined. A 2 x 7 (Target [object, feature] x Probe Position [+1 through +7]) split-plot ANOVA was conducted using the probability of accurate target detection as the dependent variable when both the target and probe were presented. The analysis revealed a significant main effect of Probe Position, $F(6, 228) = 31.271$, $p < .001$. None of the other effects reached significance ($F < 1$ in all cases). Thus, the accuracy of target detection increased with the increasing of the SOA between the target and the probe.

Probe Detection

Overall, probe detection accuracy for trials on which there was a correct response to the target was also high at 0.977 ($SE = .003$). The probability of a correct response on probe-present trials (hit) was 0.960, and the probability of an incorrect response on probe-absent trials (false alarms) was 0.010. Thus, average d' was 4.65. Clearly, therefore, participants found the probe quite easy to detect as well.

Performance in each condition is described graphically in Figure 3. A 2 x 2 x 2 x 7 split-plot ANOVA (Task [one, two] x Target [object, feature] x Target Presence

Table 1

Target detection accuracy (mean and standard error) in Experiment 1A as a function of sequence type and probe presence when the target was present.

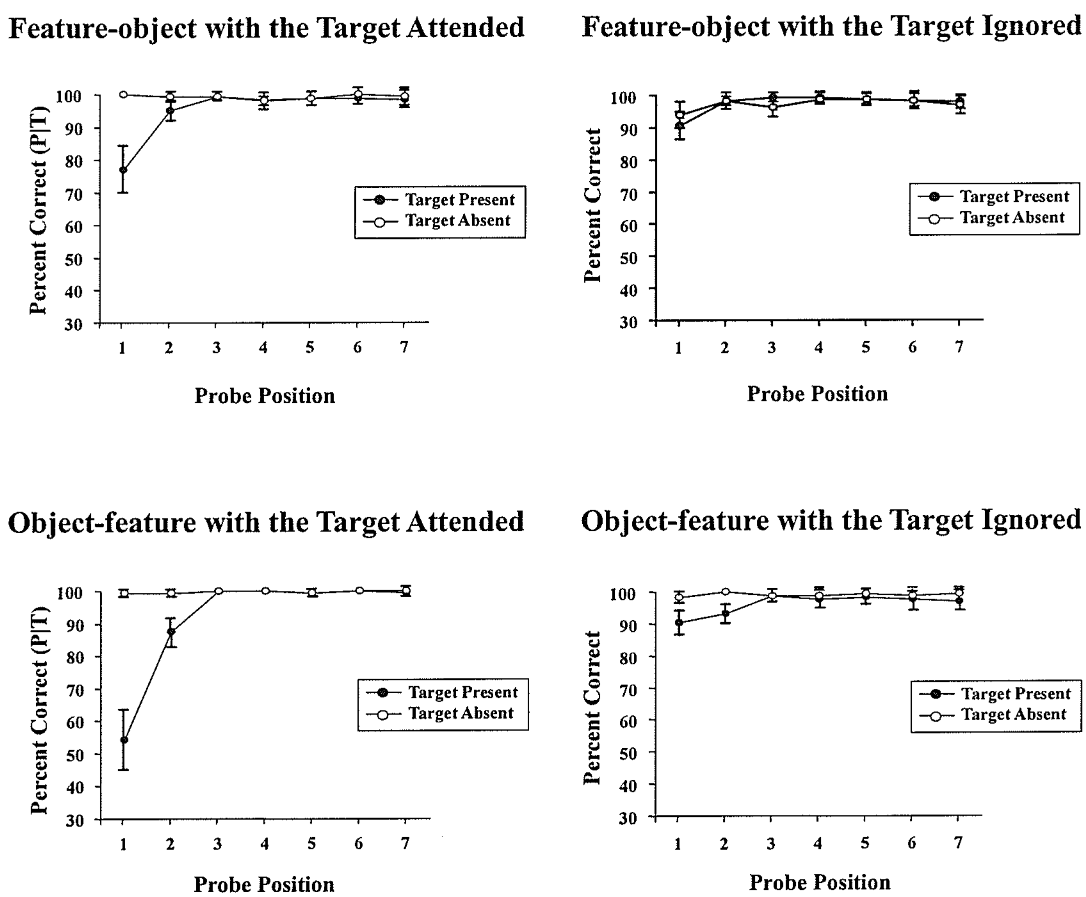
SEQUENCE TYPE	PROBE PRESENCE	
	Yes	No
Feature-object	.963 (.008)	.980 (.007)
Object-feature	.952 (.009)	.948 (.013)

Table 2

Target detection accuracy (mean and standard error) in Experiment 1A as a function of probe position when both the target and the probe were present.

SEQUENCE TYPE	PROBE POSITION						
	+1	+2	+3	+4	+5	+6	+7
Feature-object	.784 (.054)	.982 (.010)	1.000 (0)	1.000 (0)	.988 (.013)	.994 (.006)	1.000 (0)
Object-feature	.758 (.052)	.952 (.016)	1.000 (0)	.988 (.008)	.988 (.008)	1.000 (0)	.988 (.008)

Figure 3. Probe detection accuracy in Experiment 1A (The distractors were pure tones at 1000 Hz. The feature-target [or feature-probe] was a pure tone at 1500 Hz. The object-target [or object-probe] was comprised of six, 5 ms pulses at 1500 Hz.) as a function of the relationships between the target and the distractors and between the probe and the distractors (feature-object vs. object-feature) both when the target was to be attended and when it was to be ignored. Error bars represent ± 1 standard errors.



[present, absent] x Probe Position [+1 to +7] was conducted using the conditional probability of accurate probe detection given a correct target detection response as the dependent variable. This analysis revealed significant main effects of Target Presence, F (1, 76) = 42.063, $p < .001$, and Probe Position, F (6, 456) = 39.493, $p < .001$. The main effects of Task, $F < 1$, and of Target F (1, 76) = 2.156, $p = .15$, did not reach significance. In general, the accuracy of the probe detection was higher when the target was absent and when the SOA between the target and the probe was longer. Two-way interactions between Target and Target Presence, F (1, 76) = 9.595, $p < .01$, Task and Target Presence, F (1, 76) = 17.421, $p < .001$, Target Presence and Probe Position, F (6, 456) = 35.007, $p < .001$, Task and Probe Position, F (6, 456) = 11.336, $p < .001$, were all statistically significant. The interaction between Target and Probe Position, F (6, 456) = 2.858, $p = .07$, was marginally significant. However, the interaction between Task and Target was not significant, F (1, 76) = 1.281, $p = .261$.

Of more importance, however, is the fact that there were significant three-way interactions between Task, Target Presence and Probe Position, F (6, 456) = 18.026, $p < .001$, between Target, Target Presence and Probe Position, F (6, 456) = 3.954, $p < .05$, and between Task, Target and Probe Position, F (6, 456) = 4.452, $p < .05$. However, neither the three-way interaction between Task, Target and Target Presence, $F < 1$, nor the four-way interaction between Task, Target, Target Presence and Probe Position, F (6, 456) = 2.273, $p = .113$, was significant.

The three-way interaction between Task, Target Presence and Probe Position was evaluated by examining the AB in the two Task conditions separately. This analysis revealed that the main effect of Target Presence was significant when participants were instructed to attend to the target, F (1, 38) = 35.603, $p < .001$, and when they were instructed to ignore it, $F\ (1, 38) = 6.609, p < .05$. The main effect of Probe Position was also significant when participants were instructed to attend to the target, $F\ (6, 228) = 35.262, p < .001$, and when they were instructed to ignore it, $F\ (6, 228) = 6.469, p < .01$. Similarly a significant interaction between Target Presence and Probe Position was apparent both when participants were instructed to attend to the target, $F\ (6, 228) = 34.181, p < .001$, and when they were instructed to ignore it, $F\ (6, 228) = 3.528, p < .05$. Tests of the simple effect of Target Presence indicated a significant probe processing deficit at the +1 and +2 positions when the target was attended. In contrast, when the target was ignored no significant deficit in processing the probe was apparent at any position. A 2 x 2 (Target Judgment [required, not required] x Target Presence [present, absent]) within-subjects ANOVAs performed for each probe position revealed a significant interaction between Target Presence and Target Judgment at the +1 position, $F\ (1, 76) = 22.776, p < .001$, and a marginally significant interaction at +2 position, $F\ (1, 76) = 3.196, p = .078$. These effects arose because the probe processing deficit was larger when the target was attended than when it was ignored at these two positions. Thus, a larger and longer-lasting AB deficit was associated with the requirement to attend to the target.

To evaluate the second of these three-way interactions between Target, Target Presence and Probe Position, AB deficits in the feature-object and object-feature sequences were examined separately. This analysis revealed that the main effect of Target Presence was significant for the feature-object sequences, $F\ (1, 38) = 7.097, p < .05$, and for the object-feature sequences, $F\ (1, 38) = 38.545, p < .001$. The main effect of Probe Position was also significant for both feature-object sequences, $F\ (6, 228) = 11.837, p < .001$, and object-feature sequences, $F\ (6, 228) = 29.547, p < .001$. The interaction between Target Presence and Probe Position was significant both for the feature-object sequences, $F(6, 228) = 9.457$, $p < .001$, and the object-feature sequences, $F(6, 228) = 26.956$, $p < .001$. Tests of the simple effect of Target Presence indicated a significant probe processing deficit only at the +1 position in the feature-object sequences. In contrast, significant deficits for the object-feature sequences were apparent at the +1 and +2 positions. A 2 x 2 (Target [feature, object] x Target Presence [present, absent]) within-subjects ANOVAs performed for each probe position revealed significant interactions between Target Presence and Target at the +1 ($F(1, 76) = 4.167$, $p < .05$) and +2 positions ($F(1, 76) = 7.697$, $p < .01$). These effects arose because the AB deficit was larger in the object-feature sequences than in the feature-object sequences.

Finally, the three-way interaction between Task, Target and Probe Position was evaluated by comparing the difference in probe processing accuracy between object-feature and the feature-object sequences for the target-attended and target-ignored conditions separately. This analysis revealed that the main effect of Target was not significant for both the target-attended condition, $F(1, 38) = 2.200$, $p = .146$, or the target-ignored condition, $F < 1$. However, the main effect of Probe Position was significant for both target-attended condition, $F(6, 228) = 35.262$, $p < .001$, and target-ignored condition, $F(6, 228) = 6.469$, $p < .01$. The interaction between Target and Probe Position was significant for the target-attended condition, $F(6, 228) = 5.245$, $p < .05$, but not significant for the target-ignored condition, $F < 1$. Tests of the simple effect of Target did not reveal significant deficit at any probe positions in both conditions. A 2 x 2 (Target [feature, object] x Task [one, two]) within-subjects ANOVAs performed for each probe position revealed significant interactions between Target and Task only at the +1 position, $F(1, 76) = 5.024$, $p < .05$. These effects arose because there was a significant difference in probe detection accuracy between the object-feature and feature-object sequences at the +1 position when the target was attended condition but not when the target was ignored.

Probe Detection in Each of the Four Main Conditions

Performance was also examined separately for each principal condition using 2 x 7 (Target Presence x Probe Position) within-subjects ANOVAs using the conditional probability of accurate probe detection when the probe was present given a correct target detection response as the dependent variable.

Feature-object Sequences with the Target Attended. The analysis revealed significant main effects of Target Presence, $F(1, 19) = 11.123$, $p < .01$, and of Probe Position, $F(6, 114) = 8.642$, $p < .01$. A significant interaction between Target Presence and Probe Position was apparent, $F(6, 114) = 9.549$, $p < .01$. Simple effect tests indicated that there was a significant processing deficit at +1 temporal position. Thus, there was a significant AB in this condition.

Feature-object Sequences with the Target Ignored. The analysis revealed only a significant main effect of Probe Position, $F(6, 114) = 3.779$, $p < .05$. Further analysis confirmed that there was no significant effect of probe-processing deficit at any position. Thus, there was no AB in this condition.

Object-feature Sequences with the Target Attended. The analysis revealed significant main effects of Target Presence, $F(1, 19) = 24.620$, $p < .001$, and of Probe Position, $F(6, 114) = 27.866$, $p < .001$. A significant interaction between Target Presence and Probe Position was apparent, $F(6, 114) = 25.300$, $p < .001$. Significant probe processing deficits were apparent at the +1, and +2 positions. Thus, there was a significant AB in this condition.

Object-feature Sequences with the Target Ignored. The analysis revealed significant main effects of Target Presence, F (1, 19) = 17.410, $p < .01$, and of Probe Position, F (6, 114) = 3.097, $p < .05$. A significant interaction between Target Presence and Probe Position was apparent, F (6, 114) = 3.197, $p < .05$. Simple effect tests revealed a significant probe processing deficit at the +1 and +2 positions. Thus, there was an AB in this condition.

Finally, whether there was any difference in the magnitude of the AB deficit was examined for the two object-target conditions. A 2 x 2 x 7 (Task [one, two] x Target Presence [present, absent] x Probe Position [+1 through +7]) within-subjects ANOVA revealed a significant three-way interaction between the Task, Target Presence, and Probe Position, F (6, 228) = 14.364, $p < .001$. 2 x 2 (Task [one, two] x Target Presence [present, absent]) ANOVAs at each probe position revealed a significant interaction at the +1 position, F (1, 38) = 17.459, $p < .001$ (all others $p > .10$). Thus, for the object-target conditions the AB was larger when the target was attended than when the target was ignored at the +1 position.

The magnitudes of the auditory AB apparent for the two types of sequences were directly compared when the target was attended by using a 2 x 2 x 7 (Sequence Type x Target Presence x Probe Position) within–subjects ANOVA. A significant three-way interaction emerged from this analysis, F (6, 228) = 3.928, $p < .05$. A series of 2 x 2 (Sequence Type x Target Presence) ANOVAs performed for each probe position revealed a significant interaction at the +1 position, F (1, 38) = 4.346, $p < .05$, and a marginally-significant interaction at the +2 position, F (1, 38) = 2.900, p =.097 (all others $p > .15$). Thus, the AB deficit was larger for the object-feature sequences than for the feature-object sequences when the target was attended.

Discussion

This experiment was conducted to examine whether the auditory AB also reflects the requirement to create a new object file for the target. The results revealed a larger AB when the target was different from the distractors at the object level, than when the target was different from the distractors at the feature level. Thus, it appears that creating a new object file for the target does affect the magnitude of the auditory AB.

The experiment was also conducted to examine whether the low level sensory masking (target to probe) caused the auditory AB. In the feature-object sequences, there was an AB in the target-attended condition but no significant AB in the target-ignored condition, this result indicated that the AB was caused by the limitation of attention rather than by the sensory masking in this type of sequences. Moreover, the results showed that the magnitude of the AB was larger in the target-attended condition than in the target-ignored condition for the object-feature sequences, and this means that at least part of the AB deficit was caused by an attentional limitation. There are two possible explanations for the small AB deficit in the target-ignored condition for the object-feature sequences. The first possibility is that sensory masking caused it, and the second possibility is that the involuntary attentional capture caused it. Regarding the first possibility, because there was no AB in the target-ignored condition for feature-object sequences, it must be assumed that pulses could mask the pure tone but the pure tone could not mask pulses. However, this lacks empirical evidence (see Experiment 1B for the opposite performance pattern). The second possibility is more reasonable because studies of attentional capture (e.g., Hillstrom & Yantis, 1994) have shown that when a to-be-ignored target is different from the distractors at the object level, visual attentional capture is more likely to occur. This account is consistent with the results of the present experiment that there was a significant AB for the object-feature sequences but not for the feature-object sequences when the target was ignored.

Another goal of the experiment was to examine whether task-switching caused the AB. Since a larger AB was apparent for the object-feature sequences than for the feature-object sequences when the both target and the probe were attended, it is impossible to conclude that the AB was completely caused by task-switching because the target and the probe were exchanged in the two conditions. Thus, at least part of the AB appears to reflect the requirement to create a new object file for the target. With regard to the small AB apparent for feature-object sequences, task-switching could play a role. However, this deficit may also have arisen either because the feature difference was large enough to break object file continuity or because some capacity-limited resource was required to incorporate a new feature with the existing object file.

EXPERIMENT 1B

In Experiment 1A, the distractors were 1000 Hz pure tones, the target and the probe were either a 1500 Hz pure tone (different feature from distractors) and a 1500 Hz tone composed of six, 5 ms pulses, or a 1500 Hz tone composed of six, 5 ms pulses (different object from distractors) and a 1500 Hz pure tone. In the present experiment, the distractors were six, 5 ms pulses at 1000 Hz, the target and the probe were either six, 5 ms pulses at 1500 Hz (different feature from distractors) and a 1500 Hz pure tone or a 1500 Hz pure tone (different object from distractors) and a 1500 Hz tone composed of six, 5 ms pulses. Thus, the target and the probe in the object-feature sequences in the present experiment were same as those in the feature-object sequences in Experiment 1A. In contrast, the target and the probe in the feature-object sequences in the present experiment were the same as those in the object-feature sequences in Experiment 1A. If there is a larger AB in the object-feature sequences than in the feature-object sequences in both experiments, then this will provide further evidence that the auditory AB is mainly caused by the relation between the target and probe and the distractors rather than by the relation only between the target and the probe, or by their own acoustic characteristics.

Method

Participants

Eighty undergraduate students, enrolled in an Introduction to Psychology course at the University of Manitoba participated in the experiment in exchange for course credit. They all had normal hearing according to self-report.

Materials

The computer and sound system and the sounds used were the same as those used in Experiment 1A except that the distractors were six, 5 ms pulses at 1000 Hz. In the object-feature sequences the target was a 1500 Hz pure tone and the probe was comprised of six, 5 ms pulses at 1500 Hz. In the feature-object sequences the target was comprised of six, 5 ms pulses at 1500 Hz and the probe was a 1500 Hz pure tone.

The procedure, design, data analysis were the same as in Experiment 1A.

Results

Target Detection

Overall, participants found the target quite easy to detect. The probability of a correct response to the target task when the target was attended was 0.963 (*SE* = .006). The probability of a correct response on target-present trials (hit) was 0.955, and the probability of an incorrect response on target-absent trials (false alarms) was 0.030. Thus, average d’ was 4.02.

Performance in each condition is described in Table 3 and Table 4. A 2 x 2 (Target [object, feature] x Probe Presence [present, absent]) split-plot subjects analysis of variance (ANOVA) was conducted using the probability of accurate target detection as the dependent variable when the target was present. The analysis revealed a significant interaction between Target and Probe Presence, $F(1, 38) = 4.668, p < .05$. This interaction arose because the presence of the probe was associated with more accurate target detection for the object-feature sequences but not for the feature-object sequences. Other effects were all not significant ($p > .10$ in all cases). Whether performance on the target detection task may have been influenced by the position of the probe was examined. A 2 x 7 (Target [object, feature] x Probe Position [+1 through +7]) split - plot ANOVA was conducted using the probability of accurate target detection as the dependent variable when both the target and probe were presented. The analysis revealed significant main effects of Target, $F(1, 38) = 7.771, p < .01$, and of Probe Position, $F(6, 228) = 17.491, p < .001$. It also revealed a significant interaction between the two, $F(6, 228) = 7.012, p < .01$. Thus, the accuracy of target detection increased as the SOA between the target and the probe increased. And the size of this increase was larger for feature-object sequences than for object-feature sequences.

Probe Detection

Overall, probe detection accuracy for trials on which there was a correct response to the target was also high at 0.972 ($SE = .003$). The probability of a correct response on probe-present trials (hit) was 0.972, and the probability of an incorrect response on probe-absent trials (false alarms) was 0.029. Thus, average d' was 3.80. Clearly, therefore, participants found the probe quite easy to detect as well.

Table 3

Target detection accuracy (mean and standard error) in Experiment 1B as a function of sequence type and probe presence when the target was present.

SEQUENCE TYPE	PROBE PRESENCE	
	Yes	No
Feature-object	.943 (.014)	.949 (.016)
Object-feature	.983 (.004)	.947 (.012)

Table 4

Target detection accuracy (mean and standard error) in Experiment 1B as a function of probe position when both the target and the probe were present.

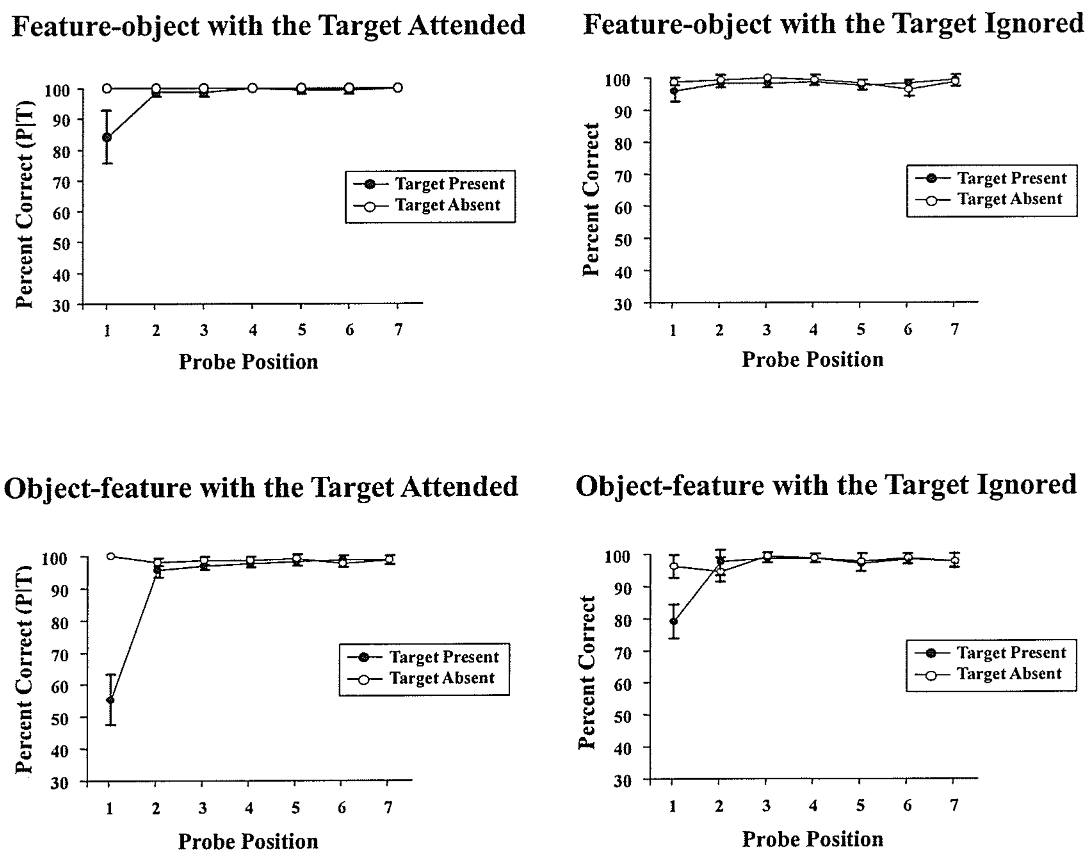
SEQUENCE TYPE	PROBE POSITION						
	+1	+2	+3	+4	+5	+6	+7
Feature-object	.689 (.083)	.952 (.021)	.988 (.008)	.994 (.006)	.994 (.006)	.994 (.006)	.994 (.006)
Object-feature	.927 (.019)	.988 (.008)	.994 (.006)	.994 (.006)	1.000 (0)	.994 (.006)	.994 (.006)

Performance in each condition is described graphically in Figure 4. A 2 x 2 x 2 x 7 split-plot ANOVA (Task [one, two] x Target [object, feature] x Target Presence [present, absent] x Probe Position [+1 to +7] was conducted using the conditional probability of accurate probe detection given a correct target detection response as the dependent variable. This analysis revealed significant main effects of Target Presence, $F\,(1, 76) = 48.302, p < .001$, Probe Position, $F\,(6, 456) = 42.290, p < .001$, and Target, $F\,(1, 76) = 19.375, p < .001$. The main effects of Task, $F < 1$, did not reach significance. In general, the probe detection accuracy was higher when the target was different from the distractors at feature level, when the target was absent, and when the SOA between the target and the probe was longer. Two-way interactions between Target and Target Presence, $F\,(1, 76) = 9.848, p < .01$, Task and Target Presence, $F\,(1, 76) = 13.978, p < .001$, Target Presence and Probe Position, $F\,(6, 456) = 41.212, p < .001$, Target and Probe Position, $F\,(6, 456) = 12.797, p < .001$, and Task and Probe Position, $F\,(6, 456) = 7.783, p < .01$, were all statistically significant. However, the interaction between Task and Target was not significant, $F\,(1, 76) = 1.476, p = .23$.

Of more importance, however, is the fact that there were significant three-way interactions between Task, Target Presence and Probe Position, $F\,(6, 456) = 10.036, p < .001$, and between Target, Target Presence and Probe Position, $F\,(6, 456) = 12.118, p < .001$. However, the three-way interaction between Task, Target and Target Presence $F\,(6, 456) = 1.975, p = .164$, and between Task, Target and Probe Position, $F < 1$, were not significant. The four-way interaction between Task, Target, Target Presence and Probe Position, $F\,(6, 456) = 1.586, p = .21$, was not significant either.

The three-way interaction between Task, Target Presence and Probe Position was evaluated by comparing AB in the two task conditions separately. This analysis revealed

Figure 4. Probe detection accuracy in Experiment 1B (The distractors were comprised of six, 5 ms pulses at 1000 Hz. The feature-target [or feature-probe] was comprised of six, 5 ms pulses at 1500 Hz. The object-target [or object-probe] was a pure tone at 1500 Hz.) as a function of the relationships between the target and the distractors and between the probe and the distractors (feature-object vs. object-feature) both when the target was to be attended and when it was to be ignored. Error bars represent ± 1 standard errors.



that the main effect of Target Presence was significant when participants were instructed to attend to the target, F (1, 38) = 46.708, $p < .001$, and when they were instructed to ignore it, F (1, 38) = 6.636, $p < .05$. The main effect of Probe Position was also significant when participants were instructed to attend to the target, F (6, 228) = 32.327, $p < .001$, and when they were instructed to ignore it, F (6, 228) = 11.083, $p < .001$. Similarly a significant interaction between Target Presence and Probe Position was apparent both when participants were instructed to attend to the target, F (6, 228) = 34.882, $p < .001$, and when they were instructed to ignore it, F (6, 228) = 7.998, $p < .001$. Tests of the simple effect of Target Presence indicated a significant probe processing deficit at the +1 position when the target was attended and when the target was ignored. A 2 x 2 (Target Judgment [required, not required] x Target Presence [present, absent]) within-subjects ANOVAs performed for each probe position revealed a significant interaction between Target Presence and Target Judgment at the +1 position, F (1, 76) = 11.531, $p < .01$, and at the +2 position, F (1, 76) = 4.238, $p < .05$. These effects arose because the probe processing deficit was larger when the target was attended than when it was ignored at these two positions at the +1 and +2 positions. Thus, a larger AB deficit was associated with the requirement to attend to the target.

To evaluate the second of these three-way interactions, AB deficits in the feature-object and object-feature sequences were examined separately. This analysis revealed that the main effect of Target Presence was significant for the feature-object sequences, F (1, 38) = 8.769, $p < .01$, and for the object-feature sequences, F (1, 38) = 43.435, $p < .001$. The main effect of Probe Position was also significant for both feature-object sequences, F (6, 228) = 5.928, $p < .05$, and object-feature sequences, F (6, 228) = 41.020, $p < .001$. The interaction between Target Presence and Probe Position was significant both for the feature-object sequences, $F(6, 228) = 5.967$, $p < .01$, and the object-feature sequences, $F(6, 228) = 39.243$, $p < .001$. Tests of the simple effect of Target Presence indicated an insignificant probe processing deficit at all positions in the feature-object sequences. In contrast, the tests revealed significant deficit in the object-feature sequences at the +1 position. A 2 x 2 (Target [feature, object] x Target Presence [present, absent]) within-subjects ANOVAs performed for each probe position revealed significant interactions between Target Presence and Target at the +1 position, ($F(1, 76) = 13.176$, $p < .01$. This effect arose because the probe processing deficit was larger in the object-feature sequences than in the feature-object sequences at the +1 position. Thus, a larger AB deficit was associated with the object-feature sequences.

Probe Detection in Each of the Four Main Conditions

Performance was examined separately for each principal condition using 2 x 7 (Target Presence x Probe Position) within-subjects ANOVAs using the conditional probability of accurate probe detection when the probe was present given a correct target detection response as the dependent variable.

Feature-object Sequences with the Target Attended. The analysis revealed significant main effects of Target Presence, $F(1, 19) = 7.827$, $p < .05$, and of Probe Position, $F(6, 114) = 5.289$, $p < .05$. A significant interaction between Target Presence and Probe Position was apparent, $F(6, 114) = 5.289$, $p < .05$. Simple effect tests indicated that there was no significant processing deficit at any temporal position. Thus, there was a little AB in this condition.

Feature-object Sequences with the Target Ignored. The analysis did not reveal any significant effect ($p > .15$ in all cases). Further analysis confirmed that there was no significant effect of probe-processing deficit at any position. Thus, there was no AB in this condition.

Object-feature Sequences with the Target Attended. The analysis revealed significant main effects of Target Presence, $F(1, 19) = 46.786$, $p < .001$, and of Probe Position, $F(6, 114) = 31.688$, $p < .001$. A significant interaction between Target Presence and Probe Position was apparent, $F(6, 114) = 34.681$, $p < .001$. Significant probe processing deficits were apparent at the +1 position. Thus, there was a significant AB in this condition.

Object-feature Sequences with the Target Ignored. The analysis revealed significant main effects of Target Presence, $F(1, 19) = 5.539$, $p < .05$, and of Probe Position, $F(6, 114) = 11.239$, $p < .001$. A significant interaction between Target Presence and Probe Position was apparent, $F(6, 114) = 7.887$, $p < .01$. Simple effect tests revealed a significant probe processing deficit at the +1 position. Thus, there was a significant AB in this condition.

Finally, whether there were any differences in the magnitude of the AB deficits for the two object-feature conditions was examined. A 2 x 2 x 7 (Task [one, two] x Target Presence [present, absent] x Probe Position [+1 through +7]) within-subjects ANOVA revealed a significant three-way interaction between the Task, Target Presence, and Probe Position, $F(6, 228) = 7.582$, $p < .001$. 2 x 2 (Task [one, two] x Target Presence [present, absent]) ANOVAs at each probe position revealed significant interaction at the +1 position, $F(1, 38) = 10.698$, $p < .01$, and at the + 2 position, $F(1, 38) = 6.013$, $p < .05$ (all others $p > .10$). Thus, for the object-feature sequences the AB deficit was larger when the target was attended than when the target was ignored.

Discussion

Experiments 1A and 1B were both conducted to examine whether the auditory AB reflects a limitation in processing new information caused by ongoing creation of a new object file. However, in contrast with Experiment 1A, in the present experiment the distractors were changed from pure tones to pulses. This change had only a very minor influence on performance. Thus, as was the case in Experiment 1A, when the target was different from the distractors at the object level, there was a larger AB than when the target was different from the distractors at the feature level. These results suggest that the AB deficit is affected by a requirement to create a new object file for the target.

In addition, with regard to whether low level sensory masking may cause the auditory AB, as was the case in Experiment 1A, little or no AB deficit was apparent when the target was to be ignored. Recall that, the target and probe in the feature-object (target-ignored) sequences in this experiment were the same as those in the object-feature (target-ignored) sequences in Experiment 1A. If the sensory masking of the probe by the target caused the AB, there should have been deficits for both sequences. However, an AB was apparent only for object-feature sequences. Similarly, the target and the probe in the object-feature (target-ignored) sequences in this experiment were same as those in the feature-object (target-ignored) sequences in Experiment 1A. If sensory masking of the probe by the target caused the AB in these conditions, then there should have been deficits in both cases. However, a significant AB was apparent only for the object-feature (target-ignored) sequences in both Experiments 1A and1B. Thus, these results indicate that the AB was not caused by sensory masking. In contrast, the fact that significant ABs were apparent for object-feature sequences but not for feature-object sequences, indicates that involuntary attentional capture is more likely to occur when the to-be-ignored target is different from the distractors at the object level (e.g., Hillstrom & Yantis, 1994).

As was evident in Experiment 1A, a small AB was apparent for the feature-object sequences when the target was attended in the present experiment and this might be taken as indicating a contribution of task-switching to the AB. It is also possible however that the change in frequency from 1000 Hz (distractors) to 1500 Hz (target) may have been large enough to require formation of a new object file, or that incorporating a new feature into an existing object file also draws to a small degree on capacity-limited attentional resources.

EXPERIMENT 2

In Experiment 1, the probe always differed from the distractors by one feature when the target was a different object from the distractors. In contrast, the probe was a different object than the distractors when the target differed from the distractors by a single feature. This design permits the logical possibility that a robust AB in the object-feature sequences may actually be caused by the similarity of the probe to the distractors. Arnell and Jenkins (2004) have argued that such similarity is very important with regard to generating an AB. The study reported by Shen and Mondor (2006) provided evidence that overwriting of the probe by distractors following it is the major factor in generating the auditory AB. Thus, it is possible that more overwriting of the probe by the distractors following it may occur when the probe differs from the distractors in a single feature than when it differs from them at the object level. In early studies (e.g., Baddeley, 1966; Hull, 1964, Mondor & Morin, 2004), the researchers found that similarity can interfere with short-term memory in serial recall or recognition paradigms. In general, this type of interference is thought of as occurring at a retention stage (that is, after encoding; see Baddeley, 1997, p. 180). In contrast, the two-stage model suggests that overwriting of the probe occurs in a holding buffer when the probe is waiting to be consolidated (encoded), and thus it occurs before encoding. However, it is possible that similarity may also affect the likelihood of overwriting of the probe in the holding buffer since some researchers have reported that the similarity of the probe to the distractors is important to the emergence of the AB (e.g., Arnell & Jenkins, 2004; Chun & Potter, 1995). Thus, an attenuated AB apparent in the feature-object sequences may result from less overwriting of the probe in this condition and not because of any difficulty in creating new object representations. The present experiment was conducted to examine this possibility.

There were two types of sequences in this experiment. In one type, the target and the probe both differed from the distractors at the object level (similar to a condition in Experiment 2 of Raymond, 2003). In the other type of sequence, the target and the probe both differed from the distractors in a single feature (similar to a condition in Experiment 1 of the Raymond (2003) study). In both types of sequences, the target and probe were always different. In addition, the target and the probe were always the same type of sounds, either both were pure tones or both were pulses. Thus, task-switching was unlikely to occur in the present experiment. Moreover, performance was examined for both target-attended and target-ignored conditions for both sequence types to allow assessment of the effect of sensory masking.

EXPERIMENT 2A

The distractors were always pure tones at 1000 Hz. For the feature-feature sequences, the target and the probe were both different from the distractors at the feature level (frequency). The target was a 1250 Hz or 1500 Hz pure tone, and the probe was a 1500 Hz or 1250 Hz pure tone. For the object-object sequences, the target and the probe were both different from the distractors at the object level. The target was comprised of six, 5 ms pulses at 1250 Hz or 1500 Hz, and the probe was a six, 5 ms pulse at 1500 Hz or 1250 Hz.

Method

Participants

Forty undergraduate students, enrolled in an Introduction to Psychology course at the University of Manitoba participated in the experiment in exchange for course credit. They all had normal hearing according to self-report.

Materials

Computer and Sound System. The computer and sound system were the same as those used in Experiments 1A and 1B.

Sounds. Most of the sounds were same as those used in Experiment 1A. The distractors were always pure tones at 1000 Hz. The target and probe were always different. In the 'object-object' condition, whereas the target was composed of six, 5 ms pulses at either 1500 Hz or 1250Hz, the probe was composed of six, 5 ms pulses, at either 1250 Hz or 1500Hz. In the 'feature-feature' condition, whereas the target was a pure tone at either 1500 Hz or 1250 Hz, the probe was a pure tone at either 1250 Hz or 1500 Hz. As in Experiments 1A and 1B, the relative intensities of the left and right channels of each tone were varied.

Procedure

Half the participants (20) were instructed to listen for both the target and the probe. The other half of participants (20) was instructed to listen only for the probe. There were two types of sequences for each participant. In the feature-feature sequences the target and the probe both differed from the distractors in a single feature (frequency). For half of the participants, the target was a 1250 Hz pure tone, and the probe was a 1500

Hz pure tone. For the other half of participants, the target was a 1500 Hz pure tone, and the probe was a 1250 Hz pure tone. For the object-object sequences the target and the probe both differed from the distractors at the object level. For half of the participants, the target was formed of six, 5 ms pulses at 1250 Hz, and the probe was formed of six, 5 ms pulses at 1500 Hz. For the other half of participants, the target was comprised of six, 5 ms pulses at 1500 Hz, and the probe was comprised of six, 5 ms pulses at 1250 Hz.

There were four blocks of trials created by the combination of two tasks (detect both the target and the probe, or only the probe) and target type (object-object and feature-feature). For each of these blocks, there were 32 practice trials and 224 experimental trials. Each participant completed both object-object and feature-feature sequences for either the target-attended conditions or the target-ignored conditions. The order in which the two conditions were completed was counter-balanced. Random selection was used to determine which participants were tested in the target-attended or the target-ignored conditions. With regard to the practice trials, each participant was required to meet a criterion of 80% correct on target and probe judgments before beginning the experimental trials.

Design

A split-plot design was used with one between-subject factor (Task [listen for both the target and the probe or only the probe]) and three within-subjects factors (Object [feature-feature, object-object]), Target Presence [present, absent], and (Probe Position [+1 to +7]).

Data Analysis

The methods of analyses were the same as those in Experiments 1.

Results

Target Detection

The probability of a correct response to the target task when the target was attended was 0.918 (*SE* = .011). The probability of a correct response on target-present trials (hit) was 0.913, and the probability of an incorrect response on target-absent trials (false alarms) was 0.077. Thus, average d' was 2.79.

Performance in each condition is described in Table 5 and Table 6. A 2 x 2 (Target [object, feature] x Probe Presence [present, absent]) within-subjects analysis of variance (ANOVA) was conducted using the probability of accurate target detection as the dependent variable when the target was present. The analysis revealed a significant main effect of Probe Presence, $F\,(1, 19) = 28.725, p < .001$. The accuracy of the target detection was higher in the probe-present sequences than in the probe-absent sequences. Neither the main effect of target, $F\,(1, 19) = 1.268, p = .274$, nor the interaction between the two, $F\,(1, 19) = 1.330, p = .263$, were significant. It seems that the presence of the probe benefited the detection of the target.

Performance on the target detection task was examined to determine whether it may have been influenced by the position of the probe. A 2 x 7 (Target [object, feature] x Probe Position [+1 through +7]) within-subjects ANOVA was conducted using the probability of accurate target detection as the dependent variable when both the target and probe were presented. The analysis revealed a significant main effect of Probe Position, $F\,(6, 114) = 3.088, p < .05$. None of the other effects reached significance ($F < 1$ in all cases). Thus, the accuracy of target detection increased with the increasing of the SOA between the target and the probe.

Table 5

Target detection accuracy (mean and standard error) in Experiment 2A as a function of sequence type and probe presence when the target was present.

SEQUENCE TYPE	PROBE PRESENCE	
	Yes	No
Feature-feature	.986 (.004)	.862 (.035)
Object-object	.985 (.007)	.835 (.026)

Table 6

Target detection accuracy (mean and standard error) in Experiment 2A as a function of probe position when both the target and the probe were present.

SEQUENCE TYPE	PROBE POSITION						
	+1	+2	+3	+4	+5	+6	+7
Feature-feature	.970 (.012)	.982 (.010)	.994 (.006)	.994 (.006)	.988 (.008)	.994 (.006)	.988 (.008)
Object-object	.951 (.023)	.976 (.014)	.976 (.014)	.994 (.006)	.982 (.019)	.982 (.010)	.994 (.006)

Probe Detection

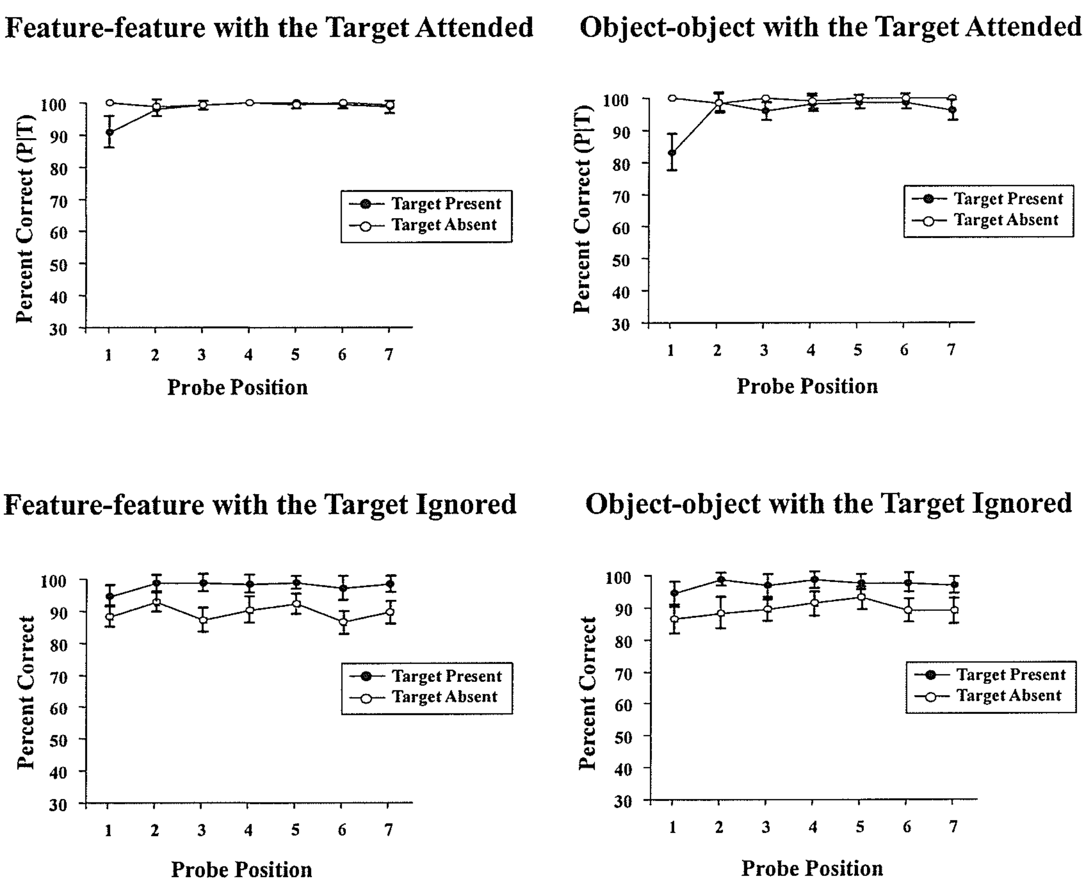
Overall, probe detection accuracy for trials on which there was a correct response to the target was very high at 0.954 ($SE = .008$). The probability of a correct response on probe-present trials (hit) was 0.958, and the probability of an incorrect response on probe-absent trials (false alarms) was 0.057. Thus, average d' was 3.31. Clearly, therefore, participants found the probe quite easy to detect.

Performance in each condition is described graphically in Figure 5. A 2 x 2 x 2 x 7 split-plot ANOVA (Task [one, two] x Object [object, feature] x Target Presence [present, absent] x Probe Position [+1 to +7]) was conducted using the conditional probability of accurate probe detection given a correct target detection response as the dependent variable. This analysis revealed significant main effects of Task, $F(1, 38) = 21.935, p < .001$, Target Presence, $F(1, 38) = 7.581, p < .01$, and Probe Position, $F(6, 228) = 6.308$, $p < .001$. The main effects of Object did not reach significance, $F < 1$. In general, the accuracy of the probe detection was higher when the target was attended, when the target was absent, and when the SOA between the target and the probe was longer.

Two-way interactions between Task and Target Presence, $F(1, 38) = 31.777, p < .001$, and between Target Presence and Probe Position, $F(6, 228) = 3.450, p < .05$, were statistically significant. However, the interactions between Task and Object, Task and Probe Position, Object and Target Presence, and Object and Probe Position were all not significant ($p > .20$ for all these cases). The three-way interaction between Task, Target Presence, and Probe Position was significant, $F(6, 228) = 2.823, p < .05$. Other three-way interactions were all not significant ($F < 1$ for all cases).The four-way interaction, Task, Object, Target Presence, and Probe Position was not significant, $F < 1$.

The three-way interaction between Task, Target Presence, and Probe Position was

Figure 5. Probe detection accuracy in Experiment 2A (The distractors were pure tones at 1000 Hz. The feature-target [or feature-probe] was a pure tone at 1250 or 1500 Hz. The object-target [or object-probe] was comprised of six, 5 ms pulses at 1250 or 1500 Hz.) as a function of the relationships between the target and the distractors and between the probe and the distractors (feature-feature vs. object-object) both when the target was to be attended and when it was to be ignored. Error bars represent ± 1 standard errors.



evaluated by examining the AB in the two task conditions separately. This analysis revealed that the main effect of Target Presence was significant when participants were instructed to attend to the target, $F\ (1, 38) = 10.750, p < .01$, and when they were instructed to ignore it, $F\ (1, 38) = 21.820, p < .001$. The main effect of Probe Position was significant when participants were instructed to attend to the target, $F\ (6, 228) = 6.872, p < .01$, but not when they were instructed to ignore it, $F\ (6, 228) = 1.944, p = .101$. A significant interaction between Target Presence and Probe Position was apparent when participants were instructed to attend to the target, $F\ (6, 228) = 8.399, p < .01$, but not when they were instructed to ignore it, $F < 1$. Tests of the simple effect of Target Presence when the target was attended indicated a significant probe processing deficit at the +1 position. These results indicated that there was an AB when the target was attended but not when the target was ignored.

Probe Detection in Each of the Four Main Conditions

Performance was examined separately for each principal condition using 2 x 7 (Target Presence x Probe Position) within-subjects ANOVAs using the conditional probability of accurate probe detection when the probe was present given a correct target detection response as the dependent variable.

Feature-feature Sequences with the Target Attended. The analysis revealed marginally significant main effects of Target Presence, $F\ (1, 19) = 4.137, p = .056$, and of Probe Position, $F\ (6, 114) = 2.921, p = .084$. A significant interaction between Target Presence and Probe Position was marginally apparent, $F\ (6, 114) = 3.491, p = .055$. Simple effects revealed that no significant probe processing deficit was apparent at any position. Thus, there was a little AB in this type of sequences.

Object-object Sequences with the Target Attended. The analysis revealed significant main effects of Target Presence, F (1, 19) = 9.380, $p < .01$, and of Probe Position, F (6, 114) = 6.100, $p < .01$. A significant interaction between Target Presence and Probe Position was apparent, F (6, 114) = 6.749, $p < .01$. Simple effects revealed that a significant probe processing deficit was apparent at the +1 position. Thus, there was a significant auditory AB in this condition.

Performance in the feature-feature and object-object sequences was compared when the target was attended using a 2 x 2 x 7 (Sequence Type [object, feature] x Target Presence [present, absent] x Probe Position [+1 through +7]) within-subjects ANOVA. This analysis revealed an insignificant three-way interaction, F (1, 19) = 1.221, $p = .307$. However, a marginally significant two-way interaction between the Sequence Type and Target Presence was apparent, F (1, 19) = 3.615, $p = .073$. The results of a series of 2 x 2 (Target/Probe Type [object, feature] x Target Presence [present, absent]) ANOVAs performed for each probe position revealed only a marginally significant interaction at the +3 position, F (1, 38) = 4.031, $p = .059$ (all others $p > .10$). Thus, the probe processing deficit at the +3 position was marginally larger for the object-object sequences than for the feature-feature sequences.

Feature- feature Sequences with the Target Ignored. The analysis revealed a significant main effect of Target Presence, F (1, 19) = 32.263, $p < .001$, but not of Probe Position, F (6, 114) = 1.411, $p = .240$. The interaction between Target Presence and Probe Position was not apparent, $F < 1$. Simple effect tests indicated that there were significant processing deficits at +3, +6 and +7 temporal position. In addition, as shown in Figure 5, the accuracy of probe detection was higher when the target was present than when the target was absent. Thus, this is not an AB deficit.

Object-object Sequences with the Target Ignored. The analysis revealed significantly main effects of Target Presence, $F(1, 19) = 10.605$, $p < .01$, but not of Probe Position, $F(6, 114) = 1.144$, $p = .342$. The interaction between Target Presence and Probe Position was not significant, $F < 1$. Simple effect tests indicated that there was a significant processing deficit at the + 6 temporal position. As shown in Figure 5, the accuracy of probe detection was higher when the target was present than when the target was absent. Thus, this is not an AB deficit.

Discussion

Experiment 2A was performed primarily to evaluate the possibility that the larger AB that was observed for object-feature sequences than for feature-object sequences in Experiment 1 may have arisen because of an increased probability of the probe being overwritten by the post-probe distractors. If this was the case, there should have been a large AB for the feature-feature sequences but not for the object-object sequences in the present experiment. The results showed that there were small AB in both the object-object sequences and the feature-feature sequences. In fact, the AB in the object-object sequences was slightly larger than that apparent for the feature-feature sequences. Thus, the requirement of creating a new object for the target does appear to have affected the auditory AB in this experiment. Moreover, these results indicated that the auditory AB may emerge even under conditions in which the task-switching is unlikely to occur because the target and the probe always belonged to the same category in the present experiment. In addition, a small AB in feature-feature sequences may have arisen either because the feature difference was large enough that participants may have occasionally created a new object file for the target, or because processing a new feature also drew some capacity-limited resources.

Of course, these results did not eliminate entirely the possibility that the larger AB apparent for the object-feature sequences in Experiments 1 occurred because of greater overwriting of the probe by the distractors following it since there was a large AB in the object-feature sequences in Experiment 1 but only a small one in the object-object sequences in the present experiment. It appears that there was a greater overwriting of the probe when it differed from the distractors following it at the feature level than that at the object level.

It seems most likely that the small AB apparent for feature-feature sequences in the present experiment was caused by a minimal demand on attentional resources to create a new object file for the target, coupled with a high probability of the probe being overwritten by the highly similar distractors following it. In contrast, the small AB apparent for the object-object sequences seems most likely to have resulted because although there was a substantial demand on attentional resources to create a new object file for the target, there was a very low probability of the probe being overwritten by the dissimilar distractors following it.

This experiment was also conducted to assess the effect of sensory masking. The results showed that there were no AB deficits in either of the two target-ignored conditions. Thus, the auditory AB does not appear to reflect the effect of sensory masking. In fact, the accuracy of probe detection was lower in target-absent sequences than it was in target-present sequences. This effect may have occurred because of the similarity of the target to the probe. When the probe was present alone, it was difficult for participants to judge whether it was the target or the probe. In contrast, when both the target and the probe were present, no such determination was required. These results, then, provide further evidence that task-switching did not contribute in any meaningful way to performance because the target and the probe were so similar in this experiment.

EXPERIMENT 2B

As in Experiment 2A performance was studied for two type of sequences in the present experiment; namely, object-object sequences and feature-feature sequences. However, different auditory materials were used. For both types of sequences, the distractors were always six, 5 ms pulses at 1000 Hz. For the object-object sequences, the target and the probe were both different from the distractors at the object level. The target was a 1250 Hz or 1500 Hz pure tone, and the probe was a 1500 Hz or 1250 Hz pure tone. For the feature-feature sequences, the target and the probe were both different from the distractors at the feature level (frequency). The target was a sound composed of six, 5 ms pulses at 1250 Hz or 1500 Hz, and the probe was a sound composed of six, 5 ms pulses at 1500 Hz or 1250 Hz. The target and the probe were always different. In addition, performance was examined both when the target was to be attended and when it was to be ignored in order to evaluate the possibility of sensory masking.

Method

Participants

Twenty undergraduate students, enrolled in an Introduction to Psychology course at the University of Manitoba participated in the experiment in exchange for course credit. They all had normal hearing according to self-report.

Materials

Computer and Sound System. The computer and sound system were the same as those in Experiments 1A, 1B, and 2A.

Sounds. Most of the sounds were the same as those used in Experiment 1B. The distractors were always six, 5 ms pulses at 1000 Hz. For the feature-feature sequences, the target was a sound composed of six, 5 ms pulses, at either 1250Hz or 1500 Hz, and the probe was composed of six, 5 ms pulses, at either 1500 Hz or 1250Hz. For the object-object sequences, the target was a pure tone at either 1250 Hz or 1500 Hz, and the probe was a pure tone at either 1500 Hz or 1250 Hz. All other details of sound synthesis were the same as in the previous experiments.

The procedure, design, data analysis were all the same as those in Experiment 2A.

Results

Target Detection

The probability of a correct response to the target task when the target was attended was 0.919 (*SE* = .012). The probability of a correct response on target-present trials (hit) was 0.923, and the probability of an incorrect response on target-absent trials (false alarms) was 0.091. Thus, average d' was 2.76.

Performance in each condition is described in Table 7 and Table 8. A 2 x 2 (Target [object, feature] x Probe Presence [present, absent]) within-subjects analysis of variance (ANOVA) was conducted using the probability of accurate target detection as the dependent variable when the target was present. The analysis revealed a significant main effect of Probe Presence, $F(1, 19) = 33.616, p < .001$. The accuracy of the target detection was higher in the probe-present sequences than in the probe-absent sequences. None of other effects was significant, neither the main effect of target, $F(1, 19) = 2.920$, $p = .104$, or the interaction between the two, $F < 1$.

Whether performance on the target detection task may have been influenced by the position of the probe was also examined. 2 x 7 (Target [object, feature] x Probe Position [+ 1 through 7] within-subjects ANOVA was conducted using the probability of accurate target detection as the dependent variable when both the target and probe were presented. The analysis revealed a significant main effects of Target, $F(1, 19) = 6.990$,

Table 7

Target detection accuracy (mean and standard error) in Experiment 2B as a function of sequence type and probe presence when the target was present.

SEQUENCE TYPE	PROBE PRESENCE	
	Yes	No
Feature-feature	.951 (.013)	.862 (.023)
Object-object	.987 (.003)	.890 (.023)

Table 8

Target detection accuracy (mean and standard error) in Experiment 2B as a function of probe position when both the target and the probe were present.

SEQUENCE TYPE	PROBE POSITION						
	+1	+2	+3	+4	+5	+6	+7
Feature-feature	.839 (.046)	.951 (.026)	.964 (.013)	.988 (.008)	.970 (.020)	.976 (.014)	.982 (.010)
Object-object	.988 (.008)	.988 (.008)	1.000 (0)	.988 (.008)	.988 (.008)	.988 (.008)	.982 (.010)

$p < .05$, and of Probe Position, $F(6, 114) = 5.783$, $p < .01$. The interaction between the Target and Probe Position was also significant, $F(6, 114) = 5.783$, $p < .01$ Furthermore, the simple effect of Probe Position was significant for the feature-feature sequences, $F(6, 114) = 6.469$, $p < .01$, but not for the object-object sequences, $F < 1$. Thus, the accuracy of target detection increased with the increasing of the SOA between the target and the probe for the feature-feature sequences, but not for the object-object sequences.

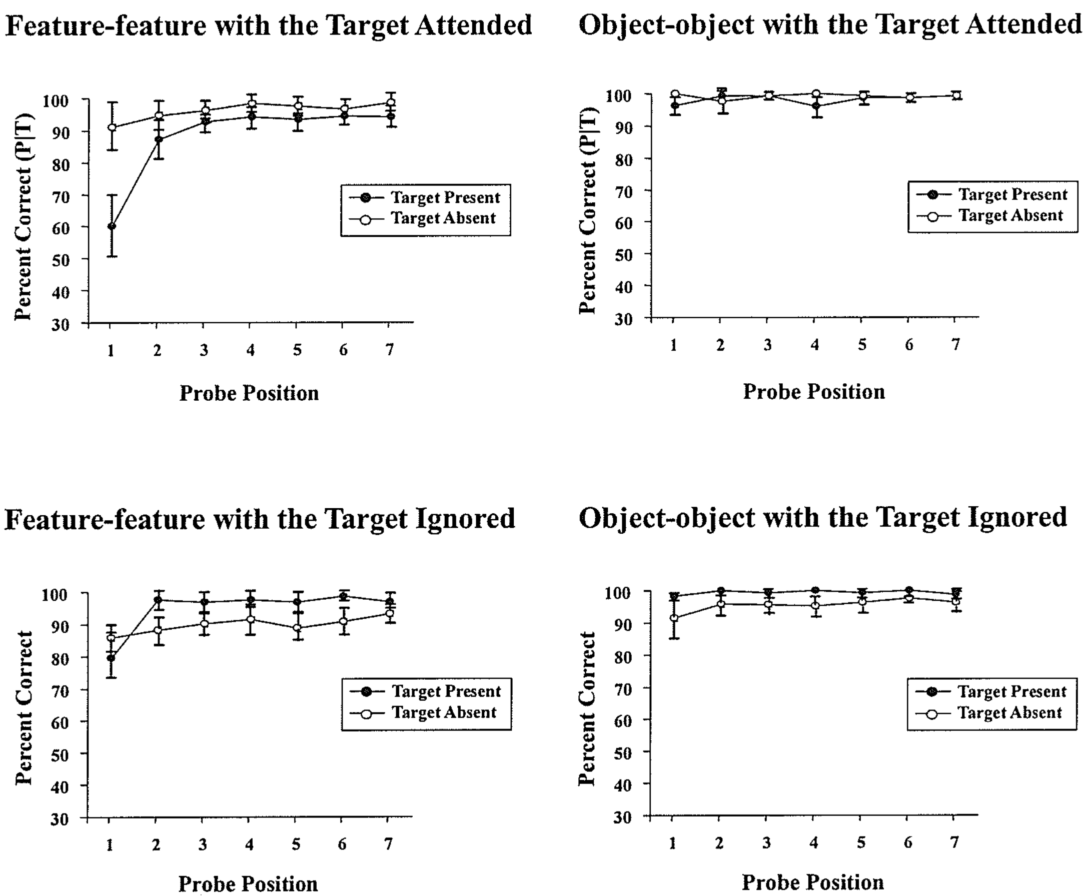
Probe Detection

Overall, probe detection accuracy for trials on which there was a correct response to the target was very high at 0.948 ($SE = .006$). The probability of a correct response on probe-present trials (hit) was 0.953, and the probability of an incorrect response on probe-absent trials (false alarms) was 0.059. Thus, average d' was 3.24. Clearly, therefore, participants found the probe quite easy to detect.

Performance in each condition is described graphically in Figure 6. A 2 x 2 x 2 x 7 split-plot ANOVA with one between-subjects factor (Task [one, two]) and three within-subjects factors (Object [object, feature] x Target Presence [present, absent] x Probe Position [+1 to +7]) was conducted using the conditional probability of accurate probe detection given a correct target detection response as the dependent variable. This analysis revealed significant main effects of Object, $F(1, 38) = 29.580$, $p < .001$, and of Probe Position, $F(6, 228) = 18.408$, $p < .001$. The main effects of Task and Target Presence did not reach significance, $F < 1$. In general, the probe detection accuracy was higher for the object-object sequences, and when the SOA between the target and the probe was longer.

Two-way interactions between Task and Target Presence, $F(1, 38) = 17.133$, $p < .001$, Object and Probe Position, $F(6, 228) = 7.372$, $p < .001$, and Target Presence and

Figure 6. Probe detection accuracy in Experiment 2B (The distractors were comprised of six, 5 ms pulses at1000 Hz. The feature-target [or feature-probe] was comprised of six, 5 ms pulses at 1250 or 1500 Hz. The object-target [or object-probe] was a pure tone at 1250 or 1500 Hz.) as a function of the relationships between the target and the distractors and between the probe and the distractors (feature-feature vs. object-object) both when the target was to be attended and when it was to be ignored. Error bars represent ± 1 standard errors.



Probe Position, F (6, 228) = 12.563, $p < .001$, were all statistically significant. However, the interactions between Task and Object, $F < 1$, Task and Probe Position, $F < 1$, and Object and Target Presence, F (1, 38) = 2.155, $p = .150$, were all not significant. Three-way interactions were significant between Task, Object, and the Target Presence, F (1, 38) = 4.127, $p < .05$, and between Object, Target presence, and Probe Position, F (6, 228) = 8.485, $p < .001$, and the interaction between Task, Target Presence, and Probe Position was marginally significant, F (6, 228) = 2.168, $p = .098$. Neither the interaction between Task, Object and Probe position, F (6, 228) = 2.010, $p = .134$, nor the four-way interaction between Task, Object, Target Presence, and Probe Position, $F < 1$, was significant.

The three-way interaction between Task, Target Presence and Probe Position was evaluated by examining AB in the two Task conditions separately. This analysis revealed that the main effect of Target Presence was significant both when participants were instructed to attend to the target, F (1, 19) = 16.351, $p < .01$, and when they were instructed to ignore it, F (1, 19) = 13.245, $p < .01$. The main effect of Probe Position was also significant when participants were instructed to attend to the target, F (6, 114) = 13.953, $p < .001$, and when they were instructed to ignore it, F (6, 114) = 5.886, $p < .01$. Similarly a significant interaction between Target Presence and Probe Position was apparent both when participants were instructed to attend to the target, F (6, 114) = 10.565, $p < .001$, and when they were instructed to ignore it, F (6, 114) = 2.840, $p = .057$. Tests of the simple effect of Target Presence indicated a significant probe processing deficit at the +1 position when the target was attended. In contrast, when the target was ignored a significant deficit in processing the probe was apparent at + 3, +4, and + 6 positions. A 2 x 2 (Task [one, two] x Target Presence [present, absent]) within-subjects

ANOVAs performed for each probe position revealed a significant interaction between Target Presence and Attend at all positions ($p < .05$ for all cases). These effects arose because the accuracy of probe detection was higher when the target was absent than when it was present in target-attended sequences, but it was higher when the target was present than when it was absent in target-ignored sequences.

To evaluate the three-way interaction between Object, Target presence, and Probe Position, the AB was examined in the feature-feature and object-object sequences separately. This analysis revealed that the main effect of Target Presence was not significant for the feature-feature sequences, $F < 1$, but was significant for the object-object sequences, $F\ (1, 38) = 4.602, p < .05$. The main effect of Probe Position was significant for feature-feature sequences, $F\ (6, 228) = 19.651, p < .001$, but not for object-target sequences, $F\ (6, 228) = 1.258, p = .292$. The interaction between Target Presence and Probe Position was significant for the feature-feature sequences, $F\ (6, 228) = 10.168$, $p < .001$, but not for the object-object sequences, $F < 1$. In brief, there was no AB for either feature-feature or object-object sequences.

The three-way interaction between Task, Object and Target Presence was examined to compare how the difference in probe processing accuracy when the target was attended and when it was ignored was affected by target presence for the object-object and the feature-feature conditions separately. This analysis revealed that the main effect of Task was not significant for the feature-feature sequences, $F < 1$, and for the object-object sequences, $F\ (1, 38) = 2.589, p = .116$. The main effect of Target Presence was not significant for feature-feature sequences, $F < 1$, but was significant for object-object sequences, $F\ (1, 38) = 4.602, p < .05$. The interaction between Task and Target Presence was significant for both feature-feature sequences, $F\ (1, 38) = 10.916, p < .01$, and the object-object sequences, $F(1, 38) = 11.927, p < .01$. These effects arose because the accuracy of probe detection was higher when the target was absent than when it was present in target-attended sequences, but it was higher when the target was present than when it was absent in target-ignored sequences.

Probe Detection in Each of the Four Main Conditions

Performance was examined separately for each principal condition using 2 x 7 (Target Presence x Probe Position) within-subjects ANOVAs using the conditional probability of accurate probe detection when the probe was present given a correct target detection response as the dependent variable.

Feature-feature Sequences with the Target Attended. The analysis revealed significant main effects of Target Presence, $F(1, 19) = 5.770, p < .05$, and of Probe Position, $F(6, 114) = 13.679, p < .001$, and a significant interaction between the two, $F(6, 114) = 7.927, p < .01$. Simple effect tests indicated that there was a significant processing deficit only at +1 position. Thus, in this condition, there was a significant AB.

Object-object Sequences with the Target Attended. The main effects of Target Presence, $F(1, 19) = 1.574, p = .225$, and Probe Position, $F < 1$, and the interaction between Target Presence and Probe Position, $F(6, 114) = 1.797, p < .156$, all failed to reach significance. Simple effect tests indicated that there was no significant processing deficit at any temporal position. Thus, there was no AB in this condition.

Feature-feature Sequences with the Target Ignored. The analysis revealed significant main effects of Target Presence, $F(1, 19) = 5.668, p < .05$, and of Probe Position, $F(6, 114) = 6.343, p < .01$. The interaction between Target Presence and Probe Position was also significant, $F(6, 114) = 2.932, p < .05$. Simple effect tests indicated that there was no significant processing deficit at any position. In addition, as shown in

Figure 6, the accuracy of probe detection was actually higher when the target was present than when the target was absent. Thus, there was no AB in this condition.

Object-object Sequences with the Target Ignored. The analysis revealed a significant main effect of Target Presence, $F(1, 19) = 10.764, p < .01$. However, neither the main effect of Probe Position, $F(6, 114) = 1.077, p = .351$, nor the interaction between Target Presence and Probe Position, $F < 1$, were significant. Significant probe processing deficits were not apparent at any position. As shown in Figure 6, probe detection accuracy was higher when the target was present than when the target was absent. Thus, there was no AB in this condition either.

Discussion

The present experiment was designed to determine the effects of requiring creation of a new object file for the target and of the overwriting of the probe by the distractors following it on the auditory AB in the context of a distractor sequence comprised of pulses. The results showed that there was a significant AB for the feature-feature sequences, but that there was no AB for the object-object sequences.

The distractors in this experiment were six, 5 ms pulses at 1000 Hz (shown in Figure 2). Because each pulse is based on a pure tone of 1000 Hz, the pulse sounds have a carrier frequency (Fc) of 1000 Hz. Each pulse was 5 ms in duration, and, therefore, the pulse sounds may be said to have a modulation frequency (Fm) of 200 Hz (i.e., 200 repetitions per second). There have been a large number of studies regarding perception of modulated sounds (e.g., Moore & Jorasz, 1996; Yost, 2000; Yost & Sheft, 1989; Yost, Sheft, & Opie, 1989). In general, when a target (or a probe) is a modulated sound and has the same modulation frequency as distractors (i.e., comodulation), target (or probe) perception will be impaired because of the operation of a primitive perceptual grouping mechanism which acts to group sounds with the same modulation frequency as arising from the same sound source. Critically, such grouping may occur even when carrier frequency varies across sounds, and in this circumstance distinguishing one modulated sound from another draws on central, capacity-limited processing resources (e.g., Moore & Jorasz, 1996). It is possible then that, in the present experiment, for feature-feature sequences the target and the probe were grouped with the distractors as a consequence of their common comodulation, and this may have increased the demand for capacity-limited resources to process the target and, thereby, extended the delay in processing the probe. Of course, according to the two-stage model, an increased delay in processing the probe should provide an increased opportunity for overwriting or decay of its representation. Furthermore, this effect may apply also to probe perception in that a probe with the same modulation frequency may be more easily integrated into a stream with the distractors and thereby be more easily overwritten. Thus, it is possible that for these reasons a relatively large AB arose for feature-feature sequences in the present experiment.

It stands to reason that the object file for the pulse distractors includes both modulation frequency and carrier frequency components. Moreover, to use the same object file, the modulation frequency must match but the carrier frequency may be quite different (e.g., Moore & Jorasz, 1996). For object-object sequences in the present experiment, the distractors were pulses and the target was a pure tone. Because the object file created at the beginning of the sequence for the pulse distractors included both modulation frequency and carrier frequency components, it may have been possible that creating a new object file for the pure tone target with carrier frequency component in the middle of a sequence only needed a minimal degree on capacity-limited resources.

(Actually, the existing object file for the distractors has all components of the new object file for the target.) Thus, the duration of the probe processing delay would be very short, and the opportunity for the probe to be overwritten and passively decay was small. In addition, the possibility of the object-probe (pure tone) being overwritten by the pulse distractors following it was also small because of their dissimilarity to one another. (A pure tone probe is unlikely to be integrated into a stream with the pulse distractors and, therefore, is not easily overwritten. Thus, when all distractors were comodulated, a pure tone probe could 'pop out'.) These effects meant that perception of the probe was unlikely to be impaired. Thus, this reasoning provides an explanation of why there was no AB for the object-object sequences. However, such a result would not be expected for sequences within which distractors were pure tones. Recall that, in Experiment 2A, for object-object sequences the target and the probe were pulses and the distractors were pure tones. Thus, a new object file for the target with a new component may have had to be created for the target because the object file for the pure tone distractors created at the beginning of the sequences opened only for a certain range of carrier frequencies but included no information regarding modulation frequency, and this drew a significant amount of capacity-limited resources. The duration of the probe processing delay was extended in this situation and the opportunity for the probe to be overwritten and passively decay was increased. Thus, an AB occurred.

In summary, then, it appears that for feature-feature sequences in the present experiment the target and the probe may have been grouped with the distractors and this may have produced a higher demand for attentional resources to process the feature-target, thereby increasing the possibility of the overwriting of the feature-probe by the distractors following it, and these factors acted to generate a large auditory AB. In contrast, for object-object sequences in the present experiment it appears that the existing object file for the pulse distractors may have been used in deriving an object file for the object-target (pure tone) and this may have produced a relatively low demand for attentional resources. Moreover, the possibility of the overwriting of the object-probe (pure tone) by the pulses distractors following it was also low. Together, these effects eliminated any evidence of an AB.

Taken together, the results of Experiments 1 and 2 may be interpreted in light of the effects of the requirement to create a new object file for the target, the likelihood of the probe representation decaying or being overwritten while awaiting processing, the effect of grouping of the target and probe with the distractors, and the characteristics of modulated sounds. In Experiment 3 converging evidence of the role of these factors in generating the auditory AB was sought.

EXPERIMENT 3

Raymond (2003) has argued that the AB is a consequence of the requirement to create a new object file for the target. Therefore, according to this view, if the target is the first sound in a trial, then it should be irrelevant whether or not it differs from the subsequent distractors – a significant AB should be apparent. This should be the case because a new object file must be created in any event. Experiments 3A and 3B were designed to study this issue and to provide an opportunity to replicate the result reported by Shen and Mondor (2006) that only a very small AB remains when all distractors following the probe are deleted.

EXPERIMENT 3A

There were two basic types of sequences. In one type the target differed from the distractors at the object level (object-feature sequences) and in the other the target differed from the distractors at the feature level (feature-feature sequences). In both types of sequences the probe was set to differ from the distractors at the feature level in hopes of showing a robust effect of deleting distractors from different parts of the sequences.

In this experiment, the distractors were pure tones at1000 Hz. The probe was a pure tone with at 1500 Hz. For the object-feature sequences, the target was comprised of six, 5 ms pulses at 1500 Hz (the same distractor sequence was used for the object-feature sequences in Experiment 1). For the feature-feature sequences, the target was a pure tone at 1250 Hz (the same distractor sequence was used for the feature-feature sequences in Experiment 2).

Method

Participants

Forty undergraduate students, enrolled in an Introduction to Psychology course at the University of Manitoba participated in the experiment in exchange for course credit. They all had normal hearing according to self-report.

Materials

Computer and Sound System. The computer and sound system used were the same as those in Experiments 1 and 2.

Sounds. Most of the sounds were the same as those used in Experiments 1A and 2A. The distractors were pure tones at 1000 Hz. For the object-feature sequences, the target was composed of six, 5 ms pulses, at 1500 Hz. The probe was a pure tone at 1500 Hz. For the feature-feature sequences, the target was a pure tone at 1250 Hz, and the probe was a pure tone at 1500 Hz. All other details of sound synthesis were the same as in the previous experiments.

Procedure

For each of the object-feature and the feature-feature sequences, there were four conditions which differed in the placement of distractor sounds; namely: 1) full-stream, 2) replacement of all items prior to the target with silence, 3) replacement of all items following the probe with silence, and 4) replacement of all items prior to the target and following the probe with silence. The participants were required to make detection judgments for both the target and the probe. For each of these conditions, there were 32 practice trials and 224 experimental trials. Each participant completed all four conditions for either the object-feature or the feature-feature sequences. A Latin square was used to balance the order in which the four conditions were completed across participants. Random selection was used to determine which participants would be tested in the object-feature or the feature-feature sequences. Each participant was required to meet a criterion of 80% correct on target and probe judgments on the practice trials before beginning the experimental trials.

Design

A split - plot design with one between-subjects factor (Target [object, feature]) and three within-subjects factors (Stream [full, deleting all items prior to the target, deleting all items following the probe, and deleting all items prior to the target and following the probe], Target Presence [present, absent], and Probe Position [+1 to +7]) was used.

Data analysis

The analyses were the same as those used in Experiments 1 and 2.

Results

Target Detection

The probability of a correct response to the target task was 0.948 (SE = .007). The probability of a correct response on target-present trials (hit) was 0.943, and the probability of an incorrect response on target-absent trials (false alarms) was 0.049. Thus, average d' was 3.23.

Performance in each condition is described in Table 9 and Table 10. A 2 x 4 x 2 split-plot ANOVA with one between-subjects factor (Target [object, feature]) and two within-subjects factors (Stream [full, deleting all items prior to the target, deleting all items following the probe, and deleting all items prior to the target and following the probe] x Probe Presence [present, absent]) was conducted using the probability of accurate target detection as the dependent variable when the target was present. The analysis revealed significant main effects of Probe Presence, F (1, 38) = 4.646, p < 05, and of Target, F (1, 38) = 7.357, p < 05, but not of Stream, F (3, 114) = 2.167, p = .111. In general, the accuracy of target detection was higher when the probe was present and when the target was different from distractors at the object level.

The two-way interactions between Target and Probe Presence, F (, 38) = 4.091, p < .05, and between Stream and Probe Presence, F (3, 114) = 5.236, p < .01, were significant. Although the interaction between the Target and Stream was not significant, F (3, 114) = 1.358, p =. 263, the three-way interaction between Target, Stream, and Probe Presence was significant, F (3, 114) = 7.830, p < .001. This three-way interaction was decomposed by examining performance for the two sentences types separately. For object-feature sequences, there was no significant main effect of Stream, F (3, 57) = 1.548, p = .223, or Probe Presence, F < 1, nor was there an interaction between the two,

Table 9

Target detection accuracy (mean and standard error) in Experiment 3A as a function of sequence type, distractor stream, and probe presence when the target was present.

SEQUENCE TYPE	DISTRACTOR STREAM	PROBE PRESENCE	
		Yes	No
Feature-feature	Full Stream	.967 (.011)	.868 (.025)
	Silence Prior to Target	.934 (.011)	.928 (.013)
	Silence Following Probe	.942 (.017)	.929 (.017)
	Silence Prior to Target & Following Probe	.895 (.022)	.903 (.036)
Object-feature	Full Stream	.959 (.011)	.965 (.010)
	Silence Prior to the Target	.957 (.010)	.957 (.012)
	Silence Following the Probe	.977 (.010)	.977 (.007)
	Silence Prior to Target & Following Probe	.969 (.009)	.960 (.010)

Table 10

Target detection accuracy (mean and standard error) in Experiment 3A as a function of distractor stream and probe position when both the target and the probe were present.

SEQUENCE TYPE	DISTRACTOR STREAM	PROBE POSITION						
		+1	+2	+3	+4	+5	+6	+7
Feature-feature	Full Stream	.864 (.043)	.951 (.024)	.994 (.006)	.994 (.006)	.988 (.008)	.988 (.013)	.994 (.006)
	Silence Prior to Target	.820 (.058)	.939 (.025)	.958 (.016)	.970 (.015)	.939 (.021)	.970 (.012)	.958 (.016)
	Silence Following Probe	.764 (.068)	.913 (.040)	.988 (.008)	.976 (.011)	.976 (.011)	.982 (.010)	1.000 (0)
	Silence Prior to Target & Following Probe	.749 (.047)	.920 (.040)	.927 (.024)	.895 (.033)	.926 (.029)	.945 (.021)	.920 (.038)
Object-feature	Full Stream	.890 (.033)	.939 (.025)	.976 (.014)	.969 (.018)	.988 (.008)	.976 (.014)	.957 (.019)
	Silence Prior to Target	.907 (.031)	.952 (.021)	.970 (.015)	.988 (.008)	.957 (.022)	.976 (.011)	.957 (.019)
	Silence Following Probe	.895 (.039)	.982 (.014)	.994 (.006)	1.000 (0)	.994 (.006)	.988 (.013)	.988 (.013)
	Silence Prior to Target & Following Probe	.902 (.041)	.982 (.010)	.988 (.008)	.988 (.008)	.970 (.015)	.988 (.008)	.969 (.018)

$F < 1$. For feature-feature sequences, the main effect of Probe Presence was significant, F (1, 19) = 4.916, $p < .05$, but the main effect of Stream was not, F (3, 57) = 1.829, p =.176, the interaction between the two was significant, F (3, 57) = 8.395, p < .001. The two-way interaction was decomposed by examining performance for the probe-present and probe-absent conditions separately. When the probe was present, the simple effect of stream was significant, F (3, 57) = 5.111, p < .05, When the probe was absent, the simple effect of stream was not significant, $F < 1$. In general, for the feature-feature sequences deleting a part of a sequence reduced the accuracy of target detection when the probe was present but not when the probe was absent.

Performance on the target detection task was examined to determine whether it may have been influenced by the position of the probe. A 2 x 4 x 7 (Target x Stream x Probe Position) split-plot ANOVA was conducted using the probability of accurate target detection as the dependent variable when both the target and probe were presented. The analysis revealed significant main effects of Target, F (1, 38) = 4.467, $p < .05$, Stream, F (3, 114) = 3.650, $p < .05$, and Probe Position, F (6, 228) = 26.217, $p < .001$. In general, the accuracy of target detection was higher when the target was different from distractors at the object level, when the items prior to the target were presented, and when the SOA between the target and the probe was longer.

The two-way interaction between Target and Stream was significant, F (3, 114) = 5.303, $p < .01$. For feature-feature sequences, the simple effect of Stream was significant, F (3, 57) = 6.138, $p < .01$. In general, deleting a part of a sequence reduced the accuracy of target detection. However, for object-feature sequences, the simple effect of Stream was not significant, F (3, 57) = 1.146, p = .332. The two-way interaction between Target and Probe position was marginally significant, F (6, 228) = 3.089, p = .053, but that between Stream and Probe Position not significant, $F < 1$. The three-way interaction between Target, Stream, and Probe Position, was not significant either, $F < 1$.

Probe Detection

Overall, probe detection accuracy for trials on which there was a correct response to the target was very high at 0.977 ($SE = .003$). The probability of a correct response on probe-present trials (hit) was 0.972, and the probability of an incorrect response on probe–absent trials (false alarms) was 0.021. Thus, average d' was 3.93. Clearly, therefore, participants found the probe quite easy to detect.

Performance in each condition is described graphically in Figure 7. A 2 x 4 x 2 x 7 split-plot ANOVA treating Target (object, feature) as a between-subjects factor and Stream (full, deleting all items prior to the target, deleting all items following the probe, and deleting all items prior to the target and following the probe), Target Presence (present, absent), and Probe Position (+1 to +7) as within-subjects factors was conducted using the conditional probability of accurate probe detection given a correct target detection response as the dependent variable. This analysis revealed significant main effects of Stream, $F(3, 114) = 14.363, p < .001$, Target Presence, $F(1, 38) = 53.812, p < .001$, and Probe Position, $F(6, 228) = 47.337, p < .001$. However, the main effect of Target was not significant, $F(1, 38) = 1.744, p = .195$. In general, the accuracy of probe detection was higher when the target was absent, when the SOA between the target and the probe was longer, and when the distractors following the probe were replaced by silence.

Two-way interactions between Target and Stream, $F(3, 114) = 5.658, p < .01$, Target and Target Presence, $F(1, 38) = 5.300, p < .05$, Target and Probe Presence, $F(6, 228) = 7.365, p < .01$, Stream and Target Presence, $F(3, 114) = 15.370, p < .001$, Stream

Figure 7. Probe detection accuracy in Experiment 3A (The distractors were pure tones at 1000 Hz. The feature-probe was a pure tone at 1500 Hz. For the feature-feature sequences, the feature-target was a pure tone at 1250 Hz; for object-feature sequences, the object-target was comprised of six, 5 ms pulses at1500 Hz.) as a function of the presence of distractors (full, deleting all items prior to the target, deleting all items following the probe, and deleting all items prior to the target and following the probe). Error bars represent ± 1 standard errors.

Feature-feature sequences

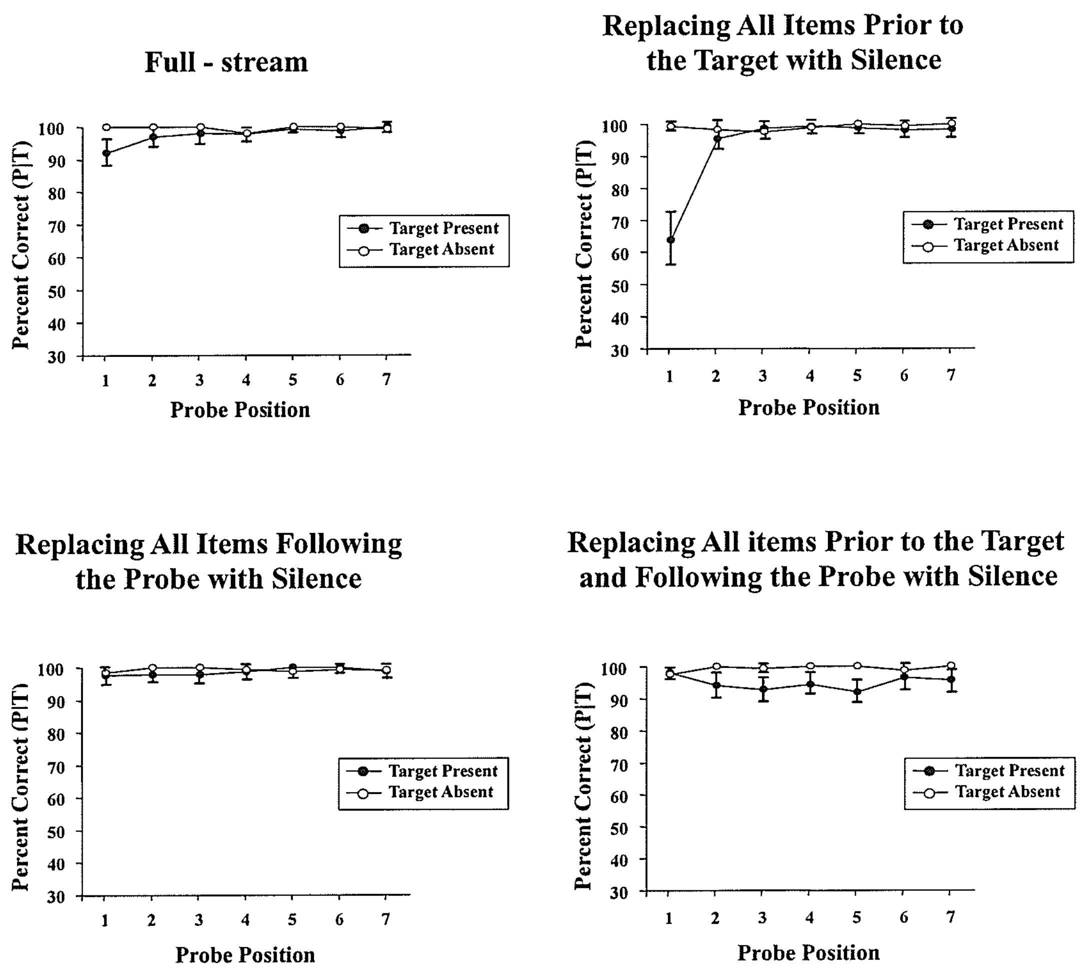
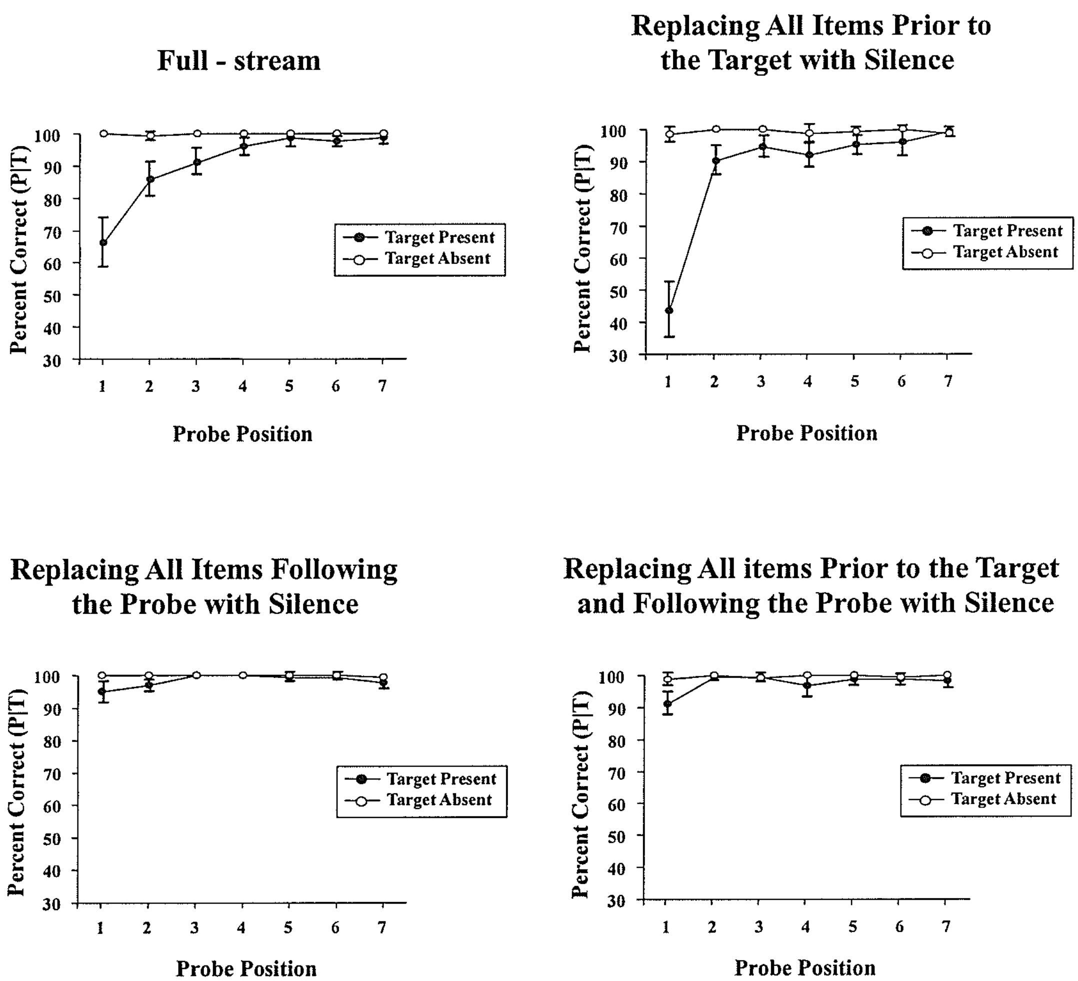


Figure 7 (continued)

Object-feature sequences



and Probe Position, $F(18, 684) = 22.535, p < .001$, and Target Presence and Probe Position, $F(6, 228) = 42.709, p < .001$, were all statistically significant.

In addition, three-way interactions between Target, Stream, and Target Presence, $F(3, 114) = 6.959, p < .001$, Target, Target Presence and Probe Position, $F(6, 228) = 7.861, p < .01$, and Stream, Target Presence and Probe Position were all significant, $F(18, 684) = 22.953, p < .001$. The interaction between Target, Stream, and Probe Position was marginally significant, $F(18, 684) = 2.190, p = .064$.

The four-way interaction between Target, Stream, Target Presence and Probe Position was not significant, $F(18, 684) = 1.633, p = .155$.

The three-way interaction between Target, Stream, and Target Presence was evaluated by comparing how the difference in probe processing accuracy when the target was present and when it was absent was affected by different stream conditions for the two target sequences separately. This analysis revealed that the main effect of Stream was significant for feature-target sequences, $F(3, 57) = 4.654, p < .01$, and for object-feature sequences, $F(3, 57) = 13.813, p < .001$. The main effect of Target Presence was significant for feature-feature sequences, $F(1, 19) = 20.039, p < .001$, and also for object-feature sequences, $F(1, 19) = 33.954, p < .001$. The interaction between the two was significant for feature-feature sequences, $F(3, 57) = 4.923, p < .01$, and for object-feature sequences, $F(3, 57) = 15.184, p < .001$. For feature-feature sequences, the simple effect of Target Presence was significant when all items prior to the target were replaced by silence and when items prior to the target and following the probe were replaced by silence but not for either of the other two types of distractor conditions. These results indicated that for the feature-feature sequences the difference of the accuracy in probe detection between the target-present and the target-absent conditions was significant when the items prior to the target were replaced by silence. For object-feature sequences, the simple effect of Target Presence was significant for all types of distractor conditions.

The three-way interaction between Target, Target Presence and Probe Position was evaluated by examining the AB for the two types of sequences separately. This analysis revealed that the main effect of Target Presence was significant for both feature-feature sequences, $F\ (1, 19) = 20.039, p < .001$, and object-feature sequences, $F\ (1, 19) = 33.954, p < .001$. The main effect of Probe Position was also significant for feature-feature sequences, $F\ (6, 114) = 12.677, p < .001$, and for object-feature sequences, $F\ (6, 114) = 35.081, p < .001$. Similarly a significant interaction between Target Presence and Probe Position was apparent for both types of sequences, $F\ (6, 114) = 34.882, p < .001$, and $F\ (6, 114) = 9.984, p < .001$, for the feature-feature and object-feature sequences, respectively. Tests of the simple effect of Target Presence indicated a significant probe processing deficit at the +1, +2, and +5 positions for the feature-feature sequences, and at the +1, +2, +3, and +4 for the object-feature sequences. A 2 x 2 (Target [feature, object] x Target Presence [present, absent]) within-subjects ANOVAs performed for each probe position revealed a significant interaction between Target and Target Presence at the +1 position, $F\ (1, 38) = 10.582, p < .01$. This effect arose because the auditory AB was larger when the target was different from the distractors at object level than when it differed from the distractors at the feature level. Thus, a larger AB deficit was associated with the object-feature sequences.

The three-way interaction between Stream, Target Presence and Probe Position was evaluated by examining the AB in each of the four distractor conditions separately. In full-stream sequences, the analysis revealed significant main effects of Target Presence, $F\ (1, 39) = 22.649, p < .001$, and of Probe Position, $F\ (6, 234) = 13.654, p <$

.001. The interaction between the two was also significant, F (6, 234) = 14.374, $p < .001$. Tests of the simple effect of Target Presence indicated a significant probe processing deficit at the +1, +2, and +3 positions. When all items prior to the target were replaced by silence, the analysis revealed significant main effects of Target Presence, F (1, 39) = 40.344, $p < .001$, and of Probe Position, F (6, 234) = 50.870, $p < .001$. The interaction between the two was also significant, F (6, 234) = 49.278, $p < .001$. Tests of the simple effect of Target Presence indicated a significant probe processing deficit at the +1 position. When all items following the probe were replaced by silence, the analysis revealed significant main effects of Target Presence, F (1, 39) = 7.136, $p < .05$, and of Probe Position, F (6, 234) = 2.806, $p < .01$. The interaction between the two was marginally significant, F (6, 234) = 2.198, $p = .092$. Tests of the simple effect of Target Presence indicated a significant probe processing deficit at the +2 position. When all items both prior to the target and following the probe were replaced by silence, the analysis revealed a significant main effect of Target Presence, F (1, 39) = 13.373, $p < .01$, but not of Probe Position, F (6, 234) = 1.358, $p = .260$. The interaction between the two was not significant, $F < 1$. These results indicated that there was a robust AB deficit in full-stream and when all items prior to the target were replaced by silence, a small AB when all items following the probe were replaced by silence, and no AB when all items both prior the target and following the probe were replaced by silence.

Probe Detection in Each of the Eight Main Conditions

Performance was examined separately for each principal condition using 2 x 7 (Target Presence x Probe Position) within-subjects ANOVAs using the conditional probability of accurate probe detection when the probe was present given a correct target detection response as the dependent variable.

Feature-feature Sequences with a Full Stream of Distractors. The analysis revealed a marginally-significant main effect of Target Presence, $F(1, 19) = 3.922$, $p = .062$, a significant main effect of Probe Position, $F(6, 114) = 3.092$, $p < .05$, and a significant interaction between Target Presence and Probe Position, $F(6, 114) = 3.051$, $p < .05$. Simple effect tests indicated that there was no significant processing deficit at any position. Thus, in this condition, there was little evidence of an auditory AB.

Feature-feature Sequences with No Distractors prior to the Target. The analysis revealed significant main effects of Target Presence, $F(1, 19) = 23.972$, $p < .001$, and of Probe Position, $F(6, 114) = 17.650$, $p < .001$, and a significant interaction between Target Presence and Probe Position, $F(6, 114) = 18.456$, $p < .001$. Simple effect tests indicated that there was a significant processing deficit only at the +1 position. In this condition, the probe processing deficit reached significance, and its magnitude decreased as the time between the target and probe increased. Thus, there was a robust AB in this condition.

The magnitude of the AB apparent in this condition was compared with that observed in the full-stream condition using a 2 x 2 x 7 within-subjects ANOVA (Stream [full, Deleting all items prior to the target] x Target Presence [present, absent] x Probe Position [+1 through + 7]). The three-way interaction between Stream, Target Presence, and Probe Position was significant, $F(6, 114) = 10.127$, $p < .001$. 2 x 2 within-subjects ANOVAs (Stream x Target Presence) at each position revealed that there was an interaction at the + 1 position ($p < .01$; $p > .10$ for all other effects). These results indicated that the magnitude of the auditory AB was larger when the distractors prior to the probe were replaced by silence.

Feature-feature Sequences with No Distractors Following the Probe. The analysis did not reveal any significant effects ($p > .31$ in all cases). Simple effect tests indicated that there was no significant processing deficit at any position. Namely, there was no AB deficit in this condition.

Feature-feature Sequences with No Distractors Either Prior to the Target or Following the Probe. Whereas the main effect of Target Presence, $F(1, 19) = 7.597, p < .05$, was significant, neither the main effect of Probe Position, $F < 1$, nor the interaction between Target Presence and Probe Position, $F(6, 114) = 2.002, p = .135$, were significant. Simple effect tests indicated that there was no significant processing deficit at any position. Thus, there was no AB deficit in this condition, although there was an overall probe processing deficit. (The definition of an AB being used in the present study requires that there be an improvement in probe performance as a function of its position. As Potter et al. (1998) have suggested, an overall deficit maybe simply reflect the cost of dividing attention.)

Object-feature Sequences with a Full Stream of Distractors. The analysis revealed significant main effects of Target Presence, $F(1, 19) = 25.491, p < .001$, and of Probe Position, $F(6, 114) = 13.137, p < .001$, and a significant interaction between Target Presence and Probe Position, $F(6, 114) = 13.293, p < .001$. Simple effect tests indicated that there were significant processing deficits at the +1, +2, and +3 positions. Thus, in this condition, the probe processing deficit reached significance, and its magnitude decreased as the time between the target and probe increased. Thus, there was a robust AB deficit in this condition.

Object-feature Sequences with No Distractors prior to the Target. The analysis revealed significant main effects of Target Presence, $F(1, 19) = 25.419, p < .001$, and Probe Position, $F(6, 114) = 36.771, p < .001$, and a significant interaction between

Target Presence and Probe Position, $F\,(6, 114) = 33.408, p < .001$. Simple effect tests indicated that there was significant processing deficit only at the +1 position. Thus, in this condition, the probe processing deficit reached significance, and its magnitude decreased as the time between the target and probe increased. Thus, there was a robust AB in this condition.

The magnitude of the AB apparent in this condition was compared with that observed in the full-stream condition using 2 x 2 x 7 within-subjects ANOVA (Stream x Target Presence x Probe Position). The three-way interaction between Stream, Target Presence, and Probe Position was significant, $F\,(6, 114) = 5.873, p < .01$. 2 x 2 within-subjects ANOVAs (Stream x Target Presence) at each position revealed there was an interaction at the + 1 position ($p < .01$; $p > .10$ for all other effects). These results indicated that the magnitude of the auditory AB was increased when the distractors prior to the probe were replaced by a silent period.

Object-feature Sequences with No Distractors Following the Probe. The analysis revealed a significant main effect of Target Presence, $F\,(1, 19) = 7.392, p < .05$, and a marginal main effect of Probe Position, $F\,(6, 114) = 3.016, p = .056$. The interaction between Target Presence and Probe Position approached significance, $F\,(6, 114) = 2.728$, $p = .071$. Simple effect tests indicated that there was no significant processing deficit at any position. Thus, there was little evidence of an AB in this condition.

The magnitude of the AB apparent in this condition was compared with that observed in the full-stream condition using 2 x 2 x 7 within-subjects ANOVA (Stream x Target Presence x Probe Position). The three-way interaction between Stream, Target Presence, and Probe Position was significant, $F\,(6, 114) = 8.536, p < .01$. 2 x 2 within-subjects ANOVAs (Stream x Target Presence) at each position revealed there was an interaction at the + 1, +2, +3, and +4 positions ($p < .05$; $p > .10$ for all other effects). These results indicated that the magnitude of the auditory AB was significantly reduced when the distractors following the probe were replaced by a silent period.

Object-feature sequences with No Distractors Either Prior to the Target or Following the Probe. The analysis revealed significant main effects of Target Presence, $F(1, 19) = 8.220$, $p < .05$, and Probe Position, $F(6, 114) = 4.148$, $p < .05$. The interaction between Target Presence and Probe Position was marginally-significant, $F(6, 114) = 2.912$, $p = .071$. Simple effect tests indicated that there was no significant processing deficit at any position. Thus, there was little AB in this condition. The magnitude of the AB apparent in this condition was compared with that observed in the full-stream condition using 2 x 2 x 7 within-subjects ANOVA (Stream x Target Presence x Probe Position). The three-way interaction between Stream, Target Presence, and Probe Position was significant, $F(6, 114) = 9.523$, $p < .01$. 2 x 2 within – subjects ANOVAs (Stream x Target Presence) at each position revealed that there was a significant interaction at the + 1, +2, and +3 positions ($p < .05$; $p > .10$ for all other effects). These results indicated that the magnitude of the auditory AB was significantly reduced when all items prior to the target and following the probe were replaced by a silence.

In summary, significant probe processing deficits were apparent for both object and feature targets when full-stream sequences were presented and when sequences with no distractors prior to the target were presented. A 2 x 2 x 7 (Target Type x Target Presence x Probe Position) split-plot ANOVAs was conducted to compare these deficits. For full-stream sequences, the analysis revealed that the three-way interaction between Target Type, Target Presence, and Probe Position was significant, $F(6, 228) = 6.073$, $p < .01$. A series of 2 x 2 split-plot ANOVAs (Target Type x Target Presence) at each position revealed significant interactions at the + 1, +2, and +3 positions ($p < .05$ for the first two, and $p = .066$ for the third; $p > .10$ for all other effects). These results indicated that the auditory AB was larger for object-feature sequences than that for feature-feature sequences when target and probe were embedded in a full set of distractors. However, for sequences in which the distractors prior to the target were eliminated, the analysis revealed that the three-way interaction was not significant, $F(6, 228) = 2.178, p = .128$.

Discussion

This experiment was conducted to examine whether the distractors prior to the target and following the probe have any influence on the magnitude of the auditory AB. For object-feature sequences, as was shown by Shen and Mondor (2006), the distractors following the probe had tremendous effect on the magnitude of the AB. When those distractors were replaced by silence, only a small AB was apparent. Similarly, when both the distractors prior to the target and following the probe were replaced by silence, only a small AB was apparent as well. This residual AB could be caused by the passive decay of the probe as Shen and Mondor argued. In any event, these results showed that the overwriting of the probe by the distractors is a major factor in determining the magnitude of the auditory AB.

Most importantly, for feature-feature sequences, there was only a small AB in the full-stream sequences, and there was no AB both when the distractors following the probe were replaced by silence and when the distractors prior to the target and following the probe were replaced by silence. In contrast, there was a large AB when items prior to the target were replaced by silence. This result is consistent with the view of Raymond (2003). It appears that when the target was the first sound in a sequence, regardless of its similarity to the subsequent distractors, a new object file needed to be created. This processing drew to a significant degree on capacity-limited resources, and the duration of the probe processing delay was long. In this situation, if the distractors following the probe were present, then the possibility of the overwriting of the probe by those distractors would be high. Thus, a large AB was apparent. These results provided further evidence for that a requirement to create a new object file for the target is also a major factor to generating the auditory AB.

It is interesting to note that for the object-feature sequences as well a larger AB emerged when the distractors prior to the target were replaced by silence than when they were present. Although beyond the scope of the present study this difference does suggest that creating an object file for the first item in a sequence may be slightly more resource-consuming than creating an object file for an item in the middle of a sequence, possibly because all components are new when an object file is created at the beginning of a sequence.

EXPERIMENT 3B

Experiment 3B was designed with the same goal in mind as was Experiment 3A but used different auditory materials. Specifically, in this experiment the distractors were comprised of six, 5 ms pulses at 1000 Hz. The target was a pure tone at 1500 Hz. For the object-feature sequences, the probe was comprised of six, 5 ms pulses at 1500 Hz (similar to that used in one type of sequence in Experiment 1B). For the object-object sequences, the probe was a pure tone at 1250 Hz (similar to that used in one type of sequence in Experiment 2B).

Performance for object-object sequences rather than for feature-feature sequences was examined because in Experiment 2B a significant AB was apparent for feature-

feature sequences but not for object-object sequences. As discussed in Experiment 2B, creating a new object file for a pure tone target embedded in a sequence of pulse distractors may draw to only a very limited extent on attentional resources. However, if the pure tone target is the first sound in a sequence, then this situation should require creating a completely new object file and, therefore, an AB should be apparent regardless of its similarity to the subsequent distractors.

For object-feature sequences the effect of replacing the distractors prior to the target, following the probe, or both by silence was examined in the context of a sequence in which the probe differed from the distractors at the feature level. For object-object sequences, the effects of replacing the distractors prior to the target, following the probe, or both by silence were examined in the context of a sequence in which the probe and the distractors differed from the distractors at the object level.

Method

Participants

Forty undergraduate students, enrolled in an Introduction to Psychology course at the University of Manitoba participated in the experiment in exchange for course credit. They all had normal hearing according to self-report.

Materials

Computer and Sound System. The computer and sound system used were the same as those used in the previous experiments.

Sounds. Most of the sounds used in the experiment were the same as those used in the 'object-target' conditions of Experiment 1B and 2B. Thus, for the object-feature sequences, twenty-one sounds each comprised of six, 5 ms pulses at 1000 Hz were used as distractors, the target was a pure tone at 1500 Hz, and the probe was a pulse composed of six, 5 ms pulses, at 1500 Hz. For the object-object sequences, the target was a pure tone at 1500 Hz, and the probe was a pure tone at 1250 Hz.

The procedure, design, and data analysis were the same as in Experiment 3A.

Results

Target Detection

The probability of a correct response to the target task when the target was attended was 0.969 (*SE* = .004). The probability of a correct response on target-present trials (hit) was 0.969, and the probability of an incorrect response on target-absent trials (false alarms) was 0.033. Thus, average d' was 3.71.

Performance in each condition is described in Table 11 and Table 12. A 2 x 4 x 2 split-plot ANOVA with one between-subjects factor (Probe [object, feature]) and two within-subjects factors (Stream [full, no distractors prior to the target, no distractors following the probe, and no distractors prior to the target or following the probe], Probe Presence [present, absent]) was conducted using the probability of accurate target detection as the dependent variable when the target was present. The analysis revealed significant main effects of Probe Presence, $F(1, 38) = 23.862$, $p < .001$, and Stream, $F(3, 114) = 4.344$, $p < .01$. However, the main effect of Probe did not reach significance, $F < 1$. In general, the accuracy of target detection was higher when the probe was present and when all the items prior to the target and following the probe were replaced by silence.

Two-way interactions between Probe and Probe Presence, $F(1, 38) = 15.973$, $p < .001$, Stream and Probe Presence, $F(3, 114) = 9.550$, $p < .001$, and Probe and Stream, $F(3, 114) = 3.979$, $p < .05$, were all significant. More importantly, the three-way interaction between Probe, Stream, and Probe Presence was also significant, $F(3, 114) = 4.305$, $p < .01$. Furthermore, for feature-probe sequences, neither the main effects of Stream or

Table 11

Target detection accuracy (mean and standard error) in Experiment 3B as a function of sequence type, distractor stream, and probe presence when the target was present.

SEQUENCE TYPE	DISTRACTOR STREAM	PROBE PRESENCE	
		Yes	No
Object-object	Full Stream	.996 (.002)	.902 (.022)
	Silence Prior to Target	.994 (.003)	.936 (.014)
	Silence Following Probe	1.000 (0)	.928 (.020)
	Silence Prior to Target & Following Probe	.993 (.003)	.983 (.006)
Object-feature	Full Stream	.977 (.007)	.968 (.006)
	Silence Prior to Target	.977 (.007)	.977 (.007)
	Silence Following Probe	.965 (.008)	.976 (.007)
	Silence Prior to Target & Following Probe	.970 (.008)	.976 (.007)

Table 12

Target detection accuracy (mean and standard error) in Experiment 3B as a function of distractor stream and probe position when both the target and the probe were present.

SEQUENCE TYPE	DISTRACTOR STREAM	PROBE POSITION						
		+1	+2	+3	+4	+5	+6	+7
Object-object	Full Stream	.994 (.006)	1.000 (0)	.988 (.013)	.994 (.006)	1.000 (0)	1.000 (0)	1.000 (0)
	Silence Prior to Target	.988 (.008)	.988 (.008)	1.000 (0)	1.000 (0)	1.000 (0)	994 (.006)	1.000 (0)
	Silence Following Probe	1.000 (0)	1.000 (0)	1.000 (0)	1.000 (0)	1.000 (0)	1.000 (0)	1.000 (0)
	Silence Prior to Target & Following Probe	.994 (.006)	.988 (.008)	.994 (.006)	1.000 (0)	.994 (.006)	.988 (.008)	.994 (.006)
Object-feature	Full Stream	908 (.032)	.976 (.011)	.994 (.006)	1.000 (0)	.988 (.008)	.994 (.006)	.988 (.008)
	Silence Prior to Target	.976 (.011)	.994 (.006)	.964 (.016)	.982 (.014)	.994 (.006)	.982 (.010)	.951 (.019)
	Silence Following Probe	.927 (.030)	.970 (.015)	1.000 (0)	.988 (.008)	.988 (.013)	.982 (.010)	.982 (.014)
	Silence Prior to Target & Following Probe	.946 (.017)	.970 (.015)	.958 (.020)	.994 (.006)	.976 (.019)	.970 (.015)	.988 (.008)

Probe Position, nor their interaction, was significant ($p > .150$ for all cases). In contrast, for object-probe sequences, the main effects of both Stream, $F(3, 57) = 6.266, p < .01$, and Probe Presence, $F(1, 19) = 21.668, p < .001$, were significant. The interaction between the two was also significant, $F(3, 57) = 8.842, p < .001$. When the probe was absent, the simple effect of Stream was significant, $F(3, 57) = 7.701, p < .01$, indicating that replacing distractors in part of a sequence with silence increased the accuracy of target detection. When the probe was present, the simple effect of Stream was not significant, $F(3, 57) = 1.786, p = .179$.

Whether performance on the target detection task may have been influenced by the position of the probe was also examined. A 2 x 4 x 7 (Probe [object, feature] x Stream [full, no distractors prior to the target, no distractors following the probe, and no distractors prior to the target or following the probe] x Probe Position [+1 through +7]) split-plot ANOVA was conducted using the probability of accurate target detection as the dependent variable when both the target and probe were presented. The analysis revealed significant main effects of Probe, $F(1, 38) = 12.484, p < .001$, and Probe Position, $F(6, 228) = 5.426, p < .01$, but not of Stream, $F < 1$. In general, the accuracy of target detection was higher when the probe was different from distractors at the object level, and when the SOA between the target and the probe was longer.

Although two-way interactions between Probe and Stream, $F < 1$, and Stream and Probe Position, $F(18, 684) = 1.501, p = .180$, were not significant, that between Probe and Probe position, $F(6, 228) = 4.010, p < .05$, was significant. The three-way interaction between Probe, Stream, and Probe Position was marginally significant, $F(18, 684) = 2.074, p = .059$. This interaction was decomposed by examining performance for the object-feature and object-object sequence separately. For object-feature sequences, the main effect of Probe Position was significant, F (6, 114) = 5.147, $p < .05$, but the main effect of Stream was not, $F < 1$. The interaction between Stream and Probe Position was marginally significant, F (18, 342) = 1.918, $p = .099$. Furthermore, this interaction was decomposed by examining performance for the four types of steams separately. The effect of Probe Position was significant for full-stream sequences, F (6, 114) = 6.889, $p < .01$, not significant when distractors prior to the target were replaced by silence, F (6, 114) = 1.886, $p = .133$, marginally significant when distractors following the probe were replaced by silence, F (6, 114) = 2.650, $p = .092$, and not significant when distractors both prior to the target and following the probe were replaced by silence, F (6, 114) = 1.412, $p = .244$. In general, for the full-stream sequences, the accuracy of target detection was increased when the SOA between the target and the probe increased. However, after replacing distractors from part of the sequence with silence, the accuracy of target detection was not changed as a function of the SOA between the target and the probe. For object-object sequences, performance did not vary significantly as a function of the independent variables, either alone or in combination ($p > .20$ for all cases).

Probe Detection

Overall, probe detection accuracy for trials on which there was a correct response to the target was very high at 0.978 (*SE* = .004). The probability of a correct response on probe-present trials (hit) was 0.970, and the probability of an incorrect response on probe-absent trials (false alarms) was 0.017. Thus, average d' was 4.00. Clearly, therefore, participants found the probe quite easy to detect.

Performance in each condition is described graphically in Figure 8. A 2 x 4 x 2 x 7 split-plot ANOVA with one between-subjects factor (Probe [object, feature]) and three within-subjects factors (Stream [full, no distractors prior to the target, no distractors

Figure 8. Probe detection accuracy in Experiment 3B (The distractors were comprised of six, 5 ms pulses at 1000 Hz. The object-target was a pure tone at 1500 Hz. For the object-object sequences, the object-probe was a pure tone at 1250 Hz; for object-feature sequences, the feature-probe was comprised of six, 5 ms pulses at1500 Hz.) as a function of the presence of distractors (full, deleting all items prior to the target, deleting all items following the probe, and deleting all items prior to the target and following the probe). Error bars represent ± 1 standard errors.

Object-object sequences

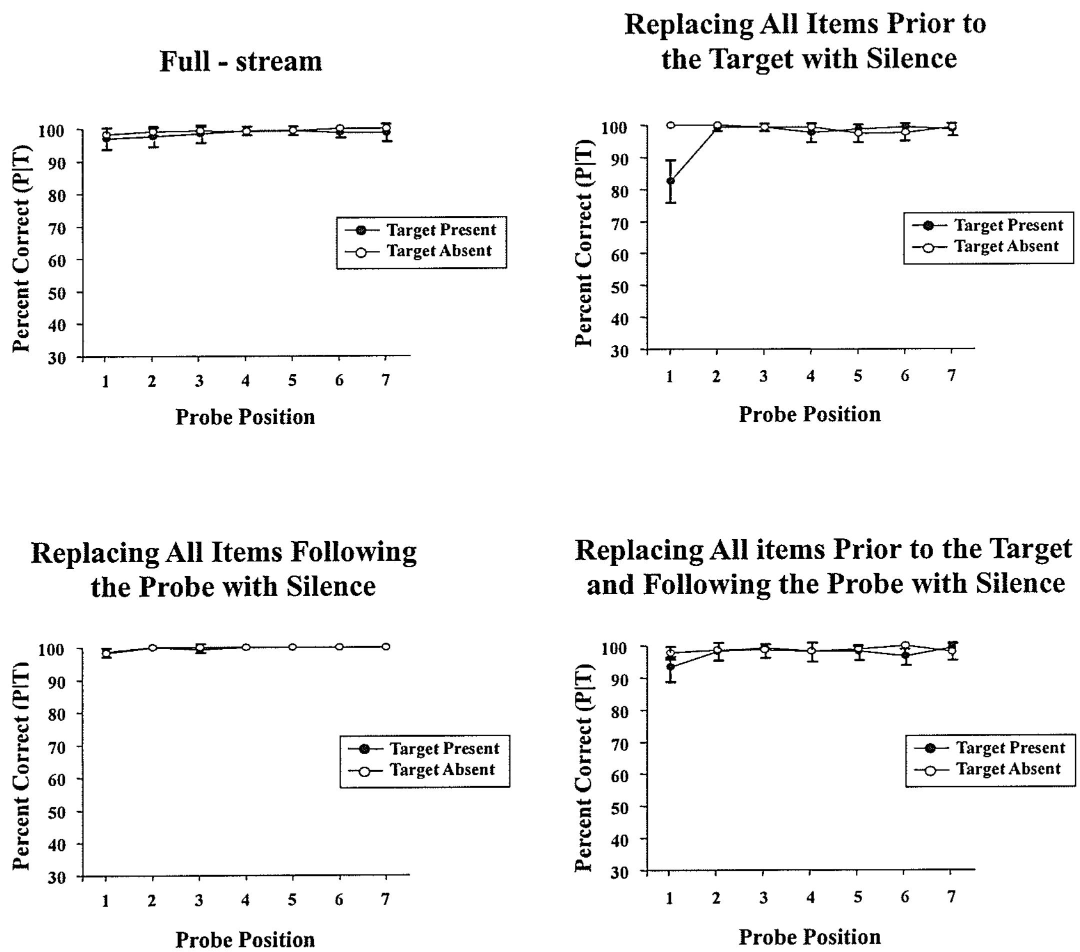
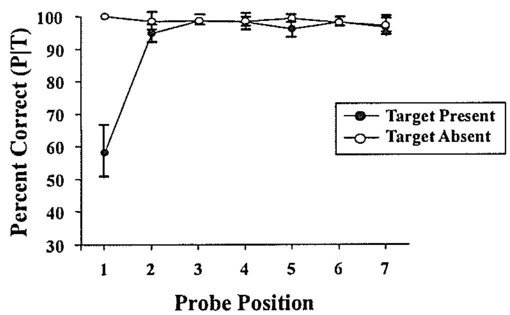


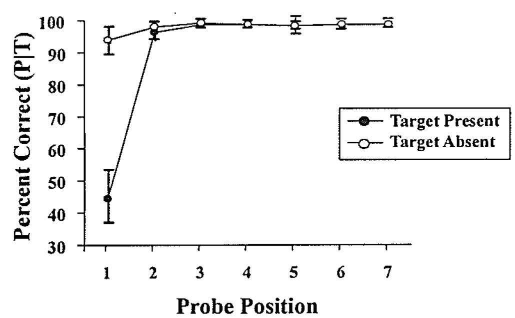
Figure 8 (continued)

Object-feature sequences

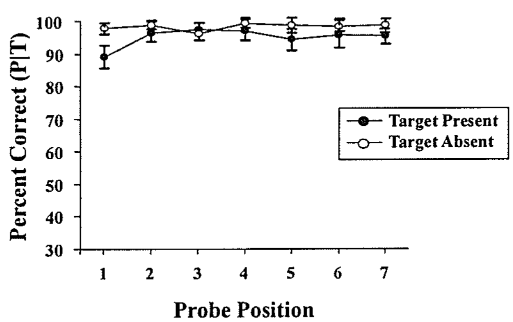
Full - stream



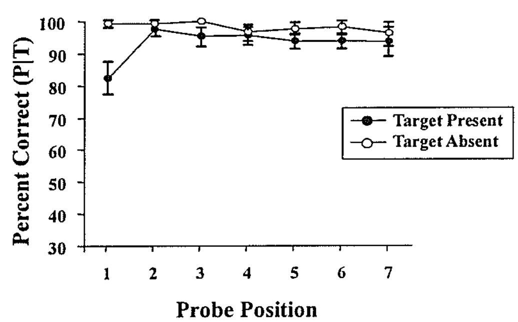
Replacing All Items Prior to the Target with Silence



Replacing All Items Following the Probe with Silence



Replacing All items Prior to the Target and Following the Probe with Silence



following the probe, and no distractors prior to the target or following the probe], Target Presence [present, absent], and Probe Position [+1 to +7]) was conducted using the conditional probability of accurate probe detection given a correct target detection response as the dependent variable. This analysis revealed significant main effects of Probe, F (1, 38) = 11.556, $p < .01$, Stream, F (3, 114) = 3.922, $p < .05$, Target Presence, F (1, 38) = 50.488, $p < .001$, and Probe Position, F (6, 228) = 39.354, $p < .001$. In general, the accuracy of probe detection was higher when the target was absent, when the SOA between the target and the probe was longer, when no distractors followed the probe, and when the probe was different from the distractors at the object level.

Two-way interactions between Probe and Target Presence, F (1, 38) = 23.616, $p < .001$, Probe and Probe Position, F (6, 228) = 15.119, $p < .001$, Stream and Target Presence, F (3, 114) = 5.215, $p < .01$, Stream and Probe Position, F (18, 684) = 10.175, $p < .001$, and Target Presence and Probe Position, F (6, 228) = 36.331, $p < .001$, were all statistically significant. The two-way interaction between Probe and Stream was not significant, $F < 1$.

The three-way interactions between Probe, Stream, and Probe Position, F (18, 684) = 5.052, $p < .01$, between Probe, Target Presence and Probe Position, F (6, 228) = 16.759, $p < .001$, and between Stream, Target Presence and Probe Position, F (18, 684) = 10.292, $p < .001$, were all significant. However, the interaction between Probe, Stream, and Target Presence was not significant, F (3, 114) = 1.083, $p = .347$.

The four-way interaction between Probe, Stream, Target Presence and Probe Position was also significant, F (18, 684) = 3.875, $p < .01$. We evaluated the four-way interaction by examining the probe processing deficit in the two Probe conditions separately.

For object-object sequences, a 4 x 2 x 7 within-subjects ANOVA (Stream x Target Presence x Probe Position) was conducted using the conditional probability of accurate probe detection given a correct target detection response as the dependent variable. This analysis revealed significant main effects of Target Presence, $F(1, 19) = 7.890, p < .05$, and of Probe Position, $F(6, 114) = 8.013, p < .01$, but not of Stream, $F(3, 57) = 1.970, p = .166$. The two-way interaction between Target Presence and Probe Position was significant, $F(6, 114) = 4.633, p < .05$, and the interaction between Stream and Probe Position was marginally significant, $F(18, 342) = 2.439, p = .076$. The interaction between Stream and Target Presence was not significant, $F(3, 57) = 1.577, p = .221$. The three-way interaction between Stream, Target Presence and Probe Position was also significant, $F(18, 342) = 5.294, p < .01$. These results indicated that there was an overall AB; however, the magnitudes of the AB in the four types of the sequences were different. Separate evaluation of performance for each of the four types of the sequences is given in next section.

For object-feature sequences, a 4 x 2 x 7 within-subjects ANOVA (Stream x Target Presence x Probe Position) was conducted using the conditional probability of accurate probe detection given a correct target detection response as the dependent variable. This analysis revealed significant main effects of Target Presence, $F(1, 19) = 42.599, p < .001$, and of Probe Position, $F(6, 114) = 31.465, p < .001$. The main effect of Stream was not significant, $F(3, 57) = 2.386, p = .109$. Two-way interactions between Stream and Target Presence, $F(3, 57) = 4.278, p < .05$, Stream and Probe Position, $F(18, 342) = 8.802, p < .001$, and Target Presence and Probe Position, $F(6, 114) = 32.287, p < .001$, were all statistically significant. The three-way interaction between Stream, Target Presence and Probe Position was also significant, $F(18, 342) = 7.558, p < .001$. These results indicated that there was an overall AB; however, the magnitudes of the AB in the four types of the sequences were different. Separate evaluation of performance for each of the four types of the sequences is given in next section.

Probe Detection in Each of the Eight Main Conditions

Performance was examined separately for each principal condition using 2 x 7 (Target Presence x Probe Position) within-subjects ANOVAs using the conditional probability of accurate probe detection when the probe was present given a correct target detection response as the dependent variable.

Object-object Sequences with a Full Stream of Distractors. The analysis did not reveal any significant effects. Neither the main effects of Target Presence, $F < 1$, or Probe Position, $F\ (6, 114) = 1.534$, p = .209, nor the two, $F < 1$, were significant. Simple effect tests indicated that there was no significant processing deficit at any position. Thus, there was no probe processing deficit in this condition.

Object-object Sequences with No Distractors prior to the Target. The analysis revealed significant main effects of Target Presence, $F\ (1, 19) = 4.840, p < .05$, and Probe Position, $F\ (6, 114) = 6.492, p < .05$, as well as a significant interaction between Target Presence and Probe Position, $F\ (6, 114) = 8.257, p < .01$. Simple effect tests indicated that there was a significant processing deficit only at the +1 position. Thus, in this condition, the probe processing deficit reached significance, and its magnitude decreased as the time between the target and probe increased. Therefore, there was a robust AB in this condition.

Object-object Sequences with No Distractors Following the Probe. The analysis did not reveal a significant effect either of Target Presence, $F < 1$, or of the interaction between Target Presence and Probe Position, $F < 1$. The main effect of Probe Position was marginally significant, F (6, 114) = 3.408 p = .067. Simple effect tests indicated that there was no significant processing deficit at any position. Thus, there was no evidence of an AB in this condition.

Object-object Sequences with No Distractors prior to the Target or Following the Probe. The analysis revealed a marginally significant main effect of Target Presence, F (1, 19) = 3.237, $p < .05$. Neither the main effect of Probe Position, F (6, 114) = 1.726, p = .197, nor the interaction between Target Presence and Probe Position, F (6, 114) = 1.511, p = .228, were significant. Simple effect tests indicated that there was no significant processing deficit at any position. Thus, there was no AB in this condition.

Object-feature Sequences with a Full Stream of Distractors. The analysis revealed significant main effects of Target Presence, F (1, 19) = 25.073, $p < .001$, and Probe Position, F (6, 114) = 17.260, $p < .001$, and a significant interaction between Target Presence and Probe Position, F (6, 114) = 17.949, $p < .001$. Simple effect tests indicated that there was a significant processing deficit only at the +1 position. Thus, in this condition, the probe processing deficit reached significance, and its magnitude decreased as the time between the target and probe increased. Therefore, there was a robust AB in this condition.

Object-feature Sequences with No Distractors prior to the Target. The analysis revealed significant main effects of Target Presence, F (1, 19) = 40.861, $p < .001$, and Probe Position, F (6, 114) = 30.828, $p < .001$, and a significant interaction between the two, F (6, 114) = 33.771, $p < .001$. Simple effect tests indicated that there was significant processing deficit only at the +1 position. Thus, in this condition, the probe processing deficit reached significance, and its magnitude decreased as the time between the target and probe increased. Thus, there was a robust AB in this condition.

The magnitude of the AB apparent in this condition was compared with that observed in the full-stream condition using 2 x 2 x 7 within-subjects ANOVA (Stream x Target Presence x Probe Position). The three-way interaction, between Stream, Target Presence, and Probe Position, was not significant, $F < 1$. In addition, 2 x 2 within-subjects ANOVAs (Stream x Target Presence) at each position did not reveal any significant interactions ($p > .10$ for all effects). These results indicate that the magnitude of the auditory AB was not significantly affected when the distractors prior to the probe was replaced by a silent period relative to when a full sequence of distractors was presented.

Object-feature Sequences with No Distractors Following the Probe. The analysis revealed a significant main effect of Target Presence, $F(1, 19) = 9.196$, $p < .05$. However, neither the main effect of Probe Position, $F(6, 114) = 1.545$, $p = .212$, nor the interaction between Target Presence and Probe Position, $F(6, 114) = 1.353$, $p = .270$, were significant. Simple effect tests indicated that there was no significant processing deficit at any position. Thus, although there was an overall probe processing deficit in this condition, there was no AB deficit.

Object-feature Sequences with No Distractors prior to the Target or Following the Probe. The analysis revealed a significant main effect of Target Presence, $F(1, 19) = 19.238$, $p < .001$, and a significant interaction between Target Presence and Probe Position, $F(6, 114) = 3.979$, $p < .05$. The main effect of Probe Position was not significant, $F(6, 114) = 2.220$, $p = .111$. Simple effect tests indicated that there was a significant processing deficit only at the +1 position.

The magnitude of the AB apparent in this condition was compared with that observed in the full-stream condition using 2 x 2 x 7 within-subjects ANOVA (Stream x

Target Presence x Probe Position). The three-way interaction between Stream, Target Presence, and Probe Position was significant, F (6, 114) = 6.680, $p < .01$. 2 x 2 within – subjects ANOVAs (Stream x Target Presence) performed for each probe position revealed there was an interaction at the + 1 position ($p < .01$; $p > .10$ for all other effects). Thus, the magnitude of the auditory AB was significantly reduced at the +1 position when no distractors were presented either prior to the target or following the probe relative to when a full sequence of distractors was presented.

Finally, significant probe processing deficits were apparent for both object-feature and feature-feature sequences when no distractors were presented prior to the target. We used 2 x 2 x 7 (Target Type x Target Presence x Probe Position) split-plot ANOVAs to compare these deficits. For sequences in which the distractors prior to the target were eliminated, the analysis revealed that the three-way interaction between Target Type, Target Presence, and Probe Position was significant, F (6, 228) = 9.114, $p < .01$. A series of 2 x 2 split-plot ANOVAs (Target Type x Target Presence) at each position revealed a significant interaction at the + 1 position ($p < .01$; and $p > .10$ for all other effects). These results indicate that the auditory AB was larger for object-feature sequences than that for object-object sequences when no distractors were presented prior to the target.

Discussion

Experiment 3B was performed to examine whether the distractors prior to the target and following the probe have any influence on the magnitude of the auditory AB. However, in contrast with Experiment 3A, the distractors were pulses rather than pure tones, and the target differed from the distractors at the object level while the probe could differ from the distractors at either the feature level or the object level.

For object-feature sequences, large ABs were apparent when a full stream of distractors was presented and when the distractors prior to the target were replaced by silence. However, the distractors following the probe had a tremendous effect on the magnitude of the AB. When no distractors followed the probe, no AB was apparent. Similarly, when both the distractors prior to the target and following the probe were replaced by silence, only a very small AB was apparent. Once again, these results provided evidence that the overwriting of the probe by the distractors following it is a major factor to the emergence of the auditory AB.

In contrast, for object-object sequences, whereas there was no AB when a full stream of distractors was presented, when the distractors following the probe were replaced by silence, and when both the distractors prior to the target and following the probe were replaced by silence, there was a significant AB when no distractors preceded the target. This result is also consistent with the view of Raymond (2003). It appears that when the target was the first sound in a sequence, regardless of its relation to the subsequent distractors, a new object file needed to be created and this required capacity-limited resources. This processing resulted in a long duration of the probe processing delay. In this situation, if the distractors following the probe were present, then the possibility of the overwriting of the probe by those distractors would be high. Thus, a significant AB was apparent.

In summary, results obtained in Experiments 3A and 3B further support the idea that the auditory AB is affected both by a requirement to generate a new object file for the target, and by the overwriting of the probe by the distractors following it.

General Discussion

This study was conducted to examine whether object file continuity plays a role in generating the auditory AB. On each trial in all experiments, listeners were required to detect a target and/or a probe sound presented in a rapid series of distractor sounds. In experimental conditions both the target and the probe were present. In contrast, in control conditions only the probe was present. In general, if the accuracy of probe perception is higher in the control condition than in the experimental condition and this difference decreases as the time between the target and the probe increases, then an AB is concluded to have occurred (e.g., Seiffert & Di Lollo, 1997). Across experiments, the target and the probe could differ from the distractors at the feature level or at the object level (e.g., an 'object-feature' sequence was defined as one in which the target differed from the distractors at the object level and the probe differed from the distractors at the feature level). The feature difference was defined as a frequency difference, and the object difference was defined as difference in the type of tone (i.e., pure tone vs. pulses). There were two parts for each of the three experiments. In part A, the distractors were pure tones, the feature-target and feature-probe were also pure tones but with a different frequency from the distractors, and the object-target and object-probe were comprised of six, 5 ms pulses. In part B, the distractors comprised of six, 5 ms pulses, the feature-target and feature-probe were also comprised of six, 5 ms pulses but with a different carrier frequency from the distractors, and the object-target and the object-probe were pure tones. In addition, a condition in which the target was to be ignored (target-ignored condition) was used in Experiments 1 and 2 to address the possibility that low-level masking of the probe by the target may contribute to the auditory AB. Target-ignored conditions were not used in Experiment 3 because the full-stream sequences were the same as the several types of sequences in Experiments 1 and 2.

As discussed in the Introduction, in visual studies there is no absolute differentiation between a feature change and an object change. Some researchers (e.g., Hillstrom & Yantis, 1994; Rauschenberger, 2003) have found that a feature change may be treated as an object change if the difference is large enough. In general, however, auditory objects are associated with sound sources (e.g., Bregman, 1990; Moore, 2003). For example, Bregman (1990) demonstrated that a large frequency difference between two rapidly repeating tones may lead to the perception of two different streams or sounds. In the classical paradigm, a rapidly alternating sequence of high- and low-frequency tones is presented. When the difference between the two frequencies is large enough (in general, the difference needs to be over one octave), participants typically report hearing two separate sequences, one composed of the low-frequency tones and the other composed of the high-frequency tones. Sounds are perceived as coming from two different sources (objects). In the present study, the frequency difference used was much smaller than one octave in order to minimize the possibility of a large feature change breaking object file continuity.

The results of Experiments 1A and 1B revealed that a larger auditory AB was apparent for object-feature sequences than for feature-object sequences when the target was attended, and that there was small AB for object-feature sequences but no AB for the feature-object sequences when the target was ignored. Experiment 2A indicated that there were small auditory AB deficits in both the object-object and feature-feature sequences when the target was attended and there was no AB for either type of sequence when the target was ignored. Experiment 2B showed that when the target was attended there was a large auditory AB deficit for the feature-feature sequences but not for the object-object sequences and when the target was ignored there was no AB for the either type of sequence. Experiment 3A revealed that for object-feature sequences there was a large AB in the full-stream condition but only a small AB remained when all post-probe distractors were replaced by silence. More importantly, for feature-feature sequences in Experiment 3A there was a small AB in the full-stream condition, but there was a large AB when all distractors prior to the target were replaced by silence. In Experiment 3B, for object-object sequences there was no AB for full-stream sequences, but there was a significant AB when all distractors prior to-target were replaced by silence. A summary of the results obtained in present study is shown in Table 13.

An Account of the Results of the Experiments

The paragraphs below provide an interpretation of the results based on a combination of the effects of object file creation, overwriting of the probe, grouping of the target and probe with the distractors, and the characteristics of modulated sounds.

Experiment 1. In Experiment 1A performance was studied for object-feature sequences and for feature-object sequences. The object-target and object-probe were pulses, the feature-target and the feature-probe were pure tones, and the distractors were pure tones. The results revealed that there was a larger AB for object-feature sequences than for feature-object sequences when the target was attended, and there was a small AB for object-feature sequences but no AB for feature-object sequences when the target was ignored. When the target was attended, for object-feature sequences significant resources were required to create a new object file for the object-target and this resulted in a lengthy probe processing delay. Thus, the opportunity for the overwriting and decay of the probe was high. Moreover, there was also a high possibility of the feature-probe being overwritten by the distractors following it because of high similarity between the feature-probe and the distractors. These effects seriously impaired the perception of the probe. Thus, a large AB was apparent for these sequences. In contrast, for the feature-object

Table 13

Summary of the three experiments

Experiment	Target	Probe	Distractors	Sequence Type	Distractor Stream	Target Attended	AB
1A	1500 Hz pure	1500 Hz pulse	1000 Hz pure	Feature-Object	Full Stream	Yes	Yes-S
1A	1500 Hz pure	1500 Hz pulse	1000 Hz pure	Feature-Object	Full Stream	No	No
1A	1500 Hz pulses	1500 Hz pure	1000 Hz pure	Object-Feature	Full Stream	Yes	Yes-L
1A	1500 Hz pulses	1500 Hz pure	1000 Hz pure	Object-Feature	Full Stream	No	Yes-S
1B	1500 Hz pulse	1500 Hz pure	1000 Hz pulse	Feature-Object	Full Stream	Yes	Yes-S
1B	1500 Hz pulse	1500 Hz pure	1000 Hz pulse	Feature-Object	Full Stream	No	No
1B	1500 Hz pure	1500 Hz pulse	1000 Hz pulse	Object-Feature	Full Stream	Yes	Yes-L
1B	1500 Hz pure	1500 Hz pulse	1000 Hz pulse	Object-Feature	Full Stream	No	Yes-S
2A	1250 or 1500 Hz pure	1500 or 1250 Hz pure	1000 Hz pure	Feature-Feature	Full Stream	Yes	Yes-S
2A	1250 or 1500 Hz pulses	1500 or 1250 Hz pulses	1000 Hz pure	Object- Object	Full Stream	Yes	Yes-S
2A	1250 or 1500 Hz pure	1500 or 1250 Hz pure	1000 Hz pure	Feature-Feature	Full Stream	No	No
2A	1250 or 1500 Hz pulses	1500 or 1250 Hz pulses	1000 Hz pure	Object- Object	Full Stream	No	No
2B	1250 or 1500 Hz pulses	1500 or 1250 Hz pulses	1000 Hz pulse	Feature-Feature	Full Stream	Yes	Yes-L
2B	1250 or 1500 Hz pure	1500 or 1250 Hz pure	1000 Hz pulse	Object- Object	Full Stream	Yes	No
2B	1250 or 1500 Hz pulses	1500 or 1250 Hz pulses	1000 Hz pulse	Feature-Feature	Full Stream	No	No
2B	1250 or 1500 Hz pure	1500 or 1250 Hz pure	1000 Hz pulse	Object- Object	Full Stream	No	No

Note: Yes-S indicates a small but significant AB; Yes-L indicates a large and significant AB. In Experiment 3, the target was always attended

Table 13 (Continued)

Summary of the three experiments

EXPERIMENT	TARGET	PROBE	DISTRACTORS	SEQUENCE TYPE	DISTRACTOR STREAM	TARGET ATTENDED	AB
3A	1250 Hz pure	1500 Hz pure	1000 Hz pure	Feature-Feature	Full Stream	Yes	Yes-S
3A	1250 Hz pure	1500 Hz pure	1000 Hz pure	Feature-Feature	Silence Prior to Target	Yes	Yes-L
3A	1250 Hz pure	1500 Hz pure	1000 Hz pure	Feature-Feature	Silence Following Probe	Yes	No
3A	1250 Hz pure	1500 Hz pure	1000 Hz pure	Feature-Feature	Silence Prior to Target & Following Probe	Yes	No
3A	1500 Hz pulses	1500 Hz pure	1000 Hz pure	Object-Feature	Full Stream	Yes	Yes-L
3A	1500 Hz pulses	1500 Hz pure	1000 Hz pure	Object-Feature	Silence Prior to Target	Yes	Yes-L
3A	1500 Hz pulses	1500 Hz pure	1000 Hz pure	Object-Feature	Silence Following Probe	Yes	Yes-S
3A	1500 Hz pulses	1500 Hz pure	1000 Hz pure	Object-Feature	Silence Prior to Target & Following Probe	Yes	Yes-S
3B	1500 Hz pure	1250 Hz pure	1000 Hz pulse	Object-Object	Full Stream	Yes	No
3B	1500 Hz pure	1250 Hz pure	1000 Hz pulse	Object-Object	Silence Prior to Target	Yes	Yes-S
3B	1500 Hz pure	1250 Hz pure	1000 Hz pulse	Object-Object	Silence Following Probe	Yes	No
3B	1500 Hz pure	1250 Hz pure	1000 Hz pulse	Object-Object	Silence Prior to Target & Following Probe	Yes	No
3B	1500 Hz pure	1500 Hz pulse	1000 Hz pulse	Object-Feature	Full Stream	Yes	Yes-L
3B	1500 Hz pure	1500 Hz pulse	1000 Hz pulse	Object-Feature	Silence Prior to Target	Yes	Yes-L
3B	1500 Hz pure	1500 Hz pulse	1000 Hz pulse	Object-Feature	Silence Following Probe	Yes	No
3B	1500 Hz pure	1500 Hz pulse	1000 Hz pulse	Object-Feature	Silence Prior to Target & Following Probe	Yes	Yes-S

Note: Yes-S indicates a small but significant AB; Yes-L indicates a large and significant AB. In Experiment 3, the target was always attended sequences the target could be integrated within an existing object file (established by the pre-target distractors) so few resources were required and therefore the duration of the probe processing delay was brief, and thus the opportunity for overwriting and passive decay of the probe was low. Moreover, there was also a low possibility of the object-probe being overwritten by the distractors following it. These effects resulted in, at most, slight impairment in the perception of the probe. Thus, a small AB was apparent for these sequences.

Performance for object-feature and feature-object sequences was also studied in Experiment 1B. In contrast with Experiment 1A, however, the object-target and object-probe were pure tones, the feature-target and feature-probe were pulses, and the distractors were pulses. Similar to the pattern of the results of Experiment 1A, when the target was attended there was a larger AB for object-feature sequences than for feature-object sequences, and when the target was ignored there was small AB for object-feature sequences but no AB for feature-object sequences.

When the distractors were pulses, an object file created for them at the beginning of the sequence included both modulation frequency and carrier frequency components. When the target was attended, for object-feature sequences a new object file derived from this initial one (based on carrier frequency) was created for the object-target (pure tone) and this required few processing resources. Thus, the duration of the probe processing delay was relatively brief and the opportunity for the overwriting and passive decay of the probe was correspondingly reduced. Notwithstanding this brief probe processing delay, however, there was quite a high possibility of the feature-probe being overwritten by the post-probe distractors owing to their similarity (both the feature-probe and the distractors were modulated). Consequently, probe perception was impaired and a large

AB was apparent for these object-feature sequences. For the feature-object sequences when the target was attended, although no new object file might be required for the feature-target, a significant amount of resources was still required to process it because of the high similarity of the target and the distractors due to their common modulation profile (e.g., Moore & Jorasz, 1996). Thus the duration of the probe processing delay was relatively long and the opportunity for the overwriting and decay of the probe was relatively high. However, in spite of the lengthy delay in processing the probe, there was a very low possibility of the probe being overwritten by the post-probe distractors because of the low similarity of the pure tone probe to the pulse distractors. Thus, for object-feature sequences although the delay in processing the probe was relatively long, the dissimilarity of the probe and the distractors meant that there was little overwriting of the probe representation and, therefore, only a small AB was apparent for these sequences.

It is important to note that the target and probe in the feature-object (target ignored) and object-feature (target ignored) sequences in Experiment 1A were the same as those used in the object-feature (target ignored) and feature-object (target ignored) sequences in Experiment 1B correspondingly. If sensory masking of the probe by the target causes the auditory AB, then there should have been deficits for both the feature-object sequences in Experiment 1A and the object-feature sequences in Experiment 1B, or for both the object-feature sequences in Experiment 1A and the feature-object sequences in Experiment 1B. However, there was a small AB in both experiments for object-feature sequences and no AB at all for the feature-object sequences. Thus, it does not appear that sensory masking played a role in generating the auditory AB in this experiment. The small AB for object-feature sequences when the target was ignored could be caused by involuntary attentional capture. This is consistent with previous reports that involuntary attentional capture is more likely to occur when a to-be-ignored item differs from distractors at the object level (e.g., Hillstrom & Yantis, 1994).

The results of Experiment 1 also show that a second potential explanation of the AB is incorrect; namely, that it results because of task-switching. It is impossible that the AB deficits were caused entirely by tasking-switching because when the target was attended the AB was larger for object-feature sequences than for feature-object sequences and the target and the probe were simply exchanged in these two types of sequences. It is true that a small AB was apparent for the feature-object sequences when the target was attended and this might be taken as indicating a contribution of task-switching to the AB. However, it is also possible that the change in frequency (feature-target) may have been large enough to require formation of a new object file occasionally, or that incorporating a new feature into an existing object file also draws to a small degree on capacity-limited resources.

Experiment 2. In Experiment 2A performance was studied for object-object and feature-feature sequences. The object-target and the object-probe were pulses, the feature-target and feature-probe were pure tones, and the distractors were pure tones. The results revealed that when the target was attended there was a small AB for both object-object and feature-feature sequences, and when the target was ignored there was no AB for either type of sequence.

When the target was attended, for the object-object sequences significant resources were required to create a new object file for the object-target and this resulted in a long probe processing delay. Thus the opportunity for the overwriting and decay of the probe was high. However, because of low similarity between the object-probe and the distractors, there was little overwriting of the object-probe by the distractors following it. These effects resulted in only a small impairment in probe perception, and therefore only a small AB was apparent for these sequences. In contrast, when the target was attended for the feature-feature sequences few resources were required to process the feature-target because it could be incorporated into the existing object file and the delay in processing the probe was relatively brief. However, because of high similarity between the feature-probe and the distractors, there was substantial overwriting of the feature-probe by the distractors following it. These effects also resulted in a small impairment in probe perception, and a small AB was apparent for these sequences as well.

Performance for object-object and feature-feature sequences was also studied in Experiment 2B. In contrast with Experiment 2A, however, the object-target and object-probe were pure tones, the feature-target and feature-probe were pulses, and the distractors were pulses. The results showed that when the target was attended there was a large auditory AB deficit in feature-feature but not in the object-object sequences and when the target was ignored there was no AB for either type of sequence.

When the distractors were pulses, an object file created for the pulse distractors at the beginning of the sequences included both modulation frequency and carrier frequency components. When the target was attended, for object-object sequences a new object file derived from the existing object file (i.e., incorporating old components, e.g., carrier frequency) was created and this required few processing resources. Thus, the duration of the probe processing delay was brief and, in consequence, the opportunity for the overwriting and decay of the probe was low. In addition, there was minimal overwriting of the object-probe by the distractors following it because of their dissimilarity (the probe was a pure tone and all distractors were modulated). These effects meant that there was very little, if any, impairment in probe perception. Thus, no AB was apparent for these sequences. In contrast, for the feature-feature sequences significant resources were required to process the feature-target because of its similarity to the distractors (both were modulated), even though no new object file needed to be created for it. Moreover, there was a high possibility of the overwriting of the feature-probe by the distractors following it because the probe and the distractors were similarly modulated. These effects resulted in a large impairment in probe perception, and, thus, a large AB was apparent for these sequences.

The results of Experiment 2 showed that there were no AB deficits when the target was in to be ignored. Thus, as also suggested by the results of Experiment 1, it does not appear that the auditory AB reflects the effect of sensory masking. The results of Experiment 2 provided further evidence that task-switching did not contribute in any meaningful way to performance because AB deficits were apparent even though the target and the probe were so similar in those experiments.

Experiment 3. In Experiment 3A, performance was studied for object-feature and feature-feature sequences. For each of these sequences, performance was studied in four conditions defined by the placement and presence of distractors; a full set of distractors could be present as had been the case for all sequences in Experiment 1 and 2 (the 'full stream' condition). There were four conditions for each of the two types of sequences, namely, full-stream, all distractors prior to the target could be replaced by silence, all distractors following the probe could be replaced by silence, and all distractors prior to the target and following the probe could be replaced by silence.

The feature-feature sequences when a full-stream of distractors were present were the same as the feature-feature sequences in Experiment 2A, and a small AB was apparent for these sequences just as it was in the earlier experiment. In addition, for these sequences no AB was apparent both when the distractors following the probe were replaced by silence and when the distractors prior to the target and following the probe were both replaced by silence. However, a large auditory AB was apparent when all items prior to the target were replaced with silence. The later result presumably occurred because the feature-target was the first sound in the sequence and a new object file needed to be created for it. This processing resulted in a long duration of the probe processing delay. In this situation, if the distractors following the probe were present, the possibility of the overwriting of the probe by the distractors following it would be high. Thus, a large AB was apparent. This result provided further evidence that the requirement of creating a new file for the target is an important factor in generating the auditory AB.

The object-feature sequences when the full-stream of distractors were presented were the same as the object-feature sequences used in Experiment 1A, and a large AB was apparent just as it was in Experiment 1A. More importantly, for this type of sequence replacement of all items following the probe with silence resulted in a markedly reduced AB. Similarly, when both the distractors prior to the target and following the probe were replaced by silence, only a small AB was apparent. These results suggest that overwriting of the probe by the distractors following it is a major factor in generating the auditory AB. In addition, replacement of all items prior to the target resulted in a larger AB than in full-stream condition. It seems that creating an object file for the first item in a sequence may be slightly more resource-consuming than creating an object file for an item in the middle of a sequence, possibly because all components are new when an object file is created at the beginning of a sequence.

Performance for object-feature and object-object sequences was studied in

Experiment 3B under the same four conditions as in Experiment 3A. In contrast with Experiment 3A, however, the object-target and object-probe were pure tones, the feature-target and feature-probe were pulses, and the distractors were pulses. The object-feature sequences used when a full set of distractors was presented was the same as the object-feature sequences used in Experiment 1B, and a large AB was apparent as it was in the earlier experiment. In addition, there was also a large AB when the distractors prior to the target were replaced by silence. For these sequences replacement of all items following the probe with silence or replacement of all items both prior to the target and following the probe resulted in a substantially reduced ABs, and this provided further evidence that the overwriting of the probe by the distractors following it is a major factor in generating the auditory AB.

The object-object sequences that included a full set of distractors were the same as the object-object sequences used in Experiment 2B, and again no AB was apparent. In addition, there was no AB either when the distractors following the probe were replaced by silence or when the distractors prior to the target and following the probe were both replaced by silence. More importantly, replacement of all items prior to the target with silence resulted in a large auditory AB presumably because the object-target was the first sound in the sequence and a new object file had to be created for it. This drew on significant resources and thus the duration of the probe processing delay was long. In this situation, if the distractors following the probe were present, then the possibility of the overwriting of the probe by those distractors would be high. Thus, a significant AB was apparent. This provides additional evidence that the requirement of creating a new file for the target is also an important factor to the auditory AB.

A Revised Two-stage Model

The present study has provided evidence consistent with the conclusion that there are two major causes of the auditory AB; namely the requirement to generate a new object file for the target, and overwriting of the probe by the post-probe distractors. Below we discuss whether some of the existing theoretical accounts of the visual AB can account for these characteristics of the auditory AB.

Early selection models of the visual AB such as the two-stage detect-then-identify model (Broadbent & Broadbent, 1987), the attentional gate model (Raymond et al, 1992), and the object file continuity theory (Raymond, 2003) all assume that selection occurs prior to stimulus identification. These models can not easily explain the importance of the post-probe distractors because they include no mechanism by which a representation of the probe may be held, and compromised, prior to processing.

In contrast with early-selection accounts, the two-stage model (Chun and Potter, 1995), the central interference theory (Jolicoeur, 1998), the object-substitution account (Giesbrecht & Di Lollo, 1998), and the two-stage competition model (Potter, Staub, & O'Connor, 2002) all appear to be able to explain the importance of the post-probe distractors in generating the probe processing deficit. All of these models are based on the idea that, because of limited-capacity, the target and the probe cannot be processed simultaneously in a short-term consolidation stage. Thus, processing of the probe must be delayed until target processing is complete. During this delay, the memorial representation of the probe can passively decay or be overwritten by the items following it, and these effects result in the probe processing deficit.

Another late selection model, the competition hypothesis (Shapiro et al., 1994), proposes that besides the target and the probe, the item immediately following each of them also can enter into the visual short-term memory (VSTM) because of their similar temporal position to the target and the probe. According to this model, deleting the distractors following the probe can reduce competition in VSTM, and, thereby, reduce the magnitude of the AB. However, this model cannot explain why deleting +1 item does not reduce the magnitude of the auditory AB (Mondor, 1998; Shen & Mondor, 2006). For this reason, the competition hypothesis (Shapiro et al., 1994) does not appear to provide a full account of the auditory AB.

In contrast, as Shen and Mondor (2006) argued, a modified version of the two-stage models may be able to explain why replacement of the +1 by silence does not influence the magnitude of the auditory AB because they are based on the notion that the items immediately following the target and the probe have, respectively, different effects. Recall that the models state that whereas the +1 item can be processed together with the target thereby increasing the difficulty of target processing during short-term consolidation and increasing the magnitude of the AB, the item immediately following the probe can overwrite or replace the probe in memory thereby causing a larger AB deficit. It seems quite likely that there is no substantive effect of deleting the +1 item on the auditory AB because it is not processed along with the target and therefore does not affect short-term consolidation of the target. This seems reasonable because the auditory system generally has better temporal resolution, but poorer spatial resolution, than the visual system (e.g., Neath, 1998, p. 47).

The results regarding the role of object file continuity in generating the auditory AB are, of course, consistent with the 'object file continuity theory' advanced by Raymond (2003). According to her model, at the beginning of each RSVP sequence, an object file is created and this file is continually updated as each, similar, subsequent object is presented. Presentation of a target that differs substantially from the preceding distractors requires creation of a new object file and this draws on capacity-limited attentional resources. If, while the target object file is being created, the probe is presented, then its processing will be impaired because of a scarcity of resources, and an AB will result. However, as I have mentioned earlier in this section, this early selection model cannot explain the effect of the post-probe distractors because it includes no mechanism by which a representation of the probe may be held prior to processing.

The present study has shown that the auditory AB is influenced by both the requirement to create a new file for the target and by the local effect of the distractors following the probe. In addition, grouping of the target and probe with the distractors, and the characteristics of modulated sounds also have effects on the auditory AB. On the basis of the review above, it is clear that none of the theoretical accounts of the visual AB can provide a full account of the auditory AB. Whereas, the object file continuity theory (Raymond, 2003) can explain the effect of the requirement to create a new file for the target, the two-stage models (Chun & Potter, 1995; Giesbrecht & Di Lollo, 1998; Jolicoeur, 1998) can explain the effect of overwriting of the probe. (Chun, 1997, and Raymond, 2003, have suggested that the two-stage model might be able to explain the effect of the requirement of creating a new file for the target if it is modified to state that second stage processing is initiated only when the target is a new object. However, this potential account has not yet been fully developed.)

The results of both the present study as well as of a recent study by Shen and Mondor (2006) appear to be most consistent with a revised two-stage model of the auditory AB. Listeners create an object file when the first sound in a sequence is presented and continuously update the file when subsequent sounds are presented. This represents the first stage of processing. Typically, in order to report the target and the probe successfully, the target items must be processed in a capacity-limited second stage, such as short-term memory consolidation. However, it appears that, if the target is a new object, then, in general, a new object file must be created and it must enter into the second stage to be consolidated (under some circumstances [e.g., a pure tone target among pulse distractors], a new object file comprised of old components may not require consolidation in the second stage). To accomplish this, a large amount of resources are used and a significant amount of time is required in this stage. In contrast, if the target differs from the distractors at the feature level then, in general, it may be incorporated into the object file established for the preceding distractors and little second stage processing will be required (under some situations [e.g., the target and the distractors are similarly modulated], the feature target may be difficult to perceive and more resources and processing time will be required). Second stage processing takes time and processing of the probe will not begin until target processing is complete because of limited capacity. During this delay, the representation of the probe sound may be subject to both passive decay and overwriting by the distractor sounds following it. In this view the probe processing deficit will be greatest when the probe is presented immediately following the target, because the delay is longest. Therefore, the deficit will decrease as the SOA increases.

Conclusion

In summary, the results of the present study have shown that the auditory AB is primarily attentional in nature and is not the product of either sensory masking of the probe by the target or of task-switching between the target and the probe. The requirement of creating and consolidating a new object file for the target and the overwriting of the probe by the distractors following the probe are two major generators of the auditory AB. Of course, a global discriminablity effect of all distractors also has an influence on the auditory AB (e.g., Shen & Mondor, 2006) by affecting the demand for capacity-limited resources to consolidate the target and by affecting the possibility of the overwriting of the probe by the distractor following it. In fact, the object file continuity can be seen as a special case of this global effect. These effects can be all explained by the revised version of the two-stage model proposed above.

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