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Attentional Requirements in Visual Detection and Identification: Evidence From the Attentional Blink

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Perception of the 2nd of 2 targets (T1 and T2) is impaired if the lag between them is short (0–500 ms). The authors used this *attentional blink* (AB) to index attentional requirements in detection and identification tasks, with or without backward masking of T2, in 2 stimulus domains (line orientation, coherent motion). With masking, the AB occurred because T2 was masked during the attentional dwell time created by T1 processing (Experiments 1, 2, and 3). Without masking, an AB occurred only in identification because during the attentional dwell time, T2 decayed to a level that could support simple detection but not complex identification. However, an AB occurred also in detection if T2 was sufficiently degraded (Experiment 4). The authors drew 2 major conclusions: (a) Attention is required in both identification and detection, and (b) 2 factors contribute to the AB, masking of T2 while attention is focused on T1 and decay of the T2 trace while unattended.

There is a cost to distributing attention among visual stimuli. The cost is seen in many visual search tasks, where the time to find a target among distractors increases with the number of distractors (Neisser, 1967). In fact, the slope of the function relating search time to the number of distractors is often used to index the need for limited attentional resources in the processing of particular stimulus features (Treisman & Gelade, 1980; Wolfe, 1998). But it is not only stimulus relations that determine the demand for attention; the specific task performed by the observer also has an influence. For example, tasks requiring only stimulus detection tend to be less attention-demanding than tasks involving stimulus identification, discrimination, or localization (e.g., Bennett & Jaye, 1995; Bonnel & Hafter, 1998; Bonnel, Stein, & Bertucci, 1992; Braun & Sagi, 1990; Brawn & Snowden, 2000; Joseph, Chun, & Nakayama, 1997; Müller & Humphreys, 1991; Sagi & Julesz, 1985a, 1985b). The outcomes of these studies, however, have been inconsistent, especially on the issue of whether attentional resources are required in simple detection tasks. The main objective of the present work was to examine possible reasons for the inconsistencies.

Apparently Inconsistent Outcomes

An examination of the literature points to terminology as a prime source of inconsistency, with the same term often being used to refer to quite different things. This is especially true for the term *detection,* which has been used to denote a wide range of very different tasks. For example, Bonnel et al. (1992) required observers to report on the presence or absence of an increment in the luminance of a lighted disk. Detection of this sort was contrasted with *identification,* where observers named the direction of luminous change (increment of decrement). The main finding was that dividing attention by engaging in a concurrent task impaired performance on the identification but not the detection task.

Detection was used to denote a totally different task in a study by Sagi and Julesz (1985a). The display consisted of a field of segmented, uniformly oriented lines, except for a few that were vertical or horizontal. In the detection condition, observers were required to report the number of nondiagonal lines, a task that differed fundamentally from Bonnel et al.'s (1992). Indeed, to the extent that it involved discriminating the orientations of the target lines from the background lines, Sagi and Julesz's detection task was closer to Bonnel et al.'s (1992) identification task. Yet the results showed no effect of increasing numbers of distractors, supporting the conclusion that detection does not require attention.

The term *detection* was also used by Joseph et al. (1997), who used stimuli similar to those of Sagi and Julesz (1985a) but a somewhat different task. The stimulus pattern consisted of a field of diagonally oriented Gabor patches, with observers reporting on the presence or absence of an oddball, namely, a patch of the opposite orientation. The results led Joseph et al. (1997) to conclude that detection requires attention, which is the opposite of Sagi and Julesz's (1985a) and Bonnel et al.'s (1992) conclusions.

Yet another use of the term *detection* is illustrated in a study by Raymond, Shapiro, and Arnell (1992), where observers detected the presence or absence of the letter *X,* which was the second of two targets displayed among distractors in a rapid sequential visual presentation (RSVP). This second target was distinguished from the first target-letter, which had to be identified. The results strongly implicated the need for attention in the detection task.

There is no question that some element of detection was involved in these and in other similar experiments (e.g., Hawkins et al., 1990; Müller & Findlay, 1987; Müller & Humphreys, 1991).

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Yet, in view of the differences among the tasks, it is perhaps not surprising that some studies revealed attentional influences on detection, whereas others did not. It would be unrealistic to expect that performance was subserved by the same mechanisms in every case. On these considerations, it is understandable that the studies often yielded apparently inconsistent outcomes. This is seen most clearly in the issue of whether attentional resources are required in detection tasks, as in Raymond et al. (1992) and Joseph et al. (1997), or whether they are not required, as in Bonnel et al. (1992) and Sagi and Julesz (1985a). This is not to say, however, that the issue of attentional requirements in specific tasks is not worth pursuing. Rather, such a pursuit must be governed by definitions that are operational as distinct from semantic or vernacular. The taxonomic classification emerging from this approach would then serve to guide the search for underlying mechanisms.

Definition of Terms

In the interest of clarity, we propose the following distinction between the terms *detection* and *identification. Detection* denotes a task in which the observer is asked to distinguish between a uniform stimulus and a stimulus that contains a nonuniformity or discontinuity in space or time. Only the presence or absence of the nonuniformity is to be reported, not its identity. An example of detection over time was provided by the work of Bonnel et al. (1992), in which observers reported on a luminance increment that occurred at a point in time in an otherwise unchanging light source. An example of detection across space was provided by the work of Joseph et al. (1997), in which observers reported on the presence or absence of an orientation discontinuity, namely a Gabor patch of different orientation.

By contrast, in an *identification* task, the observer is asked to identify the nature of the discontinuity. Thus, in the identification condition of Bonnel et al.'s (1992) study, observers reported whether the luminance discontinuity was an increment or a decrement. Similarly, although the study of Joseph et al. (1997) did not include an identification condition, this could have easily been included by asking observers to name the actual orientation of the oddly oriented Gabor patch. As for a definition of *attention,* we follow Raymond (2000) in using the term to denote "those neural processes (at any stage) that promote preferential processing of stimuli relevant to a particular task and inhibit processing of task-irrelevant stimuli" (p. 42). In the present context of divided attention, this definition could be expanded to include the concept of limited resources (Norman & Bobrow, 1975), whereby deployment of attention to a given task reduces its availability for another similar task.

Yet, even within the confines of these definitions, the literature does not agree on the need for attention in detection tasks. This disagreement can be illustrated by comparing the studies of Bonnel et al. (1992) and Joseph et al. (1997). In both studies, the degree of attention allocated to the detection task was manipulated by implementing a concurrent task. In the study of Bonnel et al., the concurrent task caused attention to be distributed across multiple locations in space. In the study of Joseph et al., attention was distributed over time by means of the attentional-blink paradigm, which is described in the following paragraphs. Both studies used detection tasks in that they involved perception of discontinuities, whether in luminance or orientation. Why, then, did the two studies come to different conclusions? Several factors could have been responsible, including differences in stimulus domain (luminance vs. orientation), in how attention was distributed (across space or over time) and whether visual masking was used (Joseph et al. used a backward mask, whereas Bonnel et al. did not).

Differences in stimuli are unlikely to have played a major role because the findings with luminance transients have been replicated with auditory changes (Bonnel & Hafter, 1998). This cross-modal equivalence implicates central processing rather than early sensory events. Distribution of attention in space versus time is also an unlikely candidate because the available evidence strongly suggests that these two ways of manipulating attention yield broadly equivalent results (Visser, Bischof, & Di Lollo, 1999). Rather, there are reasons to believe that backward masking might have been the critical factor. The present experiments were designed to explore how backward masking of the target object can affect the conclusion of whether attention is required in detection as distinct from identification tasks. Because some of the earlier studies, as well as the present experiments, were carried out in the context of a phenomenon known as the attentional blink, we first provide a brief description of that phenomenon and its relationship to backward masking.

The Attentional Blink

When two targets are presented in rapid sequence within a stream of distractors, correct identification of the first target usually hinders identification of the second. This second-target deficit, known as attentional blink (AB), is most evident when the temporal lag between the two targets is in the range 100–500 ms. A common paradigm for studying the AB is the RSVP, in which two targets, such as letters, are inserted in a stream of distractors, such as digits. All items are presented in the same spatial location at a rate of approximately 10 items/s. Within the RSVP stream, each target is masked by the next item in the sequence.

Theoretical interpretations of the AB have emphasized different aspects of the phenomenon. In one class of models, the AB is said to stem from interference among items in a short-term visual store (e.g., Shapiro, Raymond, & Arnell, 1994). Such interference is thought to underlie the "dwell time of attention," which mediates the AB deficit (Duncan, Ward, & Shapiro, 1994). In another class of models, the AB is said to stem from a system bottleneck between early and late visual processes (Chun & Potter, 1995; Jolicoeur & Dell'Acqua, 1998). On this view, the AB arises because the second target cannot be attended while the required high-level analyzers are busy with the first target. In a recent synopsis, Shapiro, Arnell, and Raymond (1997) concluded that far from being mutually exclusive, all models of the AB share broad characteristics and are in many respects equivalent.

In the present work, a specific theoretical formulation in terms of interference, dwell time, or bottleneck is not necessary because the AB is used strictly as a tool of convenience for distributing attention over time. All that matters in the present context is that this procedure make attentional resources more or less available, depending on the temporal interval between the first and the second targets.

Masking in the AB

Among the factors known to be important in obtaining an AB deficit, two are especially relevant for the present purpose: backward masking of and inattention to the second target. The literature indicates further that backward masking and inattention act jointly and interactively as factors in the AB deficit (Brehaut, Enns, & Di Lollo, 1999; Giesbrecht & Di Lollo, 1998; Ross & Jolicoeur, 1999). Masking alone is not sufficient, as shown by a control condition in which observers are not required to identify the first target. In that condition, the second target is followed by a mask; nevertheless, without the attentional drain caused by the first target, identification of the second target is invariably near-perfect. Nor is inattention alone sufficient. Observers are able to report the second target with no difficulty if there is no trailing mask. This is true even at short inter-target lags, when attention is maximally preoccupied with the first target.

An account of how backward masking and inattention combine to produce the AB deficit has been proposed, based on a process called *object substitution* (Di Lollo, Enns, & Rensink, 2000; Enns & Di Lollo, 1997; Giesbrecht & Di Lollo, 1998). Basic to the object-substitution account is the assumption that while unattended, the representation of the second target is vulnerable to replacement by a trailing mask. In this event, an AB deficit occurs because it is the mask, not the second target, that eventually gains access to high-level processing mechanisms. Studies examining the nature of the errors that were made when the second target was misidentified confirm this prediction (Chun, 1997; Isaak, Shapiro, & Martin, 1999). The most common misidentification of the second target arose from reporting the next item instead, suggesting that the trailing item in the RSVP stream replaces the second target while the latter is unattended.

Attentional Requirements in Detection and Identification

As is evident from this review, considerations of masking in the AB are directly relevant to the issue of whether attentional resources are required in detection and identification tasks. At a minimum, masking should be explored as a factor in the diverging conclusions reached by Bonnel et al. (1992), who found that detection did not require attention using nonmasked displays, and those reached by Joseph et al. (1997), who found that detection did require attention using masked displays.

Indeed, a consideration of the role of masking suggests an alternative interpretation of Joseph et al.'s (1997) results. Suppose that the odd-ball detection task in Joseph et al.'s study was performed without attention but that the information resulting from that detection was vulnerable to masking by a trailing stimulus while attention was diverted to the first target. In other words, suppose that the discontinuity in the orientation gradient was detected at a preattentive processing stage, and the resulting preattentive representation of the visual discontinuity was encoded in what might be referred to as a *detection code*. However, that code could not be used as the basis for a response while attentional resources were still engaged by the first target. While so delayed, the detection code would therefore remain vulnerable to substitution masking. On this option, it would be inappropriate to conclude that detection cannot be performed without attention. Rather, it should be concluded that the information resulting from a preattentive detection process cannot be expressed in a response while attention is otherwise engaged. That information, however, is vulnerable to masking during the period of inattention.

To investigate this option, a study is required in which the type of task (detection vs. identification) is varied orthogonally with the presence or absence of a backward mask. To avoid ambiguities arising from procedural differences, the same paradigm should be used in both tasks. Such a study was carried out in Experiment 1, using the AB paradigm.

Experiment 1: Detection Versus Identification of Oriented Line Segments

In Experiment 1, the AB paradigm was used with a 2 × 2 factorial design in which a detection and an identification task were crossed with the presence or absence of a mask after the second target. The task was similar to that used by Joseph et al. (1997). In the present study, distractors in the RSVP stream were digits, the first target was a letter, and the second target was a set of 12 line segments arranged in a circle, as on a clock face. In the detection task, all line segments had the same orientation on half the trials, but, on the other half of the trials, one segment had a different orientation. Observers indicated the presence or absence of the oddball. In the identification task, observers named the actual orientation of the odd-ball line.

In the backward-masking conditions, a mask followed the presentation of the second target in each of the 12 clock positions. In the no-mask conditions, there was no trailing mask after the second target. The outcome of Experiment 1 supported the view that attentional resources are required for identification but not for detection.

Method

Observers

Sixty-four undergraduate volunteers participated for class credit. All reported normal or corrected-to-normal vision and were naive to the purpose of the experiment. They were assigned randomly to one of four conditions, each with 16 observers.

Apparatus and Stimuli

All stimuli in the present experiments were displayed on a Tektronix 608 oscilloscopic point-plotter equipped with P15 phosphor. The stimuli consisted of digits and letters, presented in the center of the screen, and 12 line segments arranged in a circle as in a clock face. All digits and letters subtended approximately 1° of visual angle in height at a viewing distance of 57 cm, set by a headrest. The line segments were 1° in length, less than 0.1° in thickness, and formed a circle of 3° radius, centered on fixation. Digits and letters were displayed at a luminance of 20 cd/m^2, as measured by a Minolta LS-100 luminance meter. The line segments were displayed at a luminance of 8 cd/m^2. The distractor items were digits (0–9), the first target was a letter, and the second target was a ring of line segments, as described below.

Procedure

There were four experimental conditions, with 16 observers in each. The procedural details common to all four conditions were as follows. At the beginning of each trial, a small fixation cross was presented in the center of the screen, indicating the location in which an RSVP stream of digits and letters was about to appear. Observers initiated each trial by pressing the space bar. After a 500-ms delay, an RSVP stream was displayed, which contained a variable number of digits (distractors) and one letter (the first target). Each item in the stream was displayed for 30 ms and was separated from the next item by an interstimulus interval of 70 ms, yielding a presentation rate of 10 items/s. On any given trial, the distractors were selected randomly with replacement from the set of digits, with the constraint that the selected digit was not one of the two immediately preceding items. The target letter was selected randomly from all letters of the English alphabet, except *I, O, Q,* and *Z,* which were omitted because of their visual similarity with some digits. The number of distractors preceding the first target was determined randomly on each trial and varied between 5 and 10. Observers were required to ignore the distractors and to report the identity of the first target by pressing the corresponding key on the keyboard. The second target was presented at one of five lags after the first: 100, 200, 300, 500, or 700 ms. The response that observers were required to make to the second target depended on the experimental condition, as explained in the following paragraphs. After presentation of the first target, the RSVP stream continued for a total of 14 digits, with the second target appearing at the appropriate lag during this stream. A typical sequence of events within a trial is illustrated in Figure 1. The displays and the response requirements in the four experimental conditions were identical throughout the RSVP stream up to and including the first target. The four conditions differed, however, in respect to the displays and the response requirements of the second target, according to the following design.

Experimental Design

The design was a 2 × 2 × 5 factorial, with two between-subject factors: task (detection or identification of the second target) and trailing mask after the second target (present or absent), and one within-subject factor (lag, at the five levels listed above). The combination of the two between-subject factors yielded four conditions, as follows.

Detection with trailing mask. This condition was essentially a replication of Joseph et al.'s (1997) study, except that we used line segments instead of Gabor patches. On half of the trials, 11 of the 12 line segments in the second target were all oriented in the same direction (45° clockwise or anticlockwise, determined randomly on each trial), and the 12th segment was oriented in the opposite direction. On the remaining half of the trials, all line segments were oriented in the same direction (45° clockwise or anticlockwise, determined randomly on each trial). Within a session, the odd-ball segment was located an equal number of times in each of the 12 clock locations. The exposure duration of the second target was 150 ms, which was followed immediately by a mask consisting of 12 sets of 60 dots each. Within each set, the 60 dots were distributed randomly within a 1° × 1° square area. One set of masking dots was centered on each of the 12 clock locations previously occupied by the line segments. This random-dot mask was displayed for 150 ms at a luminance of 8 cd/m^2. Observers were required to press one of two keys on the keyboard (yes or no) to indicate whether or not the second target contained an odd-ball element on that trial. Thus, on each trial, observers made two responses: first, they identified the first target, and, second, they detected the odd-ball in the second target.

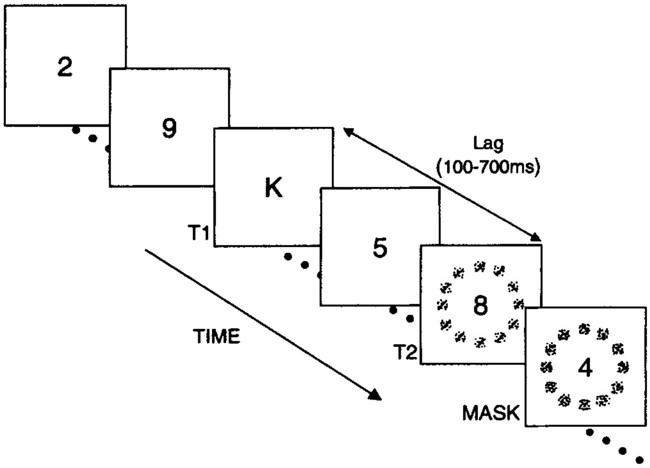

Figure 1. Schematic representation of the display sequence in Experiment 1. All stimuli were presented sequentially in the center of the screen. The first target was always masked by the next item in the sequence. The second target consisted of 12 line segments and was backward-masked by 12 corresponding groups of random dots. Observers made two responses. First, they identified the first target. Second, they either detected the presence or absence of an oddly oriented line in the second target (detection task) or identified the orientation of the oddly oriented line in the second target (identification task). T1 = first target; T2 = second target.

To keep the level of odd-ball detection below the 100% maximum and above the 50% chance level, we added five noise dots around each line segment in the second-target display (see Figure 1). In the course of the experimental session, the number of noise dots was varied dynamically for each observer to maintain the mean level of correct detections of the second target within a measurable range. For each observer, the percentage of correct detections, averaged over the five intertarget lags, was calculated automatically every 30 trials. If it was below 70%, the number of noise dots was decreased by four; if it was above 80%, the number of noise dots was increased by four. The average number of noise dots presented with the second target in the present condition was 8.6.

Detection with no trailing mask. This condition was the same as Condition 1 (detection with trailing mask), except that there was no trailing mask after the second target. The average number of noise dots presented with the second target was 18.1.

Identification with trailing mask. This condition was the same as Condition 1 (detection with trailing mask), except for the following. The displays used in the detection task, although similar to those used by Joseph et al. (1997), were not appropriate for the identification task because observers could guess the orientation of the target line merely by naming the orientation opposite that of the remaining 11 lines. Thus, a correct response could be made by checking the orientation of only 2 of the 11 lines in the distractor set and naming the opposite orientation. To exclude this possibility, we modified the display as follows. On each trial, 11 of the 12 line segments in the second target were all oriented in the same given direction (either vertical or horizontal, determined randomly on each trial); the twelfth segment was tilted by 45°, either clockwise or anticlockwise, determined randomly on each trial. In so doing, a confound was introduced between type of task and orientation of background lines; namely, the background lines were oriented diagonally in the detection task and vertically (or horizontally) in the identification task. However, the variation in background-line orientation is unlikely to have affected the results for two reasons. First, the results obtained in Experiment 1 were replicated in Experiment 2 with motion stimuli, which did not involve line orientation. Second, the identification results obtained in Experiment 1 were replicated closely in Experiment 2b with stimuli identical to those in Experiment 1, except that there were no background lines.

Within a session, the tilted segment was located an equal number of times in each of the 12 clock locations. Observers were required to identify the orientation of the tilted line and to respond by pressing one of two keys on the keyboard (left-tilt or right-tilt). The average number of noise dots presented with the second target was 7.9.

Identification with no trailing mask. This condition was the same as Condition 3 (identification with trailing mask), except that there was no trailing mask after the second target. The average number of noise dots presented with the second target was 15.8.

In each of the four conditions, observers were given 40 practice trials at the beginning of the session. These were followed by 360 experimental trials, which lasted approximately 40 min. Observers were allowed several brief rest periods during the session.

Results

In this and all subsequent experiments, estimates of second-target detection or identification were based only on those trials in which the first target had been identified correctly. This procedure is commonly adopted in AB experiments on the grounds that on trials in which the first target is identified incorrectly, the source of the error is unknown, thus its effect on second-target processing cannot be estimated. Correct identifications of the first target, averaged across lags separately for each condition, were detection-with-trailing-mask (93%), detection-with-no-trailing-mask (93%), identification-with-trailing-mask (91%), and identification-with-no-trailing-mask (91%). Figure 2 shows percentages of correct detections or identifications of the second target as a function of lag, averaged over all observers, separately for each condition. The percentages of false alarms were 13% for the detection-with-trailing-mask condition and 13% for the detection-with-no-trailing-mask condition. The corresponding percentages of misses were 14% and 13%. Neither false alarms nor misses interacted with lag in this or any of the following experiments.

A three-way analysis of variance (ANOVA) was conducted with two between-subject factors (task: detection or identification, mask: present or absent) and one within-subject factor (lag: 100, 200, 300, 500, and 700 ms). The analysis revealed a significant effect of lag, $F(4, 240) = 44.85$, $p < .001$, $MSE = 27.55$, and a significant interaction effect between mask and lag, $F(4, 240) = 11.41$, $p < .001$, $MSE = 27.55$. Notably, the three-way interaction between task, mask, and lag was significant, $F(4, 240) = 4.37$, $p < .01$, $MSE = 27.55$. Separate tests aimed at examining the three-way interaction revealed that the effect of lag was significant in identification-with-trailing-mask, $F(4, 240) = 19.96$, $p < .001$, $MSE = 27.55$; identification-with-no-trailing-mask, $F(4, 240) = 5.80$, $p < .001$, $MSE = 27.55$; and detection-with-trailing-mask, $F(4, 240) = 33.27$, $p < .001$, $MSE = 27.55$, but not in detection-with-no-trailing-mask, $F(4, 240) = 1.89$, $.10 < p < .12$, $MSE = 27.55$. No other effects were significant. In brief, these analyses revealed significant AB deficits in all conditions except the detection-with-no-trailing-mask condition.

Discussion

In Experiment 1 we used an AB paradigm to assess the need for attention in detection and identification tasks. We began with the widely accepted view that the AB deficit occurs because the second target is unattended while the first target is being processed. From this it follows that if the second-target task does not require attention, the scarcity of attentional resources should be irrelevant to its processing, and an AB deficit should not occur. On the hypothesis that attention is required in identification but not in detection, an AB deficit was expected in the identification task but not in the detection task.

Performance in the identification task confirmed this expectation. Accuracy of identification revealed an AB deficit regardless of masking condition (Figure 2B), supporting the claim that attention is required for stimulus identification (Bonnel et al., 1992; Braun & Sagi, 1990). Performance in the detection task, however, presented a less uniform picture (Figure 2A). When the second target was followed by a mask, accuracy of detection exhibited a pronounced AB deficit, comparable to that obtained by Joseph et al. (1997) under similar conditions. Considered in isolation, this outcome would be consistent with Joseph et al.'s (1997) claim that detection requires attention. But when the second target was not followed by a mask, an AB deficit failed to materialize, consistent with the opposite claim that detection can be performed without attention (Bonnel et al., 1992).

What can these results tell us about the need for attention in detection processes? An answer hinges on several factors. The role of masking is obviously important and needs to be understood. However, there are other issues to be considered as well. One concerns the detection-no-mask condition: Accuracy of detection in that condition showed some evidence of improvement over the three shortest lags, suggestive of a muted AB deficit (Figure 2A). This suggestion is consistent with the statistical analysis, which

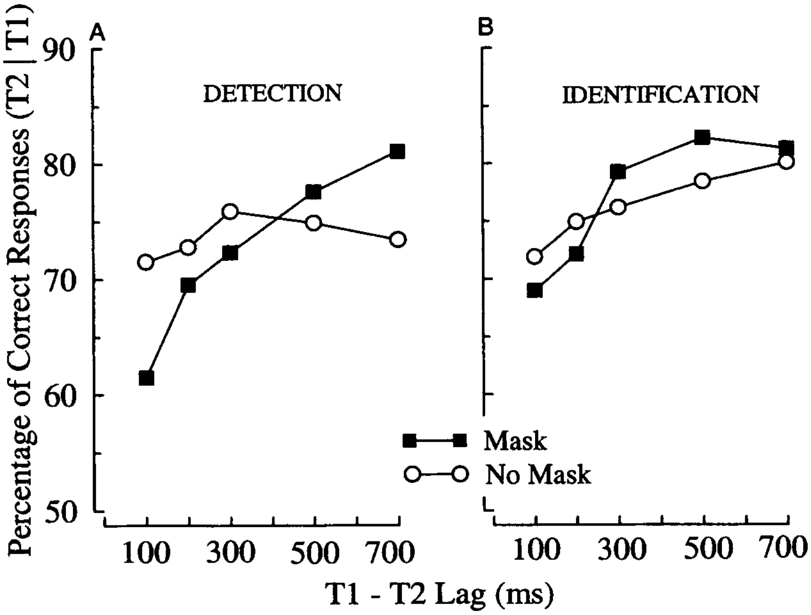

Figure 2. Results of Experiment 1. A: Mean percentage of correct detections of the second target, given accurate identification of the first target. B: Mean percentage of correct identifications of the second target, given accurate identification of the first target. T1 = first target; T2 = second target.

revealed a marginally significant effect of lag ($p < .12$). More evidence on this marginal result was collected in Experiment 2. A further objective of Experiment 2 was to explore the generality of the results of Experiment 1 across stimulus domains. Specifically, in Experiment 2 we studied detection and identification of stimuli in motion, as distinct from line orientation. The combined evidence from Experiments 1 and 2 provided a firmer basis on which to interpret the interdependence between task and masking observed in Figure 2.

Experiment 2: Detection Versus Identification of Coherent Motion

A factorial design similar to that of Experiment 1 was used in Experiment 2, but instead of oriented line segments, the second target consisted of random dots seen in apparent motion. The basic motion display was composed of a series of sequential frames, each containing one or more patches of random dots (Figure 3). To produce apparent motion, a subset of dots within each patch was displaced coherently in the same horizontal direction in each successive frame. The remaining dots in each patch were displaced randomly in each successive frame, producing the appearance of random motion, as in a snow storm. The ratio of coherently moving to randomly moving dots was varied dynamically for each observer to keep the perception of coherent motion within a measurable range.

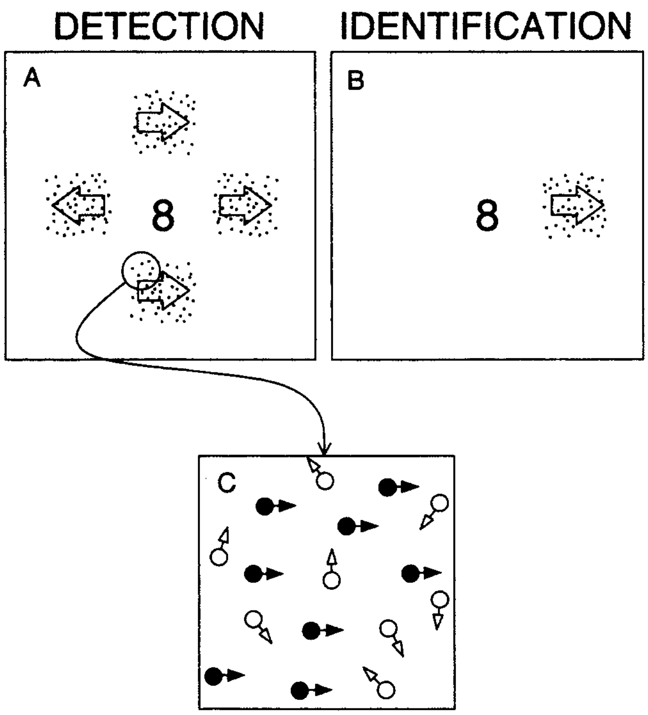

Figure 3. Schematic representation of the stimuli in Experiment 2. A: Black arrows indicate the predominant direction of motion of the dots within each patch. On half the trials, the coherently moving dots in all four patches appeared to move in the same direction. On the remaining trials, the dots in one of the patches appeared to move in a direction opposite to that in the other three patches. Observers reported the presence or absence of the oddball. B: The black arrow indicates the predominant direction of motion of the dots within the patch. Observers reported the direction of apparent motion of the dots. C: Detail of the dots in one of the patches illustrated in A. Arrows indicate the direction of motion of the dots. On every trial, a proportion of the dots within each patch appeared to move in a coherent direction, illustrated here as solid dots and arrows, whereas the remaining dots appeared to move in random directions, illustrated here as open dots and arrows.

In the detection task, four patches of dots were presented as in Figure 3A. On half the trials, the coherent dots moved in the same direction within each of the four patches. On the other half, the coherent dots in one of the patches moved in the opposite direction. Observers indicated the presence or absence of the odd-ball. In the identification task, a single patch of dots was displayed in one of four screen locations, unpredictably, and observers identified the predominant direction of motion (Figure 3B). Only one patch of dots was used in the identification task, instead of four as in the detection task, because observers found it difficult to name the direction of motion in the target patch when there were other patches on the screen. This procedure departed from that of Experiment 1, in which the number of display elements was the same in both the detection and the identification tasks. To maintain comparability between the two experiments, we performed Experiment 2b, in which the two identification conditions in Experiment 1 (mask and no-mask) were replicated with displays in which the second target consisted of a single oriented line. The results of Experiment 2b (see continuous lines in Figure 5, later) were virtually identical to the corresponding results of Experiment 1 (see dotted lines in Figure 5, later). This permitted a direct comparison to be made between the identification results obtained with coherent motion and with line orientation.

Method: Experiment 2a

The method in Experiment 2 was the same as in Experiment 1, except as specified below.

Observers

Sixty-four undergraduate volunteers participated for class credit. All reported normal or corrected-to-normal vision and were naive to the purpose of the experiment. They were assigned randomly to one of four conditions, each with 16 observers.

Stimuli and Procedure

The RSVP sequence was similar to that of Experiment 1. The distractors were digits, and the first target was a letter, all presented in the center of the screen. Different from Experiment 1, the second target consisted of either one or four patches of dots (depending on the condition) seen in apparent motion, presented at the top, bottom, right, or left of the screen, as illustrated in Figures 3A and 3B. Any given patch contained 50 dots, each about 1 in diameter, plotted randomly within a 2 square area. Dot luminance was 9 cd/m^2, and the distance from the central fixation cross to the center of a patch was 3°. To produce the appearance of motion, the patches were displayed in five sequential frames, each of 30 ms duration. Coherently moving dots were displaced by 0.1° in the same horizontal direction on each successive frame. If the displacement was to a location outside the patch, the dot was wrapped around to the opposite edge of the patch. All remaining dots were repositioned at random on each successive frame to new locations within the patch. The relationship between coherently moving and incoherently moving dots is illustrated in Figure 3C.

The level of coherence (the ratio of coherently moving to randomly moving dots) was varied dynamically for each observer to maintain the mean level of correct second-target responses within a measurable range.

For each observer, the percentage of correct responses to the second target was calculated automatically every 30 trials. If it was below 70%, the level of coherence was increased by 4%; if it was above 80%, the level of coherence was decreased by 4%.

Experimental Design

The experimental design was the same as in Experiment 1. It was a 2 × 2 × 5 factorial with two between-subject factors: task (detection vs. identification of the second target) and trailing mask after the second target (present or absent), and one within-subject factor: lag (100, 200, 300, 500, or 700 ms). The combination of the two between-subject factors yielded the following four conditions. In each of the four conditions, observers were given 40 practice trials and 320 experimental trials.

Detection with trailing mask. The second-target display consisted of four patches of moving dots, as illustrated in Figure 3A. On half the trials, the coherently moving dots in three of the four patches moved in the same direction (left or right, determined randomly on each trial), and those in the fourth patch moved in the opposite direction (Figure 3A). On the remaining trials, the direction of coherent motion was the same in all patches (either left or right). Observers were required to identify the first target and to report the presence or absence of the motion odd-ball in the second target. Within a session, the odd-ball motion patch appeared an equal number of times in each of the four possible locations. The second target was followed immediately by a mask consisting of four 2 × 2 patches of randomly moving dots, presented in the four locations previously occupied by the coherent motion patches. Each masking patch contained 50 dots, which were repositioned randomly on each of five successive 30-ms frames, for a total duration of 150 ms. The luminance of the masking dots was 9 cd/m^2. The average level of coherence in the present condition was 78%.

Detection with no trailing mask. This condition was the same as the preceding condition, except that there was no mask after the second target. The average level of coherence was 24%.

Identification with trailing mask. This condition was the same as Condition 1 (detection with trailing mask), except that the second target consisted of a single motion patch displayed for five 30-ms frames in one of four equally probable locations (Figure 3B). The motion patch was followed by a single-patch mask similar to that in Condition 1. Observers were required to indicate the prevalent direction of motion in the second target by pressing one of two keys on the keyboard. The average level of coherence was 64%.

Identification with no trailing mask. This condition was the same as the preceding condition, except that there was no mask after the second target. The average level of coherence was 20%.

Method: Experiment 2b

Experiment 2b was a close replication of the identification-with-trailing-mask and the identification-with-no-trailing-mask conditions in Experiment 1. The method was the same as in the corresponding conditions in Experiment 1, except that the second target consisted of a single oriented line segment presented randomly in 1 of the 12 locations occupied by line segments in Experiment 1. The line appeared an equal number of times in each of the 12 locations and was displayed embedded in random-dot noise, as in Experiment 1. The average number of noise dots was 23.5 in the identification-with-trailing-mask condition, and 46.6 in the identification-with-no-trailing-mask condition.

Results

The results of Experiment 2 are illustrated in Figure 4, which shows percentages of correct detections or identifications of the second target as a function of lag, averaged over all observers, separately for each condition. Mean levels of identification of the first target, collapsed across lags, separately for each of the four conditions, were as follows: detection-with-no-trailing-mask (96%); detection-with-trailing-mask (91%); identification-with-no-trailing-mask (93%); identification-with-trailing-mask (91%). The percentages of false alarms were 12% and 13% for the detection-with-trailing-mask and detection-with-no-trailing-mask

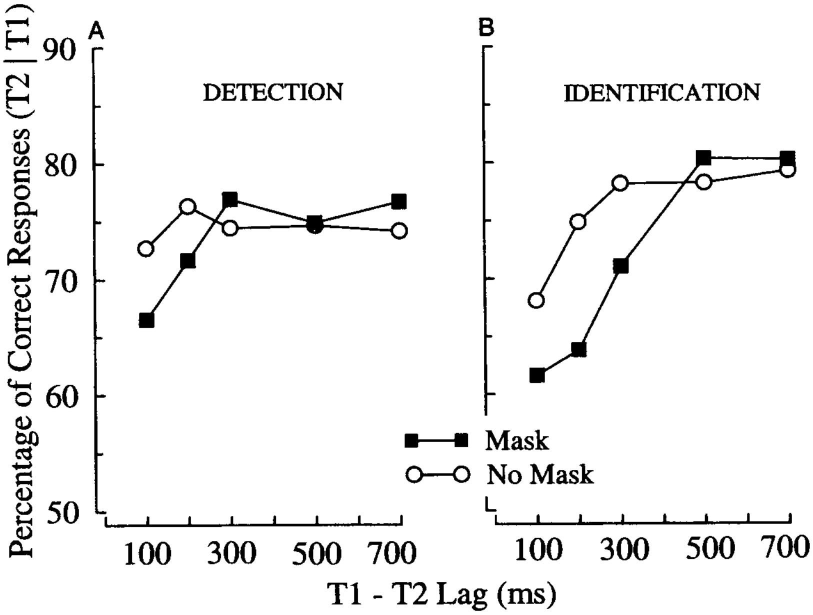

Figure 4. Results of Experiment 2a. A: Mean percentage of correct detections of the second target, given accurate identification of the first target. B: Mean percentage of correct identifications of the second target, given accurate identification of the first target. T1 = first target; T2 = second target.

conditions, respectively. The corresponding percentages of misses were 12% and 13%.

A three-way ANOVA was conducted with two between-subject factors (task: detection or identification, mask: present or absent) and one within-subject factor (lag: 100, 200, 300, 500, or 700 ms). The analysis revealed a significant effect of mask, $F(1, 60) = 6.60$, $p < .02$, $MSE = 89.07$; a significant effect of lag, $F(4, 240) = 33.42$, $p < .001$, $MSE = 35.36$; a significant interaction effect between task and lag, $F(4, 240) = 9.44$, $p < .001$, $MSE = 35.36$; and a significant interaction effect between mask and lag, $F(4, 240) = 8.43$, $p < .001$, $MSE = 35.36$. As in Experiment 1, the three-way interaction between task, mask, and lag was significant, $F(4, 240) = 2.50$, $p < .05$, $MSE = 35.36$. Separate tests aimed at examining the three-way interaction revealed that the effect of lag was significant in identification-with-trailing-mask, $F(4, 240) = 35.04$, $p < .001$, $MSE = 35.36$; identification-with-no-trailing-mask, $F(4, 240) = 9.44$, $p < .001$, $MSE = 35.36$; and detection-with-trailing-mask, $F(4, 240) = 8.65$, $p < .001$, $MSE = 35.36$; but not in detection-with-no-trailing-mask, $F(4, 240) < 1$, $MSE = 27.55$. No other effects were significant. This pattern of results is similar to that of Experiment 1: An AB deficit was obtained in all conditions except the detection-with-no-trailing-mask condition.

The results of Experiment 2b are illustrated in Figure 5 (continuous lines), which shows percentages of correct identifications of the second target as a function of lag, averaged over all observers, separately for the mask and no-mask conditions. The corresponding results of Experiment 1 have been entered in Figure 5 (dotted lines) for ease of comparison. We conducted a two-way ANOVA on the results of Experiment 2b, with one between-subject factor (mask: present or absent) and one within-subject factor (lag: 100, 200, 300, 500, or 700 ms). The only significant effect was lag, $F(4, 120) = 37.93$, $p < .001$, $MSE = 23.82$.

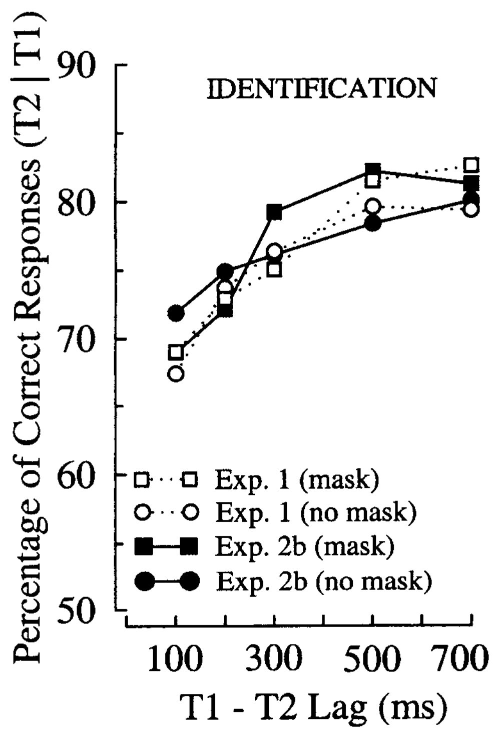

Figure 5. Results of Experiment 2b. Mean percentage of correct identifications of the second target, given accurate identification of the first target (continuous lines). The results of the corresponding identification conditions in Experiment 1 have been included for ease of comparison (dotted lines). T1 = first target; T2 = second target; Exp. = experiment.

Experiment 2b replicated the identification conditions of Experiment 1, except for the presence of distractors in the displays. In Experiment 1, the target was displayed among 11 distractors; in Experiment 2b, the target was the only item in the display. To evaluate the effect of the presence of distractors, we compared the corresponding results of Experiments 1 and 2b in a single analysis. We conducted a three-way ANOVA with two between-subject factors (Experiment: 1 or 2b; mask: present or absent) and one within-subject factor (lag: 100, 200, 300, 500, or 700 ms). The only significant effect was lag, $F(4, 240) = 56.87$, $p < .001$, $MSE = 26.51$. This analysis confirms the graphical evidence that an AB deficit occurred in the identification task whether or not the second target was followed by a mask. Notably, the outcome of Experiment 2b indicates that the same pattern of results is obtained in the identification task, whether the target is the only element or 1 of 12 elements in the display. This permits a direct comparison between the identification results obtained with line orientation (Experiments 1 and 2b) and with coherent directional motion (Experiment 2).

Discussion

The finding that a directional-motion task yields a conventional AB deficit when the first target is a letter suggests the operation of attentional mechanisms that transcend the distinction between dorsal and ventral brain streams (van Essen & DeYoe, 1995). Dorsal stream structures have been implicated in short-range motion processing, whereas the processing of form, such as letter identification, is likely to be mainly a ventral stream function (Schiller, Logothetis, & Charles, 1990). Yet, in Experiment 2, the requirement to process a letter as first target produced a substantial AB deficit when the second target involved the processing of coherent directional motion. Although not denying that an AB deficit can occur within a single stream, this result points to attentional mechanisms whose functioning is influenced by concomitant events across dorsal and ventral brain streams.

Comparison of Experiments 1 and 2 attests to the generality of the effects across stimulus domains. In the identification task, an AB deficit was in evidence both with line orientation (Figure 2b) and with coherent directional motion (Figure 4B), whether or not a mask was presented after the second target. This result is consistent with the claim that attention is required for stimulus identification (Bonnel et al., 1992; Braun & Sagi, 1990). In the detection task, on the other hand, the results depended critically on the masking condition. When the second target was followed by a mask, an AB deficit was in evidence, suggesting that attentional resources were required to perform the detection task (Figures 2A and 4A). This is precisely the conclusion reached by Joseph et al. (1997), whose results were remarkably similar to the present masking results. In contrast, the absence of an AB deficit when the second target was not masked (Figures 2a and 4a) supports the opposite conclusion, namely, that detection can be performed without attentional resources. In a nutshell, the results indicate that attention is invariably required for identification, but, in detection tasks, the need for attention is apparent only when the second target is masked.

The mask-dependent results obtained in the detection tasks allow for at least two hypotheses of the role of attention in the process of stimulus detection. We refer to these as the *attention-free* and *attention-bound* hypotheses, respectively. The attention-free hypothesis is based on the assumption that detection does not require attention. This option is supported by the no-mask results in both experiments but is contradicted by the masking results. To account for the masking results, two related assumptions are required. First, it must be assumed that detection was performed—and a detection code was generated—without attention. Second, the detection code was destroyed by the arrival of the mask before it could be expressed in a response, thus giving rise to the AB deficits seen in the masking curves in Figures 2a and 4a.

The alternative attention-bound hypothesis is based on the assumption that detection requires attention, as suggested by the masking results. On this option, the mask arrived before attention could be deployed to the second target, and it destroyed the low-level precategorical information that formed the database for the detection process. To account for the absence of an AB deficit in the no-mask results, it must be assumed that the detection process was not performed immediately but was delayed until attentional resources became available, after processing of the first target had been completed. On this account, it must also be assumed that the low-level precategorical information remained undecayed—or decayed only moderately—during the period of delay to provide a suitable database for the delayed detection process.

Both these hypotheses are consistent with the assumption that deployment of attention to the second target is delayed while the first target is being processed. This assumption can be tested directly by measuring reaction times (RTs) to the second target as a function of the intertarget lag. This test is especially informative in the detection task because the attention-bound and attention-free hypotheses predict different temporal courses of RTs over lags. If detection requires attention, as is assumed in the attention-bound hypothesis, detection must be postponed while attention is devoted to the first target. For this reason, detection RTs should decline with lag, reflecting the increased availability of attention as lag is increased. This result should be true even in the no-mask condition, where no AB was obtained in detection accuracy. On the other hand, if detection does not require attention, as is assumed in the attention-free hypothesis, the lack of attentional resources should be inconsequential, and RTs should exhibit a flat function across lags. To be entirely explicit, this latter prediction requires some elucidation. The RT depends not only on detection time but also on the time to select and execute the response. So, even if detection is not delayed at short lags, selection and execution of the response might be. Therefore, if RT is found to be a function of lag, interpretation of the outcome would be ambiguous. However, if the RT function is flat across lags, we can be confident that RT does not depend on any of these factors, notably detection time.

Such a test is relevant not only in the detection task but also in the identification task. On the present evidence that identification invariably requires attention, identification RTs should decline progressively as intertarget lag is increased, reflecting the increasing availability of attentional resources for the second target as processing of the first target approaches completion. This test was performed in Experiment 3.

Experiment 3: Response Times Throughout the Intertarget Lag

Experiment 3 was designed to measure RT to the second target under conditions equivalent to the no-mask conditions in Experiments 1 and 2. Two stimulus domains (line orientation and coherent motion) were crossed with two tasks (detection and identification) to form a 2 × 2 between-subject factorial design. As in the previous experiments, intertarget lag was a within-subject factor. In Experiment 3, the second target was never followed by a mask, nor was it degraded by visual noise. This procedure was adopted because our main interest was not in accuracy of performance. Rather, the second target functioned as a probe for sampling the delay in the availability of processing resources as a function of intertarget lag. To serve optimally as a probe, it was essential that the second target be detected or identified with a high level of accuracy.

An intrinsic requirement in measuring RTs is that the response be made immediately on target presentation. To this end, observers were required to respond to the second target as quickly as possible when it appeared on the screen and to respond to the first target later, at their leisure. In this procedure, the order of report was the reverse of that used in the previous experiments. To ensure that this reversal did not alter the response accuracy or the nature of the lag-dependent effects obtained in the previous studies, we performed a control experiment, to which we refer as Experiment 3b. In that experiment, 16 observers were presented with precisely the same stimuli as in the detection-no-mask condition of Experiment 1 but were required to respond to the two targets in the reverse order. The results of Experiment 3b, illustrated by the continuous line in Figure 6, were entirely comparable to those in the corresponding condition in Experiment 1, represented by the dotted line in Figure 6. This outcome strongly suggests that order of report was not an important factor in accuracy of performance.

RT has been used as a dependent measure in earlier investigations of the AB, especially within the framework of the psychological refractory period. In a series of extensive investigations, Jolicoeur and Dell'Acqua (1998, 1999) developed the general logic and rationale for the use of RT in a second task as a way to assess the attentional demands in a concurrent first task. The outcome of this work implicated interference with *short-term consolidation* (the process of encoding information into durable storage) as one basis for the AB deficit.

The present experiment expands on the work of Jolicoeur and Dell'Acqua (1998, 1999) in several important ways. First, the present stimuli extend the scope of Jolicoeur and Dell'Acqua's work to the domains of motion and orientation. Second, RT measures are used in the present work to compare specific hypotheses regarding the need for attention in detection and identification tasks. Finally, and perhaps most importantly, the present study decouples RT and accuracy measures of the AB using a detection task that yields an AB deficit in RT (Experiment 3) but not in accuracy (Experiments 1 and 2; see also Arnell & Duncan, 1997). Such a correlative analysis provides useful constraints both for theories of the AB and for assessing the attentional requirements in detection and identification.

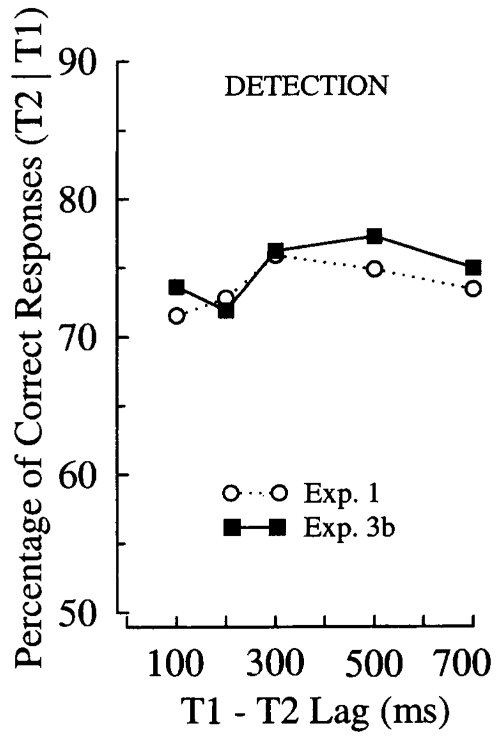

Figure 6. Results of Experiment 3b. Mean percentage of correct detections of the second target, given accurate identification of the first target (continuous lines). The results of the corresponding detection conditions in Experiment 1 have been included for ease of comparison (dotted lines). T1 = first target; T2 = second target; Exp. = experiment.

Method

Observers, Apparatus, Stimuli, and Procedure

These were the same as in the previous experiments, with the following exceptions. Sixteen observers were assigned randomly to each of four conditions. They were required to identify the first target and to make a speeded response to the second. Within the RSVP stream, the first target always preceded the second. However, to measure RT to the second target, the order of report was reversed. Observers were instructed to respond as quickly as possible to the second target by pressing the appropriate key on the keyboard and then to identify the first target at leisure by pressing the corresponding letter on the keyboard. Regardless of condition, the second target was never degraded by noise and was never followed by a mask.

Experimental Design

The design was a 2 × 2 × 5 factorial, with two between-subject factors: task (detection or identification of the second target) and stimulus feature (orientation or motion), and one within-subject factor (lag: 100, 200, 300, 500, or 700 ms). The combination of the two between-subject factors yielded the following four conditions.

Detection of orientation. Stimuli were the same as in the detection-no-mask condition in Experiment 1, except that no noise dots were added to the second target. Observers made two responses. The first was a speeded response to indicate the presence or absence of an orientation odd-ball in the second target. The second was a nonspeeded response to identify the first target.

Identification of orientation. This condition was the same as the identification-no-mask condition in Experiment 1, except that no noise dots were added to the second target. Observers made a speeded response to identify the second target and then identified the first target at leisure.

Detection of motion. This condition was the same as the detection-no-mask condition in Experiment 2, except that motion coherence was 100%. Observers made a speeded response to indicate the presence or absence of an odd-ball in directional motion and then identified the first target at leisure.

Identification of motion. This condition was the same as the identification-no-mask condition in Experiment 2, except that motion coherence was 100%. Observers identified the direction of motion in the second target and then identified the first target at leisure.

In each of the four conditions, observers were given 40 practice trials, followed by 360 (for orientation) or 320 (for motion) experimental trials.

Results

The results of Experiment 3 are illustrated in Figures 7A and 7B, which show mean RTs for correct detections or identifications of the second target, separately for orientation and coherent motion. Mean correct identifications of the second target in each of the four conditions were as follows: detection of orientation (95%), identification of orientation (97%), detection of motion (94%), and identification of motion (96%). Mean levels of identification of the first target, collapsed across lags, separately for each of the four conditions, were as follows: detection of orientation (90%), identification of orientation (93%), detection of motion (91%), and identification of motion (92%). The percentages of false alarms were 2.5 and 2.7 for the detection of orientation and detection of motion conditions, respectively. The corresponding percentages of misses were 2.6 and 2.8.

A three-way ANOVA of the RT data was conducted with two between-subject factors (task: detection or identification, stimulus feature: orientation or motion) and one within-subject factor (lag: 100, 200, 300, 500, or 700 ms). The analysis revealed a significant effect of task, $F(1, 60) = 14.49$, $p < .001$, $MSE = 144638.06$; a significant effect of lag, $F(4, 240) = 175.60$, $p < .001$, $MSE = 1383.58$; a significant interaction effect between feature and task, $F(1, 60) = 13.92$, $p < .001$, $MSE = 144638.06$; and a significant interaction effect between task and lag, $F(4, 240) = 3.29$, $p < .05$, $MSE = 1383.58$. No other effects were significant.

In the orientation task, detection RTs were much the same as identification RTs (Figure 7A). In the motion task, however, detection RTs were much slower than identification RTs (Figure 7B). It is possible that the process of establishing motion coherence within the four test patches in the detection displays took longer than within the single patch in the identification displays. It is also possible that the differences might have arisen, at least in part, from differences in response-mapping requirements between motion detection and identification. In identification, response execution was facilitated by the direct mapping between direction of motion (left or right) and the corresponding response key. In motion detection, however, response execution was hindered by the arbitrary and inconsistent mapping between direction of motion and response keys. Despite these differences in mean level, it is important to stress that lag-dependent AB deficits were very much in evidence in all four conditions.

Discussion

In the experiments reported thus far, accuracy and RT have been treated separately as measures of the AB deficit. We now consider

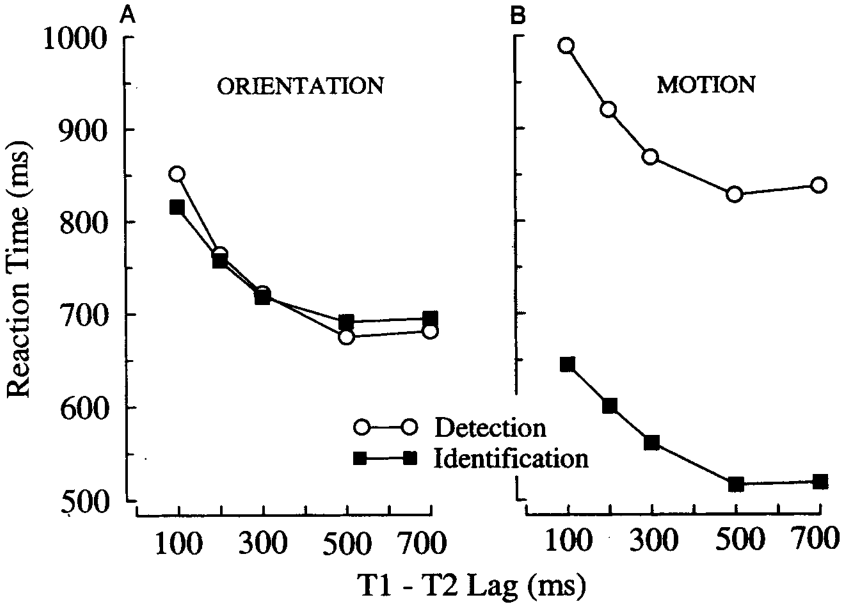

Figure 7. Results of Experiment 3. A: Mean reaction time when the second targets consisted of line segments. B: Mean reaction time when the second target consisted of random dots in apparent motion. T1 = first target; T2 = second target.

the two measures jointly, with a view to assessing the role of attention in detection and identification. It is well to be reminded that in Experiment 3 the second target was never followed by a mask. Therefore, the RT results in Experiment 3 should be compared with the accuracy results obtained in the no-mask conditions of the previous two experiments.

Pronounced lag-dependent RT deficits are seen in all conditions in Figure 7. Interpretation of these results is relatively straightforward for the identification task but is more complicated for the detection task.

Accuracy and RT in Stimulus Identification

In the identification task, an AB deficit is found reliably, whether the dependent variable is RT (Figure 7) or accuracy (Figures 2B and 4B). Relatively long RTs at the shorter lags are consistent with the idea that the response to the second target is delayed while the first target is being processed. Homologous findings have been reported by Jolicoeur and Dell'Acqua (1998, 1999) with cross-modal targets. Correspondingly, the relatively low accuracy seen at the shorter lags (Figures 2B and 4B) suggests that the second target cannot be identified reliably while attention is devoted to the first target. This coherent pattern of results is entirely consistent with the claim that attention is required for stimulus identification.

A joint analysis of the RT and accuracy results in the identification task suggests a possible account for the AB deficit in accuracy obtained in Experiments 1 and 2 when the second target was not followed by a mask. The finding that identification is delayed at the shorter lags (Figure 7) invites the hypothesis that the corresponding AB deficit seen in the accuracy scores in the no-mask conditions (Figures 2B and 4B) might stem from events that take place during the delay. Among likely events, object substitution is clearly ruled out by the absence of a backward mask. This is not to deny the importance of object substitution when the second target is followed by a mask, but other factors must be considered when the display sequence does not include a trailing mask. One plausible factor is stimulus degradation. It is conceivable that the representation of the second target may decay during the period of delay. At the end of the delay, when attention becomes available, the decayed information may be too noisy to be perceived reliably, and identification accuracy might suffer. This would give rise to the AB deficit in identification accuracy seen in Figures 2B and 4B over the delay periods indexed by the corresponding RT curves in Figure 7. At any rate, a joint analysis of the RT and accuracy results is strongly supportive of the conventional claim that attention is required for stimulus identification (Bonnel et al., 1992; Braun & Sagi, 1990).

Accuracy and RT in Stimulus Detection

The detection results, on the other hand, remain open to both the attention-free and attention-bound interpretations. Had the detection RTs in Figure 7 been uniformly flat across the domain, the attention-free option would have gained clear support. But the presence of an AB deficit in detection RTs keeps alive the attention-bound alternative. Namely, it is possible that detection occurred at the end of the delay, when attention became available. To be sure, the precategorical information would decay during the delay. However, the decay need not impair detection to the same extent that it impairs identification. It can be argued that detection requires less information than identification and can be performed on a noisy representation, which would be inadequate for stimulus identification. Thus, at the end of the delay period, the target's representation could well be too noisy to support identification but could still be suitable for detection. By its very nature, this option suggests a direct test.

Suppose that the second target is degraded by a good deal of visual noise so that, at very long lags (i.e., with focused attention), performance is only moderately above a chance level. If attention is not required for detection, performance should remain at the same level across all lags. But if attention is required, the detection process would be delayed, and the decay taking place during the delay would add to the overall degradation. The additional degradation might render the representation unsuitable even for the relatively easy process of detection. Because the amount of additional degradation would be related directly to the period of delay, accuracy of performance should exhibit an AB deficit. This conjecture was tested in Experiment 4.

Experiment 4: Detection Requires Attention

On the basis of the reasoning outlined above, an AB deficit should occur when the second target is severely degraded but not when it is degraded only moderately. Accordingly, the level of degradation of the second target in the present experiment was set to be either low or high. We refer to these as the easy and the hard conditions, respectively. In selecting the specific levels of degradation, an important consideration was to avoid floor or ceiling effects, which might obscure any AB deficit. For this reason, the easy and hard conditions were defined as those yielding averages of 85% and 65% correct responses, respectively.

Method

Observers, Apparatus, Stimuli, and Procedure

These were the same as in the detection-no-mask condition in Experiment 1, except that there were only two experimental conditions: easy and hard, with 16 observers in each. The mean correct response across lags for each observer was maintained at 85% or 65% in the easy and hard conditions, respectively, in the manner of Experiment 1. Observers were instructed to identify the first target (a letter) in an RSVP stream and to indicate the presence or absence of an oddly tilted line segment in the second target.

Experimental Design

The design was a 2 × 5 factorial, with one between-subject factor, condition (easy or hard), and one within-subject factor (lag: 100, 200, 300, 500, or 700 ms).

Easy condition. Stimuli were the same as in the detection-no-mask condition in Experiment 1, except that the mean correct response for each observer was maintained at 85% by varying the number of noise dots presented with the second target. The average number of noise dots across participants was 7.0.

Hard condition. Stimuli were the same as in the easy condition, except that the mean correct response for each observer was maintained at 65% by manipulating the number of noise dots presented simultaneously with the second target. The average number of noise dots across participants was 33.3.

Results and Discussion

The results of Experiment 4 are illustrated in Figure 8, which shows mean levels of detection of the second target across all lags, separately for the two levels of degradation. Mean correct identifications of the first target in the easy and hard conditions were 94% and 92%, respectively. The percentages of false alarms were 7% and 17% for the easy and the hard conditions, respectively. The corresponding percentages of misses were 7% and 17%.

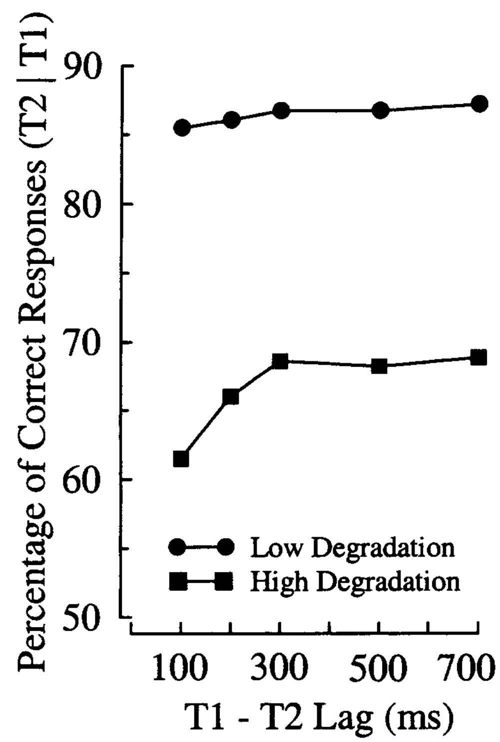

Figure 8. Results of Experiment 4. Mean percentage of correct detections of the second target, given accurate identification of the first target. T1 = first target; T2 = second target.

We performed an ANOVA on the results of Experiment 4 using orthogonal polynomials to test the significance of trends over lags. The analysis revealed only two significant effects. The mean percentage of correct responses, collapsed across lags, was higher in the easy than in the hard condition, $F(1, 30) = 365.05, p < .001$, $MSE = 42.96$. This result is not surprising because degradation was manipulated as an independent variable. The only other significant effect was the linear trend over lags in the hard condition, $F(1, 60) = 12.19, p < .001$, $MSE = 37.88$. In the easy condition, the linear trend fell far short of significance, $F(1, 60) = 1.42, p > .20$, $MSE = 18.97$, as did all other trends.

The attention-bound hypothesis is clearly supported by these results, buttressing the notion that detection requires attention. The reasoning is as follows. Detection of the odd-ball in the second target must be postponed while attention is devoted to the first target. During the period of delay, the representation of the second target undergoes progressive decay. The longer the delay, as indexed by the detection RTs in Figure 7A, the greater the decay. Whether the detection task can be carried out successfully will depend on the total degradation of the representation, namely, on the initial noise degradation plus the decay that occurs during the period of delay.

The results strongly suggest that when the initial noise degradation was modest (easy condition), the additional degradation due to decay was not sufficient to interfere with the detection process, even at the shortest lags. However, when the initial noise degradation was severe (hard condition), the additional decay rendered the representation unsuitable for successful detection. As predicted by the attention-bound hypothesis, the impairment due to decay was most evident at the shortest lags, when the delay was longest, and it diminished progressively as the lag was increased. In contrast, the attention-free hypothesis would predict that the accuracy of detection should remain constant across all lags, at the level set by the initial noise degradation.

General Discussion

We examined attentional requirements in detection and identification in the present work by means of the AB paradigm, in which the availability of attentional resources for the second of two targets was assumed to vary directly with the temporal lag between them. In this paradigm, the need for attention to process the second target is indexed by the magnitude of the AB deficit. In agreement with earlier findings (Bonnel et al., 1992; Brawn & Snowden, 2000), the need for attention in identification tasks, as distinct from detection tasks, was very much in evidence throughout. This was the case whether the attribute to be identified was line orientation or coherent motion (Experiments 1 and 2), whether the response measure was accuracy or RT (Experiment 3), and whether or not the second target was followed by a mask.

Detection tasks presented a more complex picture. In Experiments 1 and 2, AB deficits were in evidence only when the second target was followed by a mask. This left the issue of attentional involvement essentially unresolved because detection could have occurred without attention before the arrival of the mask. The mask might then have destroyed the detection code, namely, a preattentive representation of the presence or absence of a visual discontinuity, while it was unattended during the period of the AB. Experiment 3 used an RT measure to confirm the existence of a delay in processing the second target, prompting the hypothesis that the representation of the second target may decay during the period of inattention. On this hypothesis, by the time attention is again available, the degraded representation has become unsuitable for the relatively complex process of identification but not for the simpler process of detection. That hypothesis was confirmed in Experiment 4, in which an AB deficit in detection was obtained when the initial degradation of the second target was severe but not when it was moderate. Considered collectively, this evidence points to the need for attention not only in identification but also in detection tasks.

Converging Evidence on the Need for Attention in Detection Tasks

Our evidence that detection requires attention agrees with the conclusion of Joseph et al. (1997). It also fits with the more recent evidence of Brawn and Snowden (2000), who used a spatial precuing paradigm to study attentional requirements for detecting and identifying luminance transients. As in the present work, Brawn and Snowden measured RT with nonmasked displays and measured response accuracy with displays that were backward-masked. They did not, however, measure response accuracy with nonmasked displays, as was done in the present Experiments 1, 2, and 4. The results led Brawn and Snowden to conclude that both detection and identification were affected by attentional manipulations but that identification was affected more than detection. A similar conclusion was reached by Jolicoeur (1999), based on a simple RT task. Brawn and Snowden (2000) did not offer a specific explanation as to why attentional cuing affected the two tasks differently, but they rejected task difficulty as a plausible account.

Despite the obvious differences in stimuli (oriented lines or moving dots vs. luminance transients) and paradigms (AB vs. spatial precuing), there was remarkable correspondence between the present results and those of Brawn and Snowden (2000). Notably, both studies revealed the need for attention in detection tasks, whether the dependent measure was RT or accuracy. We account for both sets of results on the twin assumptions that processing of the target is delayed while attention is diverted elsewhere and that, while so delayed, the target decays and is vulnerable to masking by trailing stimuli. Thus, attentional manipulations had a pronounced effect on RT in the present Experiment 3 and in Brawn and Snowden's Experiments 1 and 2 because processing was delayed while attentional resources were less available.

We are led by this pattern of results to conclude that attention is always required in detection tasks, but the precise way in which the attentional effects are revealed depends on the experimental setting. If the target is not masked, attentional effects will be revealed in RTs. If the target is followed by a mask, the effect will be seen in accuracy measures. Under special circumstances, attentional effects can be seen on accuracy measures when the target is not masked. This occurs when the level of initial degradation is so high that the target decays beyond recognition during the period of inattention (e.g., Experiment 4).

On the face of it, this conclusion is at odds with Bonnel et al.'s (1992) claim that attention is not required in simple detection tasks. On closer inspection, however, the inconsistency is seen to be only superficial. In Bonnel et al.'s study, the dependent measure was accuracy, and the stimuli were luminance transients, which were never masked. This corresponded to the no-mask conditions in the present Experiments 1 and 2, which, in agreement with the results of Bonnel et al., revealed no attentional effects on detection. Attentional effects would have become apparent in Bonnel et al.'s study if the target had been masked or if RT had been the dependent measure. Thus, the results of Bonnel et al. fit neatly in the overall pattern outlined above.

In a nutshell, the need for attention in detection tasks is evident in all studies that used RT as a dependent measure and in all studies that used accuracy measures, provided that the target was either backward-masked or severely degraded. This is consistent with the hypotheses that processing of the target is delayed while attention is otherwise engaged and that during the period of inattention, the target's representation decays and is vulnerable to object substitution by a trailing mask.

Figure 9 contains a schematic illustration of these hypotheses. The two diagonal lines indicate the temporal course of decay of the representation of the second target. The upper function illustrates the course of decay when the initial degradation is moderate (relatively high target's signal-to-noise ratio), as was the case in the low-degradation condition in Experiment 4 (Figure 8). In the lower function, the initial degradation is severe (low initial signal-to-noise ratio), as in the high-degradation condition in Figure 8. The legibility threshold for identification (upper segmented horizontal line) denotes the minimum level of target's signal-to-noise ratio necessary for the relatively complex task of identification. The lower segmented line denotes the threshold for the simpler

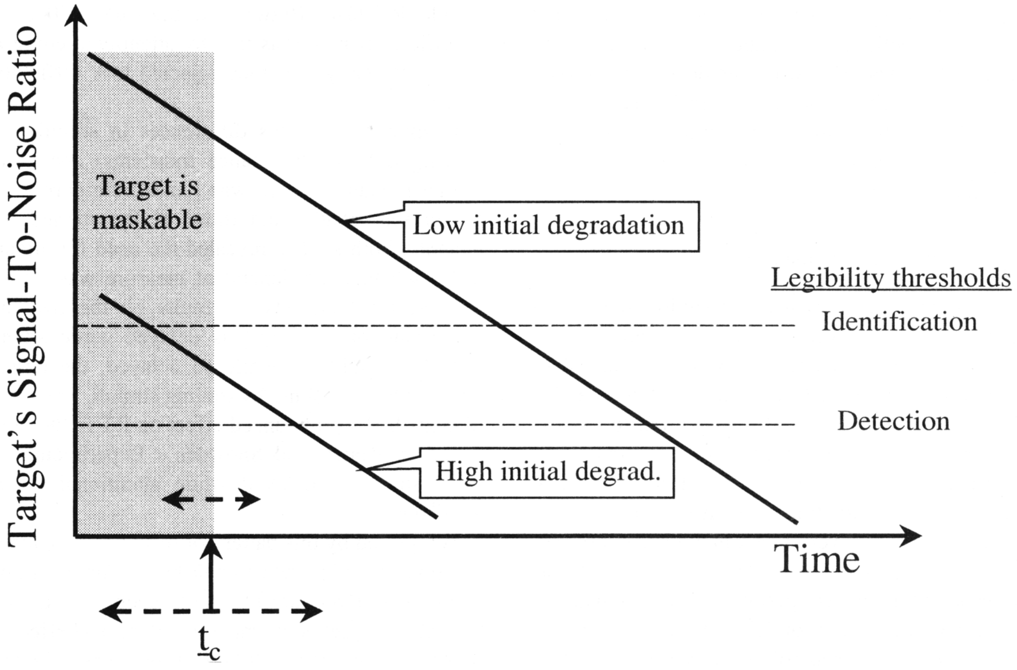

Figure 9. Schematic representation of the interplay among temporal decay, time of attentional deployment, and backward masking as determinants of accuracy and speed of responding in detection and identification tasks. See text for explanation. t_c = time of contact; degrad. = degradation.

task of detection. The vertical arrow on the abscissa indicates time of contact (t_c), namely the time at which attentional resources are allocated to the second target. As indicated by the bidirectional horizontal arrows, t_c is free to vary along the time axis. The specific value of t_c in any given instance is determined by the parameters of the attentional manipulation, such as duration of spatial precuing or number of distractors in a visual search task. For example, in the AB paradigm, the value of t_c will be relatively large (i.e., t_c will be located toward the right along the time axis) when the intertarget lag is short, reflecting the relatively long dwell-time of attention when lag is short. In contrast, the value of t_c will be relatively small (i.e., it will move toward the left) when intertarget lag is long, reflecting the readier availability of attentional resources at the longer lags. The shaded area to the left of the t_c ordinate indicates the period for which the second target is unattended and, therefore, maskable. Conversely, in the area to the right of the t_c ordinate, the target is attended and not maskable. Direct estimates of the value of t_c as a function of intertarget lag in the present AB paradigm are provided by the RT curves in Figure 7. Similar indirect estimates for high and for low initial levels of target degradation are provided by the accuracy curves in Figure 8.

At a more general level, the evidence in the present study provides converging supports for Nakayama and Joseph's (1998) claim that attention is required in all tasks, including detection and identification. The evidence is also consistent with conclusions reached by Bonnel et al. (1992) and by Brawn and Snowden's (2000) that the need for attention depends on the nature of the task. On our reasoning, the nature of the task may influence performance in two ways. In the case of a relatively complex task such as identification, it may take longer for attention to be fully deployed to the relevant stimuli. This would be represented in Figure 9 by an increment in the value of t_c and, therefore, in the period for which the information is vulnerable to masking. Identification also requires that a greater amount of information be available undecayed for the representation to be processed successfully. In Figure 9, this is represented by an upward displacement of the legibility threshold for the identification task. As we have seen, simple detection can be performed successfully when resources are limited, unless the initial representation is severely degraded. This however, is not possible with identification tasks because they cannot be performed successfully on representations that are even moderately decayed.

Implications for the Attentional Blink

We noted earlier that the AB was used in the present work strictly as a tool of convenience for manipulating the availability of attentional resources. Nevertheless, the outcomes of the present studies have definite bearings for the AB, both practically and conceptually. Here, we consider some salient implications.

An Apparent Inconsistency

We first consider an apparent inconsistency arising from the results of Experiments 1 and 2. In each case, the identification condition revealed substantial AB deficits even when the second target was not followed by a mask (Figures 2B and 4B). At first, this result may seem inconsistent with the claim that the AB deficit is absent or much reduced if the second target is not backward-masked (Brehaut et al., 1999; Giesbrecht & Di Lollo, 1998; Jolicoeur, 1999). In fact, the contradiction is only apparent, but it does serve to delineate further the factors that underlie the AB deficit. In this case, the literature points to task switching as the critical factor.

A task switch between the two targets was common to all studies in which an AB deficit was obtained without a backward mask. For example, In Experiment 3, the switch was between alphabetical characters and dots in directional motion. A switch between alphabetical characters and oriented line segments occurred both in Experiment 2 and in an experiment by Joseph, Maciokas, and Rowe (1998). Neither experiment used backward masking, yet both revealed substantial AB deficits. In a similar vein, Enns, Visser, Kawahara, and Di Lollo (in press) found substantial AB deficits without backward masking in experiments that required switches in target location, defining attribute, or both. In contrast, the AB failed to appear when no task switch was involved (e.g., when both targets were alphabetical characters), thus confirming the results of Giesbrecht and Di Lollo (1998) and Brehaut et al. (1999). In summary, given that the second target is not backward-masked, an AB deficit is obtained if processing of the two targets requires a task switch, but not if a switch is not involved.

How can a task switch bring about an AB deficit? An answer to this question hinges on the processing delay inherent in a task switch. When a switch is required, the configuration of the visual system must be changed from one tuned to the characteristics of the first target to one tuned to those of the second. This can be thought of as a time-consuming redeployment of attention that takes up to several hundred milliseconds to accomplish (Meiran, 1996; Monsell, 1996). While the system is being reconfigured, processing of the second target is delayed, and its representation decays correspondingly. This delay combines with that arising from first-target processing in the AB paradigm. During the combined delay, the representation of the second target continues to decay so that it may no longer be legible when attention can finally be deployed. When this happens, an AB deficit ensues. Thus, in the hard condition in Experiment 4 (Figure 8), it was not detection, per se, that caused the interference but rather the process of switching between task sets.

This sequence of events can be illustrated with reference to Figure 9. We hold that a task switch increases the delay of t_c, namely, the time at which attention is deployed to the second target. While delayed, the target's representation continues to decay so that it may no longer be legible at time t_c, thus yielding an AB deficit. Without the additional delay due to task switching, the target's representation may still be legible at time t_c, thus forestalling an AB deficit. We believe this to have been the case in the studies of Brehaut et al. (1999) and Giesbrecht and Di Lollo (1998). It is interesting to note that similar results were obtained by Jolicoeur (1999) with a cross-modal paradigm, which, according to Visser et al. (1999), does not have the same attentional demands as a within-modality task switch. By the same token, an AB deficit will occur in the absence of a task switch, provided that a trailing mask is presented while the target is unattended (shaded area in Figure 9). In this case, the target's representation is replaced by that of the mask through a process of object substitution (Di Lollo et al., 2000; Enns & Di Lollo, 1997). We believe this to have been the case in such studies as Raymond et al. (1992), Chun and Potter (1995), and Giesbrecht and Di Lollo (1998).

Theoretical Implications

Several aspects of the present work bear directly on current theories of the AB. Especially relevant are the results of Experiments 2 and 3, in which the first target was a letter and the second was a group of dots in motion. It can be assumed that the neural representations of these stimuli differed substantially from each other, one being a letter code, the other a motion signal. Indeed, as we noted earlier, form and motion attributes are believed to be preferentially processed along distinct neural pathways. The important issue here is that pronounced AB deficits were obtained with very different first and second targets (Figures 4 and 7B). This creates a problem for the view that the AB arises from interference in visual short-term memory (VSTM; Shapiro et al., 1994). On that view, the probability of obtaining an AB deficit increases with the degree of similarity between items competing for retrieval from VSTM. Namely, the second target should be selected more easily to the extent that it differs from the first target, thereby forestalling an AB deficit. What needs to be explained is why was a substantial AB deficit obtained when the targets were very different (Experiments 2 and 3) and not when they were very similar (Experiments 1 and 4). As presently stated, interference theory does not have a ready explanation for this pattern of results.

We hasten to add that lack of a ready account for this particular result in no way discredits interference theory as a whole. Indeed, other sources of evidence are strongly supportive of interference theory while disconfirming expectations based on bottleneck theories such as proposed by Chun and Potter (1995) and Jolicoeur and Dell'Acqua (1998). A case in point is a study by McLaughlin, Shore, and Klein (2001), which showed that in agreement with expectations from interference theory, the difficulty of the first target has no bearing on the magnitude of the AB. This finding disconfirms expectations based on bottleneck theories, which hold that the duration of the delay in second-target processing, and hence AB magnitude, depends on first-target difficulty. McLaughlin et al. (2001) showed that earlier opposite claims (e.g., Seiffert & Di Lollo, 1997) were based on a confounding introduced by mixing instead of blocking the levels of first-target difficulty across trials.

Considered together, these disparate outcomes strongly suggest that the AB may not be a unitary phenomenon, governed by a single set of rules. Rather, they point to a multidimensional phenomenon that includes aspects that have been singled out separately in models based on interference, bottlenecks, or attentional switching. On this view, similarity-based interference schemes, delay-based bottleneck schemes, and change-based attentional-switching schemes represent orthogonal dimensions of the AB. Each of these approaches clarifies a different dimension of the AB phenomenon. By the same token, all these approaches share fundamental similarities that have been described in detail by Shapiro et al. (1997) and by Isaak et al. (1999). In this respect, we concur with the views expressed recently by Isaak et al. (1999) that the failure to find evidence for one theoretical scheme under conditions appropriate for another does not constitute grounds for rejection. Rather, the present need is for developing an integrative account aimed at encompassing all schemes within a single theoretical framework.

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