Selection Difficulty and Inter-Item Competition are Independent Factors in Rapid Visual Stream Perception

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Abstract

When observers try to identify successive targets in a visual stream at a rate of 100 ms per item, accuracy for the second target is impaired for inter-target lags of 100-500 ms. Yet, when the same stream is presented more rapidly (e.g., 50 ms per item), this pattern reverses and a first target deficit is obtained. Potter, Staub, and O'Connor (2002) account for these finding with a two-stage competition theory (detection followed by identification) in which each stage is limited by its own pool of resources. In five experiments we varied the items that preceded the first target. The results show strong influences of these leading items on the first target deficit, with almost no influence on second target accuracy. This is interpreted as strong support for multiple factors influencing target accuracy in rapid visual streams (Kawahara, Enns, & Di Lollo, 2006).

Abstract = 142 words

Recent studies have demonstrated that the human visual system is capable of processing briefly presented scenes quite efficiently (e.g., Lawrence, 1971; Potter, 1976). However, it is also true that the perception of rapidly presented images is severely impaired when observers must report more than one target. In particular, accuracy for the second target is impaired when it lags the first target by 100-500 milliseconds (ms), a phenomenon called the attentional blink or AB (Raymond, Shapiro, Arnell, 1992).

Among the various models proposed to account for the AB (Chun & Potter, 1995; Jolicoeur, 1999; Raymond et al., 1992; Ward, Duncan, & Shapiro, 1996) there is general consensus on one source of the AB deficit: the impairment of second target accuracy occurs because available attentional resource are being used to process the first target (Shapiro, Arnell, & Raymond, 1997; see Di Lollo, Kawahara, Ghorashi, & Enns, 2005; Kawahara, Kumada, & Di Lollo, 2006; Olivers, 2007; Olivers, Van der Stigchel, & Hulleman, 2007 for exceptions to this consensus). Specifically, when a target is detected, attentional resources are deployed to identify it. If a second target appears shortly after the first target (e.g., Joseph, Chun, & Nakayama, 1997), there are insufficient resources to identify it simultaneously, resulting in the impairment in second target identification. On the other hand, if the second target appears after a long separation from the first target (e.g., Lag 5), there is no second-target deficit because the system has already completed the identification of the first-target.

Chun and Potter's (1995) two-stage model is one of the most widely accepted explanations of the AB. In this model, Stage 1 monitors all incoming visual stimuli in order to detect potential targets. This stage has a vast capacity and acts as conceptual short term memory, in which categorical identities of the stream items are available for a brief period (Potter, 1993, 2006). To be reported correctly, the potential targets have to be selectively identified in the next stage, before the representation in Stage 1 is lost. This involves transferring the detected item to Stage 2, for what is called "consolidation," the forming of a stable representation for conscious awareness and report. However, there is capacity limitation in Stage 2, such that only one item can be consolidated at a time. Thus when Stage 2 is occupied while identifying the first target, identification of the second target must be delayed. During this delay, the representation of the second target is susceptible to spontaneous decay or to masking of trailing items, resulting in the AB deficit.

This framework predicts that report accuracy for the first target will not be affected by the lag. Rather, accuracy for the first target is expected to always be higher than that for the second target regardless of the lag. This is because the first target can be detected in Stage 1 and transferred to Stage 2 without any delay. However, not all results have been consistent with this prediction. Chun and Potter (1995) noted that the first target report was systematically less accurate when the second target appeared at a stimulus onset asynchrony (SOA) of 100 ms than when the second target appeared at longer SOAs. Increasing the rate of presentation such that the SOA was as short as 50 ms also led to higher accuracy rates for the second target than the first (Bachmann, & Hommuk, 2005; Potter, 2006; Potter, Staub, & O'Connor, 2002). Potter et al. (2002) reported further that accuracy for the first target increased progressively as SOA increased and was accompanied by a corresponding decrease in second target accuracy. We will refer to this as a first-target deficit in the perception of high-speed visual streams, or in brief simply as a first-target deficit.

To account for the first-target deficit, Potter et al. (2002) modified their two-stage model to include competition in both stages, and critically, claimed that both the first and the second stages are limited in their attentional capacity (see also Shih, 2000). When a target is detected by the Stage 1 process, its representation remains labile until it is transferred to a more stable Stage 2, where conscious identification is possible. This transfer process requires some attentional resources in itself. If the second target is presented immediately after the first target, attention is allocated to the second target before this transfer is complete, resulting in a competition between the two items in Stage 1. In this model, the more attention is available for a given item, the greater is the probability that the item will enter Stage 2. Under very rapid rates of presentation, the first target loses the competition for attention to the second target and thus is not transferred to Stage 2 for identification.

When the SOA is increased to 100 ms or more, the two targets no longer compete for attention in Stage 1, because the transfer of the first target is complete before the second target arrives in Stage 1. In this case, Stage 2 is now occupied by the first target, which is then identified while the second target is barred from entry and so an ordinary AB occurs (a second target deficit). In a recent update of the two-stage competition theory (Potter, 2006), the competition in Stage 1 is assumed to shift attentional resource in an all-or-nothing way from the first to the second target. The shift happens when the second target is presented while the first target is being detected in Stage 1.

This model shares with other models of the AB the essential concept that limited-capacity resources are responsible for the impairment in the perception of items in rapid sequence (Shapiro et al., 1997). In contrast to this account, other theorists have argued that the source of the AB deficit is not a unitary phenomenon, but a compound failure of target identification due to several factors, including that of (1) shifting the dominant processing mode from one of rejecting distractor items in the leading stream to accepting a target item when it is detected (Kawahara et al., 2006), (2) a temporary loss of control regarding the class of items that are accepted once target identification is begun (Di Lollo et al., 2005), and (3) inter-item competition when multiple targets must be identified (Chun & Potter, 1995; Potter et al., 2002; Potter, 2006). Here, we briefly review the evidence for these three separate factors:

To focus on the role of task set or preparation, Kawahara et al. (2006) varied the similarity between the first target and the items immediately preceding it (i.e., “leading items”), finding that first target accuracy was reduced with increased similarity. At the same time, similarity between leading items and the first target had no influence on accuracy for a second and third target in the stream. This is consistent with the idea that first target accuracy depends on how efficiently observers can shift from the task set of ignoring distractor items based on their membership in a defined category (distractor-rejection mode; Olivers & Watson, 2006) to identifying an item that belongs in the target category (target-acceptance mode). Because this shift in processing mode takes time, the first target is vulnerable to masking by subsequent items before the shift is completed.

A second limit on target identification can arise from an exogenously-triggered a temporary loss of control over the prevailing task set, rendering the observer briefly vulnerable to an exogenously-triggered switch in set. Di Lollo et al. (2005) systematically varied the relationship between a single item that occurred between two targets in a temporal stream of items (i.e., "intervening item"). When the intervening item was from the same category as the target items, report accuracy for both targets remained high and equal to one another. However, when the intervening item was from a different category, accuracy was reduced, but only for the second target, namely the target that appeared after the intervening item. Di Lollo et al. (2005) interpreted this finding in much the same way as the influence of the leading items on first target accuracy. Namely, while the observer is occupied with making the shift from distractor-rejection mode to target-acceptance mode, not only do subsequent targets become vulnerable to masking by trailing items, but the observer temporarily losses executive control over the category of items that are accepted for further processing. If the intervening item is from the same category as the first target, then the target acceptance configuration is expected to remain unaltered, allowing both it and the second target to gain access to target identification processes. In this case, target accuracy seems limited only by the short-term memory span of 3-4 items. If, however, the intervening item belongs to a different category from the first target, then the target acceptance configuration will be altered involuntarily to conform to items from that category, leaving the subsequent (second) target to be processed inefficiently and vulnerable to masking by items that follow it.

A third limiting factor on target accuracy is inter-item competition that can occur when two targets must be identified (Potter et al., 2002). When the representation of one target is being consolidated for identification, it leaves the second target in an unstable state and therefore vulnerable to masking by object substitution (Brehaut, Enns, & Di Lollo, 1997; Dell'Acqua, Pascali, Jolicoeur, & Sessa, 2003; Giesbrecht & Di Lollo, 1997; Enns & Di Lollo, 1997). This form of masking is more likely to occur if the distractor items that follow a target share the same features (Kawahara et al., 2006).

From this perspective, the AB deficit arises from multiple factors working independently of one another. The question we address in the present study is whether the first target deficit in very rapid visual streams is also influenced by more than one factor. According to the competition model (Potter et al., 2002), the critical factor is the time that elapses between the two targets. If this time is very short, Stage 1 detection processes will begin with the first target, but the transfer process to Stage 2 will be applied to the second target. There is no explicit prediction made in this model regarding the influence of items that occur prior to the first target. However, it is in keeping with the idea of limited-capacity resources that an increase in the difficulty of first target detection might delay the onset of subsequent detection and identification processes, causing a reduction in accuracy for both targets in the stream. Another possibility consistent with limited-capacity resources is that a decrease in first target accuracy would result in a proportionate increase in second target accuracy, because of the competition for the same set of resources for target identification. In short, the competition model is compatible with a finding of correlated performance with regard to the two targets, whether that correlation is positive or negative.

In contrast to the prediction of correlated target performance levels, the multiple factors perspective holds open the possibility that leading items could influence first target accuracy independently of their influence on second target accuracy. What is independent is the overall level of accuracy for the first target, which is set by factors (the nature of the leading items) that turn out to have no influence on the overall level of the second target or on the presence of an interaction between the first and second targets. This means that the level of the first target accuracy is set by mechanisms that are unrelated to (independent of) the mechanisms that influence the competition between the accuracies for the two targets. In other words, if second target accuracy turns out to be unaffected by the nature of the leading items, the original competition model (Potter et al., 2002) and revised winner-take-all model (Potter, 2006) would need to be modified to account for that result.

In the experiments that follow, we adopt the strategy of holding constant the temporal relationship between two targets in a visual stream, while we vary the presence, absence, and nature, of the leading items that precede these targets. We look specifically to see whether leading items influence accuracy for both targets, as predicted by the competition model, or whether their influence is specific to the first target, as suggested by the multiple factors framework. To anticipate the results, Experiment 1 finds that the hallmark of the first target deficit (i.e., a crossover interaction between first and second target accuracy as a function of lag) occurs when leading items are presented in advance of the first target, but not when they are omitted. The following experiments are then devoted to exploring alternative explanations for this finding and to uncovering the critical factors responsible for it.

Experiment 1: No first target deficit without leading distractors

This experiment examined how the first target deficit is affected by the leading items in the stream. If there is competition for a single set of attentional resources (Potter et al., 2002), then any influence of the leading items should be felt on both the first and second targets, especially at the shortest lags where the competition will be most intense. However, if leading distractors influence first target accuracy selectively, then it suggests that different factors are involved in determining report accuracy for the two targets in very rapid visual streams (Kawahara et al., 2006).

A secondary aim was to test for a first target deficit using digit distractors and upper-case letter targets. In Potter et al.'s (2002) study of this effect, the distractors were multiple-item keyboard characters (%%%% or &&&&) and the targets were English nouns. If the first target deficit is a general finding for very rapid rates of presentation, then we should also obtain it here with single-characters when the SOA is short.

Method

Observers. Fourteen experimentally naive undergraduate students at the University of British Columbia participated. All reported normal or corrected-to-normal vision.

Stimuli and Apparatus. Stimuli were displayed as black characters on the grey background of a computer monitor operating Microsoft Windows 2000 with the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997) environment. The stimuli consisted of digits and uppercase letters subtending approximately 1 deg of the visual angle in height at a viewing distance of 57 cm. The targets were two letters chosen randomly without replacement from the English alphabet excepting I, O, Q, and Z. The distractors were digits selected randomly with replacement from the digits 0-9 displayed in a sequence with the constraint that the selected digit was not one of the two immediately preceding items.

Each item in the stream was presented for 53 ms and subsequently replaced by the next item without any inter-stimulus interval. In the leading distractors condition, the two targets were inserted in a sequence of distractor items so that there were three or four distractors before the first target. The lag between the targets was either 53, 107 or 213 ms (Lag 1, 2, and 4). At Lag 1 this meant that the second target appeared immediately after the first target; by Lag 4 there were three intervening distractors between the targets. The second target was always followed by one distractor. In the no leading distractors condition, the leading distractor frames were replaced with blank frames. Other stimuli were identical to those in the leading distractors condition.

Design and Procedure. There were two within-subject factors: the presence or absence of leading distractors and the temporal lag between the two targets. The leading distractor conditions were presented in separate blocks of trials and the lag conditions were randomly intermixed within a block.

Before starting the experimental session, the observers were read instructions by the experimenter. The same instruction was displayed in the computer screen. At the beginning of each trial, a fixation cross appeared in the centre of the screen. The observer initiated each trial by pressing the spacebar. After 500 ms, the visual stream was presented in the centre of the screen. The task of the observer was to report the identity of two letters, regardless of the presentation order, by pressing the corresponding keys of the keyboard after the visual stream disappeared. No prompt message was presented on each trial. When the observers enter two responses, a fixation cross reappeared and a next trial started. The order of the two leading distractor conditions was counterbalanced across observers. There were twelve practice trials prior to each block of 180 testing trials.

Results

Mean accuracy for the first and second target is plotted as a function of lag in Figure 1. These results show that the first-target deficit occurred only when there were leading distractors. Otherwise, the pattern of results replicated Potter et al. (2002) in the leading distractor condition (first-target deficit with short SOA) and yielded a typical AB (second-target deficit at later SOAs) in the no leading distractor condition. These observations were supported by analyses of variance (ANOVA) in each condition.

The ANOVA for the leading distractor condition indicated a significant main effect of Lag, $F(2, 26) = 8.71$, MSE = 28.50, $\eta_p^2 = .40$, $p < .005$. The interaction between Target and Lag was also significant, $F(2, 26) = 23.86$, MSE = 74.15, $\eta_p^2 = .65$, $p < .001$. The main effect of Target was not significant, $F(1, 13) = 3.64$, $p = .08$. Regarding the interaction, multiple comparisons by Ryan's method (Ryan, 1960) indicated that performance for the first target identification was lowest at Lag 1, ts(52) > 2.72, ps < .01. There was no significant difference between the scores at Lag 2 and 3. Similar comparisons for the second target performance showed that the correct rates differ significantly between all combinations of Lag 1, 2 and 4, ts(52) > 2.20, ps < .05.

The same ANOVA in the no leading distractor condition indicated a significant main effect of Lag and Target, $F(2, 26) = 46.82$, MSE = 15.28, $\eta_p^2 = .78$, $p < .001$, $F(1, 13) = 78.99$, $p < .001$, respectively. The interaction between Target and Lag was also significant, $F(2, 26) = 13.24$, MSE = 74.61, $\eta_p^2 = .50$, $p < .001$. Importantly, a simple main effect of Lag was not significant for the first target performance, but the effect was significant for the second target performance. Multiple comparisons indicated that the second target performance at Lag 1 was significantly higher than the other two Lags, ts(52) > 6.39, ps < .001 and no significant difference was found between Lag 2 and 4 scores.

To examine the effect of the leading distractor condition, we conducted an ANOVA on the first target scores. The analysis indicated significant main effects of Distractor condition and Lag, $F(1, 13) = 34.33$, MSE = 147.25, $\eta_p^2 = .73$, $p < .001$, $F(2, 26) = 8.32$, MSE = 35.96, $\eta_p^2 = .39$, $p < .005$, respectively. The interaction between Distractor condition and Lag was also significant, $F(2, 26) = 3.51$, MSE = 53.67, $\eta_p^2 = .21$, $p < .05$. The source of this interaction was that the effect of Lag was significant only when there were leading distractors, $F(2, 52) = 9.93$, MSE = 44.81, $\eta_p^2 = .28$, $p < .001$. The same analysis conducted on the second target scores indicated a significant main effect of Lag, $F(2, 26) = 66.59$ MSE = 44.92, $\eta_p^2 = .84$, $p < .001$. The effect of Distractor condition was not significant. The interaction between Lag and Distractor condition was significant, $F(2, 26) = 4.17$, MSE = 57.99, $\eta_p^2 = .24$, $p < .05$. The source of this interaction was that simple main effects of Lag were significant in both Distractor conditions, but there was no significant difference between Lag 2 and 4 scores when the leading distractors were omitted. In short, these analyses indicated a critical difference that there was no effect of Lag on first target accuracy when the leading distractors were omitted, although the effect of Lag on second target accuracy was obtained regardless of the presence or absence of the leading distractors. The negative effect at Lag 2 on second target accuracy was greater when no leading distractors were presented.

Discussion

There were two important results in Experiment 1. First, the results replicated the crossover interaction of target type and lag reported by Potter et al. (2002), even though the visual stream this time consisted of only single-character items. A first target deficit at short lags transformed into a second target deficit at longer lags. Second, and more importantly, this crossover interaction did not occur when the leading items were omitted. Instead, the influence of omitting the leading items was confined to report accuracy for the first target; second target accuracy was unaffected by the presence of leading items. This was true even at Lag 1 where the competition for common resources should have been strongest. If there was a unitary pool of resources for processing these targets, then increasing the accuracy for the first target, as occurs when there are no leading items, should have resulted in reduced second target accuracy. As the data show, if anything, second target accuracy was higher with no leading items (Figure 1b) with leading items (Figure 1c).

We also noted that the influence of the leading distractors could not be attributed to any differences in the temporal uncertainty of the first target in the two conditions. This is because the time from the initiation of the visual stream to the first target was equated by including an equal number of blank display frames in the no leading distractor condition.

The finding that the first target deficit did not occur without leading items suggests that they are not merely acting as filler items. But what aspects of these leading items are having this influence on first target accuracy? Our working hypothesis, following from Kawahara et al. (2006), is that the switch from a distractor-rejection mode to a target-acceptance mode is at the heart of this effect. The main idea is that in order to optimize performance, observers adaptively configure the attentional gating system (e.g., Reeves & Sperling, 1986) when trying to detect targets in a rapid visual stream. If observers know that targets only occur following several distractors, they must prepare to reject a few items at the beginning of the visual stream. When a first target is detected, they need to abandon this mode and begin identifying the target. As many studies of task set, expectancy, and task switching have shown, it takes time to alter one's processing mode (Allport, Styles, & Hsieh, 1994; Monsell, 2003). Our working hypothesis is that the time needed to make this switch is reflected in the first target deficit.

At the same time, we want to be clear that the present results do not exclude the possibility of attentional competition between the two targets. Indeed, if task set were the only factor that determined accuracy, then first target accuracy would remain unaffected by the lag when there are the leading distractors. These and all subsequent data clearly show that first target accuracy tends to increase and second target accuracy tends to decline as a function of lag, and this is completely consistent with inter-item competition (Potter et al., 2002). Yet when there were no leading distractors (no need to reject distractor items before switching to target items), observers were capable of identifying the first target with greater accuracy, without incurring any additional cost on second target accuracy. From this perspective, Experiment 1 reveals an important factor in rapid stream perception in addition to inter-target competition.

Before pursuing this idea in greater detail, we will first introduce and dismiss several alternative explanations for the effects of the leading distractors on first target accuracy. One of these is that the elimination of preceding distractors may result in ceiling effects, leaving little room for the first target deficits to emerge. This possibility is tested in Experiment 1A. Another possibility is that when there are no leading distractors the first target may capture attention, simply because it consists of an abrupt onset and these are known to capture focal attention (Yantis & Hillstrom, 1994). This is tested in Experiment 2. A third possibility is that the first target deficit is the consequence of forward pattern masking by the leading items (e.g., Kolers & Rosner, 1960). This is tested in Experiment 3. Finally, it is conceivable that the first target has a higher salience than any of the other items when there are no leading distractors, and this is tested in Experiment 4. We caution at the outset that even if one or more of these factors are shown to contribute to first target accuracy, they will be unable to account for the complete set of results in Experiment 1. This is because first target accuracy benefited at all lags when the leading distractors were omitted and each of these possibilities predicts influences on first target accuracy only at Lag 1. Yet, if some of these factors play a role in first target accuracy, we wish to study the way they do so.

Experiment 1A: Ceiling effects cannot explain the results

Experiment 1A examined whether the release from the first target deficit in Experiment 1 was due to ceiling effects. Although the average correct report of the first target is well below (80.6%) the nominal ceiling, accuracy may have reached its peak because of data limitations (Norman & Bobrow, 1975). To examine this possibility, a single target was inserted in the RSVP stream as a control condition. If the accuracy was restricted by a ceiling on performance, the correct rate for reporting one target would be the same as those for reporting first of two targets.

Method

The procedures were the same as in Experiment 1, except for the addition of a control condition with a single target. In this condition there was no leading distractor and the location of the second target was replaced with a distractor. Thirteen observers participated from AIST participated for pay.

Results and Discussion

Mean accuracy for the first and second target is plotted against the lag in Figure 2 (panel c). The results of the first and the second target accuracy were very similar to those of the No leading distractor condition in Experiment 1. The first target deficit was not obtained at any lags, but a second target deficit grew with longer SOAs. Importantly, the accuracy for the single target condition was higher than the first target in the dual target condition. These observations were supported by the following analyses. A two-way ANOVA with two within-subject factors (Target: first or second; Lag: 1, 2, or 4) was conducted. There were significant main effects of Target, $\underline{F}$ (1, 11) = 60.09, MSE = 290.05, η_p^2= .97, $\underline{p} < .001$, and Lag, $\underline{F}$ (2, 22) = 6.46, MSE = 52.64, η_p^2= .37, $\underline{p} < .01$. The interaction between these factors was significant, $\underline{F}$ (2, 22) = 8.60, MSE = 79.67, η_p^2= .44, $\underline{p} < .01$. Tests of simple main effects indicated the effect of Lag for the second target accuracy, $\underline{F}$ (2, 44) = 14.96, MSE = 66.16, η_p^2= .40, $\underline{p} < .001$, but not for the first target accuracy. Multiple comparisons by Ryan’s method indicated that there was no significant difference in single target accuracy across all lag conditions. Similar comparisons for the second target performance indicated that Lag 1 performance was lowest than the other two lag conditions, $\underline{t}$s(44) > 3.47, $\underline{p}$s < .01.

To test whether the scores in the single target condition differs from those in the dual target condition, a two-way ANOVA was conducted with two within-subject factors (Target: single target or dual target; Lag: 1, 2, or 4). There was a significant main effect of Target, $\underline{F}$ (1, 11) = 6.26, MSE = 58.18, $\eta_p^2 = .36$, $\underline{p} < .05$. Other effects were not significant.

Experiment 1A demonstrates that the elimination of a first-target deficit by removal of the leading distractors cannot be explained by ceiling effects. If it were, then there should have been no difference between the scores in the single target condition and that of the first target in the dual target conditions.

Experiment 2: A first target deficit is not the failure of attentional capture

Experiment 2 tested whether leading distractors caused a first target deficit because they did not permit the capture of attention normally associated with the abrupt onset of an item. Two conditions were compared: one with leading distractors, as in Experiment 1, and one with a single leading random dot pattern. A different random dot pattern was generated on every trial so that participants were unable to anticipate any specific patterns in the leading item, as they could for the leading digits in the other condition. Yet, this single item should capture attention just as effectively, because it occurs with an abrupt onset, thereby preventing the first target from being the beneficiary of the attentional capture that might occur when it is the first item to appear. If the first target cannot benefit from attentional capture, and attentional capture contributes to the absence of a first target deficit in the no leading distractors condition, then the first target deficit should occur in this condition as well.

Alternatively, if a single leading random dot pattern eliminates the first target deficit, it would be consistent with the hypothesis that the first target deficit occurs as a consequence of participants switching from distractor-rejection mode to a target-acceptance mode. The reason we would not expect such a switch for the single leading random dot pattern is because the dot pattern is presented too briefly to induce a rejection mode of processing (Kawahara et al., 2006).

Method

Observers were 12 experimentally naive undergraduate students at the University of British Columbia. All reported normal or corrected-to-normal vision. The method was identical to Experiment 1 with the following exceptions. In the single random pattern condition, one frame of random noise dots was presented for 53 ms immediately before the first target. The dot frame composed of the same mean number of dots (142 pixels scattered within an area of 32 x 32 pixels) used to create each digit in the leading distractor condition. The order of these two conditions was counterbalanced across observers.

Results

Mean accuracy for the first and second target identification is plotted against the lag in Figure 2. The pattern of the results was very similar to Experiment 1 in that the first target deficit was obtained only in the leading distractors condition. Second target deficit was obtained in both conditions at later SOAs. These observations were supported by the following analyses. A two-way ANOVA with two within-subject factors (Target: first or second; Lag: 1, 2, or 4) was conducted for the scores of the single random pattern condition. There were significant main effects of Target, $\underline{F}$ (1, 11)

= 22.07, MSE = 400.83, η_p^2= .67, p < .001, and Lag, F (2, 22) = 15.63, MSE = 40.65, η_p^2= .59, p < .001. The interaction between these factors was significant, F (2, 2) = 41.41, MSE = 29.29, η_p^2= .79, p < .001. Tests of simple main effects indicated the effect of Lag for the second target accuracy, F (2, 44) = 50.18, MSE = 34.97, p < .001, but not for the first target accuracy. Multiple comparisons by Ryan's method indicated that there was no significant difference in the first target accuracy across all lag conditions. Similar comparisons for the second target performance indicated that performance was lowest at Lag 4 and was highest at Lag 1. Lag 2 performance was intermediate and significantly different from the other two lag conditions, ts(44) > 4.78, ps < .001.

For the leading distractors condition, a similar ANOVA indicated a significant main effect of Target and Lag, F(1, 11) = 7.91, MSE = 94.88, η_p^2= .42, p < .05; F(2, 22) = 7.51, MSE = 49.30, η_p^2= .41, p < .001, respectively. The interaction between Target and Lag was also significant, F(2, 22) = 28.71, MSE = 84.65, η_p^2= .72, p < .001. Multiple comparisons by Ryan's method indicated that the first target accuracy at Lag 1 was lowest ts(44) > 3.03, ps < .001. There was no difference between Lags 2 and 4. For the second target identification, accuracy at Lag 1 was highest and that at Lag 4 was lowest; the differences between Lags 1 and 2, and Lags 2 and 4 were also significant, ts(44) > 3.89, ps < .001.

An ANOVA conducted to examine the effect of the type of leading distractors on first target accuracy indicated significant main effects of Distractor condition and Lag, F(1, 11) = 9.21, MSE = 871.68, η_p^2= .46, p < .05, F(2, 22) = 15.44, MSE = 32.68, η_p^2= .58, p < .001, respectively. The interaction between Lag and Distractor condition was also significant, F(2, 26) = 4.42, MSE = 24.19, η_p^2= .29, p < .05. The same analysis conducted on the second target scores indicated a significant main effect of Lag, $\underline{F}(2, 22) = 67.78$ MSE = 59.30, $\eta_p^2 = .86$, $\underline{p} < .001$, but no significant effect of Distractor condition and the interaction.

Discussion

The pattern of results was similar to Experiment 1. When there were leading distractors in the visual stream, a crossover interaction was obtained, with first target accuracy being lower than second target accuracy at the shortest lag and this pattern reversing as lag increased. Yet, when only a single random pattern preceded the first target, removing the opportunity for the first target to benefit from attentional capture by a sudden onset, there was still no evidence of a first-target deficit. Instead, we observed the same pattern of results as in the no leading distractors condition of Experiment 1.

This result rules out attentional capture as a critical factor leading to the absence of a first target deficit in rapid visual streams. On the other hand, it is consistent with the necessity of having a leading stream of items that must be actively ignored in order to observe the first target deficit (Potter et al., 2002; Potter, 2006). This result therefore implies that a single frame of a random-dot pattern is too brief to induce a distractor rejection mode.

Experiment 3: A first target deficit is not caused by forward pattern masking

Experiments 3 tested the possibility that forward pattern masking contributes to the first target deficit. To be specific, when a pair of items is presented very rapidly with an SOA of 0-40 ms, reports of contour visibility and shape identification in the second item can be impaired (Kolers & Rosner, 1960). Because the SOA used in the present study was 53 ms, which is just outside this range, it is possible that influence of the leading stream of distractors includes traces of a forward pattern masking effect. To examine this possibility, we compared a standard leading target condition with one in which the distractor item immediately before the first target was removed, leaving a blank frame instead. Otherwise the temporal sequence was identical in the two conditions. If the absence of a first target deficit with no leading items is due to the absence of forward pattern masking by those items, then we should obtain similar results in both conditions of this experiment.

Method

Twelve undergraduate students from AIST participated for pay. All reported normal or corrected-to-normal visual acuity and were naive with respect to the purpose of the experiment. Methods were identical to Experiment 1, except that the distractor immediately preceding the first target was replaced with a blank frame of 53 ms in duration (blank frame condition). The leading distractor condition was also included for comparison.

Results

Mean accuracy for the first and second target identification was plotted against lag for the leading distractors and blank frame conditions in Figures 3a and 3b, respectively. A two-way ANOVA with two within-subject factors (Target: first or second; Lag: 1, 2, or 4) was conducted for the scores of the blank frame condition. There were significant main effects of Target, $\underline{F}\ (1, 11) = 8.64$, MSE = 104.58, $\eta_p^2 = .44$, $\underline{p} < .05$, and Lag, $\underline{F}\ (2, 22) = 10.72$, MSE = 28.01, $\eta_p^2 = .49$, $\underline{p} < .001$. The interaction between these factors was significant, $\underline{F}$ (2, 22) = 32.53, MSE = 88.03, η_p^2= .75, $\underline{p}$ < .001.

For the leading distractors condition, a similar ANOVA indicated the significant interaction between Target and Lag, $\underline{F}$ (2, 22) = 28.70, MSE = 67.60, η_p^2= .73, $\underline{p}$ < .001. Multiple comparisons by Ryan's method indicated that the first target performance at Lag 1 was lowest $\underline{t}$s(44) > 3.03, $\underline{p}$s < .001. The main effects of Target and Lag were not significant.

To examine the effect of the blank frame, we compared the scores by a three-way ANOVA with three within-subject factors (Condition: leading distractors or blank frame; Target: first or second; Lag: 1, 2, or 4). There were significant main effects of Experiment, $\underline{F}$ (1, 11) = 6.78, MSE = 60.92, η_p^2= .38, $\underline{p}$ < .05, Target, $\underline{F}$ (1, 11) = 5.67, MSE = 115.01, η_p^2= .34, $\underline{p}$ < .05, and Lag, F (2, 22) = 12.44, MSE = 25.53, η_p^2= .53, $\underline{p}$ < .001. The interactions of Condition and Target and Target and Lag were significant, $\underline{F}$ (1, 11) = 8.24, MSE = 34.99, η_p^2= .43, $\underline{p}$ < .05 and $\underline{F}$ (2, 22) = 41.12, MSE = 114.12, η_p^2= .79, $\underline{p}$ < .001, respectively. Tests of simple main effects on the interaction of Condition and Target indicated that the accuracy for the first target in the blank condition was significantly higher than in the other conditions, $\underline{F}$s (1, 22) > 12.05, $\underline{p}$s < .01. The interaction of Condition and Lag was not significant, $\underline{F}$ (2, 22) = 1.39, $\underline{p}$ > .27. Importantly, the three-way interaction between Condition, Target, and Lag was also not significant, $\underline{F}$ (2, 22) = 2.51, $\underline{p}$ = .10.

Discussion

The same general pattern was observed in both conditions of this experiment, supported by the finding that condition (leading distractors vs. blank frame) did not interact with Lag. The only significant interaction was one of Condition and Target, reflecting the fact that omitting the item immediately preceding the first target improved first target accuracy overall. Omitting that item did not interact with the lag factor, meaning that the crossover pattern was maintained. This suggests that some amount of forward masking is involved in setting the overall level of first target accuracy in the leading item conditions of this and earlier experiments.

We conclude that the absence of a first target deficit when there are no leading items cannot be attributed solely to a reduction in forward pattern masking. Instead, these results suggest that a larger portion of the stream of leading items is critical to the first target deficit; their effects cannot be isolated to that of the immediately preceding distractor.

Our reason for removing only the one item preceding the target was based on the well-documented premise that forward masking is only effective within an SOA range of less than 100 ms (Breitmeyer, Ehrenstein, Pritchard, Hiscock & Crisan, 1999; Kolers & Rosner, 1960; Seiffert & Di Lollo, 1997; Spencer & Schuntich, 1970; Uttal, 1969). Is it worth considering the possibility of forward masking from the other items in the leading stream, those that occurred 106 or 159 ms prior to the first target? We believe this to be highly unlikely simply because previous studies that have focused directly on the relations among forward masking, SOA, and focused attention have consistently shown that although backward masking can occur with SOAs greater than 200 (and even longer when attention is widely distributed in space) the effects of forward masking are completely dissipated by an SOA of 100 ms (see review in Enns, 2004).

Experiment 4: The first target deficit increases with selection difficulty

Previous experiments varied the presence versus absence of a leading stream, or a single leading item, consistent with the hypothesis that first target accuracy is influenced by the preparatory set that observers must adopt in order to identify the target. In Experiment 4 we tested the possibility that the first target deficit was also influenced by the difficulty of selecting the first target from a stream of items. Research has shown that highly salient items attract attention, making their representations less vulnerable to perceptual decay or masking by subsequent items (Arnell, Shapiro, & Sorensen, 1999; Shapiro, Caldwell, & Sorensen, 1997; Theeuwes, 2004). If this plays a role in the first target deficit, then one consequence of removing the leading items may have been to decrease the difficulty of detecting the first target prior to beginning to identify it.

Experiment 4 compared two conditions: a leading distractor condition as in Experiment 1 (low-salience) and one in which the leading distractors were colored distinctively from the other items (high-salience). If selection difficulty plays a role separately from the inter-item competition that occurs among targets, then first target accuracy should be greater in the high-salience condition and second target accuracy should remain unaffected. Alternatively, if selection difficulty is not a separate factor from the inter-item competition, then a first target deficit should still be observed in the high salience condition and second target accuracy should be reduced proportionately.

Method

Thirteen undergraduate students from AIST participated for pay. All reported normal vision (in acuity and color vision) and were naive with respect to the purpose of the experiment. The method was identical to Experiment 1 with the following exceptions. In the high-salience condition, the 3-5 leading distractors were red (CIE x = .611, y = .353, 24.5 cd/m^2) on a grey background (CIE x = .278, y = .312, 55.5 cd/m^2), whereas in the low-salience condition they were black (1.47 cd/m^2), the same color as all other items in the visual stream.

Results

The correct rates for the first and second target identification were plotted against the lag for the low- and high-salience conditions in Figures 4a and 4b, respectively. A two-way ANOVA with two within-subject factors (Target: first or second; Lag: 1, 2, or 4) was conducted for the data of the high-salience condition. There was significant main effects of Target, F (1, 12) = 22.26, MSE = 160.30, η_p^2= .65, p < .001, and Lag, F (2, 24) = 34.07, MSE = 40.45, η_p^2= .74, p < .001. The interaction between these factors was significant, F (2, 24) = 33.84, MSE = 86.23, η_p^2= .74, p < .001. Regarding the interaction, multiple comparisons by Ryan's method on first target data indicated that Lag 1 performance was lowest, t(48) = 2.52, p < .05, and there were no significant differences between Lag 2 and 4 accuracy. Similar comparisons for the second target accuracy indicated that accuracy was lowest at Lag 4 and was highest at Lag 1. Lag 2 accuracy was intermediate and significantly different from the other two lag conditions, ts(48) > 3.51, ps < .001.

For the low-salience condition, the pattern of the results was the same as those in the high-salience condition: the same ANOVA indicated a significant main effect of Lag, F(2, 24) = 9.15, MSE = 72.19, η_p^2= .43, p < .001. The interaction between Target and Lag was also significant, $\underline{F}(2, 24) = 34.30$, MSE = 80.04, $\eta_p^2 = .74$, $\underline{p} < .001$. Multiple comparisons by Ryan's method indicated that the first target accuracy at Lag 1 was lowest $\underline{t}s(48) = 3.16$, $\underline{p} < .001$. There was no difference between Lags 2 and 4. For the second target identification, accuracy at Lag 4 was lowest, that at Lag 2 was intermediate, and that at Lag 1 was highest. The these scores were significantly different, $\underline{t}s(48) > 3.04$, $\underline{p}s < .005$.

To confirm whether the colour manipulation implemented in the present experiment affected the detectability of the first target, we ran an ANOVA comprised three within-subject factors: Leading items (red or black), Target (first or second), and Lag (1, 2 or 4). The analysis indicated main effects of Leading items, $\underline{F}\ (1, 12) = 20.00$, MSE = 46.89, $\eta_p^2 = .63$, $\underline{p} < .001$, Target, $\underline{F}\ (1, 12) = 12.29$, MSE = 202.10, $\eta_p^2 = .51$, $\underline{p} < .001$, and Lag, $\underline{F}\ (2, 24) = 30.53$, MSE = 63.80, $\eta_p^2 = .56$, $\underline{p} < .001$. Importantly, the interaction between Leading items and Target was significant, $\underline{F}\ (1, 12) = 18.84$, MSE = 63.66, $\eta_p^2 = .61$, $\underline{p} < .001$. Tests of simple main effects of this interaction indicated that when the leading distractors were red, the first target accuracy, averaged over lags, was higher than when they were black, $\underline{F}\ (1, 24) = 38.52$, $\underline{p} < .001$. This difference was not found for the second target, $\underline{F} < 1$. The interaction between Target and Lag was also significant, $\underline{F}\ (2, 24) = 70.41$, MSE = 80.02, $\eta_p^2 = .85$, $\underline{p} < .001$.

Discussion

The results were clear. Increasing the salience of the first target with respect to the leading items increased the accuracy of the first target but left accuracy for the second target virtually unaffected. Most importantly, the increase in first target accuracy with increased salience was not accompanied by a decrease in second target accuracy, as predicted by the competition model (Potter et al., 2002).

We note that this conclusion cannot be attributed to a weak manipulation of saliency, since the data showed that the manipulation of saliency through a color change was effective. First-target accuracy was higher overall in the high-salience than in the low-salience condition. The first-target was also identified more accurately when the leading distractors were red than when they were black, with no similar effects on second target accuracy. These target-specific effects of increasing selection difficulty are further evidence that there are factors besides inter-item competition influencing the first-target deficit.

Experiment 5: Selection difficulty influences first-target accuracy even when preparatory set effects are controlled

It is our interpretation that the four experiments reported so far cannot be explained solely in terms of the two-stage competition theory (Potter et al., 2002). That theory proposes limited-capacity resources in all stages of processing, implying that any factor that influences first target accuracy must therefore have a proportionate effect on second target accuracy. Yet, the results of all our manipulations on the leading distractors so far suggest that they have an affect on first target accuracy without influencing second target accuracy.

So far, we have been interpreting these results as consistent with the hypothesis that the presence of leading items in the stream encourages the participant to first adopt a distractor-rejection mode before switching to a target-acceptance mode of processing (Kawahara et al., 2006). Such switching of modes requires time (Allport et al., 1994;

Monsell, 2003) and because the switch occurs when the first target is encountered, its accuracy pays the heaviest price for the switch. When there are no leading distractors, participants can adopt a target-acceptance mode from the beginning, with first target accuracy being the direct beneficiary.

Here we tested this idea by modifying the single leading pattern condition of Experiment 2 (where a leading dot pattern was presented for 53 ms), such that the single leading random pattern was presented for a longer and more variable duration (from 3-5 frames for a total of 159-265 ms). This was similar to the duration and variability of the leading digits in the standard leading distractor condition. We predicted that increasing the duration of the leading item in this way would require participants to adopt a distractor-rejection mode prior to their detection of a member of the target category. Note too, that a first target deficit under these conditions could not be attributed to the similarity between the leading items and the items that intervene between the two targets.

A second aim of Experiment 5 was to test whether the leading distractor effect is best characterized as a general preparatory set effect or as a selection difficulty effect. This was accomplished by mixing conditions within a single block of trials. If the data from no distractor and leading distractor conditions differ when conditions are mixed, then it cannot be attributed to a general preparatory set that observers adopt prior to the onset of each trial. Mixing these trials ensures that any differences are attributed to the online difficulties encountered in trying to detect the first target item.

Method

Nineteen undergraduate students from AIST participated for pay. All reported normal or corrected-to-normal visual acuity and were naive with respect to the purpose of the experiment. The method was identical to the single leading random pattern condition in Experiment 2, with the following exception. Instead of presenting distractor digits before the first target, a single frame consisting of a random dot pattern (scattered within an area of 32 x 32 pixels) appeared for the length of 3-5 frames (159 - 265 ms) as the leading item. The no distractor- and leading distractor conditions were mixed in a single experimental block.

Results

Mean accuracy for the first and second target identification is plotted against the lag for the leading distractor and no distractor conditions in Figure 5 (panels a and b). An ANOVA with three within-subject factors (Leading distractor: present or absent; Target: first or second; Lag: 1, 2, or 4) indicated that there were significant main effects of Leading distractor, F (1, 18) = 83.98, MSE = 92.12, η_p^2= .82, $p < .001$; and Lag, F (2, 36) = 31.57, MSE = 54.29, η_p^2= .64, $p < .001$. The two-way interactions between Leading distractor and Target, F (1, 18) = 81.78, MSE = 297.57, η_p^2= .82, $p < .001$ and Target and Lag, F (2, 36) = 51.96, MSE = 93.35, η_p^2= .74, $p < .001$, were significant. The analyses of simple main effects within the two-way interaction indicated that in the no-leading-distractor condition, the mean first target accuracy was higher than that in the leading distractor condition, and that the mean second target accuracy in the no-leading-distractor condition was lower than that in the leading distractor condition.

Importantly, the three-way interaction was also significant, F (2, 36) = 3.65, MSE = 33.77, η_p^2= .17, $p < .05$. The simple main effects within this interaction indicated that the effect of lag was significant for both targets regardless of the presence or absence of the leading distractor, Fs (2, 144) > 10.04, MSE = 51.74, ps < .001, except for the first target in the no leading distractor condition, $F < 1$. That is, the first target accuracy increased as the lag increased when there was a leading distractor, but the accuracy remained high and was not affected by the lag when there was no leading distractor. The second target accuracy decreased as the lag increased irrespective of the presence or absence of the leading distractor. No other main effects and interactions were significant.

Discussion

Our hypothesis in this experiment was that given sufficient time to view a leading distractor item, participants would be required to engage in a distractor-rejection mode of processing before switching to a target-acceptance mode. Our data support this explanation. Presented with a single leading item of longer and more variable duration, one that did not even match the category of the other distractor items in the visual stream, participants showed a strong first target deficit. And, as in the previous experiments with leading distractor conditions, at longer lags this pattern transformed into the second target deficit that is the hallmark of the AB. This same leading item did not produce a first target deficit when its duration was short and constant (Experiment 2). More importantly, when there was no leading distractor, first target accuracy was very high and the second target accuracy remained largely the same, just as in previous experiments.

The results of this experiment also help to characterize the leading distractor effect as a selection difficulty effect instead of only a general preparatory set effect. We arrive at this conclusion because the differences associated with the leading distractors were obtained even though participants were unable to anticipate which condition would be tested on each trial.

It is notable that in the results of Experiment 5, in which the leading distractor conditions were mixed within a block, there were even larger differences between first and second target accuracy than we had observed in the blocked condition of Experiment 1. This suggests that the general preparatory set effects in previous experiments were, if anything, attenuating the difference between distractor and no-distractor conditions. However, this comparison may be not fair because the type of distractors also differed across experiments (i.e., distractors were digits in Experiment 1 and random dot patterns in Experiment 5). Therefore, we also tested the effect of varying the duration of the leading distractor under blocked conditions.

Experiment 5A

Method

Twelve undergraduate students from National Institute of Advanced Industrial Science and Technology (AIST; Tsukuba, Japan) participated for pay. All reported normal or corrected-to-normal visual acuity and were naive with respect to the purpose of the experiment. The method was identical to that used Experiment 5, with the exception that the distractor and no-distractor conditions were run with a blocked design.

Results and Discussion

Mean accuracy for the first and second target identification is plotted against lag in Figures 5 (panel c). An ANOVA with two within-subject factors (Target: first or second; Lag: 1, 2, or 4) indicated that there were no significant main effects of Target and Lag. The interaction between these factors was significant, F (2, 22) = 18.21, MSE = 54.49, η_p^2= .62, p < .001. Multiple comparisons by Ryan's method on first target data indicated that Lag 1 performance was lower than Lag 4 performance, t(44) = 2.74, p < .01. There were no significant differences between other pairs. Similar comparisons for the second target performance indicated that performance was lowest at Lag 4 and was highest at Lag 1. Lag 2 performance was intermediate and significantly different from the other two lag conditions, ts(44) > 2.55, ps < .05.

The pattern of the results was consistent with that of Experiment 5. Presented with a longer lasting and variable duration single leading item, one that did not even match the category of the other distractor items in the visual stream, participants showed a strong first target deficit. And as in the previous experiments with leading distractor conditions, at longer lags this pattern transformed into the second target deficit that is the hallmark of the AB. Because this same leading item did not produce a first target deficit its duration was short and constant (Experiment 2), we conclude that inter-target competition occurs only when there is sufficient time to first establish a task set for distractor-rejection.

We also tested whether the leading distractor effect differed between mixed vs. blocked conditions. An ANOVA with one between-subject factor (Blocking: mixed or blocked) and two within-subject factors (Target: first or second; Lag: 1, 2, or 4) indicated that there were significant main effects of Target, F (1, 29) = 9.55, MSE = 416.67, η_p^2= .25, p < .005; and Lag, F (2, 58) = 3.61, MSE = 54.29, η_p^2= .44, p < .001. Two-way interactions between these factors were also significant: Blocking × Target, F (1, 29) = 34.38, MSE = 416.67, η_p^2= .54, p < .001; Blocking × Lag, F (2, 58) = 3.61, MSE = 39.28, η_p^2= .11, p < .05; Target × Lag, F (2, 58) = 56.67, MSE = 44.11, η_p^2= .66, p < .001. No other effects were significant.

These analyses indicate that blocking trials influenced the level of accuracy for the first target but not for the second target. Detailed inspection of the Blocking × Target interaction indicated that the level of accuracy for the first target was higher when mixed than when blocked. No such effect was observed for the second target. Because the three-way interaction was not significant, there was no evidence that the blocking procedure influenced the first target trade-off. Taken together, these results highlight that the task-set established by blocked presentation attenuates, rather than causes, the first target impairment when the system is forced to select a target. We note that this finding should be interpreted with some caution, simply because the comparison here still involves different subjects, which may have introduced other confounding factors.

General Discussion

The present study asked whether letter identification in a very rapid serial visual presentation could be explained solely in terms of early competition between the two targets, as claimed by the two-stage competition model (Potter et al., 2002; Potter, 2006), or whether additional factors are involved. We reasoned that if first- and second-target identification were both influenced by limited-capacity resources, then the presence or absence of a leading stream should affect the identification of both targets. In particular, if leading items reduced the accuracy of the first target, then second target accuracy should also be affected. Either second target accuracy should change in a proportionate but opposite direction (because of inter-item competition), or both targets should be disadvantaged because the added difficulty of detecting the first target in the stream should reduce the overall resources available for rapid stream perception.

The results of five experiments in this study, however, were consistent with neither of these predictions. We found instead that some factors benefited first target accuracy without decreasing second target accuracy at short SOAs (lags 1 and 2). Specifically, omitting all leading distractors in Experiments 1 and 1A gave a benefit for first target accuracy, but did not affect second target accuracy. Presenting only a single, brief random pattern before the first target in Experiment 2 gave a marked improvement to first target accuracy without affecting second target accuracy. The same pattern held when a blank frame was presented before the first target (Experiment 3) or when the first target was given greater salience (Experiment 4). On the other hand, when a variable-duration random dot pattern was presented just before the first target in Experiment 5, there was a sharp decrease in first target accuracy relative to a condition in which there were no leading distractors. Once again, second target accuracy was largely unaffected by these factors, just as in previous experiments.

These findings are summarized in Figure 6. In all five of our experiments, features of the leading stream had a significant influence on first target accuracy. Relative to the standard condition, in which a leading stream of items appeared prior to the first target (Potter et al., 2002), removing the stream altogether resulted in a sharp increase in first target accuracy (Experiments 1 and 5), including only a single leading item increased accuracy (Experiment 2), deleting the last leading item in the stream increased accuracy (Experiment 3), increasing the salience of the first target with respect to the leading items increased accuracy (Experiment 4), and increasing the duration and uncertainty of a single leading item in a mixed trial design reduced accuracy (Experiment 5). Remarkably, these factors had virtually no influence on second target accuracy. Thus, in this sense, neither the original competition model (Potter et al., 2002) nor the revised winner-take-all model (Potter, 2006) is able to explain all of these results.

At the same time, each experiment also provided plenty of evidence consistent with inter-item competition in identifying the two targets, as is also summarized in Figure 6. This could be seen in the effect of increasing lag on second target accuracy, which served to reduce accuracy in these very rapid streams of items, and also in the trading relation that was always present between first and second target accuracy. The trading relationship was such that an increase in first target accuracy was invariably related to a decrease in second target accuracy, and vice versa. The most important finding of this study was that this trading relationship was affected very little by the overall level of accuracy of the first target, which was set by the factors we have already enumerated.

The theoretical idea of inter-target competition predicts an interaction in the accuracy scores of the two targets, that is a trade-off in which increased accuracy for one target results in reduced accuracy for the other. This interaction is seen in the data of all the experiments in this study. The novel contribution of the present series of experiments is therefore the demonstration that the absolute level of first target accuracy is set by factors that are independent of the trading relationship between accuracy levels for the two targets (i.e., the inter-item competition). The absolute level of first target accuracy is set by such factors as the presence, absence, salience, and duration of the leading distractors, which, in turn, seem to have no influence on the presence of an interaction between the first and second target accuracy. This means that the level of the first target accuracy is determined by the factors that are unrelated to the factors affecting the competition between two targets.

To test this interpretation directly, we entered the first target accuracy data from as many of our experiments as possible into a single ANOVA, in which experiment was a between-subject factor and lag was as a within-subject factor. This included the no leading distractor and the leading distractor conditions in Experiments 1, the single leading item condition in Experiment 2, the high salience condition in Experiment 4 and the blocked leading distractor condition in Experiment 5A. This analysis directly tested the hypothesis that the factors influencing first target accuracy (the expected main effect of Experiment) had no influence on inter-target competition (evident as an interaction between Experiment × Lag). The results confirmed these expectations. The analysis revealed significant main effects of Experiment, $\underline{F}$ (4, 58) = 6.34, MSE = 625.00, η_p^2= .30, $\underline{p}$ <.001 and Lag, $\underline{F}$ (2, 116) = 23.04, MSE = 34.70, η_p^2= .28, $\underline{p}$ <.001, but no interaction between these factors, Lag $\underline{F}$ (8, 116) = 1.44, n.s.. This pattern of additivity is consistent with our claim that first target accuracy can be influenced independently of the interaction between first and second target accuracy, that is, independent from the inter-item competition that is evident when first and second target accuracies are examined together as a function of lag.

Theoretical Implications

Taken together, these findings suggest that to fully account for rapid stream perception, one can add to the idea of inter-item competition (Potter et al., 2002) that the baseline level of first target accuracy can be set by factors that are quite independent of the competition that occurs when two target must be identified in rapid succession. One way to think of this is to return to the earlier Chun and Potter (1995) model in which the target detection process is not governed by the same pool of resources as the target identification process. If so, then the process of detecting targets is not subject to the same capacity limitations as the process of identifying targets. This would allow the factors that influence the difficulty of detection to be quite separate from the factors that influence the difficulty of identification. Such a division of labor is in many ways reminiscent of the well-worn distinction between so-called preattentive and attentive processes. Preattentive processes were thought to be responsible for detecting information relevant to an ongoing task, whereas attentive processes were thought responsible for making the information accessible to awareness and for response. However, it is no longer as clear as it once seemed that preattentive processes are without capacity limitations (Di Lollo et al., 2001; Lamme, 2003). Therefore, it is perhaps time to begin characterizing the limitations of detection processes separately from the limitations of identification, so that their true relations can be understood.

When it comes to the processes of target detection in rapid serial streams of items, an important limitation on task performance seems to arise from the requirement to shift the dominant processing mode from one of distractor-rejection (i.e., the appropriate response to the leading stream items) to one of target-acceptance (i.e., once the target has been detected) (Kawahara et al., 2006; Olivers & Watson, 2006). As can be seen in Figure 6, such shifting of the processing mode can be expected to affect the first-target accuracy independently from the second-target accuracy.

But it may also be possible to account for these results by modifying the winner-take-all model (Potter et al., 2002). One way to do so would be to propose that the shift in processing from the first to the second target occurs strictly as a function of the time that has elapsed (i.e., the inter-target SOA) and that it is unaffected by the “momentary strength" of the first target. (Footnote 1. We thank Reviewer M. Potter for this suggestion.) On this account, the factors that benefit the first target (i.e., forward masking, type of distractors, distractor salience) would influence the ability to identify the first target without affecting second target identification, presumably because target strength is not a factor in determining the competition among candidate items for attention. This is clearly a possibility that goes against conventional understandings of attentional competition (Desimone & Duncan, 1995), but it does warrant further tests.

Regardless of how future research is able to reconcile theses issues, the present study demonstrates an important boundary condition on the phenomenon of a first target deficit in the perception of very rapid visual streams. These results also add support for the view that the perception of multiple targets in a rapid stream is not a unitary phenomenon (Kawahara et al., 2006).

References

Allport, A., Styles, E., & Hsieh, S. (1994). Shifting intentional set: Exploring the dynamic control of tasks. In C. Umiltà & M. Moscovitch (Eds.), *Attention and performance XV: Conscious and nonconscious information processing* (pp. 421-452). Hillsdale, NJ: Erlbaum.

Arnell, K., Shapiro, K. L., & Sorensen, R. E. (1999). Reduced repetition blindness for one's own name. *Visual Cognition*, *6*, 609-635.

Bachmann, T., & Hommuk, K. (2005). How backward masking becomes attentional blink. *Psychological Science*, *16*, 740-742.

Brainard, D. H. (1997). The Psychophysics Toolbox. *Spatial Vision*, 10, 433-436.

Braver, T. S., Reynolds, J. R., & Donaldson, D. I. (2003). Neural mechanisms of transient and sustained cognitive control during task switching. *Neuron*, *39*, 713-726.

Brehaut, J. C., Enns, J. T., & Di Lollo, V. (1999). Visual masking plays two roles in the attentional blink. *Perception & Psychophysics*, *61*, 1436-1448.

Breitmeyer, B. G., Ehrenstein, A., Pritchard, K., Hiscock, M., & Crisan, J. (1999). The role of location specificity and masking mechanisms in the attentional blink. *Perception & Psychophysics*, *61*, 798-809.

Chun, M. M., & Potter, M. C. (1995). A two-stage model for multiple target detection in rapid serial visual presentation. *Journal of Experimental Psychology: Human Perception and Performance*, *21*, 109-127.

Dell'Acqua, R., Pascali, A., Jolicoeur, P., & Sessa, P. (2003). Four-dot masking produces the attentional blink. *Vision Research*, *43*, 1907-1913.

Di Lollo, V., Kawahara , J-I., Ghorashi, S.M., & Enns, J. T. (2005). The attentional blink: Resource depletion or temporary loss of control? *Psychological Research, 69,* 191-200.

Di Lollo, V., Kawahara, J., Zuvic, S. M, & Visser, T. A. W. (2001). The preattentive emperor has no clothes: a dynamic redressing. *Journal of Experimental Psychology: General*, *130*, 479-492.

Desimone, R, & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience, 18*, 193–222.

Enns, J. T. (2004). Object substitution and its relation to other forms of visual masking. *Vision Research, 44*, 1321-1331.

Enns, J. T., & Di Lollo, V. (1997). Object substitution: a new form of masking in unattended visual locations. *Psychological Science*, *8*, 135-139.

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 1030-1044.

Giesbrecht, B. L., & Di Lollo, V. (1998). Beyond the attentional blink: Visual masking by object substitution. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 1-14.

Hellige, J. B., Walsh, D. A., Lawrence, V. W., & Prasse, M. (1979). Figural relationship effects and mechanisms of visual masking. *Journal of Experimental Psychology: Human Perception and Performance*, *5*, 88-100.

Jolicoeur, P. (1999). Concurrent response-selection demands modulate the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 1097-1113.

Joseph, J. S., Chun, M. M., & Nakayama, K. (1997). Attentional requirements in a 'preattentive' feature search task. *Nature*, 387, 805-807.

Kawahara, J., Enns, J.T., & Di Lollo, V. (2003). Task switching mediates the attentional blink even without backward masking. *Perception & Psychophysics, 65,* 339-351.

Kawahara, J., Enns, J. T. & Di Lollo, V. (2006). The attentional blink is not a unitary phenomenon. *Psychological Research*, *70*, 405-413.

Kawahara, J., Zuvic, S. M., Enns, J. T., & Di Lollo, V. (2003). Task switching mediates the attentional blink even without backward masking. *Perception & Psychophysics*, *65*, 339-351.

Kolers P. A. & Rosner, B. S. (1960). On visual masking (metacontrast): Dichoptic observation. *The American Journal of Psychology*, *73*, 2-21.

Lamme, V. A. F. (2003). Why visual attention and awareness are different. Trends in Cognitive Sciences, 7, 12-17.

Lawrence, D. H. (1971). Two studies of visual search for word targets with controlled rates of presentation. Perception & Psychophysics, 10, 85-89.

Monsell, S. (2003). Task switching. *Trends in Cognitive Sciences*, *7*, 134-140.

Most, S. B., Scholl, B. J., Clifford, E. R., & Simons, D. J. (2005). What you see in what you set: Sustained inattentional blindness and the capture of awareness. *Psychological Review*, *112*, 217-242.

Norman, D. A., & Bobrow, D. G. (1975). On data-limited and resource-limited processes. Cognitive Psychology, 7, 44-64.

Olivers, C. N. L. (2007). The time course of attention: it is better than we thought. Current Directions in Psychological Science, 16, 11-15.

Olivers, C. N. L., Van der Stigchel, S., & Hulleman, J. (2007). Spreading the sparing: Against a limited-capacity account of the attentional blink. Psychological Research, 71, 126-139.

Olivers, C. N. L., & Watson, D. G. (2006). Input control processes in rapid serial visual presentations: Target selection and distractor inhibition. Journal of Experimental Psychology: Human Perception and Performance, 32, 1083-1092.

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision*, *10*, 437-442.

Potter, M. C. (1976). Short-term conceptual memory for pictures. Journal of Experimental Psychology: Human Learning and Memory, 2, 509-522.

Potter, M. C. (1993). Very short-term conceptual memory. *Memory & Cognition*, *21*, 156-161.

Potter, M. C. (2006). Competition for attention in space and time: The first 200 ms. In H. Ogmen, & B. G. Breitmeyer (Eds.), *The first half second: The microgenesis and temporal dynamics of unconscious and conscious visual processes* (pp. 207-224.) MIT Press.

Potter, M. C., Staub, A., & O'Connor, D. H. (2002). The time course of competition for attention: Attention is initially labile. *Journal of Experimental Psychology: Human Perception and Performance*, *28*, 1149-1162.

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of*

Experimental Psychology: Human Perception and Performance, *18*, 849-860.

Reddy, L., Reddy, L., & Koch, C. (2006). Face identification in the near-absence of focal attention. *Vision Research*, *46*, 2336-2343.

Rousselet, G. A., Fabre-Thorpe, M., & Thorpe, S. J. (2002). Parallel processing in high-level categorization of natural images. *Nature Neuroscience*, *5*, 629-639.

Ryan, T. (1960). Significance tests for multiple comparison of proportions, variances and other statistics. *Psychological Bulletin*, *57*, 318-328.

Seiffert, A. E., Di Lollo, V. (1997). Low-level masking in the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance*, *23*, 1061-1073.

Shapiro, K. L., Arnell, K. M., & Raymond, J. E. (1997). The attentional blink. *Trends in Cognitive Sciences*, *1*, 291-296.

Shapiro, K. L., Caldwell, J., & Sorensen, R. E. (1997). Personal names and the attentional blink: A visual "cocktail party" effect. *Journal of Experimental Psychology: Human Perception and Performance*, *23*, 504-514.

Spencer, T. J., & Shuntich R. (1970). Evidence for an interruption theory of backward masking. *Journal of Experimental Psychology*, *85*, 198-203.

Theeuwes, J. (2004). Top-down search strategies cannot override attentional capture. *Psychonomic Bulletin & Review*, *11*, 65-70.

Uttal, W. R. (1969). The character in the hole experiment: Interaction of forward and backward masking of alphabetic character recognition by dynamic visual noise (DVN). *Perception & Psychophysics*, 6, 177-181.

Ward, R., Duncan, J., & Shapiro, K. (1996). The slow time-course of visual attention.

Cognitive Psychology, *30*, 79-109.

Yantis, S. & Hillstrom, A. P. (1994). Stimulus-driven attentional capture: evidence from equiluminant visual objects. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 95-107.

Figure Captions

Figure 1. Mean percentage of correct responses in Experiment 1 for the leading distractor condition (a), the no leading distractor condition (b) and their replication with the control condition of reporting only the first target (c). Error bars indicate standard errors.

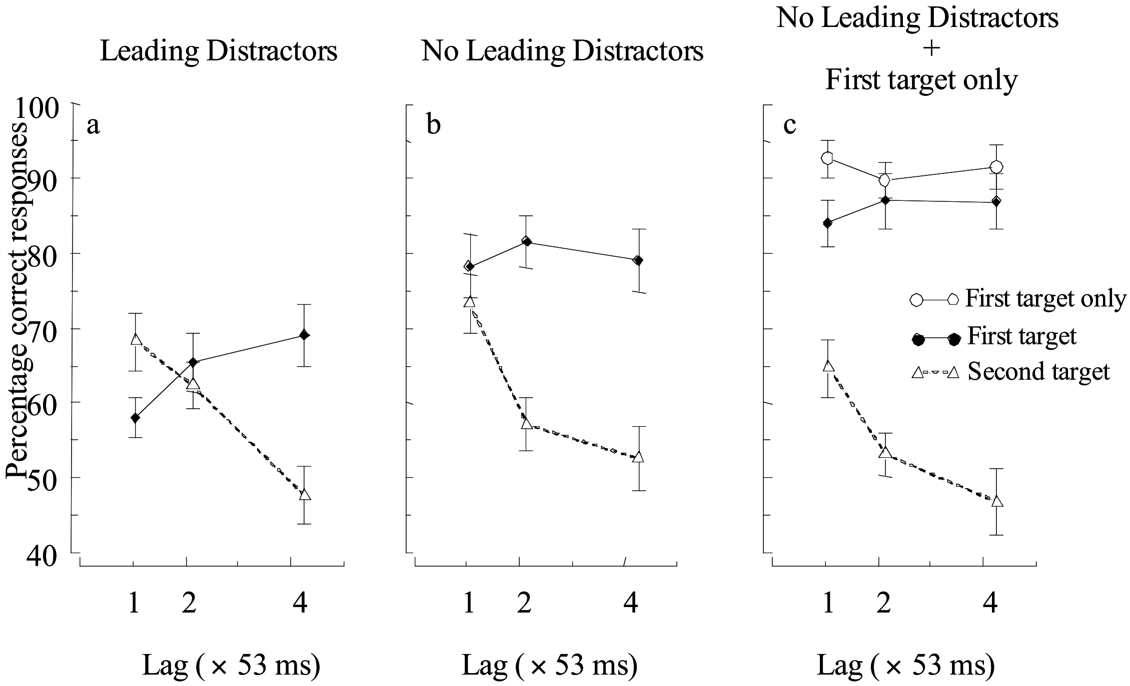
Figure 2. Mean percentage of correct responses in Experiment 2 for the leading distractor condition (a) and the single random pattern condition (b). Error bars indicate standard errors.

Figure 3. Mean percentage of correct responses in Experiment 3 for the leading distractor condition (a) and the blank frame condition (b). Error bars indicate standard errors.

Figure 4. Mean percentage of correct responses in Experiment 4 for the low salience condition (a) and the high salience condition (b). Error bars indicate standard errors.

Figure 5. Mean percentage of correct responses in Experiment 5 for the leading distractor condition (a), the no leading distractor condition (b), and that in Experiment 5A for the blocked leading distractor condition (c). The duration of the random-dot frame was extended (159 - 265 ms). Error bars indicate standard errors.

Figure 6. Summary of the main findings from Experiments 1 to 5, expressed as the factors influencing first and second target accuracy in rapid stream perception.



Leading Distractors
No Leading Distractors
No Leading Distractors + First target only
Percentage correct responses
100
90
80
70
60
50
40
a
b
c
First target only
First target
Second target
1
2
4
Lag (× 53 ms)

Figure 1

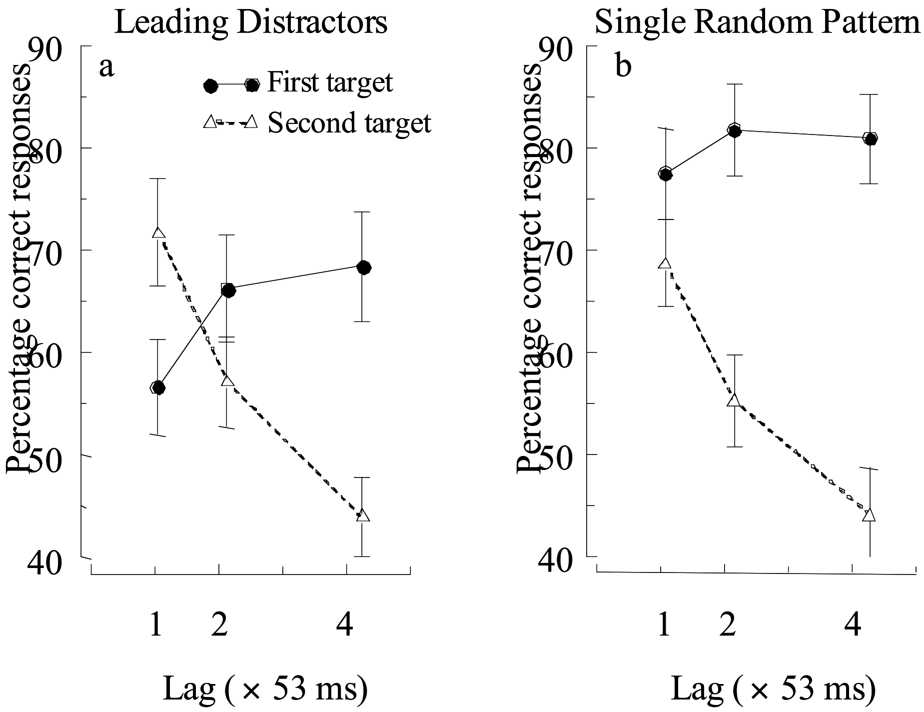
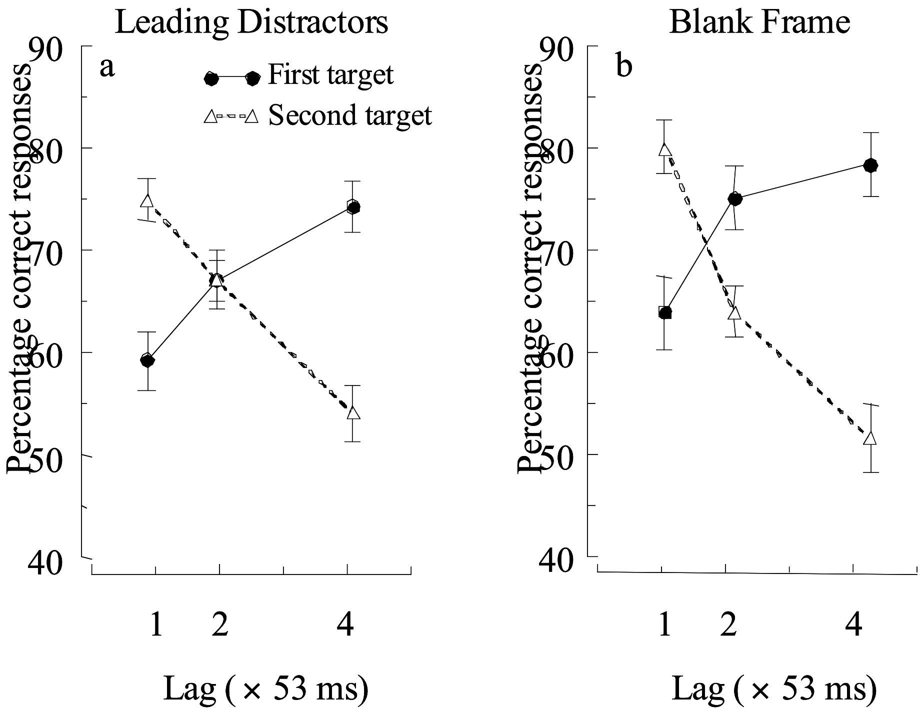

Leading Distractors
Single Random Pattern
a
b
First target
Second target
Percentage correct responses
90
80
70
60
50
40
1
2
4
Lag (× 53 ms)

Figure 2



Leading Distractors
Blank Frame
a
b
First target
Second target
Percentage correct responses
90
80
70
60
50
40
1
2
4
Lag (× 53 ms)

Figure 3

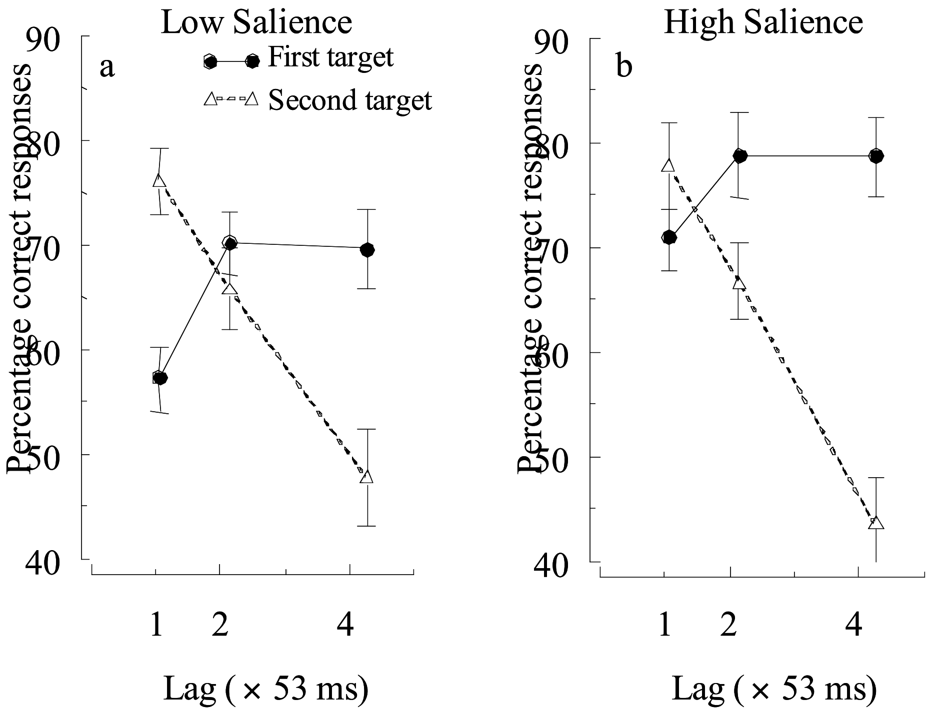

Low Salience
a
First target
Second target
Percentage correct responses
90
80
70
60
50
40
1
2
4
Lag (× 53 ms)
High Salience
b
Percentage correct responses
90
80
70
60
50
40
1
2
4
Lag (× 53 ms)

Figure 4

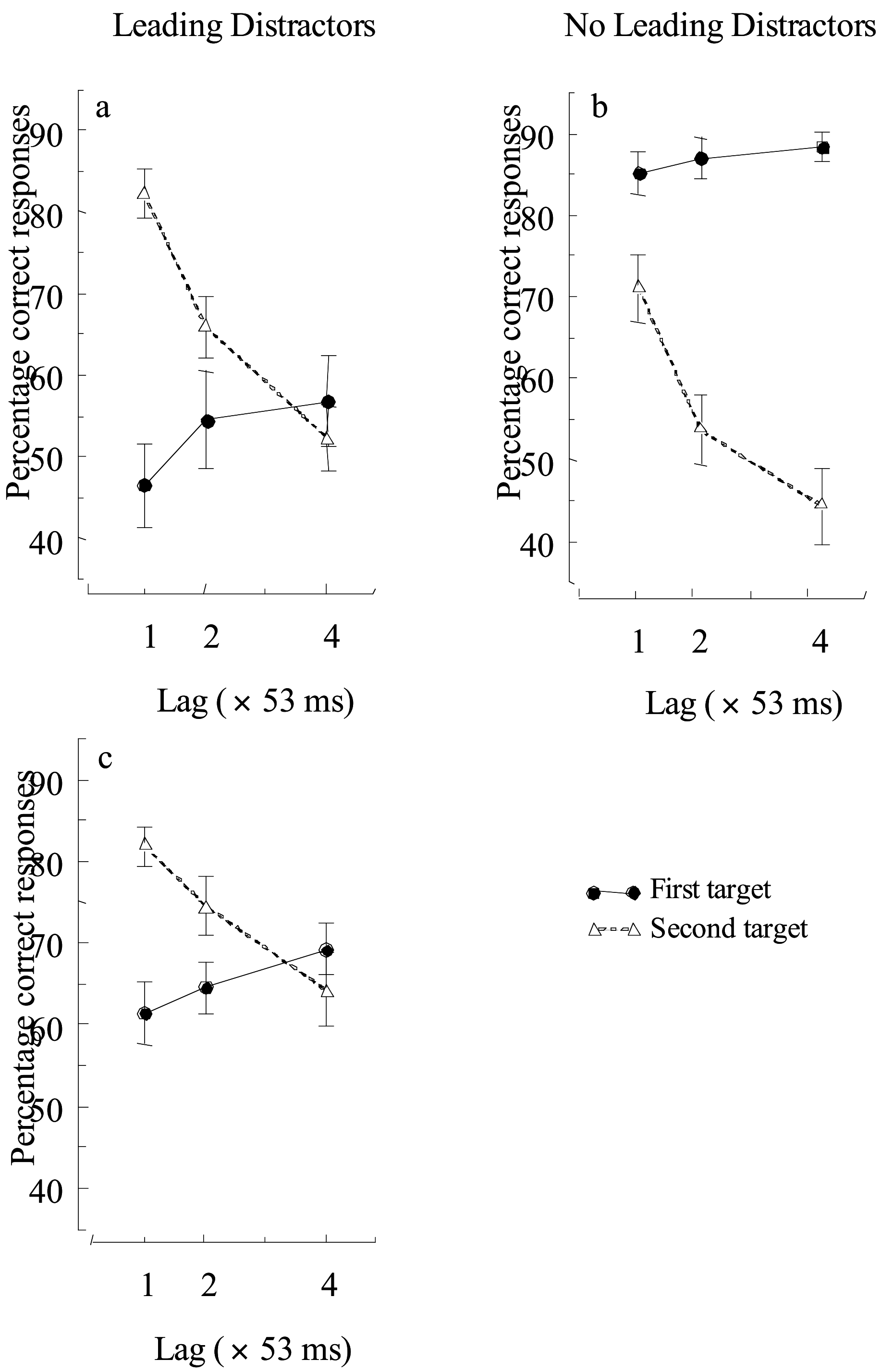

Leading Distractors
No Leading Distractors
a
b
c
Percentage correct responses
90
80
70
60
50
40
1
2
4
Lag (× 53 ms)
First target
Second target

Figure 5

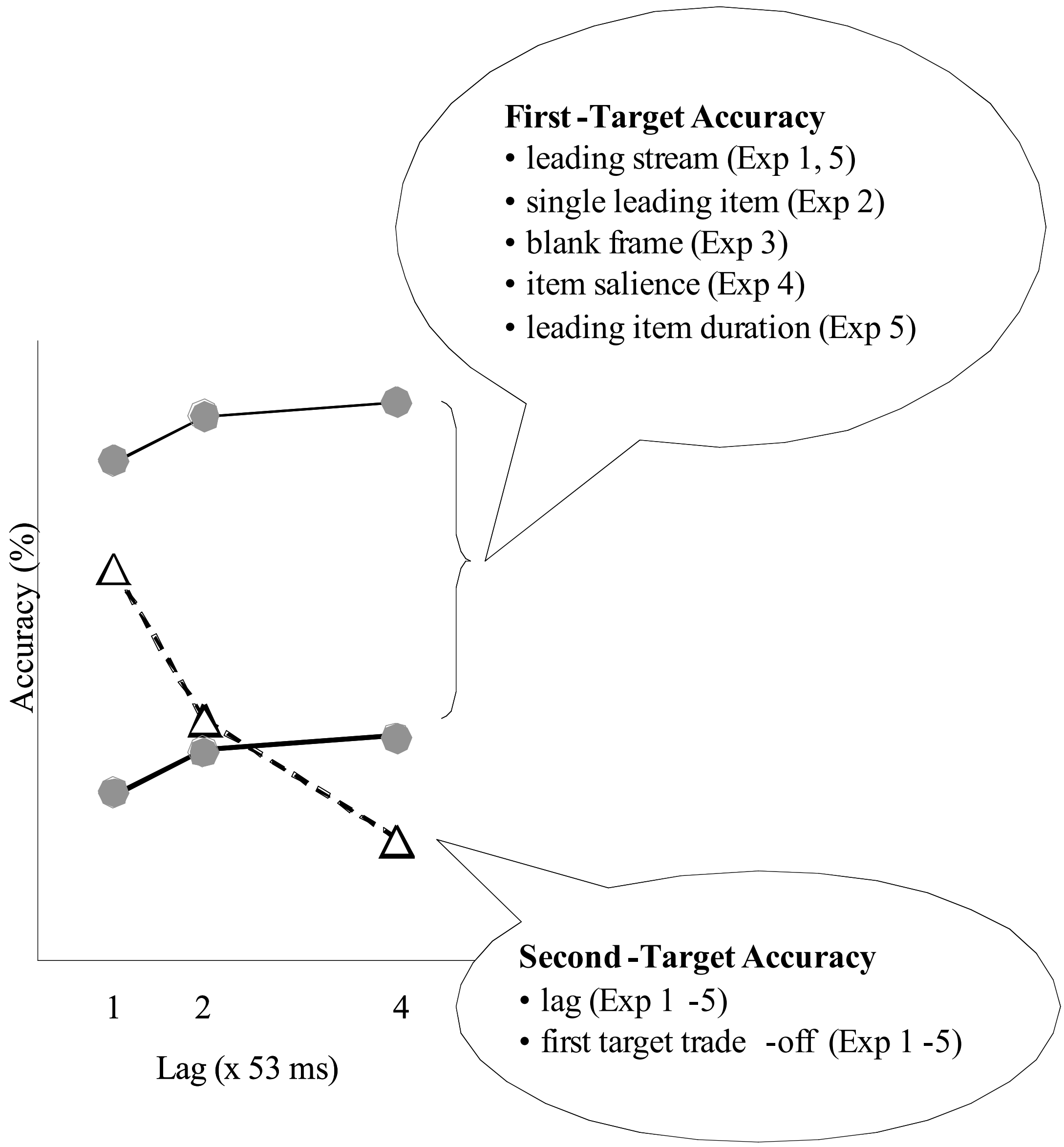

First -Target Accuracy
• leading stream (Exp 1, 5)
• single leading item (Exp 2)
• blank frame (Exp 3)
• item salience (Exp 4)
• leading item duration (Exp 5)
Accuracy (%)
1
2
4
Lag (x 53 ms)
Second -Target Accuracy
• lag (Exp 1 -5)
• first target trade -off (Exp 1 -5)

Figure 6