DYNAMIC SPATIAL TUNING OF ATTENTIONAL FOCUS IN THE ATTENTIONAL BLINK

by

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Abstract

When two sequential targets (T1, T2) are inserted in an RSVP stream of distractors, perception of T2 is impaired at inter-target lags shorter than 700 ms. Paradoxically, this deficit disappears when T2 is presented directly after T1 (Lag-1 sparing). Visser et al. (1999) found that Lag-1 sparing occurs only when T1 and T2 are presented in the same stream. In contrast, Shih (2000) obtained Lag-1 sparing with targets in separate streams. Four experiments addressed this inconsistency and revealed Lag-1 sparing with targets in different streams, but only when observers had no foreknowledge of T1's location. We hypothesized that when T1 location is known, the attentional spotlight is focused narrowly on that stream; if T2 then appears in the other stream it is missed, and Lag-1 sparing does not occur. When T1 location is not known, the spotlight is focused broadly, encompassing both streams, and Lag-1 sparing ensues.

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To my mom

For your love

And friendship

For being there

Always

I am so blessed

You inspired and guided me ...

V.D.L, J.T.E., J-I.K.

Put my feet on the path ...

V.M., R.D.W.

And kept me smiling every step of the way...

S.G., C.O., J.C.

Thank-you ... Köszönöm ... Mille Grazie ... Arigato Gozaimasu... Sepás

Introduction

Brief stimuli presented in rapid sequence may exceed the processing capability of the visual system. This gives rise to a deficit known as the attentional blink (AB), which is typically obtained when observers are required to identify two targets inserted in a stream of distractors presented in rapid serial visual presentation (RSVP). Identification accuracy for the second target is most impaired when the temporal lag between the two targets is short, and it improves as the inter-target lag is increased (Raymond, Shapiro, & Arnell, 1992).

Theoretical accounts of the AB have relied on some form of limited attentional resource that is allocated to the leading target to the detriment of the trailing target. For example, in the interference model (Shapiro, Raymond, and Arnell, 1994) resources are said to be allocated in large part to the first target, and in diminishing amounts to the ensuing items in the RSVP stream. Similar assumptions underlie the bottleneck models of Chun and Potter (1995) and Jolicoeur and Dell'Acqua (1998) in which the AB deficit is said to occur when the second target arrives while the resources at a high-level stage are preempted by the first target. On all these accounts, the AB deficit is expected to be most pronounced when the second target is presented directly after the first, in the ordinal position known as Lag 1.

Contrary to this expectation, a meta-analysis by Visser, Bischof, and Di Lollo (1999) revealed that in about half of the studies the AB deficit was much reduced or failed to occur when the second target was presented directly after the first. This yielded the characteristic U-shaped function of performance over lags often found in AB studies. Potter, Chun, Banks, and Muckenhoupt (1998) referred to this highly accurate performance at Lag-1 as Lag-1 sparing.

Lag-1 sparing has been ascribed to the sluggish closing of an attentional gate (Chun & Potter, 1995; Shapiro & Raymond, 1994). The gate is said to open rapidly upon presentation of the first target, but to close sluggishly, thus allowing the next item in the stream (i.e., the Lag-1 item) to gain access to processing resources along with the first target. If the trailing item happens to be the second target, both targets are processed together, and Lag-1 sparing ensues. An important detail that emerged from Visser et al.'s (1999) analysis was that Lag-1 sparing occurs only when the two targets are presented at the same spatial location; it never occurs when they are presented at different locations. Such location specificity is exceptionally robust: of the 41 relevant studies in which the two targets were presented at different locations, none revealed Lag-1 sparing. This finding has been confirmed by Visser, Zuvic, Bischof, and Di Lollo (1999) in a study designed explicitly to examine the effect of the relative location of the two targets on Lag-1 sparing.

An exception to this rule has been reported by Shih (2000), who found Lag-1 sparing in an experiment in which the two targets were presented in different spatial locations. In Shih's experiments, observers viewed two RSVP streams, one on either side of fixation. The first target could appear in either the left- or the right-hand stream, and the second target could occur either in the same stream as the first target or in the opposite stream. Shih's results are clearly at odds with Visser et al.'s finding that Lag-1 sparing never occurs when the two targets are presented in different spatial locations. As discussed below, this discrepancy has significant implications both for theories of the AB and for models of attentional switching. The present work was aimed at resolving the apparent inconsistency between Shih's results and the typical finding in the Lag-1 sparing literature.

In our search for the critical factors underlying this discrepancy, we began by comparing Shih's (2000) study with similar studies in the AB literature. Two key factors emerged from this review: number of RSVP streams in the display, and advance knowledge of the location of the first target. In the studies reviewed by Visser et al. (1999), the displays invariably contained only a single RSVP stream. In contrast, two concurrent streams were used in Shih's study. This gives rise to a confounding between number of streams and the observer's advance knowledge of the location of the first target. In the studies reviewed by Visser et al., the fact that the display contained only a single stream also meant that the observers always had advance knowledge of the location of the first target. In contrast, in Shih's study, observers never knew in which of the two streams the first target would appear. In the present study, we decoupled the roles of the observer's advance knowledge of the location of the first target and the presence or absence of a second RSVP stream as determinants of Lag-1 sparing.

Experiment 1

Experiment 1 was designed to determine whether Lag-1 sparing depends on the observer's advance knowledge of the first target's location, with the number of RSVP streams held constant. To this end, observers viewed two RSVP streams of digit distractors displayed one on each side of fixation. Two letter targets were inserted either in the same or in different streams. One group of observers did not know in advance where the first target would appear. This group provides a direct replication of Shih's (2000) study. A second group knew in advance that the first target would always appear in a given stream.

Method

Participants

Thirty-four undergraduate students at the University of British Columbia participated for course credit. All reported normal or corrected-to-normal vision and were naïve as to the purpose of the experiment. They were assigned randomly to one of two groups: the Known group and the Not-Known group. One observer was removed from the Not-Known group for not following instructions.

Apparatus and Stimuli

A white fixation cross, 0.25° by 0.25°, was displayed in the center of the screen. The remaining stimuli consisted of white digits and letters, all of which subtended approximately 0.9° vertically as viewed from a distance of approximately 57 cm. The luminance of all stimuli was 90 cd/m^2, and the luminance of the black background was 2.3 cd/m^2.

Procedure

At the beginning of each trial, the fixation cross was presented in the center of the screen. The observers initiated each trial by pressing the spacebar. The display sequence began with the presentation of two RSVP streams, one 1.75° to the left of fixation, the other 1.75° to the right. Each stream contained an equal number of digit distractors, and either 0, 1, or 2 letter targets. The number of leading distractors was the same in each stream on any given trial, but varied randomly between 8 and 14 across trials. The distractors were selected randomly from the digits 0-9, with the restriction that the selected digit was not the same as either of the previous two digits. Two target letters, selected randomly from the English alphabet, with the exclusion of I, O, Q, and Z, were presented. The two targets could appear in either RSVP stream, depending on the condition. In the Same condition, the two targets were presented in the same stream; in the Different condition, they appeared in opposite streams. The first and the second target could appear in the left or in the right stream with equal probability. The observers were instructed to ignore the digit distractors and to identify both targets by pressing the appropriate keys on the keyboard. The second target was presented at one of six inter-target lags: Lags 1, 3, 6, 9, 12, and 15, corresponding to stimulus-onset-asynchronies (SOAs) of 71, 214, 429, 643, 857, and 1071 ms. Inter-target lags occurred in random order and with equal frequency across trials. Distractors continued to be presented in the RSVP stream during the inter-target lag. The range of inter-target intervals used in the present experiment extends that used by Shih (2000). This was done because, in Shih's study, identification accuracy for the second target had not recovered completely, even at the longest inter-target lag of 644 ms.

The two RSVP streams were synchronized, with each item being displayed for approximately 14 ms, separated from the next item by approximately 57 ms. This resulted in a presentation rate of approximately 14 items/second, which was the same as the rate in Shih's (2000) study. Each stream terminated with a single digit distractor, which acted as a mask for the second target.

The observers in one group, the Not-Known group, were instructed that on any given trial, the first target would appear unpredictably in either the left or the right RSVP stream. Half of the observers in the second group, the Known group, were instructed that the first target would always be presented in the left RSVP stream. The remaining observers were instructed that the first target would always appear in the right RSVP stream.

In summary, three factors were manipulated in Experiment 1. The two within-subject factors were Inter-target Lag (1, 3, 6, 9, 12, and 15) and Second-target Location

(Same or Different stream, relative to the first target). The between-subjects factor was whether or not the observer knew in advance the location of the first target (Known or Not-known).

Results and Discussion

In this and all subsequent experiments, only those trials in which the first target was identified correctly were included for analysis. 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, and thus its effect on second-target processing cannot be estimated. Correct identification of the first target averaged across lags and conditions was 76.5% for the Known group and 67.2% for the Not-Known group. An independent-samples t-test showed the difference between the two means to be significant, $t(31) = 4.23$, $p < .001$. Figures 1A and 1B illustrate the percentage of correct second-target responses as a function of Lag, Relative Second-target Location, and Observer's Advance Knowledge of first target's location. The data were analyzed in a 2 x 6 x 2 analysis of variance (ANOVA) comprised of two within-subject factors and one between-subject factor. The within-subject factors were Relative Second-target Location (Same or Different stream relative to the first target) and Lag (1, 3, 6, 9, 12, and 15). The between-subject factor was Observer's Advance Knowledge of the first target's location (Known or Not-known).

The analysis revealed a significant effect of Lag [$F(5,155) = 15.70$, $p < .001$], and a significant interaction between Lag and Relative Second-target Location [$F(5,155) = 11.69$, $p < .001$]. The three-way interaction among Lag, Relative Second-target Location, and Observer's knowledge of the first target's location was also significant [$F(5,155) = 4.30$, $p = .001$]. No other effects were significant.

In considering the outcome of the present work, it is well to be reminded that the issue of principal interest was Shih's (2000) finding that, contrary to the outcome of Visser et al. (1999), Lag-1 sparing occurred when the two targets were presented in different spatial locations. Therefore, while performance at the longer lags is not devoid of interest, the focus of the present work is on the incidence of Lag-1 sparing, and therefore, on performance at the shorter lags. In this respect, it must be noted that interpretation of the three-way interaction revealed in the above analysis and illustrated in Figures 1A and 1B may involve effects at both the short and the long lags. Because the issue of principal interest in the present work was the incidence of Lag-1 sparing, which is indexed by more accurate second-target identification at Lag 1 than at Lag3, all further analyses were confined to Lags 1 and 3.

A follow-up ANOVA similar to the preceding analysis, except that it included only Lags 1 and 3, revealed a significant effect of Relative Second-target Location [$F(1,31) = 15.35$, $p < .001$] and Lag [$F(1,31) = 29.69$, $p < .001$]. As was the case in the overall analysis, the three-way interaction among Lag, Relative Second-target Location, and Observer's Advance Knowledge of the first target's location was significant [$F(1,31) = 12.20$, $p = .001$]. No other effects were significant.

To single out the Lag-1 sparing component in the three-way interaction effect revealed in the preceding ANOVA, we performed a simple simple main-effects analysis on the data for Lags 1 and 3 in Figures 1A and 1B. The analysis showed that the effect of Lag was significant in both the Same and Different conditions in the Not-Known group [$F(1,60) = 8.19$, $p =.006$ and $F(1,60) = 18.22$, $p < .001$, respectively] and in the Same condition of the Known group [$F(1,60) = 24.18$, $p < .001$]. Notably, the effect of Lag was not significant in the Different condition of the Known group [$F(1,60) = 0.02$, $p = 0.90$]. In light of this analysis, the three-way interaction can be interpreted as indicating that Lag-1 sparing occurred in both the Same and Different conditions in the Not-Known group, but only in the Same condition in the Known group. This does not mean that effects at the longer lags did not contribute to the three-way interaction in the overall analysis; however, as noted above, the present work is concerned principally with Lag-1 sparing and, therefore, with effects that occur at the shorter lags.

From a general standpoint, the results of the present experiment replicate the conventional finding that Lag-1 sparing always occurs when the two targets are presented in the same location (Figures 1A and 1B, Same condition). The important new finding is that when the two targets are presented in different locations (Figures 1A and 1B, Different condition), Lag-1 sparing still occurs, but only when the observer does not have advance knowledge of the location of the first target.

The results for the Not-known group, illustrated in Figure 1B, are virtually identical to those reported by Shih (2000, Figure 1A). The present study builds on Shih's findings by specifying the role of observer's knowledge of the first target's location, thereby permitting Shih's results and the results of Visser et al.'s (1999) meta-analysis to be explained by a unitary set of principles. Furthermore, whereas in Shih's study accuracy for the second target never returned to Lag-1 levels, the addition of longer lags in the present study allowed second-target accuracy to recover completely.

In brief, all the available evidence [the present study, Shih's (2000) study, and Visser et al.'s (1999) meta-analysis] points to the same inference: Lag-1 sparing occurs reliably when the two targets are presented in the same location. When the two targets are presented in different locations, however, Lag-1 sparing occurs only if the observers have no advance knowledge of the first target's location.

An account of the present results as well as those of Shih (2000) and Visser et al. (1999) can be couched in terms of an "attentional spotlight" or "zoom lens" model of attention. In this model, performance on a given task is said to be enhanced by the deployment of an attentional spotlight to the location of an expected target (e.g., Yeh & Eriksen, 1984; Müller & Rabbitt, 1989).

We assume with Yeh and Eriksen (1984), that the diameter of the spotlight can be adjusted so as to optimize the distribution of attention. On the hypothesis that Lag-1 sparing occurs because of a sluggish attentional gate, the diameter of the spotlight would correspond to the size of the gate. On this metaphor, when the display contains a single RSVP stream, as in the studies reviewed by Visser et al. (1999), the spotlight will always be focused narrowly on the stream's location. This will also be the case when the display contains two RSVP streams, provided that the observer knows in advance in which stream the first target will appear. If the second target then appears in the same location as the first, it will fall within the focus of attention, pass through the attentional gate, and Lag-1 sparing will occur. If, however, the second target appears in a different location, it will fall outside the narrow focus of attention, and Lag-1 sparing will not occur. This hypothesis is buttressed by the finding that accuracy for the first target was significantly greater when its location was known in advance – and the spotlight was therefore focused narrowly on the first target's location – than when the location of the first target was not known and the spotlight was focused more broadly and diffusely (76.5% vs. 67.2%).

In contrast, if the observer has no advance knowledge of which stream contains the first target, the focus of attention, and therefore the attentional gate, will be widened so as to encompass both streams. Given this wider focus of attention, the second target will pass through the attentional gate regardless of whether or not it appears in the same RSVP stream as the first target, and Lag-1 sparing will ensue.

Experiment 2

Experiment 1 examined one of the two factors that emerged from our review of the literature, namely, the observer's advance knowledge of the first target's location. The outcome of Experiment 1 supplemented the findings of Visser et al.'s (1999) meta-analysis by showing that Lag-1 sparing occurs even when the two targets are presented in different locations, provided that the observer has no advance knowledge of the location of the first target. On the basis of this evidence, we concluded that the observer's advance knowledge is a critical determinant of Lag-1 sparing. This conclusion cannot be regarded as definitive, however, because all the studies in which Lag-1 sparing was not obtained when the two targets were presented at different locations contained only a single RSVP stream (Visser et al., 1999). This raises the possibility that the Lag-1 sparing obtained in the Different condition of the Not-known group in Experiment 1 (Figure 1B, segmented line) may be contingent on the presence of two RSVP streams. Experiment 2 was designed to decouple the effects of advance knowledge of the first target's location and the number of RSVP streams.

In Experiment 2, only a single RSVP stream was presented, and the first and second targets could appear unpredictably either within the stream or at a blank location on the opposite side of fixation. If the presence of two RSVP streams were essential to Lag-1 sparing when the two targets are presented in different locations, then Lag-1 sparing should not occur in the Different condition of Experiment 2, even though the observer has no advance knowledge of the location of the first target. In a nutshell, the principal question in Experiment 2 was whether Lag-1 sparing occurs under the following conditions: when the two targets are presented at different locations, the observer has no advance knowledge of the location of the first target, and there is no second RSVP stream.

Method

Participants

Eighteen undergraduate students at the University of British Columbia participated for course credit. All reported normal or corrected-to-normal vision and were naïve as to the purpose of the experiment.

Procedure

The apparatus, stimuli, and procedure were the same as those in the Not-known condition of Experiment 1, with the exception that instead of there being two RSVP streams, there was only a single stream that appeared with equal probability to the left or right of fixation. In addition, the first target could appear with equal probability either within the RSVP stream or at the blank location on the opposite side of fixation. The second target could then appear either in the same location as the first target or in the other location.

Results and Discussion

Correct identification of the first target averaged across lags and conditions was 70%. Figure 2 illustrates the percentage of correct second-target responses as a function of Lag and of Relative Second-target Location. The data were analyzed in a 2 x 6 ANOVA comprised of two within-subject factors: Relative Second-target Location (Same or Different) and Lag

(1, 3, 6, 9, 12, and 15). The analysis revealed a significant effect of Lag [$F(5,85) = 20.16$, $p < .001$], a significant effect of Relative Second-target Location [$F(5,85)=6.28$, $p =.023$], and a significant interaction between Lag and Relative Second-target Location [$F(5,85)=9.49$, $p < .001$]. The significant interaction effect, coupled with the graphical evidence in Figure 2 indicates that performance in the Same and Different conditions differed at Lags 1 and 3, but not at the longer lags. To check on the incidence of Lag-1 sparing, separate t-tests were performed in which the mean second-target accuracy at Lags 1 and 3 were compared in the Same and the Different conditions separately. The analyses revealed that performance at Lag 1 was significantly higher than at Lag 3 in both the Same condition [$t(17)=4.24$, $p = .001$] and in the Different condition [$t(17)=2.19$, $p = .043$], confirming that Lag-1 sparing occurred whether the two targets were presented in the same location or in different locations.

The results of Experiment 2 provide an unambiguous answer to the initial question: does Lag-1 sparing occur when the two targets are presented at different locations, the observer has no advance knowledge of the location of the first target, and there is no second RSVP stream. From Figure 2 and from the outcome of the statistical analyses, it is clear that Lag-1 sparing occurred when the two targets were presented at different locations, even though the display contained only a single RSVP stream. It follows that the presence of a second RSVP stream is not necessary for Lag-1 sparing; what matters is that the observers have no advance knowledge of the location of the first target. This finding is entirely consistent with the spotlight hypothesis outlined above. When the location of the first target is not known in advance, the spotlight is set to encompass both potential target locations. This allows the second target to pass through the attentional gate regardless of whether it appears at the same location as the first target or at a different location.

A comparison of Experiment 2 with the Not-known condition of Experiment 1 (Figures 2 and 1B) permits an assessment of the relative prominence of endogenous and exogenous factors in setting the width of the attentional spotlight. It is well to be reminded that, given that the location of the first target is not known, the observer's ideal strategy would be to optimize the width of the spotlight so as to encompass both potential locations. If exogenous factors play a role, the presence of a second RSVP stream would provide an additional anchor point to mediate accurate setting of the spotlight's width. In this case, the magnitude of Lag-1 sparing should be greater in the Not-known condition of Experiment 1, where the display contained two RSVP streams, than in Experiment 2, where the display contained only a single stream. If, on the other hand, the width of the spotlight can be set entirely endogenously, then the presence or absence of a second RSVP stream should have no effect on the setting of the spotlight and hence on the magnitude of Lag-1 sparing. It goes without saying that these considerations apply only to the Different condition.

We examined this issue by comparing the magnitude of Lag-1 sparing (i.e., performance differences between Lags 1 and 3) in the Different condition of Experiment 2 and the Different condition of the Not-known group in Experiment 1. The 2 x 2 ANOVA consisted of one between-subjects factor (Experiment: the Different conditions in Experiment 2 and in the Not-known condition of Experiment 1) and one within-subject factor (Lag: 1 and 3). The analysis revealed a significant effect of Lag [$\underline{F}(1,32) = 34.05$, $\underline{p} < .001$] and a significant interaction between Experiment and Lag [$\underline{F}(1,32) = 6.87$, $\underline{p} = .013$]. The effect of Experiment was not significant [$\underline{F}(1,32) = .35$, $\underline{p} = .559$].

The outcome of this analysis indicates that the magnitude of Lag-1 sparing was significantly greater when the display contained two RSVP streams than when it contained only one. This strongly suggests that exogenous factors play a role in setting the width of the attentional spotlight. It must be emphasized, however, that exogenous factors, while important, are not necessary for Lag-1 sparing. This is revealed by the finding of a significant amount of Lag-1 sparing in the Different condition of Experiment 2, in which a wider setting of the spotlight could be mediated only by endogenous factors.

Experiment 3

Experiment 3 was designed to pursue the finding that the magnitude of Lag-1 sparing in the Different condition in Experiment 2 was significantly smaller than in the corresponding condition in Experiment 1 (segmented line in Figure 2 vs. segmented line in Figure 1B). According to the attentional spotlight hypothesis, this difference can be explained in terms of the factors that govern the width of the attentional spotlight. Because in neither case did observers have advance knowledge of the location of the first target, the optimal strategy was to maintain a focus of attention sufficiently wide to encompass both potential target locations. This strategy, however, might have been more easily implemented in Experiment 1 than in Experiment 2. This is because, in Experiment 1, the display contained two RSVP streams, which provided anchoring points that enabled the observers to set and maintain a sufficiently wide spotlight. In this case, endogenous and exogenous factors worked in conjunction with one another in setting the spotlight. In contrast, in Experiment 2, the display contained only a single stream, and it is known that under these display conditions, attention is drawn in an obligatory fashion to the location of the RSVP stream (Kawahara, 2003; Visser, Bischof, & Di Lollo, in press). In this case, endogenous and exogenous factors worked in opposition to one another: the former would make for a spotlight of an appropriate width whereas the latter would make for a spotlight more narrowly focused on the RSVP stream. In Experiment 2 this would have resulted in a somewhat narrower spotlight that failed to encompass the blank location, at least on some trials. If it is indeed the case that Lag-1 sparing occurs only when the spotlight encompasses the location of the second target, it follows that the magnitude of Lag-1 sparing would be greater in Experiment 1 than in Experiment 2.

We tested this hypothesis in Experiment 3 by introducing a second RSVP stream consisting of a series of frames of random dots. Our intent was to establish a second anchor point to provide exogenous inputs that could be used to expand the width of the spotlight. We reasoned that each frame in the random-dot stream would trigger an onset transient, thereby providing exogenous stimulation. Being meaningless, however, this random-dot stream would avoid any possible interference by endogenous factors that might accompany a stream of meaningful items, as might have been the case in Experiment 1.

Method

Participants

Sixteen undergraduate students from the University of British Columbia participated for course credit. All reported normal or corrected-to-normal vision and were naïve as to the purpose of the experiment.

Procedure

The apparatus, stimuli, and procedure were identical to those of the Not-known condition in Experiment 1 with the exception that one of the two RSVP streams of digits was replaced with a stream of random-dot patterns that differed randomly on each frame. Each pattern contained 10 dots distributed randomly over a square area of 0.9 deg centered 1.75 degrees to the left or right of fixation.

Results and Discussion

Correct identification of the first target averaged across lags and conditions was 81%. Figure 3 illustrates the proportion of correct second-target responses as a function of Lag and of Inter-target Spatial Relationship. The data were analyzed in a 2 x 6 ANOVA comprised of two within-subject factors: Inter-target Spatial Relationship (Same or Different) and Lag (1, 3, 6, 9, 12, and 15). The analysis revealed a significant effect of Inter-target Spatial Relationship [$F(1,15) = 15.41$, $p = .001$] and Lag [$F(5,75) = 17.57$, $p < .001$]. The interaction between Lag and Inter-target Spatial Relationship was also significant [$F(5,75) = 12.91$, $p < .001$]. The significant interaction effect, coupled with the graphical evidence in Figure 3 indicates that performance in the Same and Different conditions differed at Lags 1 and 3, but not at the longer lags.

To check on the incidence of Lag-1 sparing, separate t-tests were performed between Lags 1 and 3 in the Same and the Different conditions separately. The analyses revealed that performance at Lag 1 was significantly higher than at Lag 3 in both the Same condition [$t(15)=6.64$, $p < .001$] and in the Different condition [$t(15)=2.52$, $p = .024$], confirming that Lag-1 sparing occurred not only when the two targets were presented in the same location, as is commonly found in AB experiments, but also when they were presented in different locations.

The main objective of Experiment 3 was to determine whether providing a second anchor point in the form of a meaningless RSVP stream facilitates the expansion of the attentional spotlight beyond the width established in Experiment 2. A wider setting of the spotlight should cause the magnitude of Lag-1 sparing in the Different condition of Experiment 3 to be greater than that in Experiment 2. To check on this option, the results for Lags 1 and 3 of the Different condition of Experiments 2 and 3 were analyzed in a 2 x 2 ANOVA comprising one between-subjects factor (Experiment: 2 and 3), and one within-subjects factor: Lag (1 and 3). The analysis revealed a significant effect of Lag [$F(1,30) = 9.20$, $p = .005$], but no significant interaction between Lag and Experiment [$F(1,30) = .322$, $p = .575$]. On the basis of this analysis it can be concluded that the magnitude of Lag-1 sparing was no greater in Experiment 3 than in Experiment 2. In terms of the spotlight hypothesis, this means that the presence of a second, meaningless, RSVP stream does not provide a useful anchor point for setting the width of the attentional spotlight and, therefore, that exogenous factors play only a minimal role.

In contrast, an equivalent comparison between Experiment 3 and the Not-Known group in Experiment 1 revealed that the magnitude of Lag-1 sparing in the Different condition was significantly smaller in Experiment 3. This was confirmed in a subsidiary 2 (Lag: 1 and 3) x 2 (Experiment: 3 and 1) ANOVA, which revealed a significant effect of Lag [$F(1,30)=38.09$, $p < .001$] and, critically, a significant interaction between Lag and Experiment [$F(1,30) = 6.17$, $p =.019$]. This provides further confirmation that a stream of random-dot patterns does not provide a suitable anchor point for setting the width of the attentional spotlight.

The finding of primary interest that emerges from these analyses is that the magnitude of Lag-1 sparing in the Different condition was the same in Experiments 2 and 3, but was greater in the Not-Known group in Experiment 1 than in either Experiment 2 or 3. This strongly suggests that with respect to providing an anchor point for the attentional spotlight, a stream of random dots is no better than no stream at all.

Why was the magnitude of Lag-1 sparing less in the Different condition of Experiments 2 and 3 than in the corresponding condition of the Not-Known group in Experiment 1? Or, in terms of the spotlight hypothesis, why could the diameter of the spotlight be set wider in Experiment 1 than in either Experiment 2 or 3? An answer to this question may be found in the balance of meaningfulness between the streams in the two potential target locations. In Experiment 1, both streams contained meaningful items and, therefore, meaningfulness was balanced across the two locations. In Experiments 2 and 3, on the other hand, only one of the streams contained meaningful items, resulting in an imbalance across the two locations. It is conceivable that, because of this imbalance, attention was focused more narrowly on the meaningful stream with a corresponding reduction in the probability that the attentional spotlight encompassed both potential target locations on any given trial.

This possibility was examined in Experiment 4 by presenting two RSVP streams of random-dot patterns. If balance in the meaningfulness of the two streams is the critical factor underlying the greater magnitude of Lag-1 sparing in Experiment 1 than in Experiments 2 and 3, then the results of Experiment 4, in which the two streams are balanced, should be comparable to those of Experiment 1. In order to provide a complete replication of Experiment 1, Experiment 4 included a Known group as well as a Not-Known group. According to the attentional spotlight hypothesis, no Lag-1 sparing should be in evidence in the Different condition of the Known group in Experiment 4, paralleling the results in the corresponding condition of Experiment 1.

Experiment 4

Method

Participants

Thirty-four undergraduate students from the University of British Columbia participated for course credit and were randomly assigned to either the Known or the Not-Known group. All reported normal or corrected-to-normal vision and were naïve as to the purpose of the experiment.

Procedure

The apparatus, stimuli, and procedure were identical to those of Experiment 1 with the exception that both the RSVP streams of digits were replaced with streams of random-dot patterns that differed randomly on each frame. Each pattern contained 10 dots distributed randomly over a square area of 0.9 deg centered 1.75 degrees to the left and right of fixation. On any given frame, the two random-dot patterns were different from one another.

The observers in the Not-Known group were instructed that on any given trial, the first target would appear unpredictably in either the left or the right RSVP stream. Half of the observers in the second group, the Known group, were instructed that the first target would always be presented in the left RSVP stream. The remaining observers were instructed that the first target would always appear in the right RSVP stream.

Results and Discussion

Correct identification of the first target averaged across lags and conditions was 86% for the Known group and 83% for the Not-Known group. Figures 4A and 4B illustrate the percentage of correct second-target responses as a function of Lag, Relative Second-target Location, and Observer's Advance Knowledge of first target's location. The present experiment was designed as a replication of Experiment 1 with the exception that the items in the RSVP stream were meaningful in Experiment 1, but meaningless in the present experiment. Comparison of Figures 4A and 1A reveals somewhat different patterns of results for the Known group of Experiments 1 and 4. These differences are intriguing and worthy of further investigation. For the present purposes, however, the important consideration is that Lag-1 sparing did not occur in the Different condition of the Known group in either Experiment 1 or 4. In contrast, comparison of Figures 4B and 1B shows that the results of Experiment 4 replicated the two critical findings of Experiment 1. First, that Lag-1 sparing invariably occurs when the two targets are presented in the same location. Second, and more important, that Lag-1 sparing also occurs when the two targets are presented in different locations, but only when the observer does not have advance knowledge of the location of the first target.

The results of Experiment 4 were analyzed in an overall 2 x 6 x 2 analysis of variance (ANOVA) comprised of two within-subject factors and one between-subject factor. The within-subject factors were Relative Second-target Location (Same or Different stream relative to the first target) and Lag (1, 3, 6, 9, 12, and 15). The between-subject factor was Observer's Advance Knowledge of the first target's location (Known or Not-known). The analysis revealed significant effects of Lag [$F(5,160) = 40.95$, $p < .001$], Relative Second-target Location [$F(1,32) = 9.17$, $p = .005$], and Observer's Advance Knowledge of the first target's location [$F(1,32) = 5.14$, $p = .03$]. There were also significant interaction effects between Relative Second-target Location and Lag [$F(5,160) = 36.40$, $p < .001$] and among Lag, Relative Second-target Location, and Observer's Advance Knowledge of the first target's location [$F(5,160) = 5.89$, $p = .001$]. No other effects were significant.

The graphical evidence in Figures 4A and 4B strongly suggest that the three-way interaction arises from differences in performance between the Known and Not-Known groups at the shorter lags because performance at the longer lags was comparable in the two groups. Notably, Lag-1 sparing was in evidence in the results of the Different condition of the Not-known group (Figure 4B) but not in the corresponding condition of the Known group (Figure 4A), paralleling the findings of Experiment 1. The presence of Lag-1 sparing in the Different condition of the Not-Known group in Experiment 4 was confirmed by a t-test showing that accuracy of second-target identification was higher at Lag 1 than at Lag 3 [$t(16) = 7.05$, $p < .001$]. Similarly, the absence of Lag-1 sparing in the Different condition of the Known group was confirmed by a t-test showing that second-target identification was, if anything, lower at Lag 1 than at Lag 3 [$t(16) = -1.10$, $p = .286$]. The outcome of these t-tests, coupled with the graphical evidence in Figures 4A and 4B, justifies the inference that Lag-1 sparing does occur in the Different condition, but only when the observer has no advance knowledge of the location of the first target.

This pattern of results is entirely consistent with the hypothesis that balance in the meaningfulness of the two streams is the critical factor underlying the greater magnitude of Lag-1 sparing in the Different condition of Experiments 1 and 4 (Figures 1B and 4B, Not-Known groups) than in the Different condition of Experiments 2 and 3 (Figures 2 and 3). To wit, in Experiments 1 and 4 the two RSVP streams were balanced with respect to meaningfulness: both streams were meaningful in Experiment 1 and meaningless in Experiment 4. In contrast, in Experiments 2 and 3, the displays were unbalanced because only one potential target location contained a meaningful RSVP stream; the other location was either empty (Experiment 2) or contained a stream of meaningless items (Experiment 3).

A subsidiary analysis confirmed that the magnitude of Lag-1 sparing in the Different condition of the Not-Known group of Experiment 4 did not differ significantly from that in the corresponding condition of Experiment 1. The analysis involved a comparison between Lags 1 and 3 for the Different condition of the Not-Known groups in Experiments 1 and 4. The ANOVA was comprised of one between-subjects factor (Experiment: 1 or 4) and one within-subject factor (Lag: 1 or 3). The outcome revealed a significant effect of Lag [$F(1,31) = 88.86$, $p < .001$] but no other significant effects. Notably, the interaction between Experiment and Lag was not significant [$F(1,31) = .179$, $p = .675$], attesting to the equivalent magnitude of Lag-1 sparing in the two experiments. In contrast, the magnitude of Lag-1 sparing was greater in the Different condition of the Not-Known group in Experiment 4 than in the corresponding condition of either Experiment 2 or Experiment 3. This was confirmed by two additional analyses. The first involved a comparison between Lags 1 and 3 for the Different condition of the Not-Known group in Experiment 4 with the Different condition in Experiment 2. The analysis revealed a significant effect of Lag [$F(1,31) = 40.12$, $p < .001$] and a significant interaction effect between Lag and Experiment [$F(1,31) = 5.32$, $p = 0.028$], confirming that the magnitude of Lag-1 sparing was greater in Experiment 4 than in Experiment 2. The second analysis involved the same comparison between Experiments 4 and 3. The analysis again revealed a significant effect of Lag [$F(1, 33) = 35.06$, $p < .001$] and a significant interaction effect between Lag and Experiment [$F(1,33) = 5.97$, $p = 0.02$], confirming that the magnitude of Lag-1 sparing was greater in Experiment 4 than in Experiment 3.

The outcomes of the present analyses confirm the hypothesis that the magnitude of Lag-1 sparing in the Different condition is greater when the two RSVP streams are balanced with respect to meaningfulness (as in Experiments 1 and 4) than when they are unbalanced (as in Experiments 2 and 3). In this respect, the magnitude of Lag-1 sparing in the Different condition of the Not-Known group of Experiment 1 matched that of the corresponding condition in Experiment 4. A similar correspondence was obtained between Experiments 2 and 3. This pattern of results is consistent with the hypothesis that the attentional spotlight can be expanded consistently to encompass both potential target locations only if the two RSVP streams are balanced with respect to meaningfulness.

General Discussion

The primary objective of the present work was to resolve an apparent inconsistency in the Attentional Blink (AB) literature; namely, whether Lag-1 sparing occurs when the two targets are presented in different spatial locations. Lag-1 sparing denotes the finding, reported in about half of the AB experiments, that the second-target deficit does not occur – or is much reduced – when the second target is presented directly after the first. A meta-analysis by Visser et al. (1999) revealed that Lag-1 sparing never occurs when the two sequential targets are presented in different locations. An exception to this rule was reported by Shih (2000), who found substantial Lag-1 sparing when the two targets were presented in different locations.

A comparison of Shih's (2000) study with the studies reviewed by Visser et al. (1999) revealed two key factors that might account for the apparent inconsistency of results: the observer's advance knowledge of the location of the first target and the number of RSVP streams in the display. The present work demonstrates that the first factor, knowledge of the first target's location, determines whether Lag-1 sparing occurs when the two targets are presented in different locations. It further shows that the second factor, number of RSVP streams, is not in itself a direct determinant of Lag-1 sparing. Rather, it mediates the magnitude of Lag-1 sparing by determining the extent to which the two RSVP streams are balanced in the degree to which they capture attention.

In the first of four experiments, observers viewed two RSVP streams of digit distractors presented one on either side of fixation. Two letter targets could appear either in the same or in opposite streams. One group of observers knew in advance in which stream the first target would appear; a second group had no such knowledge. The results replicated the conventional finding that Lag-1 sparing invariably occurs when the two targets are presented in the same location (Visser et al., 1999) as well as Shih's (2000) finding of Lag-1 sparing when the targets appear in different locations. The outcome of Experiment 1 built on Shih's finding by showing that when the targets are presented in different locations, Lag-1 sparing occurs <u>only</u> if the observer has no advance knowledge of where the first target will appear.

The results of Experiment 1 as well as those of Shih (2000) and Visser et al. (1999) can be explained within a conceptual framework that combines the "attentional spotlight" model of attention (e.g., Yeh & Eriksen, 1984; Müller & Rabbitt, 1989) with an account of Lag-1 sparing based on the sluggish closing of an attentional gate (Chun & Potter, 1995; Potter, Chun, Banks, & Muckenhoupt, 1998). In the spotlight model, performance on a given task is said to be enhanced by the deployment of an attentional spotlight to the location of an expected target. The diameter of the spotlight is said to be dynamically adjustable so as to optimize the distribution of attention. In accounting for the present results, we combined the spotlight model with the attentional-gate model in which Lag-1 sparing is explained as follows: the arrival of the first target opens an attentional gate that closes sluggishly so as to admit the next item in the RSVP stream. If that trailing item happens to be the second target, both targets are processed and Lag-1 sparing ensues. In the combined model, the diameter of the spotlight corresponds to the size of the gate.

In the discussion of Experiment 1 we have described how this combined model can explain why Lag-1 sparing occurs when the two targets appear in different locations, but only if the observer has no advance knowledge of the location of the first target. This is because in the absence of knowledge of the first target's location, the spotlight must be set broadly so as to encompass both potential target locations. Given this wide diameter of the spotlight, both targets will pass through the gate whether they are presented in the same or in different locations, and Lag-1 sparing will ensue. By the same token, Lag-1 sparing will not occur when the observer has advance knowledge of the first target's location because the spotlight is focused narrowly on the first target's location and, therefore, does not encompass the location on the opposite side of fixation. If the second target then appears at the latter location, it will not pass through the gate and Lag-1 sparing will not occur.

Predictions from this combined model were verified in Experiments 2, 3, and 4, which confirmed the dependence of Lag-1 sparing on the observer's advance knowledge of the first target's location. In addition, the results revealed that the magnitude of Lag-1 sparing when the two targets appeared in different locations and the location of the first target was not known, is predicated on the interplay of two conflicting factors: a tendency to expand the attentional spotlight to encompass both potential target locations, and an opposing tendency to focus narrowly on the stream that contains the more meaningful stimuli. Thus, the magnitude of Lag-1 sparing was greater in Experiments 1 and 4, in which the two streams were balanced with respect to meaningfulness (in Experiment 1, both were meaningful streams of digits; in Experiment 4, both were meaningless streams of random-dot patterns), than in Experiments 2 and 3, in which meaningfulness was unbalanced across the two streams (Experiment 2 contained one meaningful stream of digits and one blank location; Experiment 3 contained one meaningful stream of digits and one meaningless stream of random-dot patterns).

The primary objective of the present work was to resolve an apparent inconsistency in the Attentional Blink literature regarding the occurrence of Lag-1 sparing when the two targets are presented at different spatial locations (Visser et al., 1999; Shih, 2000). Two factors emerged as joint determinants of the incidence and magnitude of Lag-1 sparing. The first factor, the observer's advance knowledge of the first target's location, determines whether Lag-1 sparing will occur when the two targets are presented in different spatial locations. The second factor, the degree to which the RSVP streams are balanced with respect to meaningfulness, determines the magnitude of Lag-1 sparing. It is the interplay between these two factors that provides a resolution of the apparent inconsistency in the literature.

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Figure Captions

Figure 1. Mean percentages of correct identifications of the second target in Experiment 1 for those trials in which the first target was identified correctly (T2|T1). The displays consisted of two RSVP streams of digit distractors. In the Same condition, the two letter targets were presented in the same RSVP stream; in the Different condition, they were presented in opposite streams. Observers in the T1-Known group (A) were given advance knowledge of the stream in which the first target would appear. Observers in the T1-not-Known group (B) had no such knowledge. T1 = first target; T2 = second target; RSVP = rapid serial visual presentation.

Figure 2. Mean percentages of correct identifications of the second target in Experiment 2 for those trials in which the first target was identified correctly (T2|T1). A single RSVP stream of digit distractors was presented randomly on either side of fixation with the location on the opposite side being blank. In the Same condition, the two letter targets were presented in the same location; in the Different condition, they were presented in opposite locations. T1 = first target; T2 = second target; RSVP = rapid serial visual presentation.

Figure 3. Mean percentages of correct identifications of the second target in Experiment 3 for those trials in which the first target was identified correctly (T2|T1). The displays consisted of two RSVP streams, one of digit distractors, the other of random-dot patterns. In the Same condition, the two letter targets were presented in the same stream; in the Different condition, they were presented in opposite streams. T1 = first target; T2 = second target; RSVP = rapid serial visual presentation.

Figure 4. Mean percentages of correct identifications of the second target in Experiment

4 for those trials in which the first target was identified correctly (T2|T1). The displays consisted of two RSVP streams of random-dot patterns. In the Same condition, the two letter targets were presented in the same RSVP stream; in the Different condition, they were presented in opposite streams. Observers in the T1-Known group (A) were given advance knowledge of the stream in which the first target would appear. Observers in the T1-not-Known group (B) had no such knowledge. T1 = first target; T2 = second target; RSVP = rapid serial visual presentation.

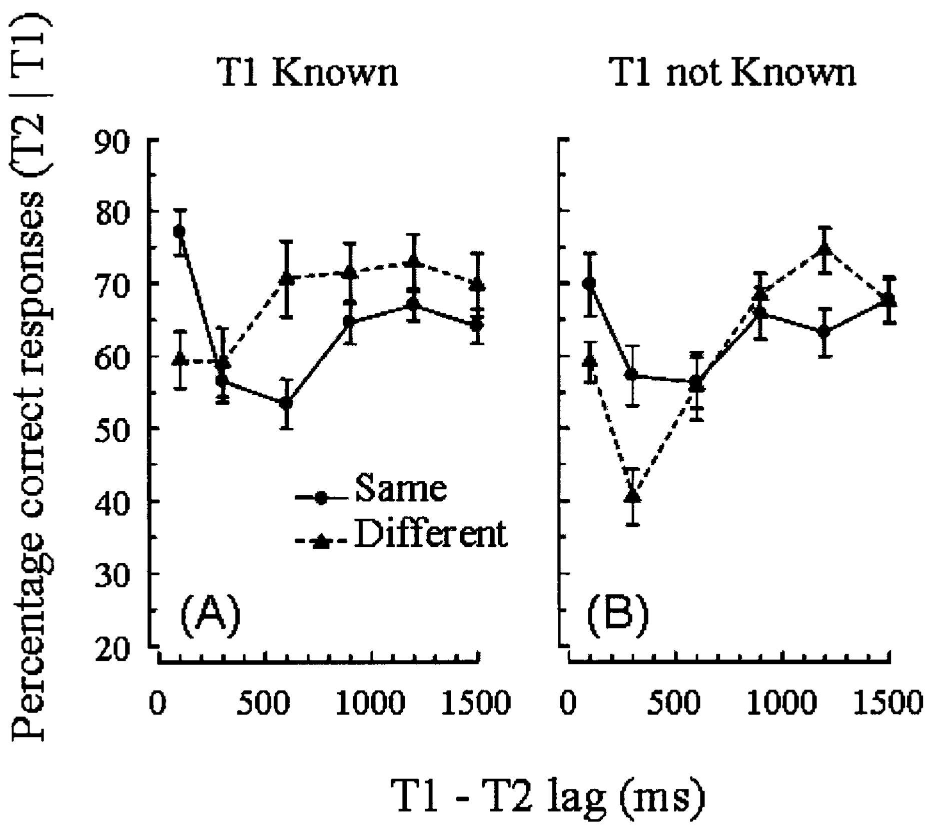

T1 Known
T1 not Known
Percentage correct responses (T2 | T1)
90
80
70
60
50
40
30
20
Same
Different
(A)
(B)
0
500
1000
1500
T1 - T2 lag (ms)

Figure 1

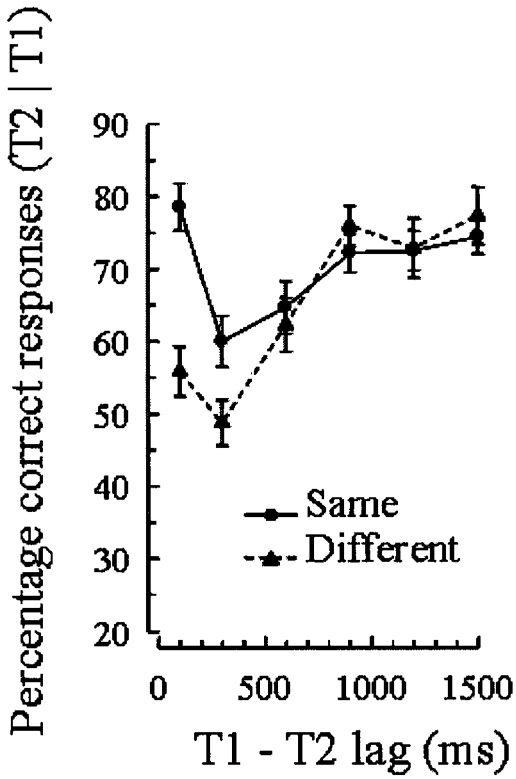
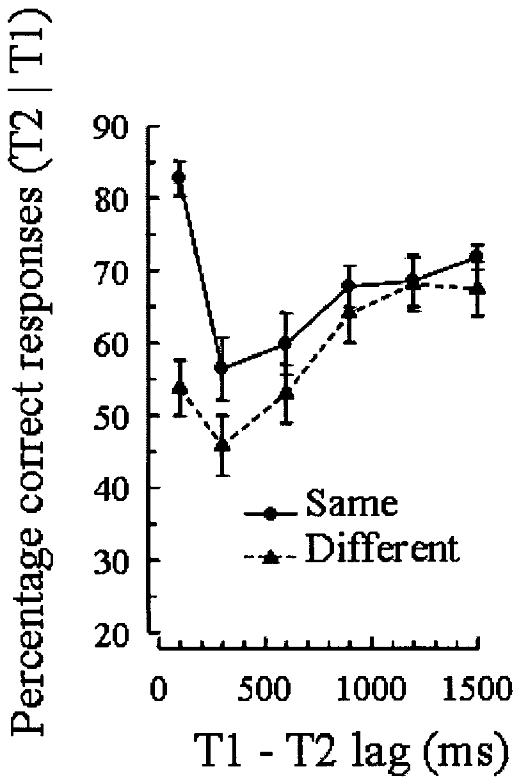

Percentage correct responses (T2 | T1)
90
80
70
60
50
40
30
20
0
500
1000
1500
T1 - T2 lag (ms)
Same
Different

Figure 2



Percentage correct responses (T2 | T1)
90
80
70
60
50
40
30
20
0
500
1000
1500
T1 - T2 lag (ms)
Same
Different

Figure 3

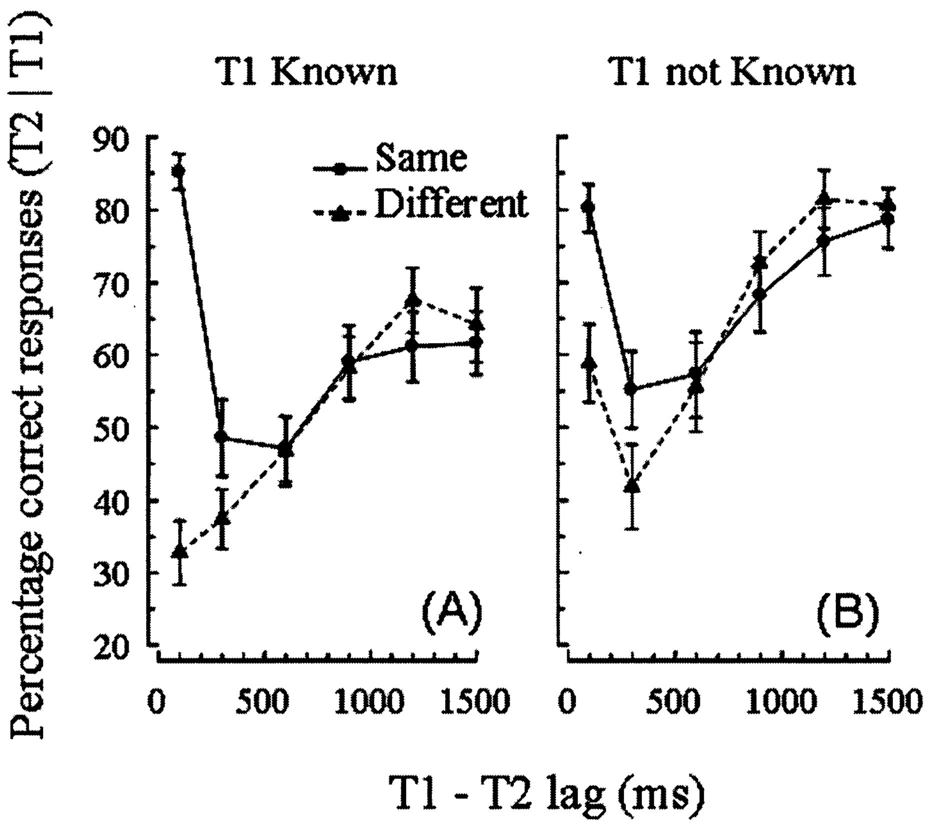

T1 Known
T1 not Known
Same
Different
(A)
(B)
Percentage correct responses (T2 | T1)
90
80
70
60
50
40
30
20
0
500
1000
1500
T1 - T2 lag (ms)

Figure 4