Psychonomic Bulletin & Review
2000, 7 (3), 472-479

Selective influence of second target exposure duration and $Task_1$ load effects in the attentional blink phenomenon

PIERRE JOLICŒUR
University of Waterloo, Waterloo, Ontario, Canada

and

ROBERTO DELL' ACQUA
University of Padua, Padua, Italy

The purpose of the experiments was to constrain the locus of interference in the attentional blink (AB) paradigm. Two visual stimuli, T_1 and T_2, were shown 300 msec apart, and each was followed by a mask. T_1 was an "H," an "S," an "&," or a blank field; T_2 consisted of five letters. In $Task_1$, blank fields and & characters could be ignored, whereas Hs and Ss had to be identified and reported. $Task_2$ was always to report as many letters as possible from T_2. $Task_2$ performance was lower when T_1 had to be reported, as expected from the attentional blink phenomenon (AB). The exposure duration of T_2 was also manipulated. More letters could be reported as exposure duration was increased. However, this effect was additive with manipulations of $Task_1$ processing load that produced the AB effect. Log-linear analyses assuming that effects of T_2 exposure duration and $Task_1$ load effects occur at functionally distinct stages of processing provided satisfactory fits to the results, suggesting that none of the AB effect occurs as early as those of T_2 exposure duration. The results suggest that the locus of the AB effect is later than the stage(s) of processing affected by exposure duration.

This article examines processing limitations on visual input. Several experimenters have demonstrated such limitations using a variety of paradigms (e.g., Arnell & Jolicœur, 1999; Broadbent & Broadbent, 1987; Chun & Potter, 1995; Duncan, 1980; Jolicœur, 1999a, 1999b; Jolicœur & Dell'Acqua, 1999; Kleiss & Lane, 1986; Raymond, Shapiro, & Arnell, 1992, 1995; Shapiro, Raymond, & Arnell, 1994; Shulman & Hsieh, 1995; Ward, Duncan, & Shapiro, 1996; Weichselgartner & Sperling, 1987). Most of these articles report experiments in which two targets (T_1, T_2) are presented in close temporal contiguity. If the two targets are presented at different times, the first target can usually be reported with high accuracy, whereas the second target is often reported with much lower accuracy. Report of the second target, however, is also highly accurate if only the second target must be reported. The reduced accuracy of report of the second target when the first one must also be reported is often called an *attentional blink* (AB; Raymond et al., 1992). The AB effect is reduced as the stimulus onset asynchrony (SOA) between the first and second targets is increased.

One reason for the interest in the AB effect is that the observed deficits in $Task_2$ performance are often very large despite seemingly simple tasks, suggesting that the paradigm reveals a fundamental constraint in our ability to process visual input. As might be expected from the list (quite incomplete) of references provided above, many aspects of the phenomenon have been the focus of empirical investigation. Much of the empirical work has examined relationships between the kind of task ($Task_1$) associated with the first target (T_1) or the presentation conditions surrounding T_1 (such as the nature of the stimulation immediately following T_1) and the magnitude of the AB effect observed in $Task_2$ (usually the deferred report of the identity of T_2; but see Ross & Jolicœur, 1999). Relatively little work has focused on the presentation parameters of T_2 (but see Giesbrecht & Di Lollo, 1998, and Jolicœur, 1999a, for two exceptions).

Several researchers have provided evidence that some of the interference producing the AB effect is likely to have a relatively late, postperceptual, locus (Arnell & Jolicœur, 1999; Chun & Potter, 1995; Jolicœur, 1998, 1999a, 1999b; Jolicœur & Dell'Acqua, 1999; Luck, 1998; Luck, Vogel, & Shapiro, 1996; Potter, Chun, Banks, & Muckenhoupt, 1998; Shapiro, Caldwell, & Sorensen, 1998; Shapiro, Driver, Ward, & Sorensen, 1997). These experiments provide evidence for a late locus by showing that manipulations (some in $Task_1$, some in $Task_2$) that

This work was supported by a research grant from the Natural Sciences and Engineering Research Council of Canada and by the Human Frontiers Science Program. The authors thank Kim Shapiro, Peter Dixon, Eric Ruthruff, Steve Luck, and an anonymous reviewer for comments and criticisms on earlier drafts of this article. The authors also especially thank Richard Schweickert for helpful comments, discussions, and help in relating his model to our results. Correspondence should be addressed to P. Jolicœur, Department of Psychology, University of Waterloo, Waterloo, ON, N2L 3G1 Canada (e-mail: pjolicoe@cgl.uwaterloo.ca).

are believed to affect late stages of processing also affect the observed AB deficit in $Task_2$. This evidence shows that some of the AB effect likely arises at a late stage of processing. Generally, however, this work cannot reject the possibility that there are multiple loci of interference and that some of the effect takes place early in processing, although one set of results reported by Luck et al. (1996), based on evoked response potentials, is not consistent with an early locus. Additional results that could corroborate the hypothesis that the AB effect arises only quite late in processing seem desirable.

In the present study, we manipulated the exposure duration of T_2 and observed whether the effects of this manipulation were additive or interactive (Schweickert, 1985; Sternberg, 1969) with the joint manipulation of variables that produce or affect the AB phenomenon. The logic of the approach is as follows. We expect that lengthening the exposure duration of T_2 would allow subjects to report more information from T_2 (Coltheart, 1982). As more time for processing T_2 is provided, before the onset of a pattern mask, more information should be encoded from T_2. The onset of a pattern mask should effectively limit how much information can be encoded (Scheerer, 1973). If some of the observed AB effect has an effect at the same stage, then we would generally expect interactive effects of exposure duration and of the variables affecting the AB effect. If, on the other hand, the locus of the AB effect is entirely different (presumably later), then we would expect additive effects of the joint manipulation of exposure duration and of variables affecting the AB.

EXPERIMENTS 1 AND 2

We performed two experiments to examine the joint effects of the exposure duration of T_2 and manipulations producing and affecting the AB effect. Because the experiments were very similar, we present them in a single section in which we will point out the similarities and differences between them.

In both experiments, the subjects were tested using a series of discrete trials. In each trial, there were two visual targets (T_1 and T_2). Each stimulus, T_i, had associated with it a task, $Task_i$. T_1 was the letter "H" or "S," the symbol "&," or a blank field. T_1 was followed by a pattern mask consisting of superimposed "$" and "0" characters. $Task_1$ was to report, at the end of the trial, whether the letter H or S had been shown, when T_1 was an H or an S, and simply to press the space bar if T_1 was either an & or a blank field. The subjects were instructed that they could essentially ignore T_1 when it was a blank field or the symbol &. These two $Task_1$ conditions served as control conditions for the H–S condition, in which the identity of T_1 had to be reported at the end of the trial.

In Experiment 1, the various $Task_1$ conditions were intermixed at random, from trial to trial, during each block of trials. In Experiment 2, in contrast, the trials were blocked by $Task_1$ conditions. There were three types of blocks: T_1 = blank, T_1 = &, and T_1 = H or S. In the first two types of blocks, T_1 could be ignored across all trials in the block, but the visual stimulation from T_1 was identical to that experienced when the trials were mixed within blocks (Experiment 1). In Experiment 1 (mixed $Task_1$ conditions), a decision had to be performed on line, to determine whether a particular T_1 display could be ignored (blank or &), or whether the information had to be encoded (H–S). This type of control condition equates $Task_1$ conditions for general dual-task load effects, such as the need to prepare for $Task_1$ and for $Task_2$ (De Jong & Sweet, 1994). In contrast, in Experiment 2, T_1 could be ignored during the control blocks (blank or &), but not during the experimental blocks (H–S). In Experiment 2, H–S blocks required that two tasks be performed, whereas essentially a single task was performed in blank and & trials. We expected the measured magnitude of the AB effect to be larger in Experiment 2 than in Experiment 1 because the difference between the control and experimental conditions in Experiment 2 also included an element of task preparation (the comparison being between dual-task performance and single-task performance).

T_2 was a display of five letters, which was followed by a pattern mask consisting of superimposed "$" and "0" characters. The exposure duration of the letters was 50, 100, 150, 200, or 250 msec. The mask was presented immediately after the offset of T_2. We expected that the number of letters that could be recalled from T_2 would increase as the duration of T_2 increased.

The SOA (300 msec) between T_1 and T_2 was chosen so as to maximize the AB effect (e.g., Chun & Potter, 1995; Duncan, Ward, & Shapiro, 1994; Jolicœur, 1998, 1999b; Raymond et al., 1992). The present paradigm was a variant on the two-event paradigm described by Duncan et al. (1994; Ward et al., 1996), in which there are two target events, each followed by a mask. In the present variant, T_2 contained more information than in the work of Duncan and his colleagues, but the experiment was otherwise conceptually very similar. Jolicœur and Dell'Acqua (1999) reported an experiment very similar to the present ones in which the SOA between T_1 and T_2 was manipulated, and they found that the magnitude of the deficit found in $Task_2$ decreased as SOA was lengthened, as expected based on previous work on the AB phenomenon.

Thus, we expected to find an AB effect within each experiment. This effect should be manifested as a deficit in $Task_2$ performance (fewer letters reported correctly) following a T_1 display containing an H or an S than following T_1 displays containing an & or a blank. The logic of the manipulation was that an H–S T_1 display required significant cognitive processing because the identity of the T_1 character had to be encoded, remembered, and recalled later (at the end of the trial). In contrast, a blank display obviously did not contain any special information to be encoded and remembered, and & displays could be ignored but contained significant visual patterning, controlling for potential masking effects on T_2. Previous work on the AB paradigm has shown that subjects have good control over what they encode or ignore, such that there is only a minimal cost associated with processing an ignored character when the response in $Task_1$ is delayed to the end of the trial (Duncan, 1980; Jolicœur, 1999b; Shapiro et al., 1994; Ward et al., 1996).

Furthermore, we expected to find a larger AB effect with a blocked presentation of $Task_1$ conditions than with a mixed presentation. The new question under study was whether this manipulation of AB magnitude would simply add to or interact with, the effects of exposure duration of T_2.

Method

Analysis. Accuracy in $Task_2$ was analyzed using log-linear methods that were motivated by Schweickert (1985). He argued that, for accuracy data, effects of variables that have selective influences at different stages of processing combine multiplicatively, assuming stages that are stochastically independent. Suppose that each of two processes must be correct for a response to be correct. If so, the probability of a correct response is simply the product of the probability that the first stage produced a correct output and the probability that the second stage produced a correct output. Following Schweickert's arguments, we neglected the very unlikely event that two errors cancel each other to produce a correct outcome. We adapted this argument for the paradigm used in our experiment by considering each letter position in T_2 separately. The probability that the letter in position $p(L_p)$ is reported correctly is the probability that L_p was processed correctly in Stage 1 multiplied by the probability that L_p was processed correctly in Stage 2, which can be written as follows:

$$R_2(t,d)_p = K(t)_p * C(d)_p, \quad (1)$$

where $R_2(t,d)_p$ is the probability of a correct response in the $Task_2$ for letter position p, $K(t)_p$ is the probability that the letter at position p is correctly processed by the stage affected by exposure duration, and $C(d)_p$ is the probability that the letter at position p is correctly processed by the stage that is affected by $Task_1$ load. The function $K(t)$ represents the probability that a letter is correctly processed through the first stage, which is selectively affected by t (the exposure duration of T_2) but not by d (the $Task_1$ processing load effect). The function $C(d)$ represents the probability that the letter is processed correctly at the second stage, which is influenced by d but not t.

Taking the logarithm of both sides of Equation 1, we obtain

$$\log[R_2(t,d)] = \log[K(t)] + \log[C(d)], \quad (2)$$

showing that additivity is expected on log accuracy.

On the basis of Equation 2, we performed log-linear fits of the observed total number of letters recalled correctly in $Task_2$ separately for each letter position, using expected cell frequency tables of observed correct and incorrect responses in $Task_2$, crossed with the levels of T_2 exposure duration and the levels of $Task_1$ load (see Bishop, Fienberg, & Holland, 1985). We also performed fits in which letter position, exposure duration, and $Task_1$ load were considered simultaneously, allowing us to look for interactions between letter position and other variables.

A successful fit (a fit with deviations from the model that had a high probability of resulting from chance variation) suggested that the results could not reject the hypothesis that T_2 exposure duration and $Task_1$ load affected distinct stages of processing (Equations 1 and 2). Therefore, a good fit was taken to support the hypothesis of functional separability of T_2 exposure duration and $Task_1$ load. In contrast, an unsuccessful fit was taken to support the hypothesis of their functional interaction (see Schweickert, 1985). The chi-square statistic (χ^2) was used to estimate the global badness of fit of a particular model after parameters were adjusted so as to minimize χ^2. Given that we analyzed each letter position separately, our analyses provided five separate opportunities to reject the independent-factor effects model. We also performed analyses after aggregating results across all five letter positions.

Standardized lambdas associated with the variables considered in each fit are reported. Standardized lambdas provide a test of the significance of specific effects within a particular fit. For sufficiently large sample sizes, standardized lambdas are normally distributed with a mean of 0 and a standard deviation of 1. Thus, lambda values greater than 1.96 in absolute value indicate a significant effect at the .05 level for a particular variable in the model.

Subjects. Sixteen subjects were tested in all: 8 in Experiment 1, and 8 in Experiment 2. They were volunteers, University of Waterloo undergraduates, who performed the experiment for pay. All had normal or corrected-to-normal vision, and none had participated in a similar experiment before.

Stimuli. The visual stimuli were black characters presented on a white background, on a SVGA color computer screen (CRT) controlled by a 486 or 586 CPU. T_1 was an H, an S, an &, or a blank screen. T_2 was a horizontal string of five letters that contained no duplications (on each trial, five letters were drawn at random without replacement from a set of 19 letters that did not include A, E, I, O, U, H, or S). The characters were presented at the center of the computer screen and subtended 0.85° (height) × 0.8° of visual angle. The space between adjacent characters in T_2 was 0.1°. The mask for both T_1 and T_2 consisted of superimposed 0 (zero) and $ characters. The exposure duration of T_1 was 100 msec, and the mask duration was 50 msec, both after T_1 and after T_2. The exposure duration of T_2 was 50, 100, 150, 200, or 250 msec.

Procedure. Each trial was initiated by a press of the space bar on the computer keyboard. A fixation point was removed from view and, 400 msec later, T_1, its mask, T_2, and its mask were presented.

In Experiment 1, the various types of T_1 displays (H–S, &, or blank) were intermixed at random, within each block. The experiment began with one block of 30 practice trials, followed by 10 blocks of 30 trials.

In Experiment 2, the various types of T_1 displays (H–S, &, or blank) defined three types of trial blocks. The order of presentation of the blocks was randomized every three blocks at the time of testing. The experiment began with three blocks of 12 trials. These practice trials were followed by 12 blocks of 30 trials (four cycles through the three block types, using a different random order of blocks in each cycle).

Each subject was tested individually in a separate room. At the end of each trial, the program prompted the subject for a response in $Task_1$. If T_1 was an H, then the ">" key was to be pressed; if T_1 was an S, then the "?" key was to be pressed; and if T_1 was an & or a blank screen, then the space bar was to be pressed. These responses were to be made without speed pressure, at the end of the presentation sequence. After this response to T_1, the program required the subject to enter five letters, in the order in which they had been presented in T_2. The instructions informed the subjects that T_2 contained only letters and that letters were never repeated in a given T_2 display. The instructions asked the subjects to guess when they were not sure. In fact, the program did not proceed to the next trial unless the subject had entered five characters in this portion of the trial.

Results and Discussion

Accuracy in $Task_2$ was computed only for trials on which a correct response was made in $Task_1$. Given the high accuracy rate in $Task_1$, this procedure excluded very few trials from the the analysis of $Task_2$ results. The results for $Task_2$ were analyzed by computing the total

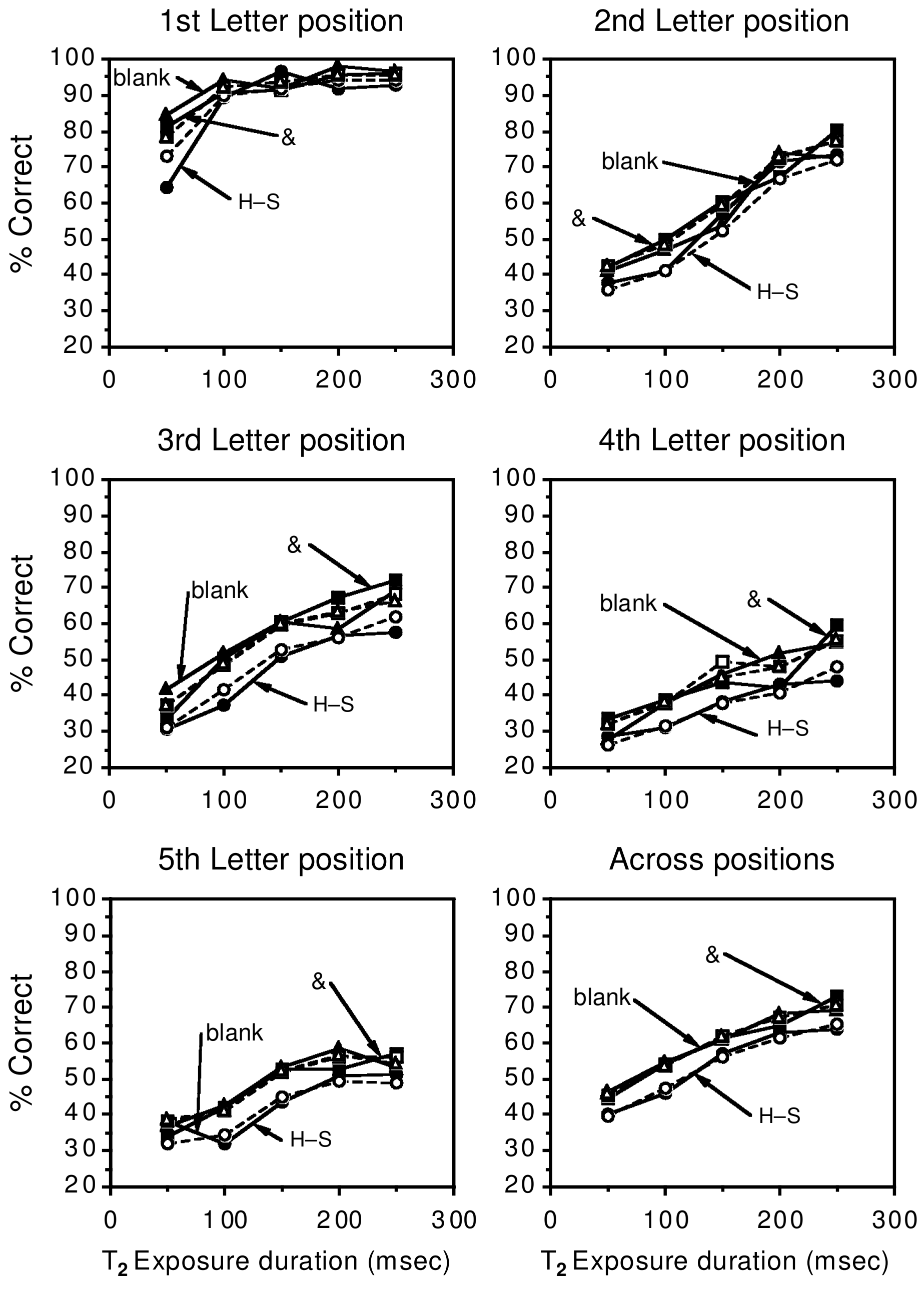

Figure 1. Results from Experiment 1. Filled symbols, solid lines: mean proportion of letters recalled correctly in $Task_2$, for each exposure duration of T_2 and for each $Task_1$ condition (H–S, &, or blank). Unfilled symbols, dashed lines: log-linear fit of the results.

number of characters recalled correctly, without regard to order of report. Although the scores are lower overall when order is taken into account, the pattern of results is very similar to that observed with order not taken into account.

The percentage of letters reported correctly in $Task_2$ of Experiment 1 is plotted in Figure 1, using filled symbols joined by solid lines. The results for Experiment 2 are shown in Figure 2. Each panel shows results for a particular letter position, except for the bottom right panel, which shows the results aggregated across all five positions. In each panel the results are shown for each exposure duration of T_2 and for the three levels of $Task_1$ load (blank vs. & vs. H–S).

We analyzed each experiment separately. In a first analysis, we fit the three-factor result matrix for the factors $Task_1$ load, exposure duration, and letter position. In both experiments, the model that provided the best fit to

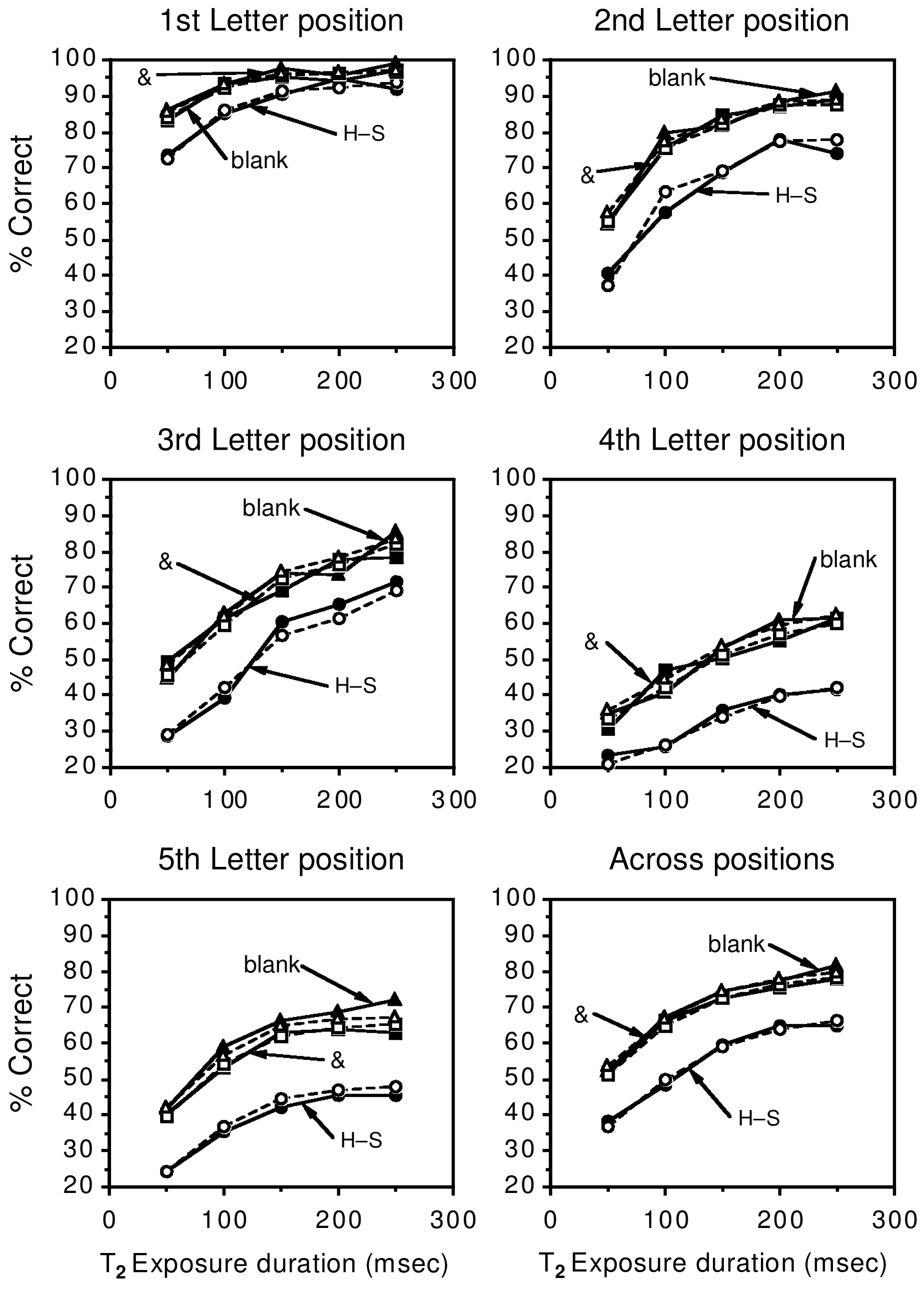

Figure 2. Results from Experiment 2. Filled symbols, solid lines: mean proportion of letters recalled correctly in $Task_2$, for each exposure duration of T_2 and for each $Task_1$ condition (H–S, &, or blank). Unfilled symbols, dashed lines: log-linear fit of the results.

the observed results included main effects of $Task_1$ load, exposure duration, and letter position and an interaction between exposure duration and letter position [Experiment 1, $\chi^2(48) = 60.04$, $p > .11$; Experiment 2, $\chi^2(48) = 38.45$, $p > .83$]. Most importantly, there was no interaction between $Task_1$ load and exposure duration. These log-linear fits are shown in Figures 1 and 2, using unfilled symbols joined by dashed lines. The lambda statistics from the log-linear analysis are shown in Tables 1A and 1B and Tables 2A and 2B.

We also performed 10 additional log-linear fits, one for each of the five letter positions in each experiment. These fits considered effects of exposure duration and $Task_1$ load. The interaction term was not significant in nine of these analyses. Only the results from Letter Position 1 in Experiment 1 had a significant interaction. The χ^2 and p values for each of the fits were as follows: Experiment 1 [Position 1, $\chi^2(8) = 15.64$, $p < .042$; Position 2, $\chi^2(8) = 6.98$, $p > .53$; Position 3, $\chi^2(8) = 7.20$, $p > .51$; Position 4, $\chi^2(8) = 7.81$, $p > .45$; Position 5, $\chi^2(8) =$

Table 1A
Lambda Values From the Log-Linear Fit (in Figure 1) for the Main Effects of Task$_1$ Load Condition, Letter Position, and Exposure Duration in Experiment 1

Task$_1$ Load Condition			Letter Position					Exposure Duration (msec)				
H–S	&	Blank	1	2	3	4	5	50	100	150	200	250
−5.736	2.931	2.678	28.53	−3.20	−8.58	−20.57	−15.40	−17.29	−6.03	1.97	7.44	10.23

Table 1B
Lambda Values From the Log-Linear Fit (in Figure 1) for the Interaction Between Letter Position and Exposure Duration in Experiment 1

	Exposure Duration (msec)				
Letter Position	50	100	150	200	250
1	−5.118	1.735	0.620	1.202	0.161
2	−0.193	−2.979	−1.906	1.833	2.768
3	−0.222	−0.033	0.866	−0.816	0.209
4	2.942	0.682	−0.442	−2.399	−0.708
5	3.962	−0.446	0.448	−0.955	−2.806

6.42, $p > .60$]; Experiment 2 [Position 1, $\chi^2(8) = 7.79$, $p > .45$; Position 2, $\chi^2(8) = 6.49$, $p > .59$; Position 3, $\chi^2(8) = 10.61$, $p > .22$; Position 4, $\chi^2(8) = 5.43$, $p > .71$; Position 5, $\chi^2(8) = 1.87$, $p > .98$].

Finally, we performed log-linear analyses of results that were aggregated across letter positions. As can be seen in the bottom right panels of Figures 1 and 2, fits of the results that did not include the interaction term were good [Experiment 1, $\chi^2(8) = 8.41$, $p > .38$; Experiment 2, $\chi^2(8) = 7.48$, $p > .48$].

Overall, the results provided strong support for a model in which exposure duration and Task$_1$ load have effects at separate stages of processing. Interestingly, there was also no interaction between Task$_1$ load and letter position, whereas letter position and exposure duration did interact significantly. These latter results suggest that exposure duration and letter position have some of their effects at a common stage. Our interpretation is that both of these variables affect encoding at an earlier stage than Task$_1$ load. This interpretation is consistent with recent results that suggest that effects of letter position occur at an early stage (Montant, Nazir, & Poncet, 1998; Nazir, Jacobs, & O'Regan, 1998).

The proportion of correct responses in Task$_1$ in Experiment 1 was analyzed using analyses of variance (ANOVAs) with Task$_1$ condition and T_2 exposure duration as within-subjects variables. Accuracy was generally very high, with an overall mean of .963. Accuracy was .951 in the H–S condition, .990 in the & condition, and .948 in the blank condition, which was not significant [$F(2,14) = 1.51$, $MS_e = 0.014646$, $p > .25$]. However, accuracy did vary slightly as a function of T_2 exposure duration (.971 ± .017 at 50 msec; .979 ± .017 at 100 msec; .944 ± .017 at 150 msec; .967 ± .017 at 200 msec; .954 ± .017 at 250 msec; error estimates are 95% within-subjects confidence intervals). The interaction between Task$_1$ condition and T_2 duration was not significant [$F(8,56) = 1.54$, $MS_e = 0.002302$, $p > .16$].

Because the trials were blocked by T_1 condition in Experiment 2, there were no Task$_1$ errors when T_1 was blank or when T_1 was an &. We analyzed Task$_1$ performance in H–S trial blocks as a function of T_2 duration using an ANOVA. Overall accuracy was .967 and did not differ across T_2 duration [$F(4,28) = 0.32$, $MS_e = 0.001541$, $p > .85$].

It is clear from the results in Figures 1 and 2 that the blank and & conditions in Task$_1$ produced results that were very similar. Log-linear fits that included only the variable T_2 exposure duration provided successful fits of the results within each experiment, showing that the effects of Task$_1$ load were not statistically different across the blank and & conditions [Experiment 1, $\chi^2(10) = 10.28$, $p > .4$; Experiment 2, $\chi^2(10) = 7.1$, $p > .7$].

Because the blank and & conditions were so similar in each experiment, we combined these two conditions in a final log-linear analysis on the results from Task$_2$ that included both experiments. This analysis was similar to those performed within each experiment, but it was performed only for the data aggregated over letter positions, and it included an additional variable: experiment (i.e., mixed vs. blocked trials). This analysis provides an additional test of the hypothesis that variables that affect the magnitude of the AB effect (i.e., mixed vs. blocked) should have effects that are functionally separate from those of T_2 exposure duration. The model that provided the best fit was one including a main effect of experiment, a main effect of Task$_1$ load (H–S trials vs. blank–& trials collapsed), and a main effect of T_2 exposure duration, along with one interaction term: the interaction between Task$_1$ load and experiment (mixed vs. blocked) [$\chi^2(24) = 24.12$, $p > .45$]. A model that did not include the interaction term provided an unsatisfactory fit [$\chi^2(26) = 59.19$, $p < .0002$]. The significant improvement in the fit from the model that did not include the interaction to the model that did shows that the interaction was statistically significant. The interaction can be seen by comparing the

Table 2A
Lambda Values From the Log-Linear Fit (in Figure 2) for the Main Effects of $Task_1$ Load Condition, Letter Position, and Exposure Duration in Experiment 2

$Task_1$ Load Condition			Letter Position					Exposure Duration (msec)				
H–S	&	Blank	1	2	3	4	5	50	100	150	200	250
−16.32	9.05	6.02	26.314	7.368	−6.310	−28.242	−19.338	−22.76	−5.96	4.12	8.33	10.72

Table 2B
Lambda Values From the Log-Linear Fit (in Figure 2) for the Interaction Between Letter Position and Exposure Duration in Experiment 2

	Exposure Duration (msec)				
Letter Position	50	100	150	200	250
1	−1.85	−0.12	0.78	0.02	0.57
2	−3.22	0.33	−0.27	1.87	0.62
3	−0.59	−1.79	−0.01	−0.09	2.09
4	3.57	−0.10	−1.19	−0.87	−1.33
5	2.67	1.74	0.12	−1.35	−2.86

results in the bottom right panels of Figures 1 and 2. As expected, there was a larger effect of $Task_1$ load when $Task_1$ conditions were blocked (Figure 2) than when they were mixed (Figure 1).

GENERAL DISCUSSION

The main results were clear-cut: An AB effect in $Task_2$ was found in both experiments when $Task_1$ required a discrimination between H and S, relative to blank-T_1 and &-T_1 control trials. This effect was larger when $Task_1$ load conditions were blocked rather than mixed. Performance in $Task_2$ also increased systematically as the exposure duration of T_2 was increased. The most important findings, however, were that the results could be fit well by log-linear models in which it was assumed that T_2 exposure duration and $Task_1$ load selectively influenced distinct sequential stages of processing (Schweickert, 1985).

The most straightforward interpretation of the results is that T_2 exposure duration affected a stage of processing that preceded the one that produced the AB effect. One possibility is that exposure duration affects the amount of information that is available for transfer to short-term memory, whereas $Task_1$ load affects the transfer process itself (Jolicœur, 1998, 1999a, 1999b; Jolicœur & Dell'Acqua, 1998). The evidence for selective influence of exposure duration and $Task_1$ load suggests that the AB effect must have a locus that is after the stage influenced by exposure duration, providing an additional constraint on the potential locus of the AB effect.

We are not claiming that T_2 exposure duration and $Task_1$ load will never interact. In fact, Jolicœur and Dell' Acqua (1999) found an interaction between the exposure duration of T_2 and the SOA between T_1 and T_2, by including a longer T_2 duration (550 msec) than the ones used in this study. The effects of SOA between T_1 and T_2 were significantly reduced for this longer T_2 duration than for two shorter ones (100 and 200 msec). Decreasing SOA generally increases the likelihood of dual-task interference due to $Task_1$ load effects. For the two shorter durations, the pattern of results was additive, as expected on the basis of the present results. As the duration of T_2 is lengthened, it will eventually become longer than the period of processing required to perform $Task_1$. As this happens, the influence of $Task_1$ load on performance in $Task_2$ should diminish, producing a shallower effect of SOA, as found by Jolicœur and Dell'Acqua (1999). In the extreme, if the duration of T_2 is very long, relative to the duration of processing required to perform $Task_1$, we would expect no effect of SOA at all. We interpret the results of Giesbrecht and Di Lollo (1998) and of Jolicœur (1999a) as providing such demonstrations. Both studies included some conditions in which there was no pattern mask following T_2. For these conditions, there was no observed influence of SOA on $Task_2$ accuracy (see also Blake & Fox, 1969). Although T_2 was exposed relatively briefly, the absence of a pattern mask presumably allowed the information in T_2 to persist for a long time (Coltheart, 1980), relative to the time required to perform $Task_1$. This long duration allowed the information in T_2 to bridge the period of time during which the processing of T_2 was subject to interference from processing in $Task_1$.

Rather than affecting distinct stages, one might argue that T_2 exposure duration and $Task_1$ load had a distinct effect on a common stage. For example, perhaps $Task_1$ load simply delayed the onset of encoding, whereas encoding was affected by exposure duration. If so, one might also expect additive effects of $Task_1$ load and T_2 exposure duration. This hypothesis runs into a significant problem, however. To see this, consider the $Task_1$ load effect in Experiment 2 (blocked $Task_1$ conditions). The difference between the number of letters recalled in the control conditions (average of blank and &) and that in the H–S condition was 0.72 letters. How much postponement in the onset of encoding would this drop in accuracy represent? To estimate this value, we regressed the average number of letters recalled correctly on the duration of T_2, using results from both experiments. The correlation was r =

.97, and the slope of the regression line was .006484 letters per millisecond of T_2 exposure duration. The drop in accuracy of 0.72 letters in the H–S condition relative to the controls in Experiment 2 corresponds to 111 msec of T_2 exposure duration. This raises an obvious problem for the notion that $Task_1$ load delayed processing, at the same stage that is affected by T_2 duration, because a delay of 111 msec should have resulted in the extraction of essentially no information when T_2 was exposed for either 50 or 100 msec. Assuming variability of stage durations, postponement of processing at a very early stage would tend to produce positively accelerated functions of T_2 duration, rather than the negatively accelerated functions that we did observe. Pashler (1989) also provides evidence that is inconsistent with the postponement of sensory encoding. Our results are best understood if we assume that the effects of $Task_1$ load are not due to a postponement of processing at an early stage or even at a stage as late as the stage(s) affected by T_2 exposure duration.

REFERENCES

Arnell, K. M., & Jolicœur, P. (1999). The attentional blink across stimulus modalities: Evidence for central processing limitations. *Journal of Experimental Psychology: Human Perception & Performance*, **25**, 630-648.

Bishop, Y. M. M., Fienberg, S. E., & Holland, P. W. (1985). *Discrete multivariate analysis: Theory and practice*. Cambridge, MA: MIT Press.

Blake, R. R., & Fox, R. (1969). Visual form recognition threshold and the psychological refractory period. *Perception & Psychophysics*, **5**, 46-48.

Broadbent, D. E., & Broadbent, M. H. P. (1987). From detection to identification: Response to multiple targets in rapid serial visual presentation. *Perception & Psychophysics*, **42**, 105-113.

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 & Performance*, **21**, 109-127.

Coltheart, M. (1980). Iconic memory and visible persistence. *Perception & Psychophysics*, **27**, 183-228.

Coltheart, M. (1982). Visual information-processing. In P. C. Dodwell (Ed.), *New horizons in psychology* (pp. 63-85). Harmondsworth, England: Penguin.

De Jong, R., & Sweet, J. B. (1994). Preparatory strategies in overlapping-task performance. *Perception & Psychophysics*, **55**, 142-151.

Duncan, J. (1980). The locus of interference in the perception of simultaneous stimuli. *Psychological Review*, **87**, 272-300.

Duncan, J., Ward, R., & Shapiro, K. L. (1994). Direct measurement of attentional dwell time in human vision. *Nature*, **369**, 313-315.

Giesbrecht, B. L., & Di Lollo, V. (1998). Beyond the attentional blink: Visual masking by item substitution. *Journal of Experimental Psychology: Human Perception & Performance*, **24**, 1454-1466.

Jolicœur, P. (1998). Modulation of the attentional blink by on-line response selection: Evidence from speeded and unspeeded $Task_1$ decisions. *Memory & Cognition*, **26**, 1014-1032.

Jolicœur, P. (1999a). Dual-task interference and visual encoding. *Journal of Experimental Psychology: Human Perception & Performance*, **25**, 596-616.

Jolicœur, P. (1999b). Restricted attentional capacity between sensory modalities. *Psychonomic Bulletin & Review*, **6**, 87-92.

Jolicœur, P., & Dell'Acqua, R. (1998) The demonstration of short-term consolidation. *Cognitive Psychology*, **36**, 138-202.

Jolicœur, P., & Dell'Acqua, R. (1999). Attentional and structural constraints on visual encoding. *Psychologische Forschung*, **62**, 154-164.

Kleiss, J. A., & Lane, D. M. (1986). Locus and persistence of capacity limitations in visual information processing. *Journal of Experimental Psychology: Human Perception & Performance*, **12**, 200-210.

Luck, S. J. (1998). Sources of dual-task interference: Evidence from human electrophysiology. *Psychological Science*, **9**, 223-227.

Luck, S. J., Vogel, E. K., & Shapiro, K. L. (1996). Word meaning can be accessed but not reported during the attentional blink. *Nature*, **382**, 616-618.

Montant, M., Nazir, T. A., & Poncet, M. (1998). Pure alexia and the viewing position effect in printed words. *Cognitive Neuropsychology*, **15**, 93-140.

Nazir, T. A., Jacobs, A. M., & O'Regan, J. K. (1998). Letter legibility and visual word recognition. *Memory & Cognition*, **26**, 810-821.

Pashler, H., (1989). Dissociations and dependencies between speed and accuracy: Evidence for a two-component theory of divided attention in simple tasks. *Cognitive Psychology*, **21**, 469-514.

Potter, M. C., Chun, M. M., Banks, B. S., & Muckenhoupt, M. (1998). Two attentional deficits in serial target search: The visual attentional blink and an amodal task-switch deficit. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **24**, 979-992.

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 & Performance*, **18**, 849-860.

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1995). Similarity determines the attentional blink. *Journal of Experimental Psychology: Human Perception & Performance*, **21**, 653-662.

Ross, N. E., & Jolicœur, P. (1999). Attentional blink for color. *Journal of Experimental Psychology: Human Perception & Performance*, **25**, 1483-1494.

Scheerer, E. (1973). Integration, interruption and processing rate in visual backward masking. *Psychologische Forschung*, **36**, 71-93.

Schweickert, R. (1985). Separable effects of factors on speed and accuracy: Memory scanning, lexical decision, and choice tasks. *Psychological Bulletin*, **97**, 530-546.

Shapiro, K. L., Caldwell, J. I., & Sorensen, R. E. (1998). Personal names and the attentional blink: The "cocktail party" effect revisited. *Journal of Experimental Psychology: Human Perception & Performance*, **23**, 504-514.

Shapiro, K. L., Driver, J., Ward, R., & Sorensen, R. E. (1997). Priming from the attentional blink: A failure to extract visual tokens but not visual types. *Psychological Science*, **8**, 95-100.

Shapiro, K. L., Raymond, J. E., & Arnell, K. M. (1994). Attention to visual pattern information produces the attentional blink in rapid serial visual presentation. *Journal of Experimental Psychology: Human Perception & Performance*, **20**, 357-371.

Shulman, H., & Hsieh, V. (1995, November). *The attention blink in mixed modality streams*. Paper presented at the 36th annual meeting of the Psychonomic Society, Los Angeles.

Sternberg, S. (1969). The discovery of processing stages: Extesions of Donders' method. *Acta Psychologica*, **30**, 276-315.

Ward, R., Duncan, J., & Shapiro, K. L. (1996). The slow time-course of visual attention. *Cognitive Psychology*, **30**, 79-109.

Weichselgartner, E., & Sperling, G. (1987). Dynamics of automatic and controlled visual attention. *Science*, **238**, 778-780.

(Manuscript received May 28, 1998;
revision accepted for publication August 27, 1999.)