Global and local attention in the attentional blink

David P. Crewther
Brain Sciences Institute, Swinburne University of Technology, Melbourne, Australia

Murray L. Lawson
School of Psychological Science, La Trobe University, Melbourne, Australia

Sheila G. Crewther
School of Psychological Science, La Trobe University, Melbourne, Australia

This study examines the attentional blink (AB) under conditions where attention was directed either to the overall (global) or to the component (local) form of compound Navon letters. Forty-five adult participants were presented RSVP sequences of compound letter stimuli and were asked to identify the prescribed attentional aspect of a red target letter (T1) and to detect the presence of a second item (T2 = letter X), again of specified global or local aspect. Trials were presented at either four or six letter forms per second (f/s). We report that the AB estimated from the mean performance across participants is much longer (1.5–2.5 s) than that reported previously with single letter RSVP (200–500 ms). A lag-1 sparing effect was not observed when data were filtered for correct identification of T1. Characteristic rapid (initial) and slower (later) recovery phases suggested the use of a bilinear (“knee”) recovery model, possibly identifying a novel slow recovery mechanism for the AB when its duration is sufficiently long. However, it is proposed that the duration of the AB should be analyzed by estimation of each individual’s AB prior to group analysis. Analysis of individual bilinear fits to the data shows a significant effect of attentional condition for the 4 f/s data, with more rapid recovery for Global–Global (GG) than Local–Local (LL) target conditions, consistent with the global precedence hypothesis. While the 6 f/s data did not demonstrate such differences between attentional conditions, it was at the expense of T1 identification performance with significantly poorer T1 identification for the LL cf GG conditions. Individual fits also demonstrate that the later slow recovery phase seen in the population mean data is clearly a result of pooling of the data from individuals reaching ceiling performance in recovery at different times. Analysis of the trials in which T1 was incorrectly identified yielded an attentional blink for T2 with delayed recovery and a manifest lag-1 sparing effect. This suggests, in the framework of the two stage model, that the duration of gate opening for target recognition requires sufficient certainty of recognition prior to closure, rather than being a fixed, process-related time.

Keywords: attentional blink, global and local attention, RSVP


Introduction

The characteristics of attentional processing differ depending on whether an observer focuses on the overall (global) form of an image or the component (local) details. This led Navon (1977) to propose the global precedence hypothesis that argues that the global aspect of a scene is preferentially processed relative to its local elements and that global processing is the default attentional state. The hypothesis has received considerable empirical support from both electrophysiological (Navon, 1991; Peressotti, Rumiati, Nicoletti, & Job, 1991) and reaction time studies (Han, Fan, Chen, & Zhuo, 1997; Heinze & Münte, 1993; Kotchoubey, Wascher, & Verleger, 1997; Navon, 1977; Pomerantz, 1983; Stoffier, 1993). Psychophysical studies have also consistently shown motor reaction time (MRT) advantages for global cf local information presented to different visual hemifields (Kimchi & Merhav, 1991; Polich & Aguilar, 1990; Polster & Rapcsak, 1994).

However, debate continues about the level at which global precedence may act to bias processing of global and local information. Heinze and Münte (1993) suggested that at the early stages of cortical processing, global and local information are processed in parallel, via independent neural pathways (Fink et al., 1996; Tanaka, Onoe, Tsukada, & Fujita, 2001).

Previously, it has also been reported that a different MRT cost occurs when shifting between global and local attentional states (Kotchoubey et al., 1997), a cost that is reflected in time to visual accommodation (Lawson, Crewther, Junghans, Crewther, & Kiely, 2005). This ability to shift between global and local levels of a visual scene is impaired by lesions to cortical areas around the temporoparietal junction in both hemispheres while it remains intact in cases of lesions to the prefrontal cortex (Robertson, Lamb, & Knight, 1991).
The rapid serial visual presentation (RSVP) based attentional blink (AB) provides an opportunity to investigate such attentional switching costs. The AB refers to the refractory period, following a conscious visual identification, during which accurate performance on a subsequent identification or detection task is impaired for approximately 200–400 ms (Raymond, Shapiro, & Arnell, 1992, 1995; Shapiro, Raymond, & Arnell, 1994). Typically, subjects in an AB experiment view RSVP of single letters and are asked to both identify a target letter T1 and to also detect the presence of a subsequent T2 item, rather than a simple masking of visual awareness (Shapiro et al., 1997). In the case of the AB, it has been suggested the short-term representation of T2 cannot be consolidated until processing of T1 is complete and consequently, under such conditions, T2 detection is reduced (Chun, 1995; Jolicoeur, 1998; Vogel et al., 1998). Indeed the ability to correctly detect the presence of T2 has been reported to be enhanced if it is in the serial position directly following the T1 (the “+1 item” effect (Chun & Potter, 1995), here called lag-1 sparing). On the basis that consolidation depends on difficulty, the duration of the AB is likely to depend on the difficulty of T1 identification (Jolicoeur, 1999; Ouimet & Jolicœur, 2007), although the literature is divided on this issue (Ward, Duncan, & Shapiro, 1996).

Investigators have attempted to separate the effects of the AB from those of task switching. Thus, Potter, Chun, Banks, and Muckenhaupt (1998) argued that when dual targets were cross modal (e.g., auditory/visual), impairment in performance was a result of task-set switching rather than an AB, though this claim has been challenged (Arnell & Jenkins, 2004). However, even within a single modality it is difficult to dissociate task switching from the fundamental basis of the AB—dual-task identification or detection. Thus, the AB is significantly reduced when combinations of two targets are reported as a single goal rather than reporting the two targets separately (Ferlazzo, Lucido, Di Nocera, Fagioli, & Sdoia, 2007).

The aim of this study was to examine the temporal limitations of global and local attentional processing by manipulating the RSVP rate and to investigate whether global precedence is evident in the duration of the AB. While the attentional blink is basically described by two parameters—depth and duration, there is no consensus on the best way to measure the latter. Three methods have been used—assaying how long dual-task T2 detection performance (filtered for T1 correct) takes to return to single (T2 detection only) trial performance (Chun, 1995; Raymond et al., 1992, 1995; Shapiro et al., 1994), recovery in T2 to an asymptotic level (at a long SOA) (Einhaüser, Koch, & Makeig, 2007) using statistical significance of the difference as the measure, or simply recovery of T2 performance to a criterion level (Lawson, Crewther, & Crewther, 1999). In all cases, mean T2 performance (percent correct) across participants has been used as the input measure.

Preliminary results suggest that the observed AB duration is longer for complex stimuli than for letter tasks (Lawson et al., 1998). Exposure duration has previously been shown to influence the processing of global–local information (Blanca, Zalabardo, García-Criado, & Siles, 1994) and stimulus rate has also been shown to influence the nature of the refractory period for probe detection in the AB (Arnell & Jenkins, 2004). Also, Jolicœur and Dell’Acqua (2000) proposed that the effects of exposure duration operate at an earlier stage of processing than the AB.

Two hypotheses were investigated. The first—global precedence, would predict that the AB for global targets should be shorter than that for local targets. The second—information processing cost, would predict that the AB should be longer for higher rates of information delivery in the RSVP sequences.

### Methods

#### Participants

Forty-five university students aged 18–30 years (M = 21.2) participated in the experiments and were considered to be novice observers according to the criteria of (Braun, 1998). All participants had normal or corrected-to-normal vision and were excluded if they reported any history of epilepsy. Only 24 participants completed both the 4 forms per second and 6 forms per second tasks and hence analysis is limited to this number.

#### Stimuli

Movies consisting of sequences of 25 complex letter stimuli presented in white on a black background (shown in Figure 1) The Navon letter sequences were created using the software Mathematica (v 3.0; Wolfram
Research, Champaign, USA) and saved in QuickTime™ format. The global/local letter form stimuli were presented using a custom designed computer interface (Authorware, v2.2; Macromedia, Redwood City, USA) including standardized auditory and written instructions for participants. Letters ("A" to "V" excluding "I") were presented in random order within the sequence; however, no letters were repeated consecutively at either the global or local level. The global aspect of the complex stimuli subtended a visual angle of approximately 4.7°/4.4 degrees, and the local items subtended 0.4°/0.5 degrees at the viewing distance of 57 cm. The sixth item in each sequence was nominated as T1 and was presented in red on the black background. In 90% of sequences T2 ('X,' in global or local form) was included in one of ten post-T1 serial positions (1, 2, 3, 4, 5, 6, 8, 10, 12, 15). In the remaining 10% of trials (randomly interleaved), no T2 item was presented at either level of the stimulus and these sequences served as control trials giving an index of the rate of correct negative identifications. Four trial blocks of 88 trials were presented for global and local T2 types at each post-T1 position.

Stimulus presentation rates were selected as either 4 or 6 f/s, i.e., exposure time for each letter stimulus was either 250 ms or 167 ms. Four f/s was chosen as the lower rate in order to make direct comparison with Lawson et al. (1998). Pilot studies showed that the extreme difficulty of the task limited the upper rate to 6 f/s even for experienced observers. The presentation rate was constant throughout a block of trials though randomly counterbalanced across subjects, with some subjects beginning trials at 4 f/s and others at 6 f/s (see Figure 1).

Procedure

Prior to commencing the experiment, participants were trained on the distinction between global and local letter forms and were initially trained on single identifications to at least 80% accuracy.

Upon self-initiating each experimental trial, participants were directed both visually and audibly to identify one (either global or local) aspect of the red T1 letter and then to detect the presence or absence of T2 (letter X) at the prescribed level (either global or local). After each trial, subjects were required to manually select T1 from four letter options presented on the monitor and the presence of T2 via a Yes/No button selection. Four attentional conditions were randomly interleaved: Global T1–Global T2 (GG), Global T1–Local T2 (GL), Local T2–Global T1 (LG), and Local T1–Local T2 (LL). Participants were informed that some trials would not contain a T2. Information identifying the subject number, type of trial, and participant’s responses were automatically recorded onto disk for later analysis.

Analysis

Data were initially filtered for correct T1 identification for each condition at each stimulus position. Percentage/fraction correct was calculated and confidence limits determined. T1 error data were retained for later analysis. Statistical analyses included repeated measure ANOVAs and t-tests. The data for the +15 item were removed from analysis because too many empty cells were encountered. As the mean recovery was manifestly non-linear, a bilinear curve-fit was chosen after comparison of goodness of fit ($\chi^2$) with other choices of fitting function involving the same number of free parameters (e.g., exponential fit). The bilinear curve fitting procedure for the data averaged across participants was coded in IGOR Pro (v6.0, Wave Metrics, Lake Oswego, USA). Two linear segments of the form

\[ y_1 = a_1 + b_1t \]
\[ y_2 = a_2 + b_2t \]

were articulated at the “knee” $k$ at time $t = k$, where

\[ k = \frac{a_1 - a_2}{b_2 - b_1}. \]

The bilinear fit was also applied to individual participant data (following a 3-point box smoothing) for each of the attentional and rate conditions, so that individual AB durations could be estimated. This has the added advantage of reducing the fluctuations (by fitting to a series of points) that might prejudice alternative methods (e.g., using the maximum performance across lags for each individual. Statistical analysis was carried out using SPSS (v 13) and IGOR (v6.0).
Results

T1 identification

Examination of Figure 2 indicates that the mean rate of correct T1 identification was lower overall for trials presented at 6 f/s compared with 4 f/s and also was affected by attentional state.

Repeated measures ANOVA showed a significant main effects for rate of presentation and attentional state on T1 identification (rate: \( F(1, 23) = 15.6, p = .001 \); attention: \( F(3, 21) = 3.74, p = .027 \)) with no significant interaction between rate and attentional state.

Attentional blink duration

The requirement of correct identification of the red T1 Navon figure and correct detection of the T2 (X) resulted in a deep reduction in performance (to approximately 30% correct) with mean recovery delayed for 1–2.5 s—i.e., the task conditions resulted in a prolonged deep attentional blink (see Figures 3 and 4) as shown by the mean T2 performance across participants for all attentional conditions and at both letter rates.

Several observations are immediately obvious. There is no evidence across any of the 4 attentional conditions and two stimulus presentation rates of a sparing of performance for the lag-1 item. At the lag-1 position, correct identification of the presence of the T2 was least in 7 of the 8 data sets (4 attentional conditions \( \times 2 \) rates) and for the remaining condition (GG at 6 f/s) there was no significant difference between lag-1 and lag-2 performance.

Inspection of the mean data shown in Figures 3 and 4 suggests an initially rapid linear recovery period, followed by a slower recovery, extending until nearly 3 s after T1 presentation. Several fitting functions were assayed and it was found that a bilinear function, articulated like a knee, gave the best fit (compared with linear or exponential fitting functions, the latter with the same number of free parameters), with chi-squared per point a mean factor of 2.8 smaller for knee fits compared with exponential fits for the 4 f/s data and marginally smaller for 6 f/s. The knee fit function is shown as the line of best fit (black) with 95% confidence for slope of the two linear limbs shaded in grey.

The data in Figures 3 and 4 show that the curve fits accommodate the mean data well in most cases. While performance overall was poorer for 6 f/s compared with 4 f/s, reflecting increased difficulty at the faster rate, the position of the knee occurred at roughly the same SOA, though performance at the knee was considerably less for 6 f/s compared with 4 f/s (see Table 1). The empty symbol in each graph shows mean performance on Null detection trials where no T2 item was included in the stream of letters following T1 at either the global or local level. The high value of this figure suggests that in all attentional conditions at 4 f/s, the data were not unduly influenced by false-positive T2 identifications. However, at 6 f/s, average correct Null detection was less for the attentional shifting (LG, GL) than for maintained attention (GG, LL) conditions (though the differences were not significant for either 4 f/s or 6 f/s).

The duration of the attentional blink in the current study was characterized in several ways. In the first method,
duration was defined by the post-T1 presentation time at which the mean T2 detection performance (as determined by the fit function) regained 80% accuracy since this level of single item identification was the criterion performance for pre-training in all participants (see Table 1).

Some qualitative differences in the shape of the AB function are evident in the mean data. Mean T2 detection performance recovers to 80% correct more rapidly with T1–T2 stimulus onset asynchrony (SOA) in the GG condition compared with the LL condition at 4 f/s (comparison of means in the region of the knee, 1.0 < t < 1.5 s, Fisher’s PLSD, p < .02).

The differences in duration at the higher presentation rate are less reliable because of the smaller slope of the second limb of the recovery curve and the higher variances compared with the 4 f/s data and are not significant.

These results are consistent with the analysis of the AB duration presented in Table 1. The effects of SOA, as well as attentional condition and frame rate, were analyzed statistically. Repeated measures ANOVA showed a significant main effect for SOA (Wilk’s lambda \( F(9, 15) = 23.62, p < .0005 \)). The main effect of frame rate was also significant (Wilk’s lambda, \( F = 16.68, p = .001 \)). However, the main effect for attentional condition (GG, GL, LG, LL) was not significant. In addition, there was not a significant interaction between SOA and attentional condition. Similarly, testing for attentional state switching (LG or GL) versus unchanged attention (GG or LL) showed insignificant differences.

The results in the above table, derived from the fit functions, show that using this method (80% T2 correct), the AB duration was shorter for GG compared to LL conditions at 4 f/s (and as noted above, post hoc testing shows mean performance under GG conditions around the knee position to be significantly greater than that for the LL condition). The differences in duration at the higher presentation rate are less reliable because of the smaller slope of the second limb of the recovery curve and the higher variances compared with the 4 f/s data, and hence are not significant.

The results presented in Figure 4 show that overall the pattern of recovery at 6 f/s follows a more linear trend than that observed at 4 f/s due to the greater slope of the

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Figure 3. Mean (across participants) correct T2 identification at 4 f/s for all attentional conditions (Global T1–Global T2, GG; Global T1–Local T2, GL; Local T1–Global T2, LG; and Local T1–Local T2, LL) shown across different SOAs. Error bars indicate standard error of the mean. Bilinear fit functions are shown as solid lines with 95% confidence for slope shown as gray shaded regions. Open symbols at the ends of the traces indicate mean Null detection performance.
second limb of the fit curve (i.e., the bend at the knee is not as great). Also the asymptotic performance level shows significant differences across condition in the 6 f/s data (repeated measures ANOVA of attentional condition on mean of last 4 data points, $F(3, 69) = 3.97, p = .012$).

The mean data averaged across participants shown in Figures 3 and 4 appear to provide evidence for two recovery mechanisms—an initial period of about 1 s during which recovery is rapid and a later, slower recovery lasting for a further 1–2 s. However, we questioned whether this method was indeed the correct way to estimate the duration of the AB. Comparing mean performance across participants and assessing when this is significantly different from some asymptotic recovery state (such as for extended SOAs of 1.5 s; Einhäuser et al. 2007) or comparing with trials in which T1 is not identified (e.g., Raymond et al., 1992) is conventional. However, further analysis is required to show whether this slower recovery phase observed in the current experiment represents a real mechanism or is a result of individual differences between participants. It is possible that individual variation in recovery time to some ceiling performance level could provide group data that resembles that recorded (see data simulation provided in supplementary materials). It is clear that if the question asked is: “What is the mean AB duration?” then the correct method for analysis is to estimate the AB duration for individuals before averaging. Thus, the bilinear fit process was extended to individual data and the position of the knee and slope of later recovery analyzed (see Figure 5, Table 2). The figure and table show that the mean knee position of individual bilinear fits is later and also at considerably higher percent correct (close to 100% correct) than that obtained by fitting the grouped data. In

![Figure 4](http://jov.arvojournals.org/) Mean correct T2 identification at 6 f/s for all attentional conditions (GG, LL, GL, LG). Error bars indicate standard error of the mean. Bilinear fit functions are shown as solid lines with 95% confidence for slope of the segments shown as gray shaded regions. Open symbols at the ends of the traces indicate mean Null detection performance.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Duration (s) (80% correct)</th>
<th>Knee (s)</th>
<th>Performance at knee</th>
</tr>
</thead>
<tbody>
<tr>
<td>GG</td>
<td>0.99 1.89</td>
<td>1.08 0.83</td>
<td>0.86 0.64</td>
</tr>
<tr>
<td>LL</td>
<td>1.55 2.15</td>
<td>1.09 0.77</td>
<td>0.77 0.60</td>
</tr>
<tr>
<td>GL</td>
<td>1.13 &gt;3</td>
<td>1.16 1.24</td>
<td>0.81 0.68</td>
</tr>
<tr>
<td>LG</td>
<td>1.16 1.67</td>
<td>1.25 0.81</td>
<td>0.84 0.69</td>
</tr>
</tbody>
</table>

Table 1. Duration of the attentional blink (s) for all attentional conditions at both 4 and 6 f/s. The knee position and performance are taken from fits to the grouped data.
addition, the slope of the second limb of the bilinear fit shows mean values consistent with zero, or perhaps slightly negative (see Figure 5B). This indicates that recovery has typically proceeded to ceiling level, with the implication that the individual knee position can be considered as the duration of the AB for that participant and condition.

Analysis of the individual knee positions across attentional conditions using separate ANOVAs for 4 and 6 f/s demonstrated a significant effect of attentional condition for 4 f/s ($F_{corr} = 2.71, p = .029$). Non-parametric post hoc tests (Newman–Keuls) demonstrated that the mean knee duration and hence mean AB was significantly longer for the LL condition than for the other three attentional conditions. Such an attentional effect was not observed at 6 f/s. Also, more rapid presentation (6 f/s) did not result in significantly longer mean AB than at 4 f/s, though a reduction in performance at the knee was obvious.

<table>
<thead>
<tr>
<th>Knee (s)</th>
<th>T2 % correct at knee</th>
<th>Final slope</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4 f/s</td>
<td>6 f/s</td>
</tr>
<tr>
<td>GG</td>
<td>1.52 ± 0.14</td>
<td>1.59 ± 0.14</td>
</tr>
<tr>
<td>GL</td>
<td>1.56 ± 0.10</td>
<td>1.56 ± 0.10</td>
</tr>
<tr>
<td>LG</td>
<td>1.66 ± 0.11</td>
<td>1.44 ± 0.08</td>
</tr>
<tr>
<td>LL</td>
<td>2.01 ± 0.14</td>
<td>1.42 ± 0.12</td>
</tr>
</tbody>
</table>

Table 2. Characteristics of the AB after individual knee fitting at 4 f/s and 6 f/s (means ± 1 SE). Compared with group analysis of Table 1, the mean knee position is later with much higher performance. In addition, the slope of the second limb is close to zero, suggesting the attainment of individual ceiling performance.
T2 detection following incorrect T1 identification

There is no inherent reason that an incorrect T1 identification, especially as administered here in a user-initiated trial sequence, should give a presumption of lack of sustained attention or a lack of intention to identify T1. Thus, T1 error trials would include those in which a participant was trying to identify T1 (but failed) and those in which attention was diverted, or those in which no effort to identify T1 was exerted (e.g., when an eyeblink coincided with T1 presentation). Thus, an AB-type effect would still be expected if a participant strove to identify T1, but failed. To investigate this possibility, mean subject performances on T2 detection were compared under T1 correct and T1 incorrect filters, pooled over the four attentional conditions in order to accumulate sufficient errors for analysis (see Figure 6).

Figure 6 shows that even under conditions where T1 was incorrectly identified, the T2 identification curve showed a characteristic recovery as a function of SOA just as with T1 error trials. However, two differences were observed. First, the recovery curve for T1 incorrect trials was both lower than that for T1 correct and shifted to the right (i.e., delayed). Repeated measures ANOVA showed differences between T1 correct and T1 error conditions ($F(1, 23) = 75.9, p < .0005$ for 4 f/s, $F(1, 23) = 39.8, p < .0005$ for 6 f/s). Secondly, the T1 error curve shows clear evidence for a lag-1 sparing effect in both the 4 f/s and 6 f/s data.

Discussion

As Lawson et al. (1998) demonstrated, the attentional blink for RSVP of Navon figures has a much longer duration than that for RSVP of single letters. This is consistent with the findings of Ouimet and Jolicœur (2007) that both the exposure duration and the difficulty of T1 identification lead to longer AB duration. Earlier research using RSVP of words rather than single letter stimuli has also reported AB durations longer than those observed in single letter tasks (Broadbent & Broadbent, 1987; Luck et al., 1996), but certainly less than the durations of up to 2 s found here (though see Ouimet & Jolicœur, 2007). The Navon letter stimuli employed in the current study are more attentionally demanding than single letter or word tasks as T1 actually involves two identities. Thus, T1 identification for the Navon figures involves selection of the correct attentional aspect of T1, given the task instructions, and suppression of the other global/local aspect of T1 as well as adjustment of ocular accommodation (Lawson et al., 2005). The influence of difficulty on performance is highlighted by the greater difficulty of T1 identification for the 6 f/s compared with 4 f/s presentation rate.

The finding of an effect of attentional state on the duration of the attentional blink for the 4 f/s data with a longer duration of the AB for the LL cf GG condition conforms with the global precedence suggestion of Navon (1991). If the global form is more rapidly recognized (for the forms used here), it is likely that recovery should be quicker. While at 6 f/s there was no main effect of attentional state on mean knee duration (and hence AB duration), the data of Figure 2 suggest that participants may have adopted a strategy that compensated between T1 and T2 identification tasks, T1 correct percentages at 6 f/s for local T1s being significantly lower than those for global T1s. The results of the current study, in terms of AB duration, would be well explained by the global precedence hypothesis suggesting that in order to process the local aspect of an image, the dominant global form must be suppressed or the default accommodation position of the system had to be altered to allow focus on a smaller local T1 (Lawson et al., 2005). Such suppression may
depend on the effect of the type of the cue used to indicate T1 (e.g., red color as a cue to T1 over the whole form may drive global precedence). While this question was not directly investigated here, coloration of only about half of the local letters comprising the global form of a Navon figure impedes global recognition and increases reaction time to global but not local form (Mevorach, Humphreys, & Shalev, 2006), presumably due to the loss of automatic grouping. Under such conditions, one would predict that global precedence would be reduced or eliminated.

The hypothesis that shorter exposure duration (faster rate) would lead to greater overall task difficulty was supported by the current results which emphasize the smaller fraction correct for T1 identifications at 6 f/s (see Figure 5) and the longer AB duration for all conditions when presented at a faster frame rate (using mean recovery—Method 1). Furthermore, analysis of T2 detection sensitivity showed a significant effect of presentation rate for all attentional conditions.

If any precedence of information processing is involved in varying the AB duration for global and local information, it is important to consider the perceptual and neural stages at which this effect may occur. In particular, it is important to consider whether the precedence leads to faster processing of global information overall, or whether precedence acts at the level of visual short-term memory in order to bias the access to identification and storage resources. Electrophysiological and psychophysical evidence has suggested that at the early stages of perceptual processing (P100) global and local information are likely processed in parallel and that differences in the processing of information only become evident at later stages of processing (Heinze, Hinrichs, Scholz, Burchert, & Mangun, 1998; Heinze & Münte, 1993). The parallel processing of both global and local forms may help explain why no definite effects of task switching of parallel processing of both global and local forms may emerge in T2 identification already complete by the presentation of the second, with T2 detection performance higher when T2 is presented immediately following T1 with minimum T2 detection found at later positions in the stream. The absence of lag-1 sparing in the data of Figures 3 and 4 could simply reflect the slower presentation rate, with T1 recognition already complete by the presentation of the next letter at 4 or 6 f/s. This would fit with the idea of gate closure, but the absence of lag-1 sparing also occurs when there is a shift of spatial attention between T1 and T2 (Visser, Zuvic, Bischof, & Di Lollo, 1999). However, lag-1 sparing is apparent in the data of Figure 6 for the trials in which T1 was incorrectly identified. Also, from this figure, it appears that the initial period of recovery from the AB in T2 identification is apparently delayed by approximately 0.5 s, with T2 detection at a minimum of around 20% correct for an SOA of 0.75 s at 4 f/s compared with T2 detection level of over 60% correct at the same SOA when T1 was correctly identified. It should also be noted that final recovery is not the same for T1 correct and T1 incorrect for both 4 and 6 f/s indicating a possible noise contribution such as that provided by random inattention.

This appears to be the first report of a lag-1 sparing effect emerging in T1 incorrect trials despite its absence in T1 correct trials. This suggests that the lack of immediate identification of T1 may cause the gate of Chun and Potter's (1995) 2-stage model to remain open allowing entry of the +1 item. Such an interpretation would be consistent with gate closure only occurring after a sufficient level of certainty of recognition is achieved. The literature does contain some related findings. Broadbent and Broadbent (1987) noted that the probability of T2 report immediately following an incorrect T1 identification (0.58) was higher than for conditions in which T1 was correctly identified (0.19). Moroni, Boucart, Humphreys, Henaff, and Belin (2000), in a study of agnosic patients, also noted that a reliable AB can be observed even when identification of T1 did not occur.

Two main methodological issues in this paper require further discussion. The first is the criterion for determining the duration of the attentional blink. Previous reports of the AB effect have utilized single T2 detection trials to estimate the control performance and have generally defined the end of the AB as the post-T1 presentation time at which mean T2 detection performance across participants reaches the control performance level. Due to the complexity of the current task and the number of trials involved in the experiment, the current study did not incorporate single T2 detection. Instead three methods were used. In the first, recovery to 80% accuracy—the performance level for initial single identification accuracy was used. While such a criterion can be used to compare performance across conditions, it has the potential disadvantage that asymptotic performance may differ across conditions and hence a fixed level of performance recovery may not truly reflect the duration of the AB. In the second, the group data were fit with a bilinear function, exposing fast and slow recovery stages and identifying the knee position as a marker of AB duration. Lastly, individual data were subjected to bilinear fits and the mean knee position and performance were determined. We argue that the third analysis is the correct approach, and that on the basis of the variability of the knee positions, the high T2 percent correct (near 90%) at the knee and the near zero mean slope for the second limb of the bilinear fits, that the recovery for each individual is simply terminated at ceiling (reached at the knee point). This also indicates that the slow recovery phase identified from averaging individual percent correct data prior to fitting tends to give a misleading picture of the termination of the AB. Also, if the mean knee duration is taken...
as the duration of the AB, then exposure duration did not significantly extend the duration of the AB, but caused significant reduction in T1 performance.

The second issue is whether percent T2 correct is a sufficiently good measure for the AB, or whether signal detection measures such as sensitivity (d-prime) would be preferable. The use of d-prime scores is recognized as useful in controlling for differences in false-positive rates across participants. However, close inspection indicates that the false alarm rate was nearly zero for all of the 4 f/s conditions, indicating that the fraction correct data were not offset by noise. It is possible that participants could have exhibited a criterion shift when attempting the more difficult 6 f/s RSVP experiments, a situation that sensitivity scores would correct for. The fact that the mean fraction correct at the lag-1 position for 6 f/s is very similar (approximately 30%) to that for 4 f/s data gives confidence that participants were reliably reflecting their perceptions across both stimulus rates. Also, in this study, the small percentage of null trials (included with the intention of eliminating a tendency to automatically respond YES to the presence of T2) would give an unreliable indication of false alarms.

However, one important problem that has not been dealt with in the current literature is the extent to which a person is likely to change their criterion level for observing T2 as a function of SOA. The methodology used here and in previous studies of the AB has estimated the number of false-positives via the use of Null trials. However, within this method, it is impossible to estimate whether the decision criterion (the level of confidence that they have or have not seen T2) alters with SOA. Until such analysis is available, it seems prudent to use percent correct data (as is common in the literature).

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Corresponding author: David P Crewther.

Email: dcrewther@swin.edu.au.

Address: Brain Sciences Institute, Swinburne University of Technology, Melbourne, VIC 3122, Australia.

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