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The role of preparation time in the attentional blink

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ABSTRACT

This research investigated the effect of foreperiod predictability in the *Attentional Blink* (AB). The AB, a cost in processing the second of two targets presented in close temporal proximity, was estimated using a minimalist procedure consisting of two letter targets and two letter fragment masks. In a four-step procedure, differences in foreperiod duration, target exposure duration, and inter-target interval were controlled in order to estimate the AB. Foreperiod was manipulated in three experiments. The AB effect was reduced when a single and relatively long foreperiod value was used (M = 880 ms, Experiment 2) in comparison to randomized (250–750 ms, Experiment 1) and single but relatively short foreperiods (M = 273 ms, Experiment 3). The results are discussed in the context of resource-sharing and preparation of a perceptual-set pertaining to physical target features including modality and intensity, as well as spatial and temporal predictability. It is concluded that foreperiods that are too brief for an individual observer or temporally unpredictable contribute to the AB.

1. Introduction

The ability to respond to a stimulus is affected by the opportunity to prepare for the response. The impact of foreperiod, that is, the duration of time from a cue signalling task onset to the presentation of a target stimulus, has been well documented with respect to reaction time performance (for a review see Niemi & Näätänen, 1981). Where reaction time is concerned, and foreperiod is constant within experimental blocks, longer foreperiods are associated with faster and more accurate responding. An interesting effect in this research is that when observers are presented with a range of foreperiods randomised over successive trials, reactions are faster to stimuli at the longest foreperiod, independent of the distribution of foreperiods. For example, if presented with foreperiods ranging from 500 ms to 3 s versus foreperiods ranging from 500 ms to 1 s, responses will be fastest to 3 and 1 s foreperiods respectively. Thus it would appear that the observers accumulate knowledge of the distribution and bias their response preparation to peak at the longer intervals (Vallesi & Shallice, 2007). As well as this cumulative effect, there is a also a trial by trial influence whereby reaction times will be slower if the current foreperiod is longer than the previous (Vallesi & Shallice, 2007; Van der Lubbe et al., 2004). Foreperiod effects have also been demonstrated to affect perceptual processing (Bausenhart, Rolke, & Ulrich, 2008; Rolke & Hofmann, 2007). The current investigation is concerned with how the foreperiod affects dual-target tasks, specifically those susceptible to the *Attentional Blink* (AB).

Visual dual-target tasks are often examined in a rapid serial visual presentation (RSVP) in which multiple stimuli, commonly letters or numbers, are presented in brief (stimulus onset asynchrony of 100 ms) succession at the same spatial location. Observers are then asked to identify or detect specified target items. With respect to letters, it may be the task of identifying two red letters in a series of black distracter letters. When the temporal separation between two targets is greater than about 500 ms, reporting accuracy for both targets is high. However, when two targets are presented within a 500 ms window, accuracy in reporting the second target (T2) is significantly reduced. This phenomenon has been labelled the AB, originally considered analogous to an eye-blink with respect to the processing of new information: whilst the eye is closed, no new information can be processed (Raymond, Shapiro, & Arnell, 1992). In light of more recent evidence, the AB might be considered a blink in conscious awareness given that there are electrophysiological responses to missed targets (Vogel, Luck, & Shapiro, 1998).

Models of the AB fall into two major categories: resource limitations and selection accounts. Both accounts consider two basic stages of RSVP processing. The first provides a subconscious sensory representation of all items and the second provides a conscious, reportable representation of the targets. It is considered that a capacity-limited set of resources is required for target processing and when two targets appear within 500 ms, resources can only be applied to one target, usually the first (Chun & Potter, 1995). A critical sub-theory in the resource limitation category is

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that of resource sharing (Jolicœur, 1998). Rather than a serial processing of one target and then another, this variation posits that resources are shared between targets, predominantly emphasising the first target (T1). For selection accounts, discriminating targets from distracters is the limiting factor. An example of a selection account comes from Di Lollo and colleagues (Di Lollo, Kawahara, et al., 2005; Di Lollo, Smilek, et al., 2005) who suggest that, in order for the targets to be consciously reported, the sensory representations must pass through a filter attuned to target features. For successful target filtering, this filter must be under endogenous control, that is, an attentional focus driven by the observer. This is in contrast to exogenous control in which attentional focus is driven by the stimulus (Monsell, 1996). The selection account proposes that the presence of distracter items following T1 forces the system into an exogenous state and it is not until endogenous control is regained that subsequent target processing can occur. During this loss of control, the representation of T2 may decay beyond that required for accurate report.

In the task-switching literature which uses a similar dual-target paradigm to that of the AB, increasing foreperiod length is considered to enhance task preparation reducing the cost of switching between tasks (Monsell, 2003). Although temporal orienting to T2 has been examined in the AB (Martens, Elmallah, et al., 2006; Martens & Johnson, 2005), specific effects of T1 foreperiod have not been considered. The aim of the current investigation is to determine whether the magnitude of the AB is reduced when adequate foreperiod durations are provided.

Rolke and Hofmann (2007) examined how foreperiod affected the sensitivity of a backward masked Landolt square to which observers were required to make a left–right judgment about the location of a gap in the square. Critically, sensitivity was higher in the longer foreperiod condition (2400 ms) compared with the shorter foreperiod condition (800 ms). They suggest that temporal uncertainly in target appearance reduces perceptual processing, therefore it is plausible that this effect may impact upon the AB. Single-target RSVP accuracy has been shown to be higher at longer foreperiods (Ariga & Yokosawa, 2008) and Martens et al. have manipulated temporal knowledge of T2, suggesting that temporal cueing reduces the magnitude of the AB (Martens, Elmallah, et al., 2006; Martens & Johnson, 2005).

The role of temporal orienting in the aforementioned research has been made using a full RSVP, including targets and distracters. Distracters in AB experiments are demonstrated to cause interference. Properties known to affect the AB include visual similarity (Maki et al., 1997), phonological similarity (Coltheart & Yen, 2007), and conceptual similarity (Dux & Coltheart, 2005). Implementing number distracters and letter targets, considered to be visually similar (Chun & Potter, 1995), may introduce an additional source of error which would be best excluded. We therefore implemented a minimalist procedure consisting of two targets and two visual masks, previously shown to be suitable for AB investigation (Duncan, Ward, & Shapiro, 1994; McLaughlin, Shore, & Klein, 2001; Rolke, Bausenhart, & Ulrich, 2007; Shore, Mclaughlin, & Klein, 2001; Ward, Duncan, & Shapiro, 1997). This minimalist procedure removes the influence of distracter items, allowing the effect to be more clearly underpinned by target processing. Recent research suggest that visual masks, formerly considered crucial to observing the AB effect (e.g., Raymond, Shapiro, & Arnell, 1992), are not required (Jannati, Spalek, & Di Lollo, 2011; Jannati et al., 2012). Therefore, the inclusion of backward masks in the current investigation merely provides a mechanism to control for target sensitivity and ensure that the results are free from ceiling effects.

To examine the effect of foreperiod on the AB, one option would be to set the same short and long foreperiods (e.g., 300 and 900 ms) for all individuals and compare the results. The weakness of this procedure is the assumption that the length of foreperiod has the same effect in all individuals. This is unlikely to be the case. It is more plausible that at 300 ms, some individuals may be less prepared and some more prepared. Therefore, the one-size-fits-all approached fails to adequately provide an equivalent manipulation of foreperiod between individuals. In order to control for foreperiod length, a methodology to enable careful control for individual differences in target and AB sensitivity was employed. Our minimalist procedure included a fixation cross, a blank foreperiod interval, T1 and a backward mask, a blank inter-target interval (ITI), followed by T2 and then a backward mask. This is depicted in Fig. 1. Utilising the minimalist display, psychophysical procedures can be used to estimate individually equated values of foreperiod, target exposure duration, and the length of the AB effect. With these values ascertained, the AB itself can then be measured. The AB effect itself refers to accuracy of detection across a number of ITIs.

We introduce a four-step procedure that utilises previous step estimates in order to equate for individual differences and control for their influence in subsequent steps. Step 1 involves estimating foreperiod. As mentioned with respect to reaction time at a range of foreperiod values, pilot testing indicated that exposure duration thresholds are lowest at longer foreperiods (for an example see Fig. 2) consistent with existing literature (Bausenhart, Rolke, & Ulrich, 2008; Rolke & Hofmann, 2007). Here we estimated the T1 exposure duration required for 75% correct identification at multiple foreperiods. An exponential decay function can then be fitted to exposure duration thresholds as a function of foreperiod length to estimate individually equivalent foreperiod values based on the half-life of this function (see Fig. 2 and Method for details). This individually fixed level of foreperiod is then implemented in Step 2 to determine exposure duration required for 75% T1 reporting accuracy. The foreperiod and exposure duration are then utilised in Step 3 in which the ITI is manipulated to determine an interval at which T2 is reported at 60% accuracy.[1] Finally, these three pieces of information are included in Step 4 in order to estimate the AB effect after controlling for individual differences in foreperiod, exposure duration, and ITI.

2. Experiment 1

In the first experiment we demonstrate the four-step procedure but do not use the foreperiod estimate for subsequent steps, using instead a randomized foreperiod (250–750 ms) to establish baseline AB pattern using this methodology. Previous experiments using the minimalist design have used foreperiod durations of 0 to 1000 ms with intervals (i.e., the minimum to maximum difference; e.g., 600–1000 = 400) ranging from 300 to 500 ms (Duncan, Ward, & Shapiro, 1994; McLaughlin, Shore, & Klein, 2001; Rolke, Bausenhart, & Ulrich, 2007; Shore, Mclaughlin, & Klein, 2001; Ward, Duncan, & Shapiro, 1996, 1997). The foreperiod range employed in Experiment 1 provides a baseline in the middle of the range used in existing research. Despite not using the foreperiod estimate, it is important that this step is included so that the procedure was equivalent in all experiments we wish to compare.

3. Materials and methods

3.1. Participants

There were 16 university students in Experiment 1. The mean age was 26.3 (SD = 6.09, min = 21, max = 42) and 5 were male. All

[1] The exposure duration of T1 and T2 is equivalent throughout: when T1 is adjusted, T2 is also adjusted. If Step 2 is successful, then the maximum expected accuracy for both targets is 75% in steps 3 and 4. In order for the adaptive procedure to operate, accuracy above and below the required threshold must be achievable, therefore, a lower threshold must be used in Step 3 and we selected 60%.

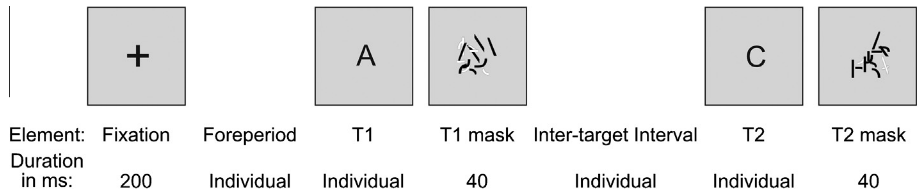

Fig. 1. Schematic representation of a single minimalist attentional blink trial. The series includes a fixation cross, a blank foreperiod, T1 and the T1 mask, a blank inter-target interval, followed by T2 and the T2 mask. The foreperiod, target and inter-target interval durations varied based upon individual performance in specific steps.

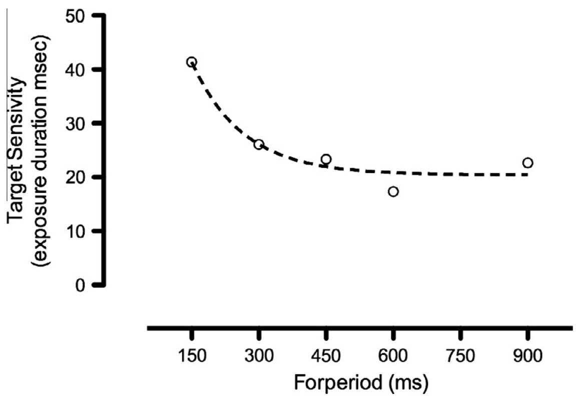

Fig. 2. Target sensitivity (exposure duration in ms) thresholds estimated at a series of foreperiods (fixation to target onset). The data depict the titrated exposure duration required for 75% identification accuracy of a backward masked letter target (A, B, or C) of a single individual and the dashed line depicts an exponential decay function fitted to these data.

had normal or corrected-to-normal visual acuity and were paid for participation.

3.2. Stimuli and apparatus

Stimuli were presented using a PC (clock rate = 933 MHz) running Matlab 6.5 to control a VSG2/3 board (Cambridge Research Systems, driving a Sony Trinitron Multiscan 20se monitor. This monitor was set to operate at 150 Hz (6.667 ms/frame). Target stimuli were the letters A, B, and C in Arial font, subtending 1° visual angle in height and width at a viewing distance of 60 cm. Black targets (luminance < 1 cd/m^2) were presented on a light grey background (CIE 1931 2° x = 0.290, y = 0.296, luminance 17.4 cd/m^2). Colours were measured using a Pritchard PR650 Spectrascan (Photo Research Inc., Chatsworth, USA).

3.3. Letter fragment masks

The targets were masked using letter fragments from the same Arial font as the targets. These were created using FontCreator, a font editing package (High-Logic, 1997–2007, FontCreator, Version 5.5, De Bilt, The Netherlands), where the 26 standard letters were split into multiple fragments. For example, the letter M was divided into a vertical line and left and right diagonal elements (e.g., |\ /). There were 46 different fragments in total. New masks were created, on a trial-by-trial basis, by randomly selecting 25 fragments and displacing each vertically or horizontally from 9 to 21 pixels (100 pixels subtended 0.124° of visual angle in height, 0.125° in width). The probability of the fragment being left or right as well as above or below the centre point was 0.5. Each fragment was black or white (CIE 1931 2° x = 0.292, y = 0.302, luminance 34.1 cd/m^2) with 0.5 probability. Luminance variation was included to avoid patches of entirely black or white fragments, which could provide a uniform square that the target could integrate with and remain visible. The exposure duration of the mask was always 40 ms.

3.4. Procedure

The AB was examined in a series of four steps designed to estimate and control for individual differences in sensitivity to foreperiod duration, target exposure duration, and ITI, and then estimate the AB. A basic trial included a 200 ms fixation-cross, a blank foreperiod, T1, a 40 ms letter-fragment mask, a blank ITI, T2, and a second 40 ms letter-fragment mask. In Experiment 1, the foreperiod derived from Step 1 was not carried forward into the subsequent steps. A foreperiod value ranging from 250 and 750 ms was randomly selected on each trial. For all steps, participants were required to identify two targets, each of which could be the letters A, B, or C. T1 and T2 were always different letters. Participants were prompted on screen (Was the first/second target A, B, or C?) following the T2 mask, and responses were made using a 3-response button box. The next trial was initiated after the T2 response was made. The four steps were conducted as follows.

3.4.1. Step 1: foreperiod estimation

Step 1 is included here to provide a complete description of the methods. Although it was conducted in Experiment 1 in order to maintain an equivalent process between experiments, the estimate was not carried through to subsequent steps as in Experiments 2 and 3.

The foreperiod procedure included a series of Parameter Estimation by Sequential Testing (Taylor & Creelman, 1967) procedures estimating T1 exposure duration required to achieve 75% correct identification. T1 and T2 were always presented at the same exposure duration with an ITI of 1000 ms, the broader AB literature and pilot studies indicating that there is minimal inter-target interference at this interval. Five interleaved staircases were completed, one at each foreperiod including 100, 300, 500, 700, and 900 ms. The target exposure durations commenced at 100 ms and there were 50 trials in each staircase, which were randomly interleaved within a 250 trial block, with self-terminating breaks at 50 trial intervals. The threshold derived from each staircase was based upon the average exposure duration of the final three reversals or, when three reversals were not achieved, the average of the final five trials.

With respect to foreperiod estimation, non-linear regression was used to fit curves to the data for each individual's session using Prism version 4.03 (Graphpad Software, San Diego, CA, www.graphpad.com) selecting the one-phase exponential decay function: $Y = (Y0\text{-plateau}) * \exp(-k * X) + \text{plateau}$ where k = rate constant, $Y0$ = maximum Y value, plateau = minimum Y value. The half-life was calculated as $\ln(2/k)$. Unstable staircase estimates were excluded. This stability was based upon the progress of the staircase: the optimal being a descending pattern with consistent performance over the final 10 trials and a problematic pattern being erratic peaks and troughs across the trials. Decay functions for three individuals in Experiment 1 failed to converge. As foreperiod values in Experiment 1 were not used for subsequent steps, this was not problematic and the procedure was adjusted in subsequent experiments.

3.4.2. Step 2: target exposure duration estimation

Step 2 estimated the average exposure duration required for 75% correct T1 identification. Foreperiod was assigned on a trial-by-trial basis by randomly selecting an interval from 250 to 750 ms. Both PEST and method of constant stimuli (MOCS) procedures were used in conjunction. Thresholds were initially estimated with PEST and the value was verified using MOCS. A third MOCS session was run if a consistent estimate (same number of frames) was not obtained. The MOCS procedures included a series of five levels of exposure duration (13.34, 26.68, 40.00, 53.36, and 66.67 ms) with 15 estimates at each level. A logistic function was fit to the data describing percentage correct as a function of duration to obtain the 75% correct point (Wichmann & Hill, 2001a, 2001b).

3.4.3. Step 3: inter-target interval estimation

Step 3 estimated the ITI required for 60% correct T2 identification. Foreperiod was randomized as in Step 2. The exposure duration of both targets was held constant at a duration estimated in Step 2 to support 75% correct identification of T1. In order to estimate the recovery ITI, MOCS was utilised first, including five levels of ITI (280, 420, 560, 700, and 840 ms) with 15 trials at each level. A threshold was selected by extracting the 60% accuracy point from a logistic fit similar to Step 2. A PEST procedure commencing at 700 ms was then used to verify this estimate. If there was a discrepancy of more than 50 ms between estimates, MOCS and then PEST estimations were repeated.

3.4.4. Step 4: attentional blink pattern estimation

Step 4 utilised the information gained in the Steps 2 and 3 to estimate the AB pattern. Foreperiod was randomized as in Step 2, target exposure duration was held constant, and ITI was modified using a MOCS procedure. T2 was presented at 0%, 25%, 50%, 75%, 100%, 125%, and 150% of observers' Step 3 ITI estimation, referred to as Inter-target Lags or Lag to avoid confusion with the ITI estimated in Step 3. There were 30 estimates at each Lag, resulting in 210 trials, completed in three equal blocks. At a Lag of 0, T2 was presented immediately following the T1 mask (see Fig. 1).

The AB pattern was analysed using a Target by Lag repeated measures ANOVA. Due to the dual-target nature of the exposure duration estimation, T1 accuracy contingent upon correct T2 identification was used as an estimate of baseline target accuracy. Due to the expectation that T2 accuracy would be lower than T1 at short Lags, indicating the AB effect, Bonferroni-corrected, single-tailed, planned comparisons were conducted to explore the nature of Target by Lag interactions.

In order to compare the shape of the AB functions between experiments, we fitted the AB function to the data and extracted the best fitting parameters (Cousineau, Charbonneau, & Jolicoeur, 2006). The Cousineau et al. methods allow for the extraction of four parameters that characterise the U-shape function of the AB (see Fig. 3). These parameters include: Lag-1 sparing, width, minimum, and amplitude. Lag-1 sparing refers to the high accuracy at the left side of the U-shape: when T2 is presented within 200 ms of T1, there is very limited cost in performance (see Section 11 for further details). Width reflects the degree of horizontal scaling of the U-shape, pertaining to the duration of AB recovery. Larger values indicate a longer recovery time. Minimum is the lowest level of T2 accuracy and is used for calculating the amplitude, which represents the difference between the maximum and minimum T2 accuracy. Therefore, amplitude provides an indication of the AB cost or interference. In order to clearly represent the group functions, these fitting procedures were applied to group means, resampled using a jack-knife method (see Robertson, 1991).[2] Because we were primarily concerned with the size of the effect, width and amplitude parameters were compared using t-tests.

This AB curve is fitted in Experiment 1 and displayed in Fig. 3 but the parameters are only reported in the context of Experiment 2 in order to compare between experiments.

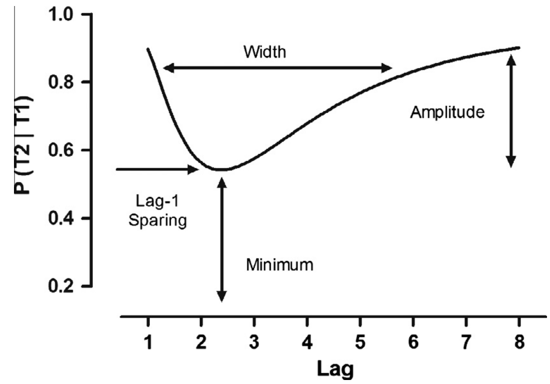

Fig. 3. Hypothetical proportion second target accuracy given correct first target report as a function of number of inter-target items (Lag). Cousineau, Charbonneau, and Jolicoeur's (2006) parameters are marked: Lag-1 sparing, width, minimum, and amplitude.

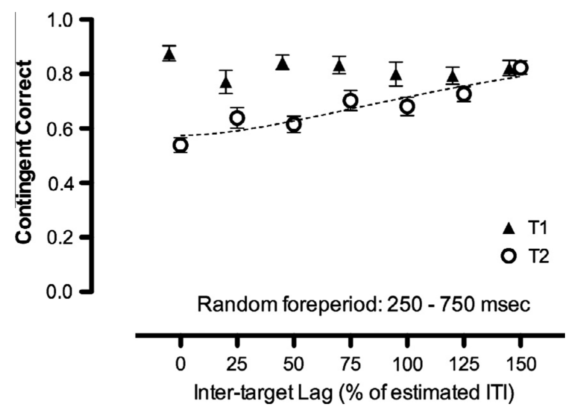

Fig. 4. Experiment 1 T1 and T2 contingent accuracy as a function of Inter-target Lag (100 = the inter-target interval estimated for T2 accuracy to be 60% in Step 3, mean = 551 ms). The dashed line represents the Cousineau, Charbonneau, and Jolicoeur (2006) AB parameter model of the effect. The error bars represent the standard error of the mean.

4. Results and discussion

Although not utilised in this experiment, for reference, the average R^2 value of the foreperiod fitting in Step 1 was 0.84 ($CI_{95\%}$ = 0.33), with an average half-life of 440 ms ($CI_{95\%}$ = 660). The average exposure duration estimated in Step 2 was 35 ms ($CI_{95\%}$ = 20), and the average ITI estimated in Step 3 was 551 ms ($CI_{95\%}$ = 352). T1 and T2 contingent accuracy as a function of Lag are presented in Fig. 4. T1 was unaffected by Lag[3] and T2 showed a monotonic AB pattern with higher accuracy at longer Lags. A 2 (target: T1, T2) by 7 (Lag: 0–150% of Step 3 ITI) repeated measure ANOVA indicated a significant effect of Target, $F(1,15) = 38.15$, $p < .001$, $\eta_p^2 = 0.72$; a significant effect

[2] Thanks to Pierre Jolicoeur for this suggestion.

[3] To clarify that T1 was not affected by Lag beyond the 2-way, Target by Lag interaction, a one-way ANOVA was conducted on T1 accuracy by Lag. This effect was not statistically significant, $F(6,90) = 1.71$, $p > .05$, $\eta^2 = 0.11$. This was also the case in Experiments 2 and 3; Experiment 2, $F(6,54) = 1.04$, $p > .05$, $\eta^2 = 0.11$; Experiment 3, $F(6,54) = 2.18$, $p > .05$, $\eta^2 = 0.24$.

of Lag, $F(6,90) = 3.26$, $p = 0.01$, $\eta_p^2 = 0.18$; and a significant Target by Lag interaction, $F(6,90) = 13.12$, $p < .001$, $\eta_p^2 = 0.47$. The main effect of Target reflected that overall T1 accuracy was higher than T2 accuracy. The main effect of Lag reflected that target accuracy was lower at Lag 25 than Lag 150. Finally the Target by Lag interaction reflected that T1 accuracy was higher than T2 accuracy at Lags less than 125% of Step 3 ITI. This therefore constitutes a significant AB effect suggesting that the procedure was successful.

5. Experiment 2

Experiment 2 aimed to examine the influence of a relatively long and predictable foreperiod on the AB effect, asking the question, does non-specific preparation contribute to the AB. To do this, foreperiod was set on an individual basis to equate for individual differences in non-specific preparation, derived from fitting an exponential decay function to T1 target sensitivity estimated over a series of foreperiods.

6. Method

6.1. Participants

There were 10 university students in Experiment 2. The mean age was 26.3 (SD = 6.09, min = 21, max = 42) and 5 were male. All had normal or corrected-to-normal visual acuity and were paid for participation.

6.2. Stimuli and apparatus

The basic procedural details were the same as Experiment 1 with the following exceptions. The Step 1 foreperiod distribution included 150, 400, 650, 900, and 1150 ms values and each staircase commenced at 80 ms of target exposure duration. The foreperiod distribution was adjusted by increasing the range of foreperiods to improve fitting success (i.e., avoid failure to converge). Despite these adjustments, the decay function failed to converge for 2 individuals and they were not included in the analysis. In Steps 2, 3, and 4 foreperiod was a constant value of 2-half-lives of the decay function. Also in Steps 2 and 3, the PEST staircases commenced at 80 ms and the number of estimates at each MOCS value was 10. This resulted in shorter sessions with 50 trials for each estimate.

7. Results and discussion

The average R^2 value of the foreperiod fitting in Step 1 was 0.81 ($CI_{95\%} = 0.33$), with an average half-life of 472 ms ($CI_{95\%} = 501$). The average exposure duration estimated in Step 2 was 35 ms ($CI_{95\%} = 20$), and the average ITI estimated in Step 3 was 545 ms ($CI_{95\%} = 313$). T1 and T2 contingent accuracy as a function of Lag is presented in Fig. 5. T1 was unaffected by Lag[3] and T2 showed a monotonic AB pattern of higher accuracy with longer Lags. A 2 (Target: T1, T2) by 7 (Lag: 0–150% of Step 3 ITI) repeated measure ANOVA indicated a significant effect of Target, $F(1,9) = 15.8$, $p < 0.001$, $\eta_p^2 = 0.64$; non-significant effect of Lag, $F(6,54) = 1.41$, $p = 0.23$, $\eta_p^2 = 0.14$; a non-significant Target by Lag interaction, $F(6,54) = 1.98$, $p = 0.09$, $\eta_p^2 = 0.18$. As in Experiment 1, the main effect of Target reflected that overall T1 accuracy was higher than T2 accuracy. Although the Target by Lag interaction was not significant, a p-value of 0.09 may be considered marginal. Follow-up tests indicated that T2 accuracy was significantly lower than T1 at Lags 0 and 25.

The effect size of the interaction was lower in Experiment 2 ($\eta_p^2 = 0.18$) compared with Experiment 1 ($\eta_p^2 = 0.47$) suggesting a

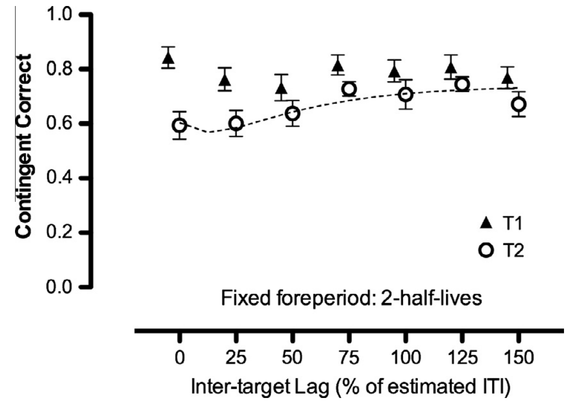

Fig. 5. Experiment 2 T1 and T2 contingent accuracy as a function of inter-target Lag (100 = the inter-target interval estimated for T2 accuracy to be 60% in Step 3, mean = 545 ms). The dashed line represents the Cousineau, Charbonneau, and Jolicoeur (2006) AB parameter model of the effect. The error bars represent the standard error of the mean.

greater AB effect in Experiment 1 with a random foreperiod. In fact, T2 accuracy was only lower at Lags of 0 and 25 in Experiment 2, corresponding to average time intervals of less than 120 ms, a period of time potentially unrelated to the AB effect (Visser et al., 1999). The AB is normally associated with maximum cost at around 300 ms, suggesting that the effect was limited when the foreperiod was constant. To directly compare the width and amplitude parameters of the AB function in Experiments 1 and 2, we used the fitting procedure outline by Cousineau, Charbonneau, and Jolicoeur (2006). The fitted curves are displayed in Figs. 4 and 5 as dashed lines. The mean (SD) width and amplitude parameters were; Experiment 1: 1.50 (0.03) and 0.43 (0.01), Experiment 2: −0.15 (0.16) and 0.17 (0.02). These parameters indicate a longer and deeper AB in Experiment 1 relative to Experiment 2. These effects were significantly different; width, $t(24) = 40.34$, $p < .001$, $R^2 = 0.99$; amplitude, $t(24) = 34.81$, $p < .001$, $R^2 = 0.98$.

These results suggest that the T1 foreperiod affects the AB. A predictable foreperiod, adjusted for individual sensitivity, significantly reduced both the duration and amplitude of the AB relative to a random foreperiod between 250 and 750 ms. There are however, two possible mechanisms for this reduction. The first is the predictability. By assigning a single foreperiod, the T1 temporal location was entirely predictable therefore it is possible that task-preparation could be tailored to this time. However, the second mechanism refers to an individually sensitive period of time. The foreperiod value was based upon 2-half-lives of the decay function fitted to a series of foreperiod values. This was selected to provide a relatively long, individually equated, time period for preparation. It is therefore possible that it was this period of time, rather than the predictability per se, that facilitated performance. To examine this possibility, we reduced the foreperiod value in Experiment 3.

8. Experiment 3

To test whether the reduced AB found in Experiment 2 could be attributed to T1 foreperiod length, in Experiment 3, a single, relatively short, foreperiod value was utilised in the four-step procedure.

9. Method

9.1. Participants

There were 10 university students in Experiment 3. The mean age was 23.4 (SD = 3.10, min = 29, max = 28), and 3 were male.

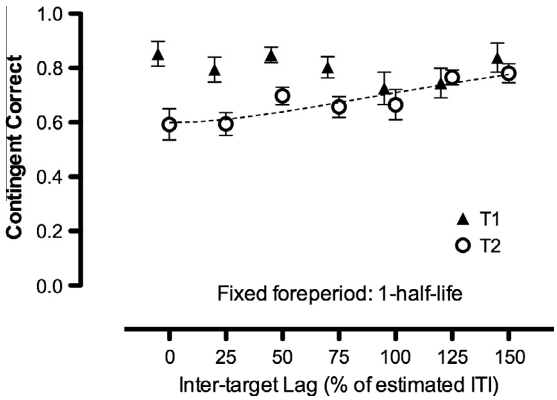

Fig. 6. Experiment 3 T1 and T2 contingent accuracy as a function of Inter-target Lag (100 = the inter-target interval estimated for T2 accuracy to be 60% in Step 3, mean = 538 ms). The dashed line represents the Cousineau, Charbonneau, and Jolicoeur (2006) AB parameter model of the effect. The error bars represent the standard error of the mean.

All had normal or corrected-to-normal visual acuity and were paid for participation.

9.2. Stimuli and apparatus

The basic procedural details were the same as Experiment 2 with the following exceptions. The Step 1 foreperiod distribution included 150, 300, 450, 600, 900, and 1200 ms values and each staircase included 40 trials, for a total of 240 trials. Again, the foreperiod distribution was adjusted to improve the fitting procedures and all were successful in this experiment. In Steps 2, 3, and 4 foreperiod was a constant value of 1-half-life of the decay function (half that in Experiment 2). The analysis and parameter extraction were completed as in Experiment 2.

10. Results and discussion

The average R^2 value of the foreperiod fitting in Step 1 was 0.83 ($CI_{95\%}$ = 0.22), with an average half-life of 273 ms ($CI_{95\%}$ = 213).[4] The average exposure duration estimated in Step 2 was 35 ms ($CI_{95\%}$ = 24), and the average ITI estimated in Step 3 was 538 ms ($CI_{95\%}$ = 347). T1 and T2 contingent accuracy as a function of Lag[3] is presented in Fig. 6. T1 was unaffected by Lag and T2 showed a monotonic AB pattern of higher accuracy at longer Lags. A 2 (target: T1, T2) by 7 (Lag: 0–150% of Step 3 ITI) repeated measure ANOVA indicated a significant effect of target, $F(1,9) = 12.59$, $p = 0.01$, $\eta_p^2 = 0.58$; a non-significant effect of Lag, $F(6,54) = 1.9$, $p = 0.1$, $\eta_p^2 = 0.17$; and a significant Target by Lag interaction, $F(6,54) = 5.59$, $p < 0.01$, $\eta_p^2 = 0.38$. As in Experiments 1 and 2, the main effect of Target reflected that overall, T1 accuracy was higher than T2 accuracy and the Target by Lag interaction reflected lower T2 accuracy at Lags less than 100% of Step 3 ITI.

The effect size of the Target by Lag interaction was higher in Experiment 3 ($\eta_p^2 = 0.38$) compared with Experiment 2 ($\eta_p^2 = 0.18$). On the surface this suggest a greater AB effect in Experiment 3 with a short foreperiod relative to Experiment 2 with a long foreperiod. To directly compare the width and amplitude parameters of the AB function across these experiments, we used the fitting procedure outline by Cousineau, Charbonneau, and Jolicoeur (2006). The fitted curve is displayed in Fig. 6 as a dashed line. The mean (SD) width and amplitude parameters in Experiment 3 were 1.56 (0.21) and 0.38 (0.05). These parameters indicate a longer and deeper AB relative to Experiment 2. These effects were significantly different with respect to Experiment 2, width, $t(18) = 20.50$, $p < .001$, $R^2 = 0.96$; amplitude, $t(18) = 11.14$, $p < .001$, $R^2 = 0.87$. These results suggest that a sufficiently long T1 foreperiod contributed towards the reduced AB in Experiment 2.

11. General discussion

Manipulations of foreperiod predictability and length altered accuracy in a dual-target AB task after controlling for individual differences in preparation (foreperiod duration), target sensitivity (exposure duration), and AB recovery (ITI). When the temporal position of T1 was unpredictable or predictable and short, a clear AB was apparent. In contrast, when the foreperiod was predictable and long, the AB effect was significantly reduced. These findings can be used to differentiate between resource limitation and selection models of the AB.

As mentioned, resource limitation models propose that a limited capacity is available for target consolidation. If these resources are occupied processing T1 while T2 is waiting to be consolidated, i.e., within approximately 500 ms, the necessary T2 details will be lost and T2 will be incorrectly reported (Chun & Potter, 1995). This model would predict an attenuated AB under circumstances where fewer resources were necessary for target consolidation such as for an easier task. As target difficulty was set to a fixed level across experiments, this cannot account for the current findings. A related model applicable to the AB is a resource-sharing which argues that the limited capacity is divided between the two targets (Jolicœur, 1998; Tombu & Jolicoeur, 2005). Whilst the idea of resource-sharing may be useful in accounting for the current findings, the limitation appears to be one of task preparation and not target consolidation. Potentially, task predictability allows for better coordination of resource deployment, which is ordinarily inefficient due to unpredictable or inadequate foreperiods. In a modified AB paradigm, Jolicoeur (1999) found that the speed of T1 response modulated the AB effect such that faster responses were associated with less cost. Jolicoeur suggested that trial-by-trial fluctuations in the availability of resources could account for this pattern. Further to this, the current findings may suggest that these fluctuations are due to differences in the level of preparation. Therefore, a limited capacity, resource-sharing model in which preparation affords balanced between-target sharing can account for the current results.

The competing selection models are less suitable at accounting for data derived from a minimalist procedure. Selecting between targets and distracters is a main feature of these accounts. For example, 'diffused' attentional states as proposed by Olivers and Nieuwenhuis (2005, 2006), suggests that when resources are overinvested in RSVP search, targets and distracters compete for report. However, when fewer resources are available or applied to the task, there is less competition between the targets and distracters and the AB effect is reduced. Consistent with Olivers and Nieuwenhuis, MacLean and Arnell (2011) found that greater physiological preparation was associated with a greater AB effect which seems at odds with the role of preparation assumed in our current findings. However, whereas a more diffuse and less prepared state may be advantageous when distracters must be ignored, this is not likely to be the case in the absence of distracters. In the minimalist procedure in which target sensitivity is carefully controlled, inattention would lead to poorer performance therefore preparation has a different role in the two experimental designs. A further selection account, Di Lollo et al.'s attentional control theory, also relies upon distracters disrupting the attentional state (Di Lollo, Kawahara, et al., 2005; Di Lollo, Smilek, et al., 2005). In both of these accounts, distracters are critical. It might be the case that

[4] The half-life value was not significantly different to those extracted in Experiments 1 and 2; $F(2,33) = 2.1$, $p = 0.14$, $\eta_p^2 = 0.06$.

the letter-fragment masks used in the current procedure provide the same role as distracter items, however, their role was equivalent between each experiment, and therefore selection models fail to explain the reduced AB effect with a predictable and long foreperiod in Experiment 2.

Therefore we are left with a timely deployment of attentional resources to account for the current findings. When an adequate and predictable period of time is available, observers are better able to allocate a limited set of resources between two rapidly presented targets for the purpose of identification. If this period of time is inadequate or unpredictable, the allocation of resources is effectively applied to the first but not the second target and additional time following the first target is required to perform the preparation for the second target. In this sense, some of the AB cost may relate to inadequate task-preparation. If dual-target preparation was incomplete at the appearance of T1, then further preparation would be required following this time, consistent with explanations of task switching (Monsell, 2003). This preparation has been related to the conceptual aspects of target processing (Monsell, 2003). Whilst it has been demonstrated that observer task-expectations influence the AB (Lagroix, Spalek, & Di Lollo, 2011), a further influence incorporating temporal expectations is required to account for the AB observed in the current investigation. A range of perceptual properties is also influential in the AB. This includes modality, intensity, and spatial location.

The existence of cross-modal AB effects between auditory and visual modalities is a debated topic (Arnell, 2001, 2006; Arnell & Duncan, 2002; Arnell & Jolicœur, 1999; Arnell & Larson, 2002; Soto-Faraco et al., 2002). Overall, limited AB effects for auditory versus visual targets as well as significant individual differences between visual and auditory versions of the task (Martens et al., 2009) suggests that modality is critical in the AB. Stimulus intensity also plays a critical role in the AB: decreased contrast being associated with larger AB effects (Christmann & Leuthold, 2004). Further to this, Shore et al. found that a clear effect of T1 difficultly was only apparent when the levels of difficulty (controlled by T1 to mask stimulus onset asynchrony: 15, 30, and 45 ms: hard, medium, easy) were blocked and therefore predictable (McLaughlin, Shore, & Klein, 2001; Shore, Mclaughlin, & Klein, 2001). This is evidence that variability may be obscuring important results. Adding spatial uncertainty to the AB presentation also increases AB magnitude (Visser, Boden, & Giaschi, 2004; Visser et al., 1999). Finally, the temporal predictability of target presentation was shown to reduce the AB effect in the current investigation as well as in previous investigations (Martens & Johnson, 2005; Martens et al., 2006a). The impact of variation in temporal location of a target stimulus is well documented (Niemi & Näätänen, 1981; Nobre, Correa, & Coull, 2007). The most relevant point appears to be that within a single block of mixed temporal target positions, target processing is more efficient at the longer positions. This mimics the accuracy effect noted within the current experiments with respect to the foreperiod estimation as well as T2 accuracy across Lags. In the current instance, is it not obvious how foreperiod and predictability interact with respect to preparation. The available evidence suggests that temporal uncertainty would override the benefit of an adequate foreperiod; however, this is an empirical question. Nevertheless, it appears that perceptual expectations are important in the AB and a concept such as *perceptual-set* that allows attention to be targeted on specific time intervals may provide an account of the current results (see Los, Knol, & Boers, 2001).

Perceptual-set can be defined as knowledge or expectations regarding the physical characteristics of the to-be-processed information. This concept has a long history (e.g., Bruner, 1957) and includes information pertaining to modality and intensity, as well as spatial and temporal location. In the current investigation, uncertainty related to temporal location exerted a significant cost in the dual-target task. The evidence reviewed above suggests that uncertainty related to modality, intensity, and spatial location may have similar influences. Perceptual-set is likely to develop with task experience. With continued exposure to the task, a representation of the physical characteristics of each target and the relationship between the targets will be established. Regarding temporal predictability, if a target occurs at a range of locations, accuracy would be expected to be highest at the later periods of this range as evidenced in foreperiod investigations (but see Bertelson, 1967; for ranges less than 300 ms). This may be a form of response bias, similar to that suggested with respect to inhibition of return (Taylor, 2007). Inhibition of return refers to slower response times to T2 when it occurs in the same spatial location as T1 (Posner & Cohen, 1984). Taylor suggested that this reflects a conservative response bias. Although the ITI is commonly balanced within AB investigations, if foreperiod is not controlled, adequate preparation is most likely afforded for those targets presented at longer ITIs. Therefore, there is a potential confound which may contribute towards the pattern of the effects commonly reported; however, it is yet to be demonstrated that T1 temporal predictability affects full RSVP AB performance although it appears to for single targets (Ariga & Yokosawa, 2008). Nevertheless, higher accuracy at longer ITIs may reflect the distribution of a limited set of resources between targets (Tombu & Jolicoeur, 2005), a distribution which improves with practice (Nakatani, Baijal, & van Leeuwen, 2009a, 2009b), potentially as the knowledge of the perceptual-set accumulates (Los, Knol, & Boers, 2001).

The concept of perceptual-set allows one to derive the hypothesis that if T1 and T2 presentation times were perfectly predictable, then there would be no AB. Therefore, not only does the temporal predictability of T1 impact upon T2 accuracy, so does the temporal predictability of T2 presentation. A direct test for a temporal predictability hypothesis would be to estimate accuracy at each Lag in a block-by-block procedure where Lags were not randomly assigned to each trial but were perfectly predictable within each block. Using this methodology, precisely the same perceptual-set could be adopted for each trial within a block. Under these conditions it would be predicted that there would be no performance cost to either T1 or T2 performance except perhaps within the initial trials of the block during which the observer is establishing perceptual-set.

11.1. Lag-1 sparing

One aspect of the AB effect that we have not yet covered in detail is that of Lag-1 sparing (referred to as 'sparing' in the followed discussion). It is commonly the case that the AB effect follows a U-shape, such that T2 accuracy at very short intervals is high: 'spared' from the cost of the AB. This sparing tends to occur when the T1 and T2 tasks are similar (Potter et al., 1998) and may actually be extended when multiple targets are presented in the absence of distracters (Visser & Ohan, 2011). Visser, Bischof, and Di Lollo (1999) suggested that sparing and the AB are independent events, therefore, the absence in the current experiments holds no bearing on the presence of the AB effect. In fact, the absence of sparing in the current experiment is consistent with other investigations using the minimalist, target-mask procedure (Duncan, Ward, & Shapiro, 1994; McLaughlin, Shore, & Klein, 2001; Rolke, Bausenhart, & Ulrich, 2007; Shore, Mclaughlin, & Klein, 2001; Ward, Duncan, & Shapiro, 1996, 1997).

Explanations of Lag-1 sparing posit that the appearance of target opens a gating mechanism that is slow to close, therefore subsequent RSVP items may also enter and compete for robust representation in short-term memory (Reeves & Sperling, 1986). If T2 follows T1 within approximately 100 ms, both targets can be accuracy reported. Consistent with this explanation, analyses of errors indicate that items immediately following targets are more often reported and T1-T2 order reversals are higher at shorter ITIs (Akyürek & Hommel, 2005; Hommel & Akyürek, 2005). McLaughlin et al. suggest that the absence of sparing in the minimalist procedure may be as simple as T1 being followed by a mask rather than T2: a view supported by Martin and Shapiro (2008). Consistent with temporal integration of T1 and T2 and provided both elements are visible in the combined percept then sparing is observed. The letter-fragment masks employed in the current investigation, render the independent recognition of the two targets in the integrated percept impossible and so no sparing is observed here. A further possibility relates to control of the gating mechanism. Akyürek and Hommel suggest that closing of this gate is under endogenous control. Therefore, in the minimalist design, with consistent and non-target backward masking, observers may time the closing of this gating mechanism, abolishing the incidence of Lag-1 sparing.

11.2. Limitations

Our comparison between foreperiod settings utilised a between-subjects design. It may be the case that group differences underpin some of the variation between experiments. Individual differences have been demonstrated within the AB (Martens, Munneke, et al., 2006) and it is possible that we randomly assigned 'better' participants to Experiment 2, although we do not think this is a strong possibility. Furthermore, the rigorous use of thresholds to equate sensitivities between individuals also reduces the likelihood that individual differences would have influenced the result. Implementing this procedure as a within-subjects design is impractical and cautioned against (Poulton, 1973, 1975); as the nature of the measurement has a tendency to reduce an individual's threshold, resulting in unwanted interactions between conditions. Interleaving the conditions to control for learning would have reintroduced the unpredictability that we were trying to eliminate.

Sensitivity to the target was equated using exposure duration and is therefore limited by the 150 Hz monitor we used. Although this delivers refresh rates of approximately 7 ms, given the steep slope of the psychometric curve, adjustments of a single refresh can deliver performance below or above the desired threshold for some individuals. Therefore, for future investigations, it may be worthwhile equating sensitivity using a more continuous property.

We altered the array of foreperiod values between experiments in order to maximise the success of the exponential decay fitting. The mean half-life value did not differ significantly between our groups, although it was lower in Experiment 3. However, unpublished data from our laboratory using the Experiment 2 foreperiod array has returned lower (less by 170 ms) half-life values, therefore it is not clear that the foreperiod array resulted in this difference.

12. Conclusions

Evidence of limited AB interference at an individually selected, long and predictable T1 foreperiod, can be explained with respect to resource-sharing and task preparation to establish temporal elements of a perceptual-set. A perceptual-set must be available to predict the physical attributes of the targets, most importantly, temporal location. This account is consistent with resource sharing and generates additional predictions with respect to physical characteristics of the target stimuli.

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