Target sparing effects in the attentional blink depend on type of stimulus

Evan J. Livesey · Irina M. Harris

Abstract In a typical attentional blink (AB) experiment, recognition of the second of two serially presented targets is impaired if it occurs around 200–500 ms after the first. However, recognition for the second item is often intact if the two targets occur consecutively (lag-1 sparing). Recent theories of the AB have placed great emphasis on the presence of lag-1 sparing and protracted sparing effects, where accurate performance is seemingly maintained across three or more targets, provided that they are presented consecutively. Here, we show that the type of stimulus (objects vs. letters) used in rapid serial visual presentation streams has a significant effect on the extent of lag-1 sparing, without a commensurate influence on the AB. In addition, multiple consecutive targets produce strikingly different patterns of sparing for objects and letters. These findings suggest that the processes mediating lag-1 sparing are independent of those underlying the AB.

Keywords Attentional blink · Lag-1 sparing · Extended sparing · Object recognition

Studies of the temporal deployment of attention, which utilise rapid serial visual presentation (RSVP), have revealed a number of striking limitations in processing visual stimuli. The attentional blink (AB) is perhaps the most prominent example: When two targets are presented amongst a sequence of distractors in RSVP, detection of the second target is often severely impaired if that target occurs shortly after the first (Broadbent & Broadbent, 1987; Raymond, Shapiro, & Arnell, 1992). The AB has become a fulcrum for current debate about the processes responsible

E. J. Livesey (✉) · I. M. Harris
School of Psychology, University of Sydney,
Sydney 2006 New South Wales, Australia
e-mail: evan.livesey@sydney.edu.au

for human visual attention. Various theories of visual attention explain the AB as a consequence of a "bottleneck" at a late stage in information processing (Chun & Potter, 1995; Jolicœur & Dell'Acqua, 1998). Such a view attributes the AB to capacity limits on processing, coupled with a depletion of available resources, as a consequence of consolidating the initial target. Others have argued that the AB may reflect an attentional deployment mechanism that gates or inhibits processing that, under some circumstances, prevents the processing of relevant information such as the second target (Olivers & Meeter, 2008; Raymond et al., 1992; Taatgen, Juvina, Schipper, Borst, & Martens, 2009).

Lag-1 sparing and its relationship to the AB

Recent theoretical attempts to distinguish between these accounts have focussed on one aspect of the AB in particular. When the targets occur consecutively in an RSVP sequence (such that they are not separated by any intervening distractors), recognition of the second target is largely unimpaired, a phenomenon referred to as *lag-1 sparing* (Potter, Chun, Banks, & Muckenhoupt, 1998). Lag-1 sparing is not typically observed when the targets appear in different spatial locations (e.g., Visser, Zuvic, Bischof, & Di Lollo, 1999b). However, a comprehensive meta-analysis of early work on the AB by Visser, Bischof, and Di Lollo (1999a) revealed that lag-1 sparing is a fairly ubiquitous phenomenon in AB studies that did not contain a shift in the task, modality, or spatial location of the serially presented targets. Several studies have recently shown that recognition of a target appearing two serial positions after the first target (T1) is markedly better if the intervening item is another target than if that item is a distractor (Di Lollo, Kawahara, Ghorashi, & Enns, 2005; Kawahara,

Kumada, & Di Lollo, 2006; Nieuwenstein & Potter, 2006), implying that the presence of an intervening distractor, rather than a depletion of attentional resources caused by T1 processing, may be the critical factor for producing the AB.

Some researchers have argued that sparing effects of this nature indicate the operation of an executive process that maintains an attentional filter tuned to target features (Di Lollo et al., 2005; Kawahara et al., 2006). The filter correctly rejects the initial distractors in the RSVP stream until the occurrence of T1. However, while the central processor is consumed with the task of processing T1, endogenous maintenance of the filter is lost, and as a consequence, exogenous events preside over its fate. If the post-T1 item is another target, and therefore possesses the characteristics to which the filter is tuned, then the configuration of the filter does not change and continues to operate effectively. This means that consecutive targets are processed without impairment (lag-1 sparing). If the post-T1 item is a distractor, the mismatch between the filter and the properties of the distractor causes a disruption in the tuning of the filter. This means that items following the post-T1 distractor are not selected correctly, resulting in impaired target processing (the AB). This temporary loss of control (TLC) hypothesis provides a clear account of lag-1 sparing: As long as RSVP items match the desired features, an optimal attentional setting can be maintained, and this allows for consecutive targets to be selected and consolidated for report. In contrast, if the target is followed by a distractor that does not match the filter configuration, the selection of subsequent targets is disrupted, resulting in an AB. Thus, according to Di Lollo et al.'s (2005) TLC hypothesis, the AB is due to the T1+1 distractor exogenously disrupting target selection processes, whereas lag-1 sparing reflects the continuous operation of this selection filter.

A somewhat different approach, which also emphasises the role of the T1+1 item, is the "boost-and-bounce" theory proposed by Olivers and Meeter (2008). In this model, T1 processing triggers a temporary enhancement (boost) in attention that carries over to the item that immediately follows T1. If this item is also a target, it will benefit from the inertia of the original attentional boost and will be encoded successfully, resulting in lag-1 (or more protracted) sparing effects for consecutive targets. On the other hand, if the T1+1 item is a distractor, the accidental attentional boost accorded to this item will, in turn, trigger a corrective inhibitory response (bounce), resulting in the loss of any subsequent targets (i.e., an AB for targets following a T1+1 distractor). Thus, unlike the TLC model, which suggests that the AB is caused by a loss of endogenous control over selection processes, the boost-and-bounce model views the AB as the result of actively correcting the overinvestment of attention in the distractors to prevent interference with the targets.

According to both TLC and boost-and-bounce models, the AB and lag-1 sparing are completely determined by the dynamics of the selection mechanisms tuned to target-defining features. This is not to say that the magnitude of lag-1 sparing and the AB will necessarily correlate across different experimental conditions (and, indeed, Visser et al., 1999a, found that they do not), but rather that a prediction of lag-1 sparing naturally follows from both of these theoretical explanations of the AB. Importantly, both models predict that when targets are presented consecutively in the same location and are selected on the basis of the same target-defining properties, processing of T2 should not be affected by an AB.

In contrast, resource limitation accounts view the AB as the result of a processing bottleneck induced by the consolidation of T1. The process that yields an AB is assumed to be general and to be in operation regardless of whether the post-T1 item is a target or a distractor, whereas lag-1 sparing is usually explained by suggesting that two consecutive targets may be processed in the same attentional episode and undergo consolidation together (e.g., Chun & Potter, 1995; Jolicœur & Dell'Acqua, 1998; Potter, Chun, Banks, & Muckenhoupt, 1998). In this sense, lag-1 sparing merely reveals a compensatory mechanism that mitigates the effect of attentional deficits under certain circumstances. Resource limitation accounts point out that sparing often occurs as a result of a trade-off between processing T1 and T2 (Dell'Acqua, Jolicœur, Luria, & Pluchino, 2009; Dux, Asplund, & Marois, 2008, 2009; Potter, Staub, & O'Connor, 2002), thus belying an underlying capacity limitation in processing multiple items, although they emphasise that the AB and lag-1 sparing are largely independent.

A recent model of the AB put forward by Wyble, Bowman, and Nieuwenstein (2009) offers an alternative explanation of lag-1 sparing. Their *episodic, simultaneous type, serial token* (eSTST) model incorporates both resource depletion and attentional selection mechanisms. Targets in RSVP are encoded in working memory through the integration of type information (i.e., abstract representations of the targets) with tokens that confer information about the episodic context in which the targets occur. The process of linking types to tokens is governed by a dynamic attentional filter (the "blaster"), which acts much like the attentional boost in the boost-and-bounce model. According to the eSTST model, the AB is the consequence of the attentional blaster being disabled in order to segregate target-encoding episodes. However, when targets are presented consecutively, they continue to excite the blaster and are successfully encoded, resulting in target sparing. Importantly, this sparing comes at the cost of episodic distinctiveness, because the encoding episodes are no longer segregated. This loss of episodic distinctiveness

leads to serial order errors, potential failures to encode repetitions (Kanwisher, 1987), and a higher probability that the first target will be lost, due to competition from the spared second target. Furthermore, the eSTST model predicts that during sparing, there will be a higher incidence of binding errors between individual elements of the targets (Wyble et al., 2009).

Limits on lag-1 sparing

Some recent findings have called into question the generality of lag-1 sparing effects. Firstly, studies by Harris and colleagues (Dux & Harris, 2007; Harris, Benito, & Dux, 2010) have observed surprisingly little lag-1 sparing when using line drawings of familiar objects as stimuli, despite finding a robust AB for these stimuli.[1] This finding stands in sharp contrast to the almost universal presence of lag-1 sparing when the stimuli are alphanumeric characters. In the studies by Harris and colleagues, targets were typically defined by colour (e.g., red items amongst black distractors) or sometimes by category (e.g., animals amongst nonanimal distractors), so the selection requirements were very similar to those used in many studies that had found lag-1 sparing using alphanumeric characters. This suggests that the presence of lag-1 sparing might be dependent on the type of stimulus used, unlike the AB, which is observed over a large range of stimuli (including words as well as pictures of objects and natural scenes; e.g., Coltheart, Mondy, Dux, & Stephenson, 2004; Dux & Harris, 2007; Einhauser, Koch, & Makeig, 2007; Evans & Treisman, 2005; Potter, Wyble, Pandav, & Olejarczyk, 2010). This apparent selectivity of lag-1 sparing poses a challenge to attentional selection accounts that assume that the mechanisms responsible for the AB generally will not affect consecutive targets (in other words, lag-1 sparing should be as general as the AB itself).

Secondly, Dell'Acqua, Jolicœur, Pascali, and Pluchino (2007) have shown a dissociation between the AB and lag-1 sparing effects according to task demands. In their study, participants monitored RSVP streams containing zero, one, or two single-digit targets presented amongst letter distractors. In one task, participants had to report the identity of the digits, whereas in another task they simply reported how many digits were present in the stream. Both tasks resulted in an

AB (i.e., decreased performance when T2 followed T1 with a short lag, as compared to a long lag). In contrast, lag-1 sparing only occurred in the identification task, not in the counting task. One could argue that the counting task enforces the need to encode separate episodic representations of the targets. Thus, this finding is consistent with the hypothesis that the processing of consecutive targets occurs at the expense of episodic distinctiveness (Wyble et al., 2009), removing the opportunity for sparing in the counting task. It is also broadly consistent with the view that sparing is served by a compensatory mechanism that is useful only in specific circumstances. However, the finding is more difficult to reconcile with selection accounts (Dell'Acqua et al., 2007).

Findings that lag-1 sparing may be task- and stimulus-specific in ways that the AB is not beg an important question: If target sparing effects are specific to particular sorts of stimuli and particular tasks, what relationship do they bear to the general mechanisms responsible for the AB? This question is addressed in the present study, which uses a series of direct comparisons of object and alphanumeric stimuli under similar task manipulations to provide further evidence of dissociations between lag-1 sparing and the AB.

Extended sparing effects

The results of several studies have suggested that lag-1 sparing can be extended for multiple targets (up to at least four, as long as the number is still within the capacity of visual short-term memory), provided that they follow each other without any intervening distractors (Di Lollo et al., 2005; Kawahara et al., 2006; Nieuwenstein & Potter, 2006; Olivers, van der Stigchel, & Hulleman, 2007). Furthermore, some of these studies have demonstrated that the typical AB function is anchored to the appearance of the first posttarget distractor rather than the appearance of the first target itself (Olivers et al., 2007; Raymond et al., 1992). For instance, Olivers et al. (2007) presented participants with RSVP streams containing either two or four targets, with some of the latter trials containing three consecutive targets and then a fourth target that appeared after a variable number of intervening distractors. When the serial position of the last target was calculated relative to the previous target and not the first target (in other words, taking into account only the number of intervening distractors before the final item), the target accuracy results for each condition mapped almost perfectly onto the same function. Olivers et al. (2007) took these findings as further evidence that the post-T1 distractors play a critical role in inducing the AB. They argue that the results are more consistent with a "selection" interpretation because they suggest that the AB reflects a loss or inhibition of attention triggered by the T1+1 distractor and not a deficit caused by processing T1 itself.

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[1] Landau and Bentin (2008), who compared the ABs induced for face and object stimuli over five experiments, also appear to have found similar levels of accuracy for an object T2 at lag-1 and lag-3, suggestive of an absence of lag-1 sparing. However, their study did not examine lag-1 sparing directly. Their experiments also included different search and selection tasks for T1 and T2, and task switches typically reduce the incidence of lag-1 sparing even for alphanumeric stimuli (Visser et al., 1999a).

The stimulus selection interpretation of protracted sparing effects has been disputed for several reasons. Dux et al. (2008) noted that in Di Lollo et al.'s (2005) consecutive-target effect, the increase in final target accuracy for three consecutive targets is accompanied by a decrease in T1 accuracy, commensurate with a processing trade-off. Dell'Acqua et al. (2009) have also contested the analyses used to demonstrate these effects, arguing that when one only uses the trials on which T1 was actually correctly reported (ensuring correct consolidation of this target), accuracy advantages for the final consecutive target are substantially reduced. This debate will be further discussed in relation to Experiment 3, but it is worth noting that to date, extended sparing effects have only been demonstrated with alphanumeric stimuli. The present study tested whether these protracted sparing effects are also observed for object stimuli and whether the pattern they follow is similar to that obtained for alphanumeric characters.

The present study

The present study sought to directly compare patterns of lag-1 sparing (as well as of the AB itself) exhibited by letters versus object stimuli. To date, no study has attempted to compare these directly, under the same task conditions.[2] Although letters and objects differ on many dimensions, including their physical characteristics and the semantic and associative characteristics conveyed by the image or symbol, it was not our intention to closely match these parameters or to identify which dimensions are the most critical for sustaining differences between the stimulus sets. Instead, the aim was to use stimulus type as an effective manipulation to examine dissociations between patterns of lag-1 sparing and the AB. If lag-1 sparing is stimulus specific in ways that the AB is not, then stimulus type provides a means of teasing the two effects apart.

Each of three experiments employed identical tasks (to identify the red targets), performed with both letters and object stimuli. In Experiment 1, we directly compared the lag-1 sparing obtained for letters and objects at varying RSVP rates. In Experiment 2, we employed a manipulation that is known to modulate the AB (presenting T1 in a rotated orientation; Dux & Harris, 2007; Martens, Korucuoglu, Smid, & Nieuwenstein, 2010) and tested the effect that this had on lag-1 sparing of objects versus letters. Experiment 3 investigated the protracted target sparing

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[2] A recent study by Martens, Dun, Wyble, and Potter (2010) directly compared the size of the ABs elicited by alphanumeric stimuli versus objects in natural scenes in individual participants who differed in their susceptibility to an AB, but that study was not concerned with lag-1 sparing effects.

effects previously reported by Di Lollo et al. (2005) and Olivers et al. (2007) to determine whether pictures of objects produce results similar to those previously reported with alphanumeric targets. This experiment examined serial position effects using three targets, where two of the targets (either the first and second or the second and third), or in some cases all three, were presented consecutively. To preview the results, although overall levels of recognition accuracy and AB patterns were comparable in the letter and the object conditions, significant differences were observed in the levels of lag-1 sparing and the relative patterns of results across serial positions when multiple targets were presented consecutively.

Experiment 1

Experiment 1 compared lag-1 sparing effects produced with letters and objects (see Fig. 1). As noted earlier, Harris et al. (2010; Dux & Harris, 2007) observed virtually no lag-1 sparing using RSVP sequences composed of line drawings of familiar objects. In contrast, Potter et al. (2010) have recently reported a lag-1 sparing effect with photographs of objects in natural scenes. At first glance, this result seems at odds with the findings of Harris et al. (2010) and Dux and Harris (2007) and warrants further investigation. Therefore, the present experiment used letters, schematic line drawings of objects (Snodgrass & Vanderwart, 1980), and naturalistic photographs of objects. In each case, the participants were required to identify two red targets presented amongst black (or greyscale) distractors.

RSVP sequences were displayed at three different presentation rates, in case sparing effects for letters and objects differed as a function of the speed with which these stimuli could be processed and identified. The difference in T2 accuracy between lag-1 and lag-2 in each presentation condition was taken as a measure of lag-1 sparing. Visser, Bischof, and Di Lollo (1999a) used a criterion of lag-1 accuracy being at least 5% greater than the lowest level of accuracy in order for it to be classified as sparing. Here, we examined statistical differences rather than numerical ones, though a similar logic was adhered to, in the sense that *any* relative improvement for lag-1 accuracy can be taken as evidence of partial lag-1 sparing. Therefore, in the present experiment, a less pronounced difference between lag-1 and lag-2 would imply less sparing.
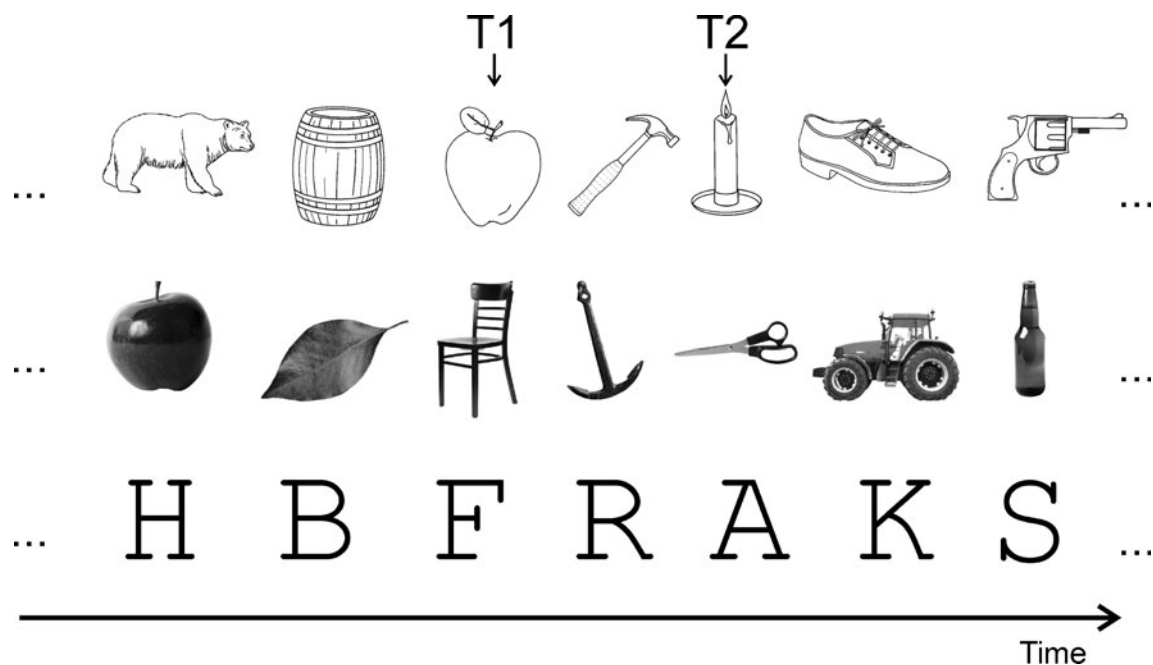
Method

Participants

A group of 36 undergraduate psychology students (22 female, 14 male; mean age = 21 years) at the University of

Fig. 1 Examples of stimuli used in Experiment 1. Line drawings, photo objects, or letters were presented in RSVP sequences with various stimulus onset asynchronies (59, 82, or 106 ms), in the same spatial location. The to-be-reported targets are denoted by T1 and T2 in the figure; in the actual experiment they were coloured red, while the distractor stimuli were black (or greyscale, in the case of photo objects). This example shows a lag-2 trial

Sydney participated in the experiment, with 12 participants allocated to each of the three stimulus conditions.

Stimuli and apparatus

Participants were tested individually in a light- and sound-attenuated cubicle. The experiment was run on an Apple Mac Mini computer attached to a 17-in. CRT monitor refreshing at 85 Hz. The Psychophysics Toolbox version 3 (Brainard, 1997; Pelli, 1997) for MATLAB was used to generate stimuli and to record responses.

The line drawing stimuli (line objects) comprised 40 objects taken from Snodgrass and Vanderwart (1980). The pictures subtended a visual angle of 3.5°–7° horizontally and 3°–5.5° vertically at the viewing distance of approximately 57 cm. The photographic stimulus set (photo objects) was composed of 40 stimuli taken from the Hemera Photo Object database (Hemera Inc., Canada). The pictures subtended a visual angle of 3°–7° horizontally and 3°–7° vertically. Each letter stimulus was presented in Courier New font, subtending an angle of 3° horizontally and 3.5° vertically. In the letter and line object conditions, the stimuli were either black (distractors) or red (targets) and were presented on a white background. In the photo object condition, all stimuli were initially transformed to greyscale. The target objects were then transformed to red by setting the red component (in RGB colour space) to maximum for all pixels and varying only the green and blue components (resulting in varying shades of red instead of grey).

Design and procedure

Two independent variables, interstimulus interval (ISI) and T1–T2 lag were manipulated in a 3 × 5 design. The ISI was 36, 59, or 82 ms, and with a fixed stimulus duration of 23 ms, this equated to a stimulus onset asynchrony (SOA) of 59, 82, and 106 ms. On each trial, T1 appeared in Serial Position 6, 7, or 8. The lag between T1 and T2, measured in numbers of items, was 1, 2, 3, 6, or 9. There were 18 trials at each combination of ISI and lag, totalling 270 trials, which were randomly intermixed in blocks of 15 trials (containing 1 trial from each ISI x lag condition). All targets and distractors were randomly chosen without replacement from the specified stimulus sets, but with the restriction that each of the stimuli could only appear once as T1 and once as T2 for each of the 15 conditions.

For the picture conditions, participants were first presented with the picture of each object in the same size used in the experiment, asked to name it, and were then given the written name of the object on screen. Participants cycled through the entire stimulus set in this fashion in the presence of the experimenter to ensure familiarity with all items. Participants in the letter condition were shown each letter serially in the font and size used in the experiment. All participants were then given verbal instructions explain-

ing the nature of the task. They were instructed to complete the experiment at their own pace and to take self-paced breaks as often as required to maintain vigilance.

Each trial started with a fixation cross in the centre of the screen for 500 ms, followed by an RSVP sequence of 20 stimuli presented with one of three SOAs (59, 82, or 106 ms).

At the completion of the stream, a selection screen appeared with the instruction "Select 1st target" at the top and the 20 stimuli presented on the preceding trial randomly ordered on the screen. This was followed by an identical screen asking for the second target. Participants were asked to guess if they did not recognise any targets; they used the mouse to select the stimuli and the space bar to proceed to the next screen.

Results

In all experiments, we used a statistical significance level of $p = .05$ and Greenhouse–Geisser correction to statistical significance for comparisons with more than two levels of a repeated measure (corrected p values, but uncorrected dfs are reported where applicable).

T2 accuracy

Target report for a given item was considered correct if it matched either response (first or second)—that is, scoring did not take order into account. T2 accuracy conditional on correct report of T1 (T2|T1) is shown in Fig. 2. We focus on this measure here, as it is the most common way to assess performance in AB studies. However, the pattern of results was very similar when unconditional T2 accuracy was considered.

Data from each of the three presentation rates were analysed separately. Each presentation rate was first analysed using a repeated measures ANOVA with Lag (1, 2, 3, 6, and 9) as the within-subjects factor and Stimulus Type (line objects, photo objects, and letters) as the between-subjects factor. These yielded significant main effects of lag [59 ms: $F(4, 132) = 12.301$, $p < .001$, $\eta_p^2 = .272$; 82 ms: $F(4, 132) = 57.640$, $p < .001$, $\eta_p^2 = .636$; 106 ms: $F(4, 132) = 126.506$, $p < .001$, $\eta_p^2 = .793$] and significant interactions between lag and stimulus type [59 ms: $F(8, 132) = 6.091$, $p < .001$, $\eta_p^2 = .270$; 82 ms: $F(8, 132) = 4.338$, $p = .001$, $\eta_p^2 = .208$; 106 ms: $F(8, 132) = 7.241$, $p < .001$, $\eta_p^2 = .305$]. The main effect of stimulus type did not reach significance for any of the presentation rates (largest $F = 1.313$, $\eta_p^2 = .074$).

It is clear in Fig. 2 that lag-1 accuracy was much higher for letters in all three SOA conditions, even though accuracy at lag-2 was similar across the stimulus conditions, suggesting differences in the amounts of lag-1 sparing. Further analyses were targeted at the *difference*

between lag-1 and lag-2 accuracy, as a measure of lag-1 sparing.[3] Univariate analyses of lag-1 sparing, with Stimulus Type as a between-subjects factor, revealed significant effects for all three presentation rates [smallest $F(2, 33) = 5.043$, $p = .012$, $\eta_p^2 = .234$]. Within each presentation rate, post-hoc comparisons (using Fisher's LSD) revealed that there was significantly more lag-1 sparing for letters than for the line objects [smallest $t(22) = 2.341$, $p < .05$], significantly more lag-1 sparing for letters than for the photo objects [smallest $t(22) = 2.386$, $p < .05$], but no difference between line drawings and photographs of objects [largest $t(22) = 0.654$]. Thus, for all three SOA conditions, the letters yielded significantly greater lag-1 sparing than the object conditions.

T1 accuracy

T1 accuracy (shown in Fig. 3) was analysed in the same fashion as the initial analyses for conditional T2 accuracy, with a separate ANOVA for each presentation rate. The main effects of lag and stimulus condition and their interaction did not approach significance in any of these analyses (largest $F = 1.306$, $\eta_p^2 = .073$).

Discussion

In Experiment 1, all conditions demonstrated at least some lag-1 sparing, with conditional T2 accuracy higher for lag-1 than for lag-2 trials. However, at each of the three presentation rates used in this experiment, the letter condition produced significantly greater lag-1 sparing than either of the two picture conditions. In contrast, the levels of lag-1 sparing produced with line drawings of objects and photograph images of objects were very similar.

Overall accuracy for T1 and T2 was otherwise comparable between the different stimulus conditions, with the exception of the T2 data for the fastest presentation rate, where objects (photo objects in particular) showed faster recovery from the AB than letters. In this condition, the longest T1–T2 SOA was still only approximately 530 ms, and still within the realms that one might expect to see an AB for a difficult target identification task. Paradoxically, even though the letter condition may be slightly more difficult at this presentation rate, it still yielded much higher accuracy at lag-1 than either of the object conditions.

This experiment confirms previous observations that pictures of objects elicit relatively little lag-1 sparing as

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[3] T2 accuracy was actually lowest at lag-3 rather than lag-2 in several conditions, particularly at the 59-ms SOA. Thus, we could have taken the lowest level of accuracy as the point to compare to lag-1 in order to measure lag-1 sparing. Note, however, that doing so would only increase the difference in lag-1 sparing between the letter and object stimuli.
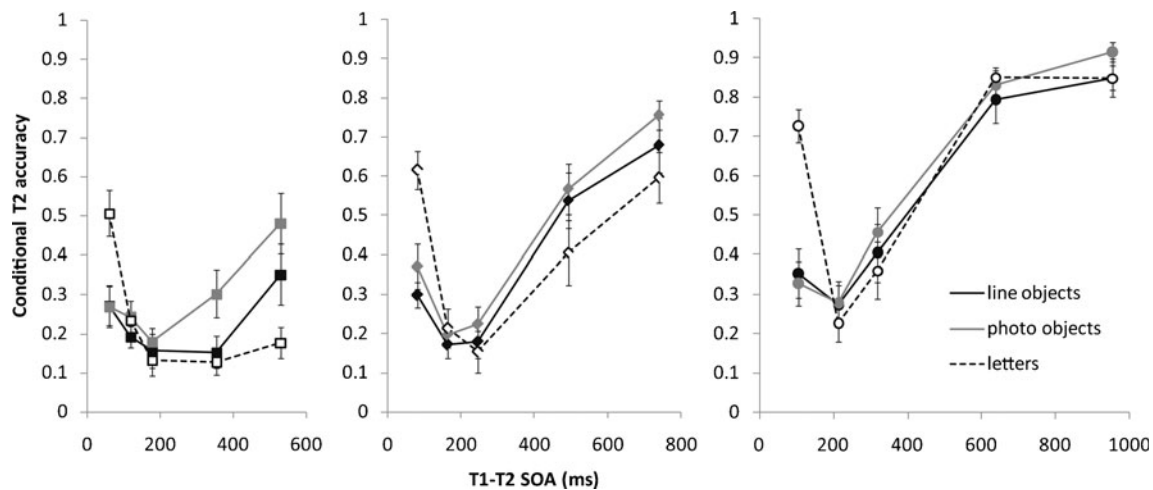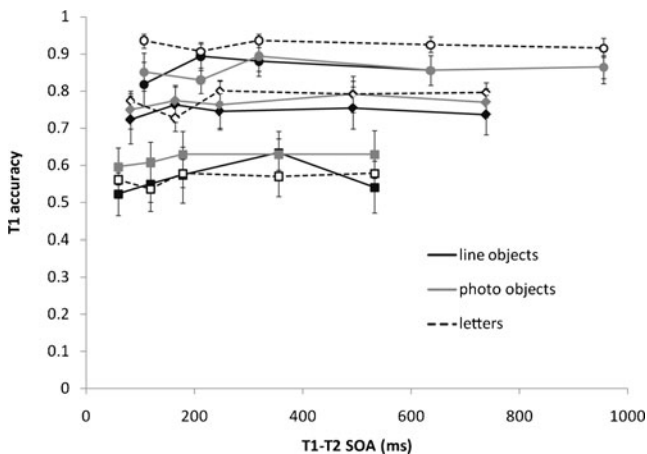
Fig. 2 Conditional accuracy for the second target (T2|T1) for the three different stimulus conditions in Experiment 1. The three panels depict results for three presentation rates (left, 59 ms; centre, 82 ms; right, 106 ms). Data are plotted as a function of the stimulus onset asynchrony between T1 and T2, which in each case represent T1–T2 lags of 1, 2, 3, 6, and 9 serial positions. Error bars show standard errors of the means

compared to the stimuli that are most commonly used in AB experiments (Dux & Harris, 2007; Harris et al., 2010). Our results show identical levels of lag-1 sparing for line drawings and photo objects. This may appear to be at odds with the study by Potter et al. (2010), in which the authors observed lag-1 sparing when photographs of objects in everyday scenes served as the target and distractor stimuli. They found that lag-1 accuracy was better than at lag-2 and comparable to accuracy at lag-4. It is possible that our results differ from theirs because of the nature of the task (select red items in our experiment, select a certain object category in theirs). These two tasks may differ in the speeds of attentional deployment, and this may account for differences in the amount of lag-1 sparing. However, Dux

and Harris also failed to find evidence of lag-1 sparing in an experiment in which targets were defined by category (select animal targets from nonanimal distractors), casting some doubt on this interpretation. It is worth noting that the purpose of Potter et al.'s (2010) study was simply to demonstrate that at least *some* lag-1 sparing was present for these photographic picture stimuli, and in this respect, our results are in agreement with theirs: We found a modest amount of lag-1 sparing for objects, albeit substantially smaller than the amount for letters. Had Potter et al. (2010) tested longer lags and compared their photographic stimuli to alphanumeric stimuli, we would predict that they would also have found evidence for reduced sparing effects for objects.

The findings of this experiment are difficult to accommodate within current accounts of RSVP processing that view both the AB and lag-1 sparing as consequences of the dynamics of attentional selection (Di Lollo et al., 2005; Olivers & Meeter, 2008). The selection requirements of the object and letter conditions are the same (in both cases, participants attempt to select two targets defined by colour and recall their identity). Therefore, to account for the differences, selection theories would have to appeal to other factors that might differ between letters and objects, such as item discriminability, differential masking, memory factors, or differences in the attentional set used in each stimulus condition (despite the identical task requirements). From the perspective of resource depletion accounts of the AB, one might appeal to a difference in the resources consumed by the two types of stimuli to explain why there is much less lag-1 sparing in the object conditions. For instance, one could assume that objects consume more attentional resources than letters, and therefore, not enough resources are available for processing T2 when it immediately follows T1. But this account does not explain why the differences

Fig. 3 T1 accuracy for the three different stimulus conditions and three different presentation rates used in Experiment 1. Marker shape indicates presentation rate (squares, 59 ms; diamonds, 82 ms; circles, 106 ms). Data are plotted as a function of the stimulus onset asynchrony between T1 and T2, which in each case represents T1–T2 lags of 1, 2, 3, 6, and 9 serial positions. Error bars show standard errors of the means

between stimuli are largely confined to the amount of lag-1 sparing, whereas the overall accuracy levels and the patterns of AB were similar for letters and objects—except at the shortest SOA, where, in fact, objects showed a faster recovery from the AB than letters, contrary to what would be expected from such a resource depletion account. Instead, the present results suggest that lag-1 sparing is dependent to a large extent on stimulus-specific processes that allow the sharing of resources for target identification when targets are encoded in close succession (possibly in the same attentional episode). This resource sharing appears to be more successful in the case of letters than in the case of objects. This explanation will be considered further in the General Discussion.

Experiment 2

Experiment 2 examined whether the difficulty of the T1 task modulates lag-1 sparing for both object and letter stimuli. T1 difficulty was manipulated by varying the orientation of this stimulus, given that rotating objects away from their usual (e.g., upright) orientation decreases the efficiency with which they are recognised (Corballis, Zbrodoff, Shetzer, & Butler, 1978; Jolicœur, 1985; Jolicœur & Landau, 1984). This performance cost is usually attributed to some kind of normalisation process that allows the representation of the rotated object to be matched to the familiar (presumably upright) representation stored in memory (Bülthoff & Edelman, 1992; Corballis, 1988; Jolicœur, 1985; Tarr & Pinker, 1989; Ullman, 1989).

Dux and Harris (2007, Exp. 3) conducted an RSVP experiment with object stimuli in which they presented T1 either in its usual upright orientation or rotated by 90° or 180°, and they found that a 90°-rotated T1 induced a deeper blink than did an upright T1. In both cases, T2 was upright, so the decrease in accuracy for this item came purely as a result of manipulating the efficiency of identifying T1. This finding is consistent with others that have shown that increasing the difficulty of the T1 task exacerbates the AB (e.g., Jolicœur, 1999; Olson, Chun, & Anderson, 2001). Dux and Harris also tested the effects of rotating distractors but found no change in the size of the AB between upright- and rotated-distractor conditions. They concluded that the viewpoint costs for rotated objects are incurred specifically at the time of consolidating an item for report (see also Harris, Dux, Benito, & Leek, 2008). If that is the case, one would predict that consolidating rotated T1 items might also interfere with processing consecutive targets and, thus, reduce lag-1 sparing. In Dux and Harris's experiment, the amounts of lag-1 sparing were very similar in the upright and the rotated conditions, although this was not formally tested. However, given that lag-1 sparing was virtually

absent in that experiment, it is possible that the perceived lack of difference in lag-1 sparing was due to floor effects. Therefore, in the present experiment, we measured the effects of rotating T1 on the amount of lag-1 sparing for objects and compared this to the lag-1 sparing obtained for letters under the same experimental conditions.

Method

Participants

A group of 24 undergraduate psychology students at the University of Sydney participated in the experiment, each paid A$15 for participating. Of these participants, 2 were excluded for having T1 accuracy below 30%. All analyses were conducted on the remaining 22 participants (13 female, 9 male; mean age = 21.7 years).

Stimuli and apparatus

The same apparatus was used as in Experiment 1. The stimuli comprised all letters of the alphabet except I, O, W, and Z (the last two were excluded to avoid potential confusion with M and N when they were rotated) and 22 line drawings of objects with a canonical upright orientation taken from Snodgrass and Vanderwart (1980). Picture and letter sizes were the same as in Experiment 1. The targets were red and the distractors were black, presented on a white background, and all stimuli were shown in an upright orientation except for rotated-T1 trials, on which T1 only was rotated 90º clockwise.

Design and procedure

Three independent variables were manipulated in a 2 × 2 × 4 design, with Stimulus Type (letters or objects), T1 Rotation (upright or rotated 90°), and Lag Between T1 and T2 (1, 2, 5, and 9) as within-subjects factors. T1 could appear in Serial Positions 6 – 8, and was then followed by 0–8 distractors and then T2. Participants completed the object and letter trials in two separate phases, with the order of the phases counterbalanced across participants. Within each of these phases, there were 18 trials at each of the four lags, for each T1 orientation—144 trials in total—randomly intermixed in blocks of 8 trials (1 of each lag x T1 rotation condition). All targets and distractors were randomly chosen without replacement from the specified stimulus sets, but with the restriction that each of the 22 stimuli appeared no more than once as T1 and once as T2 for each lag.

As in Experiment 1, participants were shown the stimuli prior to starting each phase of the experiment to ensure familiarity. They were then given verbal instructions explaining the general procedure. They were told

explicitly that sometimes one of the red targets could be rotated away from its usual upright orientation, but they should simply identify the targets regardless of orientation. Participants made their selections in the same fashion as in Experiment 1.

In all other respects, the presentation parameters for each trial were identical to those of the 106-ms condition of Experiment 1, with an RSVP sequence of 20 stimuli presented with an SOA of 106 ms.

Results

T2|T1 accuracy

Conditional T2 accuracy is shown in Fig. 4, bottom panel. As Fig. 4 illustrates, the most striking differences between the conditions occur at lag-1, where there are divergent effects of rotation on the object and letter conditions. Three analyses were conducted, one focussing on performance at lags 2 – 9 (essentially investigating the AB function), one focussing on lag-1 performance only, and one comparing lag-1 and lag-2 performance (as a measure of lag-1 sparing).

A repeated measures ANOVA of stimulus type, T1 orientation, and lag, carried out over lags 2–9, revealed
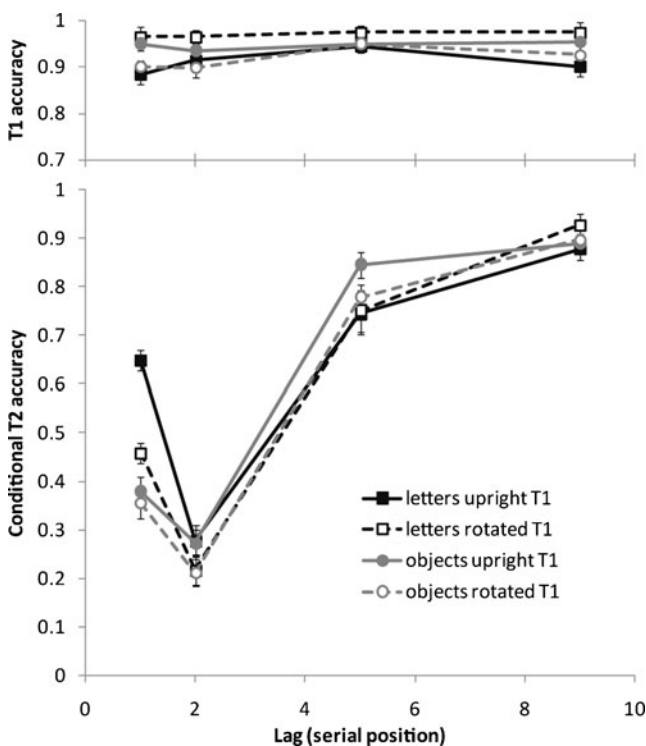
Fig. 4 Target accuracy for the four conditions in Experiment 2, as a function of the lag between T1 and T2. Top panel: T1 accuracy. Bottom panel: Conditional T2 accuracy. Error bars show the standard errors of the mean differences between upright and rotated items for each lag and stimulus type

significant main effects of T1 rotation [$F(1, 21) = 5.780$, $p = .026$, $\eta_p^2 = .216$] and lag [$F(2, 42) = 404.974$, $p < .001$, $\eta_p^2 = .951$], but no effect of stimulus type ($F < 1$, $\eta_p^2 = .036$). Stimulus type did not interact with T1 rotation [$F(1, 21) = 1.92$, $p = .180$, $\eta_p^2 = .084$] or lag [$F(2, 42) = 2.921$, $p = .084$, $\eta_p^2 = .122$], and there was no three-way interaction between these variables ($F < 1$, $\eta_p^2 = .033$). Finally, there was a significant interaction between T1 rotation and lag [$F(2, 42) = 4.900$, $p = .013$, $\eta_p^2 = .189$]. Essentially, rotating T1 had the same effect on the AB function for both letters and objects, resulting in an overall increase in the depth of the blink.

The same analysis was conducted for performance at lag-1 and yielded significant effects of stimulus type [$F(1, 21) = 32.870$, $p < .001$, $\eta_p^2 = .610$] and T1 rotation [$F(1, 21) = 22.350$, $p < .001$, $\eta_p^2 = .516$], as well as a significant interaction [$F(1, 21) = 32.171$, $p < .001$, $\eta_p^2 = .605$]. As can be seen in Fig. 4, lag-1 performance with letters was reduced in the rotated T1 condition, as compared to the upright condition, but there was no difference between the two conditions for objects.

The amount of lag-1 sparing (i.e., the difference between lag-1 and lag-2 accuracy) in the two rotation conditions was evaluated for both letters and objects. Rotating T1 did not affect the amount of lag-1 sparing for objects, as compared to when T1 was upright ($t < 1$), but it significantly reduced the amount of lag-1 sparing for letters [$t(21) = 3.042$, $p = .006$]. Whereas the amount of lag-1 sparing was significantly higher for letters than for objects when T1 was upright [$t(21) = 3.875$, $p = .001$], this difference was much reduced and was no longer significant in the T1-rotated condition [$t(21) = 1.764$, $p = .092$].

It is worth noting that the lack of a difference between the amounts of lag-1 sparing for upright and rotated objects is unlikely to be due to floor effects in performance in the objects condition. For objects in this experiment, lag-1 accuracy was significantly higher than lag-2 accuracy in both the upright [$t(21) = 3.46$, $p = .002$] and rotated [$t(21) = 4.43$, $p < .001$] conditions. At lag-2, where accuracy was lowest, there was still a significant decrement for rotated trials as compared to upright trials [$t(21) = 2.283$, $p = .033$], suggesting that there should still be sufficient sensitivity to find lag-1 sparing differences within this accuracy range. Instead there are none, whereas the lag-1 sparing differences for letters after an upright or rotated T1 are obvious.

T1 accuracy

T1 accuracy is presented in Fig. 4, top panel, and was analysed using a repeated measures ANOVA with Stimulus Type, T1 Rotation, and Lag as within-subject factors. This yielded a significant main effect of lag [$F(3, 63) = 5.117$, $p = .007$, $\eta_p^2 = .196$] and a marginally significant effect of T1 rotation [$F(1, 21) = 3.650$, $p = .070$, $\eta_p^2 = .148$]. More

revealingly, there was a significant interaction between stimulus type and T1 rotation [$F(1, 21) = 37.027$, $p < .001$, $\eta_p^2 = .638$], indicating that T1 accuracy (averaged across lags) was lower for rotated objects (.92) than for upright objects (.95), but it was higher for rotated letters (.97) than for upright letters (.91). No other main effects or two-way interactions were significant ($Fs < 1$, largest $\eta_p^2 = .037$), but there was a significant three-way interaction between stimulus type, T1 rotation, and lag [$F(3, 63) = 3.299$, $p = .038$, $\eta_p^2 = .136$], whereby the improvement for letters was evident at all lags, but the decrement in accuracy for objects was most pronounced in the lag-1 condition.

Discussion

The results of this experiment replicate the findings of Dux and Harris (2007, Exp. 3) that presenting a T1 object in a rotated orientation induces a deeper AB, and they extend this finding to letter stimuli. Indeed, T1 rotation had very similar detrimental effects on the magnitudes of the AB (measured across lags 2–9) for both objects and letters, consistent with the idea that increasing the difficulty of the T1 task—and presumably the time and resources dedicated to it—reduces the resources available for processing T2 (Dux & Harris, 2007; Jolicœur, 1999; Olson et al., 2001).

In contrast, rotating T1 had very different effects on lag-1 sparing for letters and objects. The amount of lag-1 sparing for objects was unaffected, replicating Dux and Harris's (2007) findings, and demonstrating that this lack of a difference is not due to floor effects on performance at short lags. On the other hand, rotating T1 produced a significant reduction in lag-1 sparing for letters, even though the drop in lag-2 accuracy in the rotated condition might be expected to increase the amount of lag-1 sparing (defined by the difference between lag-1 and lag-2 performance). It is clear that the reduction in lag-1 sparing for letters was caused specifically by a substantial reduction in the accuracy of reporting T2 at lag-1 in the rotated-T1 condition. A seemingly similar effect was also apparent in a recent study by Martens, Korucuoglu, Smid, and Nieuwenstein (2010), who investigated the effects of rotating targets and distractors in an AB task employing letter stimuli. However, Martens, Korucuoglu, et al.'s results are not directly comparable to ours, because they used a longer SOA in the rotated-target condition than in the upright target condition (200 vs. 100 ms), and it is arguable whether true lag-1 sparing effects occur beyond about 150 ms (Wyble et al., 2009).

It is worth noting the somewhat unexpected finding that rotating T1 had a different effect on participants' ability to report this item in the letter and object conditions. For objects, T1 accuracy was lower when this item was rotated than when it was upright, consistent with the expected

effects of rotation on object identification (e.g., Bülthoff & Edelman, 1992; Dux & Harris, 2007; Jolicœur, 1985; Jolicœur & Landau, 1984; Tarr & Pinker, 1989) and with the assumption that T1 identification is made more difficult by rotation. In contrast, rotated T1 letters were identified *better* than upright ones. It is likely that rotated target letters were more salient than upright target letters, either because they were more surprising or because they were less effectively masked by their flanking items in the RSVP stream. This suggests that the detrimental effect on the AB caused by T1 rotation is not necessarily due to an increase in the actual *difficulty* of T1 per se. It may, instead, be due to the fact that when T1 commandeers more attentional resources, either because it is more difficult or because it is more salient, T2 suffers (see also Dux et al., 2008, 2009, for related evidence that T1 saliency can impair T2 performance).

The combination of improved T1 accuracy and reduced T2 accuracy at lag-1 in the case of letters suggests a trade-off of resources between these two targets, consistent with some accounts of lag-1 sparing, notably the eSTST (Wyble et al., 2009) and Potter et al.'s (2002) competition models. It is also consistent with the idea that when T1 processing is prioritised (by its relevance or salience), the opportunity for sparing is reduced (Dux et al., 2009). Attentional control or "selection" models have some difficulty accounting for this finding. For example, the boost-and-bounce theory (Olivers & Meeter, 2008) predicts that a more salient T1 should result in an enhanced attentional boost. This correctly anticipates the deeper AB for rotated targets when T1 is followed by a distractor. But on lag-1 trials, the larger boost would also be expected to carry over to the consecutive trailing target, and thus boost T2 performance (or, minimally, leave it unchanged). The TLC model (Di Lollo et al., 2005) makes no specific prediction about the effects of increased salience of T1 (or, indeed, of increasing the difficulty of this item). According to this model, the identification of T1 leaves processing of subsequent items unsupervised by the central executive and under the influence of exogenous factors. Thus, one might surmise that the processing of *consecutive* targets should not be affected by any manipulations that make T1 more salient or more difficult, because, even under exogenous control, the input filter should remain configured to the target characteristics. Therefore, as they currently stand, neither the boost-and-bounce nor the TLC model seems to have a ready explanation for the impairment in lag-1 sparing brought about by a more successfully processed T1.

Overall, the present results suggest that this trading of resources can be performed successfully for some stimuli (e.g., letters), but not for others (e.g., objects). This hypothesis was explored further in Experiment 3, which investigated protracted sparing effects for letters versus objects.

Experiment 3

Since we had established in Experiments 1 and 2 that lag-1 sparing is affected by the type of stimulus used, Experiment 3 examined two related target sparing effects linked to the presentation of consecutive targets. The first of these is an effect reported by Di Lollo et al. (2005), in which the presentation of consecutive targets greatly improved accuracy for the final target. Di Lollo et al. presented RSVP streams of digit distractors that contained either a sequence of three consecutive letter targets or a sequence with two targets separated by a digit distractor. Thus, a target always occupied the first and third critical positions but could be interleaved with another target or a distractor. They found that accuracy for the target appearing in the third position was substantially higher when it followed another target than when it followed a distractor. In the consecutive-target condition, they also found no evidence of an impairment for T3 accuracy relative to T1, and indeed, under some conditions, performance was substantially better for T3 than for T1 (e.g., Kawahara et al., 2006). Di Lollo et al. interpreted this to mean that the attentional blink is not just the consequence of a resource limitation or depletion, but rather that it reflects the temporary loss of endogenous control of attention, coupled with a disruption to processing caused by the mismatch between the target set and the first posttarget distractor.

A related effect was reported by Olivers et al. (2007, Exp. 3) in a task in which multiple target letters (either two or four) were presented within a sequence of nonsense distractor characters. In the two-target version, the number of distractors between T1 and T2 varied as in a normal AB experiment. The four-target trials were divided into early-triplet trials, which consisted of three consecutive targets, followed by a variable number of distractors and then the fourth target, and late-triplet trials, in which the first target was followed by a variable number of distractors, then three consecutive targets. Olivers et al. found that even after an AB was induced, report accuracy for a late target improved if the target was immediately preceded by another target rather than by a distractor. For instance, presenting T2 immediately before T3 (as in late-triplet trials) substantially improved T3 accuracy: Comparing targets that were presented at the same serial position relative to T1, T3 accuracy on late-triplet trials was substantially higher than T2 accuracy on two-target trials.

Dell'Acqua et al. (2009) have since argued that these protracted sparing results depend on the manner in which final target accuracy is measured. They showed that the processing advantages for the final consecutive target are much greater when unconditional report accuracy is used rather than conditionalised report accuracy (i.e., where only the trials on which T1 is reported correctly are used in the

calculations of accuracy for subsequent targets). For instance, Dell'Acqua et al. (2009) found substantially greater deficits for T3 relative to T1 in conditions with consecutive targets once accuracy was conditionalised on T1, and even greater deficits when accuracy was conditionalised on T1 and T2. This, they argue, reveals an AB deficit for T3 when T1 is correctly consolidated, in line with the predictions of a capacity limitation account of the AB. However, a meta-analysis by Olivers, Hulleman, Spalek, Kawahara, and Di Lollo (2011) recently noted that the other critical effect reported by Di Lollo et al. (2005)—the advantage for the third of three consecutive targets over the second of two targets interleaved by a distractor—is still very reliable when target accuracy is fully conditionalised. Olivers et al. (2011) argue that this is a more valid comparison to make than the difference between T1 and T3, because it better reflects the dynamics of target selection at this position contingent on the nature (target vs. distractor) of the preceding item in the stream.

In Experiment 3, we used a simplified design that still captures the same rationale as the Olivers et al. (2007) study. Multiple red targets (2 or 3) were presented amongst black distractors. On two-target trials, the lag between T1 and T2 was varied from 1 to 6. On three-target trials, two targets were always presented consecutively, with a variable number of distractors between either T2 and T3 (early-pair trials) or between T1 and T2 (late-pair trials). The critical sparing effects reported by both Di Lollo et al. (2005) and Olivers et al. (2007) were examined using both object and letter stimuli. The letter condition served as a control for the objects, and also as a replication of the sparing effects reported by Di Lollo et al. (2005) and Olivers et al. (2007) using a different method of target identification (the targets were defined by colour rather than by category, as in their experiments).

Method

Participants

A group of 48 first-year psychology students at the University of Sydney participated for course credit. Of these participants, 4 were excluded for having T1 accuracy below 30%, leaving 44 participants (29 females, 15 male; mean age = 21.3 years), with 22 participants allocated to each condition.

Stimuli

The stimuli used in the object condition were the same line drawings used in Experiment 1. The stimuli used in the letter condition were all letters from the English alphabet except I, J, M, O, Q, and W. These were shown in Arial

font, with each letter subtending a visual angle of approximately 1.5° horizontally and 2° vertically.

Design and procedure

Three independent variables were manipulated in a 2 × (3 × 6) design. The between-subjects variable was the stimulus set (objects or letters). The first within-subjects variable was trial type: two-target trials (T . . . T), early-pair trials (TT . . . T), and late-pair trials (T . . . TT). The second within-subjects variable was the number of intervening distractors between targets, which varied from 0 to 5.

There were 12 trials at each of the six intervening distractor conditions for each of the three trial types—216 trials in total—randomly intermixed in blocks of 18 trials (i.e., 1 trial from each condition). On each trial, all targets and distractors were randomly chosen without replacement from the specified stimulus sets.

After verbal instructions, participants in the object condition cycled through the stimulus set, with both picture and name shown on screen, to ensure familiarity with all items. On each trial in the experiment, a fixation cross was shown in the centre of the screen for 500 ms, followed by an RSVP stream presented at a rate of 94 ms per item. Each trial comprised 15 items, including either two or three red targets, and otherwise black distractor stimuli; all items were presented on a white background. T1 could appear in Serial Positions 4–6, and was followed either immediately by T2 (early-pair condition) or by 0–5 distractors and then T2 (two-target and late-pair conditions). On three-target trials, T2 was followed either immediately by T3 (late-pair condition) or by 0–5 distractors and then T3 (early-pair condition).

At the completion of the stream, a selection screen appeared with the instruction "Choose 2 targets" or "Choose 3 targets" at the top and a selection of 12 stimuli randomly ordered on the screen. Two-target and three-target trials were intermixed, and the instruction to choose two or three targets always indicated the correct number of targets for that trial. The 12 choices were all stimuli that had been shown on that trial, except for the first two distractors and the last distractor in the sequence. Participants were informed that the order of presentation of the targets was unimportant, and if they did not see all of the targets to just give their best guess. Participants used the mouse to select the stimuli and the space bar to continue to the next trial.

Results

Analyses of Experiment 3 were directed specifically towards three sparing effects to examine differences between the object and letter conditions. These analyses targeted (1) lag-1 sparing, to replicate the effects observed

in the previous two experiments; (2) Di Lollo et al.'s (2005) sparing effect on the third of three consecutive targets; and (3) the rapid recovery of target accuracy for a third target immediately after the presentation of a second target, found by Olivers et al. (2007). In all analyses, we used unconditional target report accuracy (rather than the conditional T2 accuracy used in Experiments 1 and 2), in keeping with the relevant literature (Di Lollo et al., 2005). However, we also included some analysis of the effect of conditionalising target accuracy, given the recent debate about the effect of using different analyses on the overall pattern of results (Dell'Acqua et al., 2009; Olivers et al., 2011).

Lag-1 sparing effects

Unconditional target accuracy The top panel of Fig. 5 shows T2 accuracy as a function of T1–T2 lag on two-target trials and late-pair trials (i.e., T2 is preceded by a distractor, except at lag-1, when it follows T1). Once again, lag-1 sparing is far less evident for the object condition than for the letter condition. Analyses were targeted specifically at the difference between lags 1 and 2, with Stimulus Set (objects vs. letters) as a between-subjects factor and Trial Type (two-target vs. late-pair) as an additional within-subjects factor in each case. The difference between lags 1 and 2 interacted significantly with stimulus set [$F(1, 42) = 10.230$, $p = .003$, $\eta_p^2 = .196$] but not with trial type ($F < 1$, $\eta_p^2 = .006$), indicating that there was a bigger difference (i.e., more sparing) for letters ($M = .301$) than for objects ($M = .136$).

The bottom panel of Fig. 5 shows T3 accuracy as a function of T2–T3 lag on early-pair trials (i.e., T3 is preceded by a distractor, except at lag-2 relative to T1, when it directly follows T2). Again, looking relative to T2, lag-1 sparing is far more evident for letters than for objects, which show no evidence of any sparing effect (indeed, accuracy is lower at lag-1 than at lag-2 for objects). The difference between lag-1 and lag-2 accuracy (lag-2 and lag-3, relative to T1) in this condition was also significantly greater for letters ($M = .140$) than for objects ($M = -.155$), $F(1, 42) = 20.938$, $p < .001$, $\eta_p^2 = .333$.

Conditionalised target accuracy Consistent with most of the AB literature, conditionalising T2 (i.e., using T2|T1) had only a very subtle impact on the pattern of T2 accuracy. The magnitude of lag-1 sparing very slightly decreased for both letters ($M = .273$) and objects ($M = .123$). Overall, T3 accuracy on early-pair trials decreased only very slightly when conditionalised on T1 [letters: $p(T3|T1) = .452$ vs. $p(T3) = .479$; objects: $p(T3|T1) = .631$ vs. $p(T3) = .637$], but it decreased more substantially when conditionalised on both T1 and T2 [letters: $p(T3|T1\&T2) = .352$; objects: $p(T3|T1\&T2) = .442$]. However, despite this decrease, the same
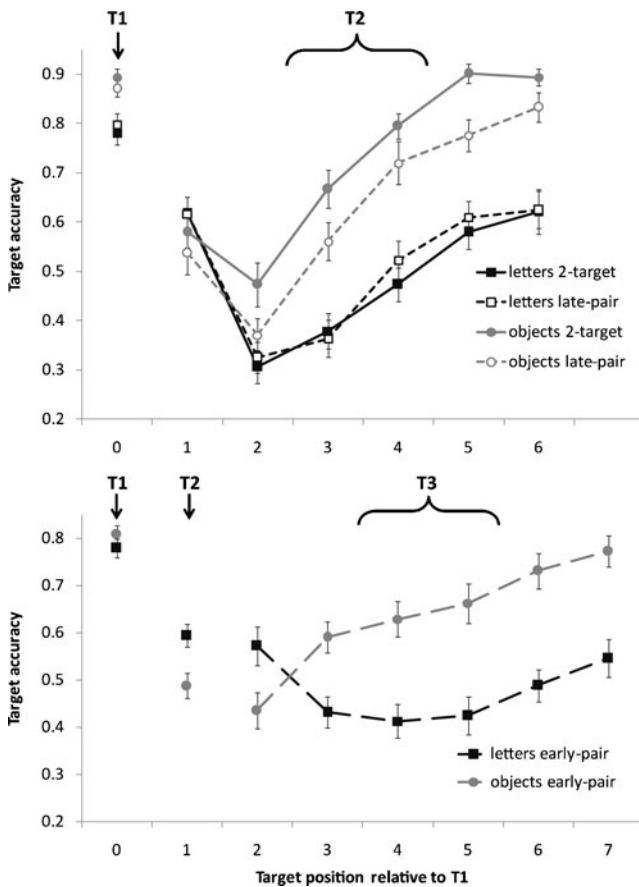
Fig. 5 Accuracy as a function of the serial position of the target (relative to T1 at Position 0) for both the object and letter groups in Experiment 3. Data depict T2 accuracy functions for the two-target and late-pair conditions in which a variable number of distractors were presented between T1 and T2 (top panel), and T3 accuracy functions for the early-pair conditions in which a variable number of distractors were presented between T2 and T3 (bottom panel). Error bars show standard errors of the means

pattern across lags was evident in the fully conditionalised T3 data, with a substantial lag-1 sparing effect for letters ($M = .213$) and no lag-1 sparing for objects ($M = -.05$).

Sparing from three consecutive targets

Unconditional target accuracy To examine the sparing effect produced by having three consecutive targets, lag-2 trials from the two-target condition were compared to three-target trials in which the three targets appeared consecutively. Figure 6 shows recognition accuracy for the target in the first serial position (always T1) versus recognition accuracy for the target in the third serial position (T2 for the two-target condition, and T3 for the three-target conditions); the top panel shows the unconditionalised data, while the bottom panel shows fully conditionalised target accuracy (see below). A repeated measures ANOVA with

target position (first vs. third) and trial type (TTT vs. TdT) as within-subjects variables and stimulus set as a between-subjects variable revealed a significant interaction between trial type and target position [$F(1, 42) = 20.987$, $p < .001$, $\eta_p^2 = .333$], a significant interaction between trial type and stimulus set [$F(1, 42) = 23.566$, $p < .001$, $\eta_p^2 = .359$], and a significant three-way interaction [$F(1, 42) = 11.849$, $p = .001$, $\eta_p^2 = .220$], confirming that the patterns of results differed markedly between the letter and object groups. The main effects of target position [$F(1, 42) = 247.344$, $p < .001$, $\eta_p^2 = .855$] and stimulus set [$F(1, 42) = 5.335$, $p = .026$, $\eta_p^2 = .113$] were also significant. No other main effects or interactions reached significance (largest $F = 1.202$, $\eta_p^2 = .028$).

Following this, each condition was examined separately to look specifically for an interaction between target position and trial type, with planned contrasts to test differences in trial type at each target position. For the
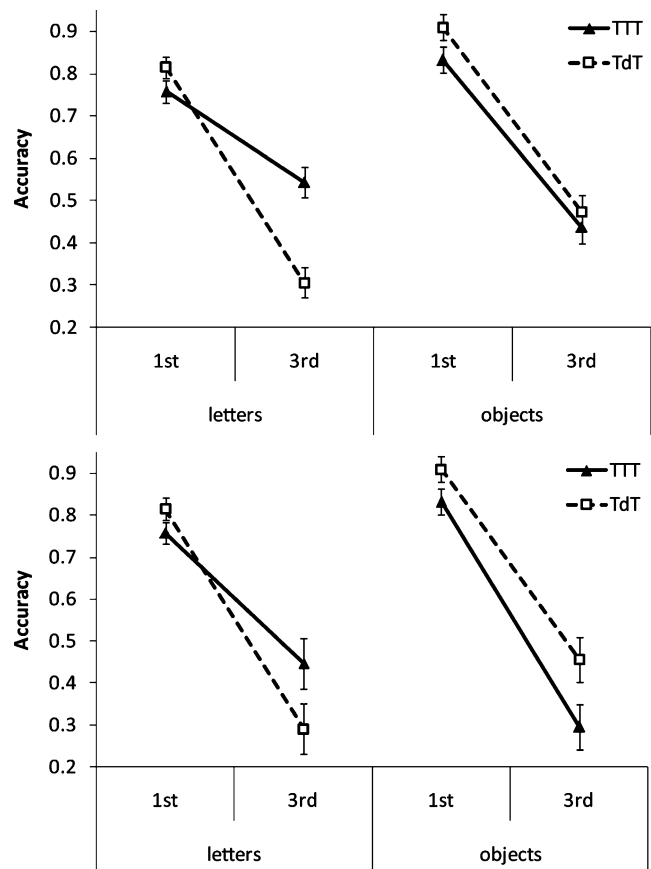
Fig. 6 Target accuracy in Experiment 3, for trials on which T1 was followed by either two consecutive targets (TTT) or by one distractor and one target (TdT). Accuracy is plotted for the first and third items in the set of three critical stimuli (TTT or TdT) and for the letter and object groups separately. The top panel shows unconditional target accuracy, whereas the bottom panel shows fully conditionalised target accuracy: $p(T2|T1)$ for TdT trials, $p(T3|T1\&T2)$ for TTT trials. Error bars show the standard errors of the mean differences between TTT and TdT conditions at each target position

letter group, the main effects of target position and trial type were both significant [smaller $F(1, 21) = 24.987$, $p < .001$, $\eta_p^2 = .543$], as was the interaction between the two factors [$F(1, 21) = 31.721$, $p < .001$, $\eta_p^2 = .602$]. The effect of trial type was significant at both the first target position [TdT > TTT; $F(1, 21) = 4.797$, $p = .040$, $\eta_p^2 = .186$] and the third target position [TTT > TdT; $F(1, 21) = 42.040$, $p < .001$, $\eta_p^2 = .667$]. This replicated the results of Di Lollo et al. (2005). For the object group, the main effects of target position and trial type were again both significant [smaller $F(1, 21) = 5.469$, $p = .029$, $\eta_p^2 = .207$], but the interaction between the two factors did not approach significance ($F < 1$, $\eta_p^2 = .030$). The effect of trial type was significant at the first target position [TdT > TTT; $F(1, 21) = 6.455$, $p = .019$, $\eta_p^2 = .235$] but, more crucially, was not significant at the third target position ($F < 1$, $\eta_p^2 = .038$). The sparing effect for the third of three consecutive targets was clearly absent for the picture condition, and the pattern of results was very different from that obtained with letter targets.

Conditionalised target accuracy Conditionalising final-item accuracy only on T1 report made very little difference to the overall pattern of results. Conditionalising accuracy on all preceding targets—p(T3|T1&T2) on TTT trials as compared to p(T2|T1) on TdT trials—resulted in a more substantial reduction in T3 accuracy, as shown in the bottom panel of Fig. 6 (compare to top panel). Following the meta-analysis reported by Olivers et al. (2011), we took each group and analysed the within-trial contingency effect by comparing p(T3|T1&T2) and p(T3) on TTT trials and the fully conditionalised sparing effect by comparing p(T3|T1&T2) on TTT trials to p(T2|T1) on TdT trials. One participant from the letter condition had to be removed from this analysis because of never reporting T1 and T2 correctly on a TTT trial. The within-trial contingency effect was significant for both the letter [$F(1, 20) = 11.034$, $p = .003$, $\eta_p^2 = .356$] and object [$F(1, 21) = 26.137$, $p < .001$, $\eta_p^2 = .554$] conditions, demonstrating a significant reduction in accuracy in both conditions when T3 analysis was conditionalised. More interestingly, examining the fully conditionalised sparing effect, T3 on TTT trials was still significantly more accurate than T2 on TdT trials for the letters [$F(1, 20) = 5.706$, $p = .027$, $\eta_p^2 = .222$], but T3 accuracy on TTT trials was significantly worse than T2 accuracy on TdT trials for the objects [$F(1, 21) = 8.937$, $p = .007$, $\eta_p^2 = .299$].

It should be noted that in the letter condition, there was a decrement from T1 to T3 in the consecutive (TTT) target condition, even when unconditional target accuracy data were used. Thus, although our results for letters arguably replicate the most revealing aspect of Di Lollo et al.'s (2005) findings (the striking difference in T3 accuracy between TTT and TdT conditions), we did not replicate their

finding of equivalent T1 and T3 accuracy in the TTT condition. This decrement is consistent with some form of resource depletion while consolidating multiple targets (Dux et al., 2008, 2009). However, it is not clear whether this decrement is indicative of an AB or whether it reflects a more general difficulty in recalling three targets. The latter explanation is perhaps more consistent with the early-pair data, in which T3 accuracy did not recover even at the longest lag between T2 and T3 tested here (564 ms; cf. Dux et al., 2009).

Spreading the sparing

The final analyses targeted two related questions posed by Olivers et al. (2007) in relation to the effect of having multiple targets after T1. First, does an immediately preceding target result in early recovery from the AB? Second, is the AB function for the final target time-locked to the processing of T1 or the processing of the penultimate target? Both questions were addressed with a series of analyses in which target position *relative to T1* was used as a critical within-subjects factor. For instance, T2 from a two-target trial with four intervening distractors and T3 from an early- or late-pair trial with three intervening distractors have the same target position relative to T1 (i.e., five serial positions).

Effects of a preceding target on the recovery from the AB

Unconditional target accuracy The first question was addressed by comparing accuracy for T2 on two-target trials to T3 on late-pair trials, matching for target position. These data are shown in Fig. 7, which graphs accuracy for each of the pairs of consecutive targets (T2 and T3, connected by solid lines) in the late-pair condition and compares these graphs to T2 accuracy in the two-target condition (dotted line). Using an equivalent analysis, Olivers et al. (2007) found better accuracy for T3, indicating that an immediately preceding target led to early recovery from the AB (see Olivers et al., 2007, Fig. 4). A similar pattern is seen here for the letters, whereby late-pair T2 accuracy matches the two-target function closely, but T3 shows a marked improvement at each target location. The objects, on the other hand, show no such improvement for T3, and even exhibit a relative impairment at longer lags from T1. An ANOVA with Trial Type (T2 accuracy on two-target trials vs. T3 accuracy on late-pair trials) and Target Position (2–6, relative to T1 at Position 0) as within-subjects factors and Stimulus Set as between-subjects factor revealed significant main effects of target position [$F(4, 168) = 48.339$, $p < .001$, $\eta_p^2 = .535$] and stimulus set [$F(1, 42) = 15.551$, $p < .001$, $\eta_p^2 = .270$], and significant
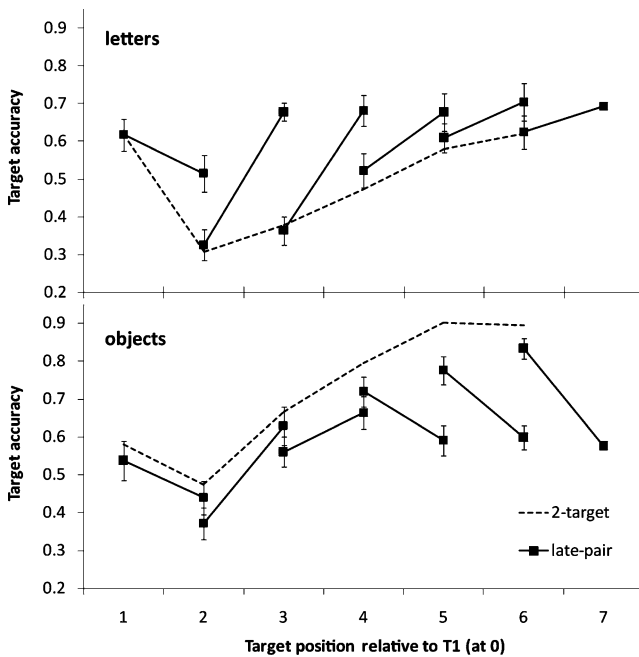
Fig. 7 Report accuracy in Experiment 3, for T2 on two-target trials (dotted lines) and consecutive pairs of targets (T2 and T3) on late-pair trials. Data are shown separately for the letter condition (top panel) and the object condition (bottom panel). Error bars show the standard errors of the mean differences between each data point and the two-target accuracy at the same target position

interactions between target position and trial type [$F(4, 168) = 13.493$, $p < .001$, $\eta_p^2 = .243$] and between trial type and stimulus set [$F(1, 42) = 143.582$, $p < .001$, $\eta_p^2 = .774$]. All other main effects and interactions were nonsignificant (largest $F = 1.632$, $\eta_p^2 = .037$).

Further analyses examined each stimulus group individually. For the letter group, the main effects of target position and trial type were both significant [smaller $F(4, 84) = 17.386$, $p < .001$, $\eta_p^2 = .453$], as was the interaction between the two factors [$F(4, 84) = 4.413$, $p = .004$, $\eta_p^2 = .174$]. The interaction between trial type and the linear trend in target position was also significant [$F(1, 21) = 10.907$, $p = .003$, $\eta_p^2 = .342$], indicating that the difference between the two conditions *decreased* with increasing serial position of the targets. This result generally accords with the findings of Olivers et al. (2007), with accuracy being significantly better for T3 on late-pair trials than for T2 on two-target trials and the difference being most pronounced at short lags from T1. For the object group, the main effects of target position and trial type were again both significant [smaller $F(4, 84) = 34.590$, $p < .001$, $\eta_p^2 = .622$], as was the interaction between the two [$F(4, 84) = 10.235$, $p = .004$, $\eta_p^2 = .328$]. The interaction between trial type and the linear trend in target position was also significant [$F(1, 21) = 25.962$, $p < .001$, $\eta_p^2 = .553$], this time indicating that the difference between the two conditions *increased* with increasing serial position of the targets. Thus, for the objects,

accuracy was significantly *worse* for T3 on late-pair trials than for T2 on two-target trials, and the difference was most pronounced at longer lags from T1, where the standard AB observed for T2 was no longer as evident.[4] This larger deficit for T3 at longer lags from T1 might reflect a stage at which T2 induces its own AB that can be observed independently of the effects of T1.

Conditionalised target accuracy Conditionalising the data solely on T1 made virtually no difference to these analyses or the patterns of results. Conditionalising on both T1 and T2 had the general effect of lowering T3 performance, diminishing the facilitatory effects for late-pair T3 observed in letters and exacerbating the impairment for late-pair T3 in objects. Four of the participants (3 in the letter condition and 1 in the object condition) were missing data from at least one cell of the late-pair T3 condition when target report was fully conditionalised. Analyses on the remaining 40 participants yielded a pattern of significant results very similar to the one from the unconditional data. Most importantly, the interaction between trial type and stimulus set was still significant [$F(1, 38) = 62.647$, $p < .001$, $\eta_p^2 = .622$], reflecting the fact that late-pair T3 accuracy (relative to two-target T2 accuracy) depended on the type of stimulus, with letters yielding a mean improvement and objects a mean decrement.

Is the AB function time-locked to T1 or to the penultimate target?

This question was addressed using T3 accuracy on the early-pair trials (unconditionalised data only). If the AB was time-locked to T1, then early-pair T3 accuracy should vary across target serial positions in much the same way as that for T2 in the two-target condition. If the AB was time-locked to the penultimate target, then early-pair T3 accuracy should be quite different (shifted out of phase by one serial position, because T2 occurs immediately after T1). This can be seen in Fig. 5, by comparing T2 for two-target trials (top panel) with T3 for early-pair trials (bottom panel), equating target position relative to T1 (i.e., Serial Positions 2–6). For the letters, it is evident that the T3

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[4] An alternative analysis that could be used here would be to compare accuracy for T2 and T3 on late-pair trials, controlling for target position (e.g., T2 after two intervening distractors vs. T3 after only one intervening distractor). This analysis yielded a similar result, most critically with a strongly significant interaction between trial type and stimulus set, significantly better T3 than T2 accuracy for letters, significantly worse T3 than T2 accuracy for objects, and the same linear trend interactions between target position and trial type for both letters (diminishing difference between T2 and T3 with lag from T1) and objects (increasing difference between T2 and T3 with lag from T1).

function is of a similar form to the T2 function, but shifted out of phase by one serial position (Olivers et al., 2007, observed a similar resemblance for T2 and early-triplet T4, shifted out of phase by two serial positions). In contrast, for the objects, the T2 and T3 functions look very similar at short lags from T1, but diverge gradually, perhaps towards different asymptotes, at longer lags from T1. An ANOVA with Trial Type and Target Position (2–6) as within-subjects factors and Stimulus Set as a between-subjects factor revealed significant main effects of trial type, target position, and stimulus set [smallest $F(1, 42) = 21.902$, $p <$ .001, $\eta_p^2 = .343$], significant two-way interactions between each pairing of these three factors [smallest $F(4, 168) =$ 10.305, $p < .001$, $\eta_p^2 = .197$], and a significant three-way interaction [$F(1, 42) = 3.436$, $p = .014$, $\eta_p^2 = .076$], which indicates that the two-target T2 and early-pair T3 functions varied from each other in different ways for the letters and objects. However, separate analyses of each group revealed that trial type and target position interacted significantly for both letters [$F(4, 84) = 21.456$, $p < .001$, $\eta_p^2 = .505$] and objects [$F(4, 84) = 3.693$, $p = .020$, $\eta_p^2 = .150$].

These "spreading the sparing" analyses, each comparing targets at the same serial position relative to T1, yielded a very different pattern of results for object stimuli than they did for letters. For letters, a preceding target immediately before T3 facilitated recognition, particularly at short lags from T1, where one would expect to see an AB effect. The AB function itself appears to be time-locked to the occurrence of the preceding target (rather than the first target). In contrast, for objects, an immediately preceding target appears to have had little effect at short lags from T1, and even impaired target recognition at longer lags from T1 after the AB effect associated with T1 diminished. The cause of this impairment is unclear, given that it emerged when the AB should have been diminishing, but it may indicate a limitation of short-term memory that limits ceiling performance.

Discussion

The results of Experiment 3 therefore replicated previous sparing effects produced with multiple consecutive targets when the stimuli were alphanumeric characters, and confirmed that these effects are present when the target is identified by colour alone. However, the results are consistent with Experiments 1 and 2 in demonstrating that object stimuli show dramatically reduced lag-1 sparing and very little evidence of the multiple-target sparing effects reported by Di Lollo et al. (2005) and Olivers et al. (2007).

The level of accuracy was generally somewhat lower for letters than for objects in this experiment, which had not been observed in the previous two experiments. This

was probably because the letters were somewhat smaller and we used a different font that did not contain distinguishing serifs. As a result, lag-1 accuracy was actually fairly similar for letters and objects in this experiment, and differences between the conditions were only evident when lag-1 performance is compared to accuracy at other lags: The decrease in accuracy from lag-1 to lag-2 was significantly smaller for objects than for letters, and lag-1 accuracy was substantially lower than lag-6 accuracy for objects, but not so for letters. Despite the increased difficulty of the letter condition, the pattern observed was very similar to those of previous experiments in terms of the extents of lag-1 sparing and the AB. Even though the letter condition was generally harder than the object condition, it still exhibited obvious extended sparing effects, whereas the object condition did not. Therefore these sparing effects do not have a simple relationship to overall difficulty; it is not merely the case that easier identification tasks afford greater sparing, as a simplistic resource-sharing hypothesis might predict. However, the results are still consistent with the idea that an additional mechanism, one that is stimulus specific and independent of the general difficulty of the task, can alleviate the effects of the AB when targets are presented consecutively. The grouping of letters within a single extended episode (e.g., Wyble et al., 2009) is one viable candidate.

Multiple-target sparing effects form a crucial piece of evidence in favour of selection theories (Di Lollo et al., 2005; Olivers & Meeter, 2008) because they show that, in the absence of intervening distractors, target processing is successfully maintained through the period in which a strong AB is normally observed. However, given the present results, one clearly needs to question the generality of protracted sparing effects. Unlike lag-1 sparing for objects, which we found to be dramatically reduced but still present to some degree in all three experiments, extended sparing effects were completely absent for objects in this experiment.

General discussion

The present study examined whether lag-1 and protracted sparing effects are stimulus specific in ways that the AB is not. This question has important implications for current theories of the AB, given the emphasis that they place on the occurrence of lag-1 and more extended sparing effects. The approach employed in the present experiments was to manipulate the type of stimulus used (letters vs. pictures of familiar objects) to test the relationship between the AB and lag-1 sparing effects, given that previous studies have suggested that objects do not produce much lag-1 sparing

(Dux & Harris, 2007; Harris et al., 2010). Our intention in using different types of stimuli was not to make any strong claims about the stimulus characteristics that might give rise to differences in sparing effects, but to demonstrate that such differences exist and need to be taken into account in developing theories of the AB.

In all three experiments, all items were presented in a single RSVP stream appearing in a fixed location, with the same target selection task (search for red items) for both T1 and T2. Lag-1 and extended sparing effects are typically strong and robust under these conditions. However, the present experiments revealed a marked and consistent difference in the sparing effects produced by simple pictures of familiar objects and those produced by letter stimuli, despite similar patterns of AB for both types of stimuli. In Experiment 1, letters showed significantly more lag-1 sparing than either line drawings or photographs of familiar objects, which did not differ in their (modest) amounts of lag-1 sparing. Experiment 2 demonstrated that a T1 manipulation (stimulus rotation) that exacerbated the AB equally for letters and objects produced a selective decrement in lag-1 sparing for letters, while leaving lag-1 performance for objects unchanged. In Experiment 3, the letter condition extended the findings of Di Lollo et al. (2005) and Olivers et al. (2007) by replicating their consecutive-target sparing effects with RSVP tasks in which the targets were defined by colour. However, in the same experiment, these target sparing effects were virtually absent for pictures of familiar objects, a result that is at odds with the specific predictions of the boost-and-bounce and TLC models (Di Lollo et al., 2005; Olivers & Meeter, 2008).

The stimulus-driven differences in target sparing seen here pose a challenge for attentional control theories of the AB that incorporate lag-1 and protracted sparing effects into their explanations of the mechanisms underlying the AB. The boost-and-bounce model (Olivers & Meeter, 2008) assumes that the AB is the direct consequence of inhibition that occurs in response to a posttarget distractor. In situations in which neither a distractor nor any disruptive change in processing (such as a shift in spatial location or search task) follows T1, no inhibition is predicted, and target sparing should be observed. The TLC hypothesis (Di Lollo et al., 2005) assumes that during T1 consolidation, endogenous control of attention is lost, meaning that its configuration is at the mercy of post-T1 events. When the configuration is disrupted (e.g., by post-T1 distractors), an AB occurs, but if its configuration persists in the absence of endogenous control (as is predicted when further targets follow T1), then target sparing should occur. It is true that both models assume that other factors—including masking and memory limits—will affect performance and may influence patterns of accuracy to differing degrees, depend-

ing on the presentation conditions. Nevertheless, due to the mechanisms by which these models operate, their default prediction is one of strong target sparing. In our experiments, we ensured that the processes of initially selecting a target for identification were equated for the different stimulus types; the targets were identified by the same search task and were always located centrally on the screen. Therefore, the logical prediction of selection models is that sparing effects should be observed for both letters and objects, but this is not what we found.

One might assume that there will be differences in the levels of masking and differences in the speeds of temporal integration for the two classes of stimuli that might affect target performance more in one condition than the other. However, the lag-1 sparing differences in Experiment 1 were consistently obtained over three very different SOAs, for which one might predict different effects of temporal integration. Furthermore, in RSVP, masking and integration are not specific to cases in which the targets occur consecutively: Distractors mask all targets and may interfere with the cohesive integration of target properties at any lag. Therefore, any difference in these factors would apply to other lags as well. With this in mind, it is worth noting that in several cases in these experiments, the differences in lag-1 sparing run in the opposite direction to general differences in accuracy. In the 59-ms SOA condition of Experiment 1, the letter condition exhibited the most pronounced AB but showed stronger lag-1 sparing than the object condition. In Experiment 3, the condition with lower overall accuracy (letters) showed clear extended sparing effects, whereas the condition that was generally easier (objects) showed profound impairments when three targets appeared consecutively. On the other hand, in Experiment 2, a manipulation that deepened the AB did not increase sparing—in fact, it decreased lag-1 performance for letters, while having no impact on lag-1 performance for objects. Therefore, there is no simple relationship between the difficulty of processing a target and the amount of lag-1 sparing.

The present finding that stimulus variables strongly influence sparing effects (and independently of their effects on the AB) complement previous research that has revealed selectivity on the basis of either the consolidation task (Dell'Acqua et al., 2007) or spatial location (e.g., Visser, Bischof, & Di Lollo, 1999a). Therefore, a future challenge for selection theories of the AB will be to develop a formal computational explanation for the task and stimulus specificity of target sparing effects.

An alternative explanation is to accept that target sparing is a fairly specialised and idiosyncratic phenomenon, caused by mechanisms independent of those responsible for the AB itself. For this reason, the present results are probably better accommodated by resource depletion or

capacity limitation accounts of the AB (e.g., Bowman & Wyble, 2007; Chun & Potter, 1995). This being said, appealing to different rates of resource depletion in a *general* sense cannot provide a satisfactory account for lag-1 sparing in general or in our present data. Instead, these models assume that the processing deficit responsible for poor accuracy in the AB is still present at lag-1, but additional mechanisms mitigate its impact on target report. In other words, lag-1 sparing is the result of a mechanism with a different set of constraints from the process that leads to the AB.

Some resource depletion accounts of the AB explain lag-1 sparing by assuming that resources for target identification might be more evenly distributed across targets when they occur in very close succession (e.g., a trade-off between T1 and T2). Our results thus suggest that this type of resource sharing, while possible with letter stimuli, does not occur with objects. However, even in the case of letters, if processing of T1 is prioritised over T2, as seemed to be the case in Experiment 2 for rotated T1s (see also Dux et al., 2008), this may reduce the opportunity for lag-1 sparing. A full consideration of the stimulus characteristics that may account for this difference between letters and objects is beyond the scope of this study, but one could speculate that objects may be more difficult to consolidate as distinct entities when multiple targets are presented consecutively. For example, Wyble et al. (2009) have recently shown that lag-1 sparing comes at the expense of the episodic integrity of the stimuli and, in particular, that configural stimuli (e.g., letter pairs such as AB and CD presented as T1 and T2, respectively) are susceptible to incorrect conjunctions of their constituent elements when they immediately follow each other. Evans and Treisman (2005) have claimed that objects viewed under RSVP conditions are typically represented as unbound features (see also Hayward, Zhou, Man, & Harris, 2010, for related evidence). These features are sufficient to detect objects of a particular target category; however, they need to be bound together for individual identification, a process that takes time, requires attention, and is implemented serially. Therefore, objects may be more vulnerable to misbindings of their features when they occur in close temporal succession, leading to poor identification of consecutive items. In contrast, letters are highly practiced and codified stimuli. This may result in relatively automatic identification, which could more easily allow for sharing of attentional resources between consecutive items.

Evans and Treisman (2005) did not test performance at lag-1 in their experiments and, thus, could not directly confirm their predictions. Our present results do offer some support for their hypothesis. On the other hand, Potter et al. (2010) have recently presented evidence of a lag-1 sparing effect for objects, which they argue is inconsistent with

Evans and Treisman's proposal. The logic is that, if object identification occurs serially and in the later stages of attentional processing, then on lag-1 trials identification of T1 should always either interfere with identification of T2 (because unbound features from both targets are consolidated in the same attentional episode) or completely prevent identification of T2 (because identification is serial, the opportunity to identify T2 might be missed altogether). Therefore, Potter et al. took the presence of lag-1 sparing in their study as evidence that object identification occurs rapidly and early. As discussed in Experiment 1, our findings do not completely conflict with those of Potter et al. because we observed some (albeit small) lag-1 sparing for objects—although these modest sparing effects clearly do not extend beyond more than two items, as demonstrated by the results of Experiment 3. However, our results are not particularly consistent with an early-identification model of object processing, if identification is taken to mean the establishment of a stable representation of an object that can be easily individuated from another presented in close temporal proximity. Rather, the weak target sparing effects for objects observed here suggest that, at the very least, identification of objects may not be accomplished as rapidly and automatically as Potter et al. suggest.

One potential difference is that Potter et al. (2010) used categorically defined targets, and the participants were cued at the beginning of each trial with the category of the relevant targets. Perhaps this procedure produced stronger lag-1 sparing than our task, in which targets had to be selected on the basis of a perceptual feature (colour). It is certainly possible that the selection task plays a role in modulating sparing effects, because of different speeds of attentional deployment in the two identification tasks. However, this does not explain why we found strong extended sparing effects for colour-defined target letters in Experiment 3, but not for colour-defined target objects. Furthermore, Dux and Harris (2007, Exp. 2) found little lag-1 sparing when using animal targets amongst nonanimal distractors. Although the role of the target selection task in producing lag-1 sparing merits further investigation, it is clear that other stimulus properties have a strong influence on target sparing effects, even when the search task is held constant.

Considerable further work is needed to isolate which particular facets of these stimuli actually controlled lag-1 sparing. It was not our intention to attempt this here, but it is worth noting that other kinds of complex stimuli have been used in AB experiments and could be incorporated into studies directed specifically at lag-1 sparing. Faces are a pertinent example. Landau and Bentin (2008) compared faces and objects in RSVP to examine the stimulus specificity of the AB produced by each type of stimulus (see also Awh et al., 2004). Their results did not reveal an

accuracy advantage for lag-1 over lag-3, but there might have been other reasons why these studies did not produce sparing effects, such as the switching of search tasks for T1 and T2 or the similarity of T1 and T2 in some experimental conditions. Jackson and Raymond (2006) compared the AB functions produced by familiar and unfamiliar faces, and also reported analyses specifically regarding lag-1 accuracy. Their results pertaining to lag-1 sparing were mixed, possibly suggesting that familiar faces exhibit greater lag-1 sparing than unfamiliar faces. These studies were not motivated by a desire to examine lag-1 sparing and did not compare target sparing effects directly, but further studies with this specific aim could be useful in revealing the mechanisms responsible for lag-1 sparing. An intriguing possibility, which could be examined in future research, is that the strong lag-1 sparing effects assumed to be the norm in previous studies might turn out to be relatively specific to highly practiced stimuli, such as letters and digits (and, perhaps, to some extent, familiar faces).

Conclusion

Recent theories of visual selective attention have focused on lag-1 sparing because it appears to be a fairly ubiquitous feature of the attentional blink. Related sparing effects caused by multiple consecutive targets have also been used to discriminate between various accounts of the AB. The assumption in both cases has been that sparing effects are an integral part of the attentional processes that drive the AB, and consequently should fall naturally from any formal theoretical explanation of the AB. In the present study, we consistently found much less lag-1 sparing for objects than for letters, despite retaining AB effects of comparable magnitude across conditions. We also found no evidence of multiple-target sparing effects for objects, but replicated those same sparing effects with letter targets selected by colour. The stimulus parameters that dictate the emergence of lag-1 sparing therefore clearly differ from those that lead to the AB, and the relationship between the two warrants closer inspection with a range of stimuli and task requirements. It may well be the case that lag-1 sparing is subserved by a stimulus-specific mechanism that is not diagnostic of the processes involved in the AB.

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