Psychological Research (2013) 77:583–598
DOI 10.1007/s00426-012-0447-7

ORIGINAL ARTICLE

Task set flexibility and feature specificity modulate the limits of temporal attention

Elkan G. Akyürek · Charlotte Köhne · Anna Schubö

Received: 23 April 2012 / Accepted: 16 July 2012 / Published online: 8 August 2012

Abstract The consequences of maintaining a task set in the context of the (speeded) attentional blink were investigated in a series of experiments. Observers were asked to either attend or ignore the first of two target stimuli (T1 and T2). The results showed that when T1 and T2 shared a task relevant feature that was unique to T2, but not to T1, a shallow attentional blink was observed, as well as a lack of Lag 1 sparing. In comparison, when the targets shared a feature that was uniquely task relevant to both targets, the blink could not be avoided. Conversely, when no feature was shared between targets, ignoring T1 was successful and virtually no attentional costs were apparent. A similar lack of costs was also observed when targets shared a task relevant feature that was unique to T1 but not to T2. Finally, matching the feature dimension of a target feature that was unique to T2, but not T1, also strongly attenuated the blink. However, it did not completely abolish Lag 1 sparing. The results are interpreted in the context of current models of the attentional blink.

E. G. Akyürek · A. Schubö
Ludwig Maximilian University, Munich, Germany

E. G. Akyürek (✉) · C. Köhne
Department of Psychology, Experimental Psychology,
University of Groningen, Grote Kruisstraat 2/1, 9712 TS
Groningen, The Netherlands
e-mail: e.g.akyurek@rug.nl

A. Schubö
Philipps University, Marburg, Germany

Introduction

Recent research on the deployment of attention over time, or temporal attention, has increasingly focused on the attentional blink phenomenon. The attentional blink (AB) is the failure to identify the second of two briefly ($\sim$100 ms) presented target stimuli if they follow each other in close temporal succession within approximately 500 ms. It has been observed in rapid serial visual presentation (RSVP) paradigms, and in isolated presentation of just the target stimuli with successive masks, suggesting that it is a fairly general limitation on the timing of visual selective attention (Broadbent & Broadbent, 1987; Raymond, Shapiro, & Arnell, 1992; Ward, Duncan, & Shapiro, 1996). An important question with regard to the attentional blink is what properties the first target must have in order for a blink to ensue. As with any visual stimulus, the allocation of attention to the first target in the RSVP is dependent on its stimulus properties, and the task relevance thereof. The degree to which attention is allocated to the first target will consequently affect the performance on the second target, and hence modulate the attentional blink.

There is increasing evidence that task relevance is an important factor in the deployment of attention. In the study of spatial attention, numerous studies have investigated the degree to which task-relevant properties of (distractor) stimuli involuntarily attract attention, and contrasted this effect with that of stimulus-based salience (Bacon & Egeth, 1994; Folk, Leber, & Egeth, 2002; Folk & Remington, 1998; Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994; Theeuwes, 1991; 1992; 1994; Theeuwes & Burger, 1998). More recently, several studies have also demonstrated the (modulating) effects of task-relevant stimulus properties on attentional deployment in the temporal domain.

In a direct test of task-related effects on temporal attention, Folk et al. (2002) and Folk, Leber and Egeth (2008) showed that the appearance of a colored box around a distractor (or a simultaneous colored flanker item) interfered with attentional deployment to a subsequent target only when the color of the distracting stimulus matched the task set of the observers (cf., Chun, 1997; Jolicœur, Sessa, Dell'Acqua, & Robitaille, 2006). However, Folk and colleagues used different, spatially separate stimuli for the items of interest (the letters) and those meant for distraction only (the box or the flanker), and it is possible that observers took advantage of this separation on the stimulus level to guide their attention. The troublesome stimulus might be ignored altogether on trials in which its task relevance was not immediately evident (such as when it did not match the exact color of T2). Indeed, there is evidence also for purely stimulus-driven effects in RSVP (Asplund, Todd, Snyder, Gilbert, & Marois, 2010a; see also Asplund, Todd, Snyder, & Marois, 2010b). Nonetheless, the results of Folk et al. (2002; 2008) clearly showed the ability of task-relevant stimulus features to draw attention.

Using a similar 'separated' RSVP-with-distractor design, Wee and Chua (2004) showed that a distracting stimulus is able to capture attention also during the attentional blink, particularly when it had the task-relevant feature that also defined the targets (in this case color). Attentional effects were observed as a prolongation of the blink. Although there remains some debate to what extent effects may be attributed to stimulus-driven and task-related factors, several other studies have demonstrated similar effects of distraction also in tasks that did not feature a spatial separation between the RSVP and the distractor (e.g., Dalton & Lavie, 2006; Maki & Mebane, 2006; for an example of semantic distraction see Barnard, Scott, Taylor, May, & Knightley, 2004).

Task-related effects in temporal attention have also been shown in a dual target RSVP paradigm without the addition of an extraneous distractor (Spalek, Falcon, & Di Lollo, 2006). The advantage of the dual target procedure in particular is that it allows direct comparison of voluntary and involuntary target selection, without introducing an extra distractor stimulus in the latter condition. Spalek et al. (2006) contrasted attentional deployment between three conditions: one without T1, one with T1 in which T1 had to be attended, and one with T1 in which it had to be ignored. At short lags, attentional costs were observed, i.e., imperfect T2 identification accuracy, even for ignore-T1 trials. The magnitude of this T2 performance deficit was affected by the degree of "similarity" between T1 and T2; trying to ignore more similar targets produced larger deficits.

Task set flexibility

These demonstrations of task-related effects on temporal attention do, however, leave the question unanswered of whether adaptive or flexible implementation of the target search template may have modulated the observed attentional costs. The present study was aimed at investigating whether flexibility of the task set (described further below) affects the efficiency of temporal attention. Two main issues were addressed: first, unlike spatial paradigms, temporal paradigms may require using different successive templates or task sets to first find T1 and then T2. It is not yet apparent how the perceptual system accomplishes this. Is it more likely to rapidly switch templates between targets, or to use a single, broad target template that encompasses features of both targets? How is the system configured when T1 is to be ignored? Second, a systematic investigation of the degree to which a particular feature is task relevant is currently lacking. For instance, if color is all that dissociates a letter target from other distractor letters (i.e., it is the single, defining target feature), that feature may be more critical, and have commensurate effects on subsequent attentional deployment, compared to a feature that is useful, but not uniquely dissociative for the target (e.g., color on a digit target amidst letter distractors). Such a 'useful' feature may be part of the task set, but since it is not critical to the search, might it be put to use in a more flexible manner, according to its perceived benefits?

Previous work, in particular, the study by Spalek et al. (2006), included some conditions that may already help to elucidate these questions about task set flexibility. Although Spalek et al. explicitly linked the critical feature(s) of T1 to the task relevance for selecting T2, their main manipulation of this relationship was "similarity", i.e., more similar targets matched on more than one feature. First, their study included a condition in which a single defining feature of T1 matched the single defining feature of T2, which resulted in a full-fledged AB even when participants were trying to ignore T1 (Experiment 1, "single ignore"). Second, their study featured a condition in which the defining feature of T1 matched one of two defining features of T2 (Experiment 2, "medium similarity"), which resulted in a minimal AB when T1 should have been ignored. Third, there was a condition in which two of two defining features of T1 matched two of two defining features of T2 (Experiment 2, "high similarity"). The result was again a strong AB.

An interpretation of these results could thus be that only full matches of all available defining features cause a substantial amount of attention to be devoted to T1 when it should be ignored. However, there are some caveats. The critical comparisons concerned conditions of their Experiment 2, which was special in that T1 should never have been attended. Thus, apart from not having a (dual target) baseline for AB magnitude in the experiment, it is not certain whether any selection criteria concerning T1 even played a role here. The authors indeed intentionally focused on T2 selection in their discussion. Furthermore, although examining the effects of matching two features between targets is certainly worthwhile in its own right, the implications for the issue of flexibility are less clear. The reason is that with multiple relevant features on each target, it becomes impossible to disentangle the target-specific selection strategy that was used (e.g., was T2 selected by means of feature A, feature B, or both?). Finally, with regard to the degree of flexibility afforded for target selection, the experiments were not intended to systematically vary T1–T2 relationships, and therefore it is difficult to conclusively infer the underlying mechanism post hoc.

The present study thus sought to augment these data to elucidate the effect of target-specific task set flexibility on temporal attention. To this end, a "speeded AB" (Jolicœur, 1999) paradigm similar to that of Spalek et al. (2006) was used. In a series of experiments, participants were asked on a trial-by-trial basis to either ignore or to attend and report T1, while also reporting T2. Comparison of these two conditions reveals the degree of involuntary attentional selection of T1 when it was to be ignored, relative to its voluntary selection. Involuntary attentional allocation towards T1 was hypothesized to depend on the presence or absence of a feature that was also relevant for the selection of T2.

In Experiment 1, one of two defining features of T1 matched the single defining feature of T2. Thereby, selection of T1 could be accomplished using either feature as a criterion, and as such was considered to be flexible. At the same time, the selection of T2 relied on a single feature, and was therefore inflexible. Experiment 1 was thus aimed at testing the degree to which allowing flexible selection of T1 might help to avoid involuntary attentional allocation towards it. In Experiments 2 and 3, the complete absence of a feature match between targets, and a match of the uniquely defining feature of both targets were tested (i.e., a full match), respectively. These experiments served to chart the boundary conditions; in Experiment 2, ignoring T1 should be easy, as it did not have any task-relevant feature in common with T2. In Experiment 3, the single defining feature of both targets matched, which should make it very difficult (if not impossible) to ignore T1. Experiment 4 mirrored Experiment 1, but now T2 had two features available for its selection, rather than T1, meaning that the selection of T2 was flexible, instead of that of T1, which might again reduce attentional allocation to T1 when it should be ignored. Finally, in Experiment 5, the degree to which a feature dimensional match, rather than a feature-specific match, changes the degree of attentional allocation in conditions otherwise similar to those of Experiment 1.

Experiment 1

The purpose of Experiment 1 was to investigate the degree to which observers are able to ignore T1 and avoid attentional costs, when the task set for T2 consists of a single property that also applies to T1. Specifically, in Experiment 1, T1 and T2 shared a task relevant feature that allowed the observers to discriminate them from the letter distractors in the RSVP, both were digits. Importantly, T1 had another feature that enabled discrimination, because it appeared in blue, whereas all other stimuli were black. As such, this color feature was also uniquely relevant to T1. Since T2 did not have any alternative feature that could be used to select it (i.e., apart from being a digit), observers were thus unable to use a flexible task set for T2, but they could for T1, and use either color or digit identity for its selection.

In order to establish the degree to which T1 and its feature can be ignored, the identification performance on T2 (after correctly responding to T1) was the primary measure. Difficulty experienced when trying to ignore T1, when asked to do so, should be evident from a performance curve across T1–T2 Lag that is similar to that of trials in which observers were asked to attend T1. Being able to successfully ignore T1 when asked should result in a difference between ignore- and attend-T1 trials, presumably in favor of higher task performance in the former, since it then essentially becomes more like a single-target task.

Method

Participants

Twenty students (13 female, 7 male) at the Ludwig Maximilian University Munich participated in the experiment for course credit or monetary compensation. Informed consent was obtained in writing and the study was conducted in accordance with the Declaration of Helsinki. Participants were unaware of the purpose of the experiment and reported normal or corrected-to-normal vision. Data from one female participant were removed from the analyses because T1 performance was abnormally low and close to chance level, indicating that the task was not properly executed. Mean age was 23.5 years (range 20–30 years).

Apparatus and stimuli

Participants were individually seated in a comfortable chair in a dimly lit and sound attenuated testing chamber at a distance of approximately 100 cm from the screen. The 20″ CRT screen was driven by a Core 2 Duo computer with a discrete graphics board, and refreshed at 100 Hz with a resolution of 800 by 600 pixels in 16 bit color. The experiment was programmed in E-Prime 1.2. Responses were logged on a standard USB keyboard polling at 125 Hz. A light gray background (RGB 192, 192, 192) was maintained throughout the experimental trials. Stimuli consisted of letters and digits, drawn in bold 18 pt. Courier New font. All stimuli were drawn randomly without replacement from their sets: 1–4 and 6–9 for T1, 2–9 for T2, and A–Z for the distractors. All of these were black (RGB 0, 0, 0), except for the digit presented as T1, which was blue (RGB 0, 0, 255). The fixation cross ("+") that was presented at the start of each trial was yellow (RGB 255, 255, 0).

Procedure and design

The experiment had a total of 480 experimental trials with an optional pause half-way, and 20 practice trials. The experiment was self-paced and participants initiated each trial by pressing Enter. Immediately after initiation of the trial, an instruction screen was shown for 1,000 ms stating either "Ignore the blue digit!" or "Watch the blue digit!" depending on the experimental condition, both of which consisted of 50 % of trials that were randomly intermixed. After a delay of 200 ms, the yellow fixation cross was shown for 250 ms. A blank screen was then shown for 30 ms after which an RSVP sequence of 19 stimuli appeared. The stimuli were on screen for 70 ms and followed by a 30 ms blank screen each. Two of these stimuli were digits (T1 and T2), while the others were letters (distractors). T1 appeared as either the fifth or the seventh item in the stream and T2 followed T1 with either 0, 2, or 7 stimuli in-between, referred to as Lag 1, 3, or 8. At the end of the stream, a 500 ms blank delay ensued before participants were prompted to enter the identity of the second digit in the stream. The first target required a speeded response, which consisted of a two-choice judgment of whether it was greater (a blue key on the keyboard; P) or smaller than five (a white key; Q). Participants were instructed to make this response only if the trial instructions stated that the digit should be attended. Accordingly, when the blue digit was to be ignored, any response given in spite of that was classified as incorrect. The speeded response to T1 was implemented to minimize offline memory effects associated with retrieving both T1 and T2 responses after the RSVP, and to promote immediate processing of T1, which should maximize the potential of T1 to cause an AB (Jolicœur, 1999). It also provided an additional measure of T1 performance: reaction time. However, since the T1 measures between ignored and attended T1's were inherently different (e.g., ignoring all T1's in the experiment would result in 100 % correct trials in the ignore condition), none of the conclusions drawn here rely directly on a comparison between the corresponding means of T1.

Mean accuracy was analyzed in a repeated measures analysis of variance with two variables. The first variable was T1–T2 Lag (1, 3, and 8), and the second variable was Selection (required, and not required). T1 accuracy was based on the percentage of correct >5 or <5 responses when it was to be attended, and based on the number of correctly withheld responses when it was to be ignored. For the analysis of reaction time to T1, the Selection variable was dropped since reaction times recorded on trials in which a response was not required represented erroneous responses only. T2 accuracy reflected the percentage of correctly identified stimuli, given that T1 was correct[1]. For significant tests of sphericity, the degrees of freedom were adjusted using the Greenhouse-Geisser epsilon correction.

Results and discussion

Performance on T1 as a function of Lag is shown in Fig. 1. Categorization accuracy on T1 was affected by Lag, $F(2, 36) = 4.47$, $\mathrm{MSE} = 0.001$, $p < 0.05$. Performance was high, as expected, but dropped slightly at Lag 1 to 89.6 %, from 91.9 % at Lag 3 and 91.8 % at Lag 8. There was no main effect of Selection ($F < 1$). The interaction between Lag and Selection was significant, however, $F(2, 36) = 6.27$, $\mathrm{MSE} = 0.001$, $p < 0.01$. The interaction pointed to Lag 1, where performance was higher when no attentional selection was required (91.3 %) than when it was 87.9 %. T1 reaction time was similarly affected by Lag, $F(2, 36) = 18.25$, $\mathrm{MSE} = 794.782$, $p < 0.001$, with higher reaction time at Lag 1 than at Lag 3 and 8, as shown in Table 1. Overall, shorter lags were associated with more difficulty, especially in the case of Lag 1: more errors were made and reaction time was increased.

Figure 2 shows the primary measure of T2 identification accuracy, given that T1 was correct, plotted over Lag. Both Lag, $F(1, 27) = 11.26$, $\mathrm{MSE} = 0.037$, $p < 0.001$, and Selection, $F(1, 18) = 20.98$, $\mathrm{MSE} = 0.004$, $p < 0.001$, had an effect. Average performance at Lag 1 (73.8 %) and Lag 3 (72.5 %) was low compared to Lag 8 (88.6 %), which represented the attentional blink deficit. It was furthermore easier to identify T2 after not selecting and withholding a response to T1 (80.9 %) than it was after actually giving one (75.7 %), which was expected as a fairly obvious result of the experimental manipulation. Lag and Selection furthermore interacted, $F(2, 36) = 32.07$, $\mathrm{MSE} = 0.005$, $p < 0.001$. Two important results were obtained here.

[1] Unconditional T2 analyses were additionally conducted, to verify whether the divergent measures of correct performance in the ignore- and attend-T1 conditions might have resulted in spurious effects on T2 performance. The analyses consistently showed highly comparable patterns, with minimal differences between unconditional and conditional means. Thus, the conditional analyses were validated with regard to this potential confound.

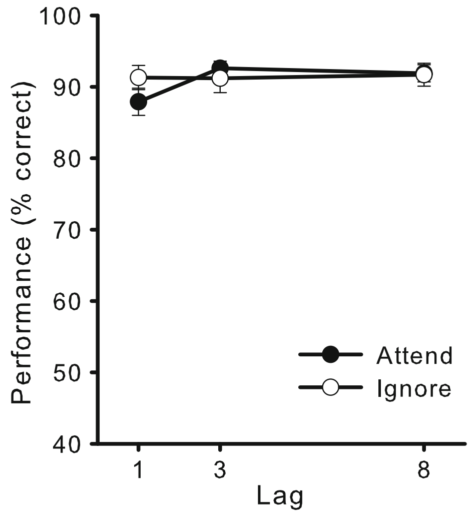

Fig. 1 Task performance on T1 in Experiment 1 in percent correct, plotted over T1–T2 Lag (1st, 3rd or 8th stimulus after T1). *Error bars* represent ±1 standard error of the mean. *Black symbols* represent trials on which T1 (a *blue digit*) was to be attended to, and *white symbols* represent trials on which T1 was to be ignored. Note that in the latter condition, the measure reflects correctly withheld responses

Table 1 T1 reaction time in ms (attend-T1 condition only)

Experiment	Lag 1	Lag 3	Lag 8
1	757	724	702
2	767	746	739
3	804	795	763
4	624	610	659
5	574	566	555

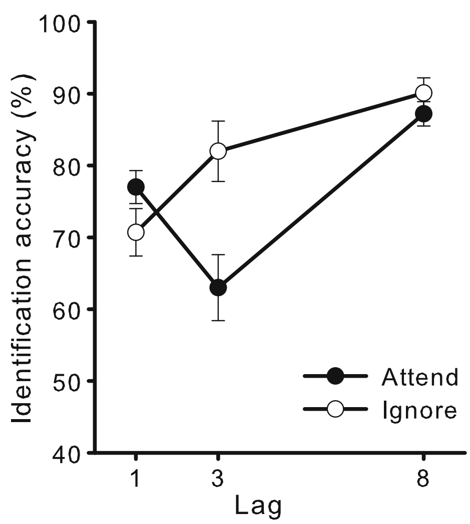

Fig. 2 Identification accuracy on T2 (a *black digit*) in Experiment 1, given that T1 was correctly responded to (T2|T1), in percent correct, plotted over T1–T2 Lag. *Black* and *white symbols* represent selection requirements as before

The first main result was that an attentional blink was found in both selection conditions. The attentional blink, however, was modulated by selection, as is evident from comparing mean performance at Lag 3 when T1 should be ignored (82 %) to when it should be attended (63 %). It seemed that in the ignore-T1 condition, the blink was reduced as well as pulled forward in time so that performance at Lag 1 rather than at Lag 3 was the lowest. A separate ANOVA on the ignore-T1 condition alone confirmed that the performance differences in this condition were reliable, $F(2, 28) = 9.36$, $\mathrm{MSE} = 0.025$, $p < 0.01$.

The second main result was that while Lag 1 sparing was observed when T1 should have been selected (77 % at Lag 1 vs. 63 % at Lag 3), no trace of it remained when T1 should have been ignored (70.7 vs. 82 %); when T1 was not to be selected, performance at Lag 1 was the lowest of all lags. Lag 1 sparing has been defined as performance at Lag 1 exceeding the lowest performance at other lags by more than 5 % (Visser, Bischof, & Di Lollo, 1999). It is thought to reflect how the attentional processing of T1 can include T2 by jointly processing both in one cognitive event (e.g., Akyürek, Toffanin, & Hommel, 2008; Hommel & Akyürek, 2005; Potter, Staub, & O'Connor, 2002). It is usually only observed when T1 and T2 are of the same type (e.g., digits) and appear at the same spatial location.

The presence of Lag 1 sparing in the attend-T1 condition in the present experiment seemed to indicate that type similarity between targets was a sufficient prerequisite for sparing to occur, even though the tasks for T1 and T2, as well as their response requirements were different (i.e., judging whether T1 was smaller or greater than 5, and identifying T2). It may be mentioned also that since the response to T1 was speeded, the current sparing effect must have been generated at a perceptual stage, rather than 'offline' (e.g., due to interference in memory). The absence of Lag 1 sparing in the ignore-T1 condition may reflect the introduction of a dissimilarity between the targets (e.g., a classification of T1 being task-irrelevant and T2 being relevant), which may have prevented the joint processing of the targets and eliminated sparing.

To further investigate the nature of the differences in performance between attend- and ignore-T1 conditions, an analysis of T1–T2 substitution errors was carried out. Such trials were the ones in which the identity of T1 was given in response to T2. The frequency of substitution errors was affected by both Lag, $F(1, 26) = 4.01$, $\mathrm{MSE} = 0.013$, $p < 0.05$, and Selection, $F(1, 18) = 5.78$, $\mathrm{MSE} = 0.001$, $p < 0.05$. Substitution errors were more frequent at Lag 1 (17.1 %) than at Lag 3 (11.3 %) and Lag 8 (11.9 %), and more frequent in the ignore-T1 condition than in the attend-T1 condition (14.3 vs. 12.6 %). However, despite this trend, the interaction term was unreliable ($F < 1$), and thus there was no evidence to support the idea that performance in the ignore-T1 condition at Lag 1, where performance on T2 was lowest, was due to an increased tendency to make a substitution error.

Overall, the results suggested that the AB, measured at Lag 3, was more prominent when T1 had to be attended and markedly reduced when T1 could be ignored. Tied in with this effect was the observation that Lag 1 sparing was abolished when T1 was ignored, and Lag 1 performance plummeted. The present data in the ignore-T1 condition resemble previous results reported by Chun (1997) (Fig. 1), and Asplund et al., (2010a) (Fig. 2c). In the former study, targets were highlighted with surrounding color frames, which constitutes a situation comparable to the present study with regard to task relevance, apart from the spatial separation of actual targets and selection features. Chun (1997) suggested that the resultant performance curve might indeed be due to imperfect attentional control (resulting in failure to ignore T1), but also that it could be due to the processing of the color itself (i.e., a stimulus-driven effect). The study by Asplund et al., (2010a) also elicited a similar performance curve by inserting irrelevant, but salient surprise stimuli in their RSVP task.

On the basis of these previous studies, one might thus tend to interpret the present results as a reflection of stimulus-specific processing, rather than due to contingencies related to task relevance. If this holds true, then removing the match between task relevant properties of the targets should not matter as long as the eliciting stimulus-specific feature of T1 (i.e., its color) is maintained. Experiment 2 was carried out to test that prediction.

Experiment 2

Experiment 2 was conducted to investigate whether the performance effects on T2 in the ignore-T1 condition of Experiment 1 would also be observed when T1 and T2 do not share any feature. In the present experiment, T1 was a blue letter while T2 remained a black digit, thus eliminating (task relevant) feature sharing between targets, but maintaining the critical color feature of T1. If performance in the ignore-T1 condition of this experiment is found to be similar to that of Experiment 1, it would support the view that stimulus-driven capture was involved in T1 processing. If no evidence of such capture is obtained, it would support the case for an account based on task relevance.

Method

Participants

Eighteen new students (13 female, 5 male) at the Ludwig Maximilian University Munich participated in the experiment. Recruitment and selection procedures were as in Experiment 1. Mean age was 23.4 years (range 19–30 years).

Apparatus and procedure

The experiment was identical to Experiment 1, with the exception that T1 was now a letter. The T1 task was to indicate whether T1 was a vowel or a consonant, which were equally distributed. The same response keys were used (Q and P, respectively), but the blue label was replaced by a yellow one to avoid any possible spurious association with the stimulus colors used in the experiment.

Results and discussion

Figure 3 shows T1 performance as a function of Lag. The new task for T1 was reflected in a significant effect of Selection on T1 performance, $F(1, 17) = 16.08$, $MSE = 0.028$, $p < 0.001$. Mean performance was 78.1 %, while a response was correctly withheld in 91.1 % of trials. There was no main effect of Lag, but its interaction with Selection was significant, $F(2, 34) = 3.43$, $MSE = 0.001$, $p < 0.05$. There was a small decrement in T1 performance at Lag 1 during the categorization task (76.1 % compared to 79 % and 79.4 % at Lags 3 and 8), but not in the absence of this task (91.3 % compared to 90.8 %, and 91.3 %). T1 reaction time (see Table 1) again showed the Lag effect, $F(2, 34) = 3.4$, $MSE = 1{,}145.016$, $p < 0.05$.

Figure 4 shows T2 identification accuracy over Lag. T2 accuracy, given a correct response to T1, was affected by Lag, $F(2, 34) = 43.32$, $MSE = 0.007$, $p < 0.001$. The attentional blink was again evident. Performance dropped

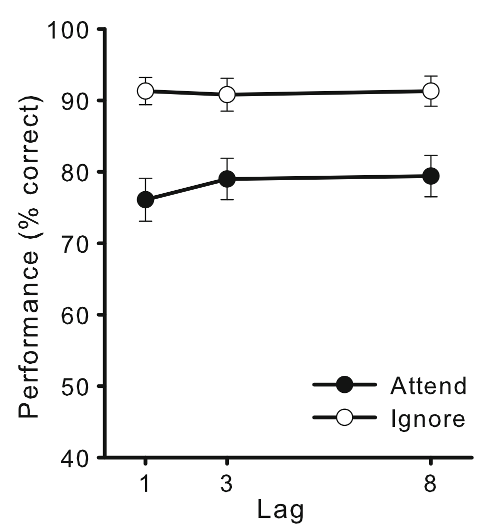

Fig. 3 Task performance on T1 (a blue letter) in Experiment 2 (%). In this and further T1 figures, figure conventions are identical to those of Fig. 1

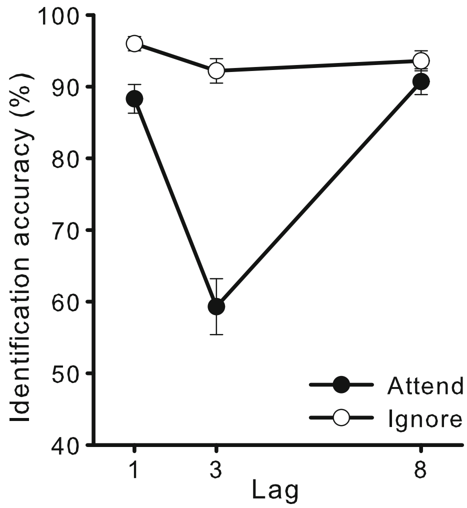

Fig. 4 Identification accuracy on T2|T1 (a *black digit*) in Experiment 2 (%). In this and further T2 figures, figure conventions are identical to those of Fig. 2

to 75.8 % at Lag 3 from 92.2 % at Lag 8. Performance on Lag 1 averaged 92.2 %, indicating the presence of Lag 1 sparing. Despite having to switch between different task sets for T1 and T2, performance seemed even a bit higher overall than in Experiment 1. Selection also had an effect, $F(1, 17) = 111.02$, $\mathrm{MSE} = 0.005$, $p < 0.001$, which indicated higher performance when T1 was not to be selected (94 %), compared to when it was 79.4 %, an effect also observed in Experiment 1. Finally, the interaction between Lag and Selection was also significant, $F(2, 34) = 79.28$, $\mathrm{MSE} = 0.003$, $p < 0.001$.

The means constituted a clear pattern; when T1 was to be ignored only a weak performance deficit at Lag 3 was apparent for T2 (which was nonetheless reliable, $F(2, 34) = 3.92$, $\mathrm{MSE} = 0.002$, $p < 0.05$; 96, 92.2, and 93.6 % at Lags 1, 3, and 8, respectively). When T1 was to be attended, however, a strong attentional blink emerged, with performance dropping from 88.3 % at Lag 1 to 59.3 % at Lag 3, before recovering to 90.7 % at Lag 8. The presence of Lag 1 sparing was remarkable, given the category and task mismatch between T1 and T2, and may be taken as an indication that the salient color of T1 boosted its processing in a way that allowed T2 to benefit. In this sense, the salient color may have served as a way of making T1 easier to perceive.

In summary, when T1 did not share category membership with T2, the attentional blink vanished all but completely when T1 was ignored, constituting a large degree of successful attentional control. This supported the idea that sharing of task relevant features was critical for the pattern of Experiment 1 to emerge. In the present experiment, the color of T1 was only able to trigger a small AB at Lag 3 when observers were instructed to ignore it.

Comparison between Experiments 1 and 2

To more formally consider the difference between the results of Experiments 1 and 2, T2 performance was analyzed in an overall ANOVA with experiment as a between-subjects variable. Performance across all conditions was higher in Experiment 2 (86.7 %) than in Experiment 1 (78.3 %), $F(1, 35) = 10.18$, $\mathrm{MSE} = 0.038$, $p < 0.005$. This was in line with expectations, given the high performance in the ignore-T1 condition of Experiment 2. Overall, both Lag and Selection were significant, $F(2, 54) = 27.97$, $\mathrm{MSE} = 0.023$, $p < 0.001$, and $F(1, 35) = 123$, $\mathrm{MSE} = 0.004$, $p < 0.001$, respectively. Performance was 83 % at Lag 1, 74.1 % at Lag 3, and 90.4 % at Lag 8. Ignore-T1 trials came to 87.4 %, compared to 77.6 % for attend-T1 trials. Further interactions were apparent between experiments for both Lag, $F(2, 70) = 7.83$, $\mathrm{MSE} = 0.018$, $p < 0.001$, and Selection, $F(1, 35) = 27.34$, $\mathrm{MSE} = 0.004$, $p < 0.001$. Between experiments, the largest performance difference was clearly obtained at Lag 1 (18.4 %), compared to Lag 3 (3.3 %) and Lag 8 (3.6 %). The largest difference between Selection conditions was observed in the ignore-T1 trials, as expected (13.1 vs. 3.7 %). Finally, the third-order interaction term was also significant, $F(2, 70) = 7.81$, $\mathrm{MSE} = 0.004$, $p < 0.001$. At Lag 1, ignoring T1 in Experiment 1 was actually more difficult than attending T1 (6.3 % decrease), while in Experiment 2, ignoring T1 produced a benefit (7.7 % increase). At Lag 3, ignoring T1 resulted in much higher performance in both experiments, although the effect was clearly stronger in Experiment 2 (19 vs. 32.9 %). At Lag 8, both experiments showed only a modest benefit that came to 2.9 % in both cases.

Taken together, the analyses showed that there were crucial differences with regard to the ignore-T1 trials across Experiments 1 and 2. Most importantly, performance initially suffered at Lag 1 in Experiment 1, while in Experiment 2, there was an immediate benefit obtained by ignoring T1.

Experiment 3

The results of Experiment 2 supported the view that the performance observed in the ignore-T1 condition of Experiment 1 was not merely elicited by the color of T1. However, another possibility is that observers were processing the digit identity of T1, and then discarding it. This alone could theoretically also have elicited the pattern observed in the ignore-T1 condition of Experiment 1, without necessarily implying a role for the color feature of T1, and by extension for the use of a more flexible task set. If this were the case, then removal of the color feature should not matter and a replication of the results of Experiment 1 should be obtained. If, on the other hand, the ability to select T1 by means of color as well as digit identity had consequences for the subsequent processing of T2, a different pattern should emerge if that option to use flexible selection is taken away. Specifically, by being forced to search for digits exclusively, it should be very difficult to successfully ignore T1. Experiment 3 was designed to put this hypothesis to the test. In this experiment, T1 shared its category membership with T2 (both were digits), but T1 no longer had the (salient) color feature.

Method

Participants

Twelve students (7 female, 5 male) at the Ludwig Maximilian University Munich participated in this experiment for course credit or monetary compensation. Mean age was 24.8 years (range 21–30 years).

Apparatus and procedure

The experiment was identical to Experiment 1, with the exception that the first target stimulus was now black. Participants were cued whether to ignore T1 or not on each trial. At this point, it may be worthwhile to note that although this task does entail detection of T1 in both conditions (i.e., to realize T2 is the second target rather than the first), it does not necessarily require full identification and consolidation of T1 in the ignore-T1 condition, which was what the experiment was aimed at. This might be elucidated by drawing a parallel between the instruction to search for a specific stimulus (find "X"), which requires full identification, and the instruction to search for a category of items ("a digit"). In the latter case, there is no need to identify, consolidate, or to prepare a response in case such an item should be ignored, as in the present experiment.

Results and discussion

Figure 5 shows performance on T1 as a function of Lag. As before, Lag affected T1 performance, $F(2, 22) = 14.49$, $MSE = 0.001$, $p < 0.001$. Performance averaged 77.3 % at Lag 1, 82.2 % at Lag 3, and 81.8 % at Lag 8. Selection did not have a reliable effect on its own ($F < 1.3$), but it did interact with Lag, $F(2, 22) = 5.93$, $MSE = 0.003$, $p < 0.01$. This interaction seemed to point towards a stronger decrease in performance when T1 was ignored at Lag 1 (10 % difference), than at the other lags. Lag also affected the reaction time to T1, $F(2, 22) = 4.81$, $MSE = 1{,}206.042$, $p < 0.05$, as shown in Table 1.

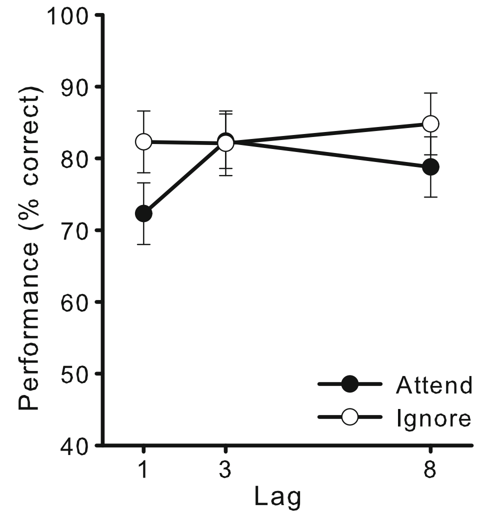

Fig. 5 Task performance on T1 (a *black digit*) in Experiment 3 (%)

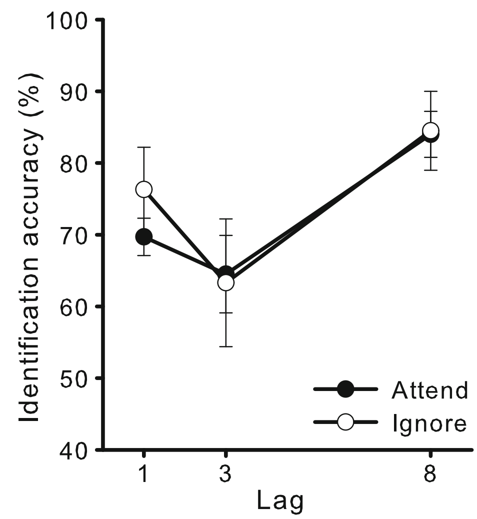

Fig. 6 Identification accuracy on T2|T1 (a *black digit*) in Experiment 3 (%)

Figure 6 shows T2 identification accuracy over Lag. Identification accuracy on T2 was again affected by Lag, $F(2, 22) = 7.52$, $MSE = 0.033$, $p < 0.005$. Again an attentional blink with Lag 1 sparing was obtained. Performance on Lag 1 averaged 73 %, dropped to 63.9 % at Lag 3, and recovered to 84.2 % at Lag 8. Neither the Selection variable nor its interaction with Lag was significant (F's < 1), suggesting that ignoring or attending to T1 did not affect T2 processing in this experiment.

Comparison between Experiments 1 and 3

The T2 data of Experiments 1 and 3 were combined in an overall ANOVA, with the addition of the experiments as between-subjects variable. The experiments did not differ reliably in overall means ($F < 1.4$). Both main effects of Lag and Selection were significant, $F(2, 47) = 17.68$, MSE = 0.037, $p < 0.001$, and $F(1, 29) = 4.85$, MSE = 0.012, $p < 0.05$, respectively. As might be expected, neither of these interacted with experiment (F's < 1). Critically, the third order interaction was also significant, $F(2, 58) = 8.51$, MSE = 0.012, $p < 0.001$, indicating that the effect of Selection was different at certain Lags between the experiments. Lag-specific analyses confirmed that this interaction was not reliable at Lag 8 ($F < 1$), whereas it was at Lag 1, $F(1, 29) = 5.86$, MSE = 0.010, $p < 0.05$, and Lag 3, $F(1, 29) = 8.28$, MSE = 0.018, $p < 0.01$.

In summary, the results showed that a full AB was observed in both attend- and ignore-T1 conditions of Experiment 3. Thus, neither the modulated AB (i.e., the result of Experiment 1) nor an absence of attentional costs was found (the result of Experiment 2). This finding prompts the conclusion that sharing a uniquely selective task relevant feature between targets results in an inability to ignore T1. As soon as another feature is added that allows an alternative method of discriminating T1 from the distractors, the full AB can be avoided, but not to the extent possible when no feature is shared between targets at all.

Experiment 4

Experiment 4 was designed to test the idea that sharing of task relevant features between T1 and T2 could be symmetrical with regard to their uniqueness as a means to select a target. This would mean sharing a task relevant, uniquely selective feature of T1 with T2, if T2 has another task relevant feature as well, should result in performance similar to that of Experiment 1. If that were to be the case, it would provide support for the idea that observers might have adopted one broad task set to fit both targets. Recall that in Experiment 1, a uniquely selective feature of T2 was shared with T1, which had another task relevant feature, which is the mirror arrangement of the present experiment.

Method

Participants

Twenty-eight students (19 female, 9 male) at the University of Groningen participated in this experiment for course credit. Data from two female participants were excluded because they were seemingly unable to respond to T1 in almost all trials. Mean age was 20.3 years (range 18–24 years).

Apparatus and procedure

As this study (and the next) was conducted in a different lab, there were some small, mostly trivial changes to the experimental environment. The most noticeable change was that the stimuli were now presented on a 19″ CRT screen, and participants were seated at a viewing distance of approximately 60 cm. The experimental design was identical to Experiment 2, with the exception that the second target stimulus was now blue (like T1). The consequences for the selection of the targets were as follows: T1 could still only be selected by one feature (its color). That feature was shared with T2, but at the same time, selection of T2 could now also be accomplished by searching for color as well as for digits (amidst the letter distractors).

Results and discussion

Figure 7 shows T1 performance as a function of Lag. Lag did not affect T1 identification performance ($F < 1$), but Selection did, $F(1, 25) = 6.15$, MSE = 0.185, $p < 0.05$. Ignoring T1 was easier than responding to it (80.5 vs. 63.4 %). The interaction was also significant, $F(2, 50) = 5.59$, MSE = 0.001, $p < 0.01$, indicating that the difference due to Selection was greater at Lag 1 (19.9 %) than at the other lags (15.5 % at Lag 3, and 15.7 % at Lag 8). T1 reaction time (see Table 1) was also affected by Lag, $F(1, 34) = 18.51$, MSE = 1,285.853, $p < 0.001$.

Figure 8 shows T2 accuracy as a function of Lag. T2|T1 performance was affected by both Lag, $F(2, 50) = 54.7$, MSE = 0.01, $p < 0.001$, and Selection, $F(1, 25) = 126.88$, MSE = 0.012, $p < 0.001$. Both a clear AB and Lag 1 sparing were obtained, with performance averaging 91.4 % at Lag 1, 71.6 % at Lag 3, and 86.7 % at Lag 8. Trials on which T1 had to be attended averaged 73.4 %, while trials on

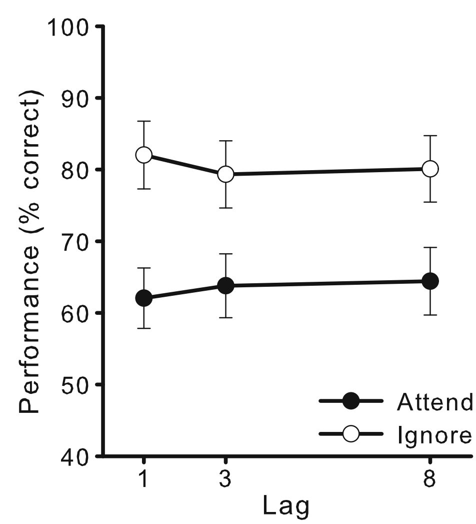

Fig. 7 Task performance on T1 (a *blue letter*) in Experiment 4 (%)

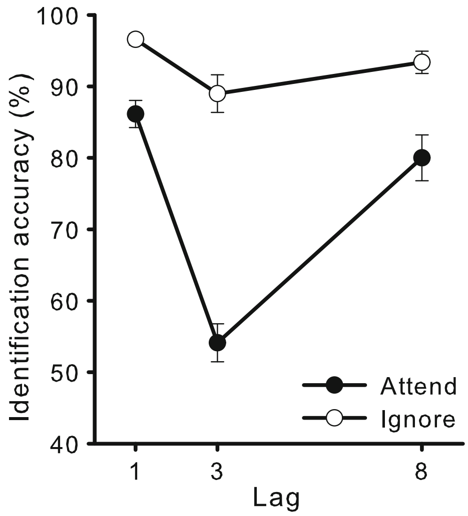

Fig. 8 Identification accuracy on T2|T1 (a *blue digit*) in Experiment 4 (%)

which it had to be ignored came to 93 %. The interaction term was reliable too, $F(2, 50) = 47.44$, $MSE = 0.005$, $p < 0.001$. The performance difference caused by Selection was most pronounced at Lag 3 (34.9 % difference), compared to Lags 1 (10.5 %) and 8 (13.4 %), suggesting it affected the AB primarily.

These results clearly replicated Experiment 2, rather than Experiment 1. Thus, there was no evidence to support the idea that T1 and T2 could be symmetrical with regard to the flexibility of their task sets. It seemed instead that the flexibility afforded for selecting T2, which could be dissociated from the distractors both because it was a digit and because it was blue, allowed an almost complete escape from the AB when T1 could be ignored.

These findings suggested that the features of T1 are registered even when the instruction was to ignore that target, and that consequently, these features are able to affect the selection of T2, if they are task-relevant to T2. In Experiment 1, even though neither the blue color nor the digit identity of T1 by themselves were the sole means of selecting T1, the digit identity of T2 was unique to its selection. The activation of digit identity in ignore-T1 trials could thus affect the selection of T2. In comparison with the present experiment, in which the blue color of T1 could theoretically have the same effect, the critical difference was that observers were able to avoid such effects by relying on the other available selection criterion for T2, i.e., its digit identity (recall that T1 was a letter).

Experiment 5

The results so far showed that sharing category-based selection criteria between targets causes attentional costs for T2 even if observers are asked to ignore T1. These costs were elicited without repeating the actual exemplar of that category, i.e., in Experiment 1, both targets were digits, but never the same one. Target selection in this paradigm is based on a relatively broad criterion of 'being a digit'. It is conceivable that using a more specific selection criterion (e.g., one particular color only, as opposed to searching for any color) could lead to a different pattern of results.

Experiment 5 was designed to examine whether selection of T2 is affected by the feature dimension of a task-relevant feature of T1, if that feature is invariant. Generally (e.g., Treisman & Gelade, 1980), the activation of a particular feature (e.g., blue) is assumed to entail also activity on its broader feature dimension (color, in this case). Thus, if a signal on a given feature dimension is critical for target selection, the presence of such a signal on another, to-be-ignored target, may elicit attentional costs, even when the actual feature value is not repeated. However, such costs may be negated if the actual feature value of T1 is invariant; for instance by selectively inhibiting said feature. In the present experiment, the costs of ignoring a blue T1 for the selection of a colored (but not blue) T2 were examined.

Method

Participants

Twenty-eight new students (26 female, 2 male) at the University of Groningen participated in this experiment for course credit. Mean age was 20.2 years (range 18–23 years).

Apparatus and procedure

The experiment was identical to Experiment 1, with the sole exception that T2 was now a colored letter. The color was randomly picked from a set of eight standard colors defined in E-Prime (labeled red, green, magenta, cyan, lime, olive, purple, and maroon). The color of T2 was thus never the same as that of T1, which was blue. Note furthermore that potential differences with regard to the detectability of the different colors of T2 were negated because the analyses always averaged across these.

Results and discussion

Figure 9 shows T1 performance over Lag. T1 identification performance was not reliably affected by Lag ($F < 1$) or Selection ($F < 2.4$). The interaction was marginally significant, however, $F(2, 54) = 2.77$, $MSE = 0.001$, $p < 0.07$, possibly reflecting a small performance drop (4.4 %) in the ignore-T1 condition at Lag 1, as compared to

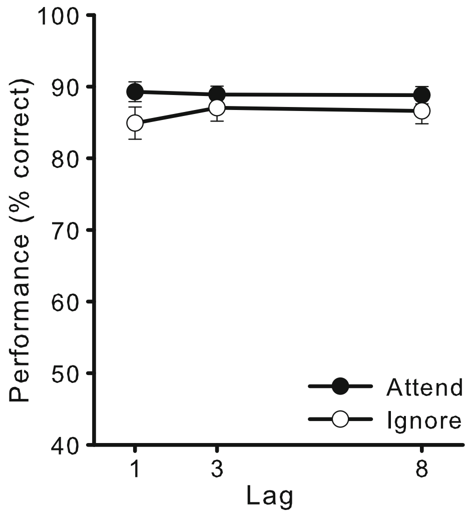

Fig. 9 Task performance on T1 (a *blue digit*) in Experiment 5 (%)

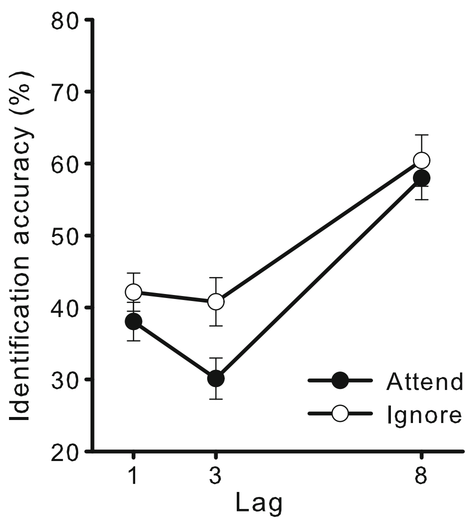

Fig. 10 Identification accuracy on T2|T1 (a *colored letter*) in Experiment 5 (%)

the attend-T1 condition. On T1 reaction time (Table 1), the familiar Lag effect was observed, $F(2, 54) = 3.9$, $MSE = 587.392$, $p < 0.05$.

Figure 10 shows T2 accuracy as a function of Lag. Both Lag, $F(1, 35) = 43.76$, $MSE = 0.031$, $p < 0.001$, and Selection, $F(1, 27) = 22.92$, $MSE = 0.006$, $p < 0.001$, influenced T2 performance. Performance was lowest at Lag 3 (35.5 %), slightly higher at Lag 1 (40.1 %) and highest at Lag 8 (59.2 %). Ignoring T1 resulted in higher performance than attending T1 (42 vs. 47.8 %). The interaction between Lag and Selection was also reliable, $F(2, 54) = 4.12$, $MSE = 0.006$, $p < 0.05$. Interestingly, rather than implicating Lag 1, the difference between ignore- and attend-T1 conditions was largest at Lag 3 (10.7 % compared to 4.1 % at Lag 1 and 2.4 % at Lag 8).

The results showed that feature dimensional costs were indeed present, and an attentional blink was observed in the ignore-T1 condition. However, the AB was attenuated compared to the attend-T1 condition, with the greatest difference emerging at Lag 3. Performance at Lag 1 in the ignore-T1 condition did not seem to be impaired, as was observed in Experiment 1. The results thus suggested that the costs observed presently were different from those previously observed when targets shared a more variable task-relevant feature. Nonetheless, these results showed that it was not possible to select T2 efficiently (i.e., without costs) when T1 was to be ignored, despite the fact that its critical feature was invariant.

General discussion

The present study explored the conditions under which involuntary attentional deployment towards the first (to-be-ignored) target stimulus in RSVP is elicited by the task relevance of its features for the selection of the second target, as reflected by lag-dependent identification accuracy of the second target. The principal findings of the five experiments reported here are summarized verbally in Table 2.

The results of Experiment 1 showed that observers faced some difficulty ignoring a T1 when one of its two defining features matched the single defining feature of T2, which was most pronounced at Lag 1. In the absence of a match, T1 could be ignored quite efficiently, and almost no lag-dependent T2 identification deficit was observed (Experiment 2). Conversely, a T1–T2 match when only a single defining feature was available for both targets resulted in a full AB (Experiment 3). Experiment 4 showed that allowing flexible selection of T2, by virtue of it having two defining features, resulted in efficient discarding of T1, even though its single defining feature matched one of T2. Finally, when the setup of Experiment 1 was repeated in Experiment 5, but now with a feature-dimensional match, rather than a feature-specific one (i.e., any color vs. a specific color), a sizeable AB (but weaker than the dual-target AB) was elicited again in ignore-T1 trials. In this case, however, performance did not suffer particularly at Lag 1 and some sparing was observed (at least nominally).

Taken together, the results first confirmed that trying to ignore stimuli that have task-relevant features can pose problems, which is in line with previous studies (Folk et al., 2002; 2008; Maki & Mebane, 2006; Spalek et al., 2006; Wee & Chua, 2004). Attentional costs of this kind were observed in Experiments 1, 3, and 5. Furthermore, and also in line with previous work, there was evidence for a role for stimulus-driven attentional allocation, albeit much more modest, at least with the stimuli used in the present

Table 2 Summary of experiments and description of results

Experiment	Condition	T1	T2	Result
1	Ignore	Blue digit	Black digit	Shallow AB, no sparing
	Attend			AB, sparing
2	Ignore	Blue letter	Black digit	Minimal AB, weak sparing
	Attend			AB, sparing
3	Ignore	Black digit	Black digit	AB, sparing
	Attend			AB, sparing
4	Ignore	Blue letter	Blue digit	Minimal AB, sparing
	Attend			AB, sparing
5	Ignore	Blue digit	Color letter	Shallow AB, weak sparing
	Attend			AB, sparing

See text for abbreviations

paradigm. In Experiments 2 and 4, there was evidence for a small but reliable AB (at Lag 3), in the ignore-T1 condition, which most likely can be attributed to the 'bottom-up' effect of the color of T1 (cf., Asplund et al., 2010a; Dalton & Lavie, 2006; Maki & Mebane, 2006; Spalek et al., 2006).

Second, the present results go beyond these previously established, more general conclusions: whether observers were able to flexibly implement target-specific task sets (search templates) or not modulated the degree to which they could ignore a T1 that had task-relevant features. When T1 carried a feature that was also uniquely relevant for T2 (i.e., constituting the only means of its selection), ignoring T1 was associated with distinct costs. These costs did vary as a result of the flexibility with which T1 could be selected. If the shared feature was also exclusively selective for T1, a full AB was elicited in all cases (Experiment 3). If another feature was available for T1, a shallower AB was observed with the biggest deficit at Lag 1 (Experiment 1). A feature-dimensional match between targets similarly resulted in difficulties ignoring T1, but in this case the deficit was most pronounced at Lag 3 (Experiment 5). By contrast, when a second feature was available to select T2, a match on that feature (even when it was uniquely selective for T1) did not elicit notable attentional costs (Experiment 4). Thus, the present results demonstrate that the 'attentional draw' of target-related features (and feature-dimensions) is highly dependent on the degree to which flexible target selection is afforded, and argue against the idea that one broad task set might be used to encompass both targets.

A priori, one might perhaps have expected a 'strategic' task set flexibility effect, resulting from a decision to split target selection criteria between T1 and T2 so as to minimize overlap and facilitate the rejection (suppression) of T1 when needed. For instance, if T1 is defined by feature A and T2 by feature A and B, selection of T2 could simply be restricted to feature B always. The results of Experiment 4 are indeed compatible with such a strategic approach; however, the results of Experiment 1 are not. In this experiment, T1 had two defining features, one of which matched T2 (digit identity), but in this case observers were unable to restrict selection of T1 to the other non-matching feature, and attentional costs were observed in ignore-T1 trials. Thus, these results suggested that only flexible selection of T2 allows efficient rejection of task-relevant features of T1.

Lag 1 sparing

The results of Experiment 1 seemed special for another reason as well. When a feature-dimensional (rather than feature-specific) match was instantiated in an otherwise similar paradigm in Experiment 5, attentional costs were again observed. However, these costs seemed to find a different expression. Rather than replicating the severe deficit at Lag 1 and a total loss of sparing as observed in Experiment 1, the biggest difference compared to the dual target AB was apparent at Lag 3. Nominally at least, performance at Lag 1 in Experiment 5 was higher. These contrasting results prompt the idea that encountering an exemplar of an exact task-relevant feature triggers an immediate, rapid attentional response, with corresponding costs at Lag 1, whereas encountering a task-relevant dimension does not. As observed in Experiment 1, after this rapid feature-specific response, however, recovery seemed faster, and performance at Lag 3 was comparatively high.

Lag 1 sparing is not always observed in AB studies; it requires a certain similarity between target stimuli (for a review, see Visser et al., 1999). Therefore, the general absence of sparing itself is not very significant with regard to involuntary attentional allocation—it is for instance not clear whether its absence had special significance in Experiment 4 of Spalek et al. (2006), which used dissimilar T1 and T2 stimuli and they made no claim in that regard. However, in the present study, the absence of sparing in the ignore-T1 condition of Experiment 1 was salient, because the attend-T1 condition shows sparing, which proves that the targets lend themselves for the phenomenon to occur.

A similar pattern of (dis-)appearing sparing was obtained by Chun (1997), who observed an impairment that was most prominent at Lag 1 when observers were trying to ignore T1, as well as Lag 1 sparing when they were attending to T1. Interestingly, in that study, targets were marked by a surrounding colored frame, which was either red or green for each target (never the same). Thus, the costs observed at Lag 1 by Chun (1997) seemed to arise due to feature-dimensional matching between targets (i.e., color) rather than feature-specific matching, which is contrary to what was presently observed in Experiments 1 and 5. One factor that might account for this discrepancy is paradigmatic; in the present study, the critical features were part of the target stimuli, whereas in Chun's study these were spatially separate. However, another account that could accommodate these results is that Chun's observers may have adopted a singleton search strategy (Bacon & Egeth, 1994), which would have made any salient singleton (feature) task-relevant, even if a feature-specific match was lacking. In the present Experiment 1, such a strategy was not feasible, as T2 required discrimination to identify it as a digit. Taken together, it seems tenable to assume that the pronounced Lag 1 deficit is due to matches of features that are uniquely and specifically relevant to selection.

Relevance to theories of the AB

In order to chart the potential relationship between processing task-relevant features of T1 and the consequences for subsequent attentional deployment, some theories of the blink will be discussed in more detail below, and the implications of the present findings will be outlined. There are currently two types of blink models. The models of the first, classic type have posited that the processing, and in particular the consolidation to memory of the first target stimulus, consumes some specific cognitive resources, the lack of which leads to a failure to identify the second target (e.g., Bowman & Wyble, 2007; Chun & Potter, 1995; Jolicœur, 1999). According to these models, any target stimulus that reaches the limited processing stage will elicit a blink. The models of the second type take a slightly different route. These new models posit that the arrival of a distractor stimulus after T1 is problematic, either because it does not match the current task set (Di Lollo, Kawahara, Ghorashi, & Enns, 2005), or because it is the recipient of a late "boost" signal meant for T1 (Olivers & Meeter, 2008; Olivers & Nieuwenhuis, 2006).

Classic models of the attentional blink

In classic models of the blink, such as the influential two-stage model originally proposed by Chun and Potter (1995), a blink is elicited when the first target reaches the limited second stage of processing. The main idea is thus that the blink is due to limitations on relatively late processes. In the two-stage model, attention is involved in rapid detection during the first stage. In this stage, features relevant for target detection are quickly processed and stimuli are selected on the basis of features (color, shape) as well as categorical identity (letters vs. digits). Processing in the first stage is assumed to be able to take place in an almost parallel fashion, and is thus not a likely bottleneck, but the representations that are created are unstable and subject to interference unless they are processed further. In the second stage of the model, processing is capacity-limited. This stage is needed to transfer selected fleeting representations from the first stage into a more durable form. It is assumed that such a step is necessary for subsequent action such as identification report. Since the second stage has a limited capacity, the blink arises when it is still occupied by the first target (T1), while the representation of the second target (T2) cannot be consolidated and therefore deteriorates rapidly.

A similar model was described by Jolicœur (1999), labeled "central interference theory". In this model, processing of T1 and T2 can also continue in parallel, but only for certain parts of the process. There are processing stages that require "central processing", and when such processing is engaged, it cannot be shared to process other things at the same time. In the case of the (speeded) attentional blink, the processes of short-term consolidation (STC; Jolicœur & Dell'Acqua, 1998) and response selection (when the response to T1 is speeded) are both central and are likely to be engaged by T1 still when T2 is presented at short temporal lag. This means that the respective processes of T2 have to wait, leaving the representation of T2 vulnerable to interference and decay, thus giving rise to the blink.

However, the empirical evidence supporting the claim that some 'early' (but not 'late') processing of T1 is possible without incurring interference with T2 is not entirely unequivocal. First, although studies by Ward, Duncan, and Shapiro (1997) and McLaughlin, Shore, and Klein (2001) showed that increasing perceptual difficulty of T1 had minimal effect on blink magnitude (cf., Chun & Potter, 1995; Ouimet & Jolicœur, 2007; Seiffert & Di Lollo, 1997; Visser, 2007), there does not seem to be a strong a priori reason why a delay in early processing would not propagate to a delayed initiation of late (stage 2) processes.

Second, there is evidence to suggest that ‘advanced’ processes are sometimes able to escape from the blink. T2 stimuli that cannot be identified due to the attentional blink have been shown to have semantic and response priming effects on subsequent tasks (Akyürek & Hommel, 2007; Shapiro, Driver, Ward, & Sorensen, 1997). Electrophysiological findings have also supported the idea that partial processing can continue while the blink prevents consolidation of target identity for later report. Early attentional event-related potential (ERP) components such as the P1 and N1 do not seem to be affected by the attentional blink, suggesting that the bottleneck must lie in downstream attentional processing. Yet, the relatively late N400 component of the ERP, which is associated with the processing of semantic information, has been shown to persist without modulation through the blink. At the same time, the P3 component that is associated with working memory operations has been shown to be suppressed by the blink (Akyürek, Leszczyński, & Schubö, 2010; Sergent, Baillet, & Dehaene, 2005; Vogel, Luck, & Shapiro, 1998).

Third, some evidence exists that ‘early’ processes associated with T2 can be subject to the blink bottleneck. Contrary to the idea that both targets need to access critical ‘late’ attentional resources in order for the blink to occur, Joseph, Chun, and Nakayama (1997) showed that the identification of a letter in an RSVP-task impaired performance on a subsequent pop-out visual search task that was considered to allow efficient search and did not require deeper attentional processing (Wolfe, 1998). That is, despite that there was no apparent need to consolidate the second target, a performance deficit on T2 was still observed. Though this is a tantalizing result, it is not entirely conclusive as the design of Joseph et al. required participants to switch between letter identification and orientation detection tasks (and between different spatial locations). Such a task switch may incur cognitive costs that need not necessarily be attentional in nature, and these may explain the performance data. Furthermore, even if the detection task did not require attention, the selection of the appropriate response may have done so. Overall, despite the aforementioned quibbles, classic models of the blink maintain that the attentional bottleneck is primarily due to late processes.

Can classic models of the AB account fully for the present results? First, the ignore-T1 conditions in the present experiments showed that the detection (or perhaps, registration) of a task-related stimulus property alone is sufficient to cause significant attentional costs, or even the full AB (Experiments 1, 3, and 5), at least with the present speeded T1 task. This finding qualifies one aspect of processing as it is thought to take place in the first stage of the classic models. The detection of a task-relevant feature has to take place early, even if it is relatively complex (such as belonging to the digit category), because it seems to trigger subsequent processing in the second stage, i.e., it thereby unavoidably leads to the AB. Second, some residual costs due to stimulus salience alone were observed. In the models, these might be accommodated as a moderator variable, such that increased representational strength of a salient target may alter its processing and affect that of the next target. Third, to account for the effects of task set flexibility, control parameters that govern target selection may have to be added, which must be able to handle trial-to-trial switches (i.e., between ignore- and attend-T1 trials). Such parameters should be able to dissociate between the availability of a single defining feature, and of multiple features specific to each target.

Recent models of the attentional blink

The first of two of the more recent models of the blink that will be discussed is the connectionist implementation by Bowman and Wyble (2007) (Wyble, Bowman, & Nieuwenstein, 2009), the simultaneous type/serial token (ST^2) unites two-stage theory with the instantiation of episodic representation. In the ST^2 model, processing in the first stage consists of parallel visual processing (including semantic categorization) that constitutes a “very short-term memory”. Consistent with the other models of the blink, the contents of this stage are vulnerable to interference and decay. Within the first stage, the ST^2 model also features a salience filter, which moderates the progress of task-relevant stimuli. At the level of this filter, the “blaster” function boosts the representations of all incoming stimuli. The end result of the interaction between the filter and the blaster is that stimuli (“types”) with task-relevant properties become activated more strongly than those without. In the second stage of the ST^2 model, information is passed on to working memory where it reaches a more durable representation. The mechanism by which this is accomplished is postulated to be the process of binding episodic instance-specific information (i.e., a token) to an activated representation of all the featural properties of an item (i.e., its type), the latter of which has to be taken from the first stage.

The interactive filter-blaster mechanism seems well suited to account for the present results of task-relevant target features, and once a task-relevant stimulus is boosted, it would elicit the blink, even when it was not actually a target (i.e., in the ignore-T1 conditions). Furthermore, in the framework of the ST^2 model, the disappearance of Lag 1 sparing observed presently in Experiment 1 might be explained by the integration or binding of the identities of T1 and T2 into one aggregated token, a mechanism which causes an improvement in identifying T2 at the expense of the loss of order information (Akyürek et al., 2008; Hommel & Akyürek, 2005). In the model, the color of T1 could be misattributed as belonging to T2, leading to the erroneous report of T1 as the second target. It should be noted that in current iterations of the model this appears to be no longer possible as types are always bound to tokens individually (Wyble et al., 2009). However, given recent results demonstrating the frequent occurrence of integration at Lag 1 in RSVP (Akyürek et al., 2012), it may be desirable for future iterations of the model to again allow for such misattributions when feature conjunctions are involved.

The second recent model is the "boost and bounce" theory developed by Olivers and Meeter (2008). This model takes a slightly different approach to explain the attentional blink phenomenon, more in line with the original theory offered by Raymond et al. (1992). There are no limited processing stages; instead it is assumed that there is an attentional filter or gate that is too slow to boost the appropriate (target) stimulus in the context of RSVP. Upon the detection of a target stimulus, the filter issues a boost signal, but since it takes a bit of time before this comes into effect, the boost ends up with the next (irrelevant) distractor stimulus instead. This situation is then in turn imperfectly corrected by the issue of an inhibitory bounce signal, which explains the blink by the suppression of subsequent incoming stimuli. In the model, the strength of the boost is dependent on the sensory properties of the stimuli. The gating function is furthermore configured by the current task set, so that the interaction between these two factors can account for the modulation of contingent capture by stimulus-based salience. In the model, only task-relevant stimuli would be able to pass the gate, while stimuli that are salient but task-irrelevant are not.

The present results are largely in agreement with this supposed gating mechanism, although the small residual blinks observed in Experiments 2 and 4 seem harder to account for, as long as it is maintained that only task-relevant stimuli pass the attentional gate. The model also offers an alternative account for the lack of Lag 1 sparing in the ignore-T1 condition of Experiment 1. If one assumes that T1 is 'transformed' into a strong distractor in that condition, it might be expected to trigger a blink that is pulled forward in time, because it is elicited by T1 itself, rather than the distractor after T1 as it would normally be. This could be expressed in maximal blink magnitude at Lag 1 rather than Lag 3.

Conclusion

The present study has demonstrated that both task set flexibility and feature specificity have modulating effects on the efficiency of the deployment of temporal attention. These effects extend beyond previously reported attentional costs due to general task relevance and stimulus salience, although both of these were also observed presently. The findings can generally be brought in line with models of the AB, and current ones in particular. Above all, the present findings show that appropriate control of attentional selection can be difficult to achieve in (speeded-T1) tasks that require frequent, unpredictable task set adjustments. At the same time, however, attentional selection can also be very efficient, if certain prerequisites concerning the presence of task-relevant features and the flexibility of their selection are met.

Acknowledgments This research was supported by the German Research Foundation (DFG) as part of the excellence cluster "Cognition for Technical Systems" (CoTeSys), project #148.

References

Akyürek, E. G., Eshuis, S. A. H., Nieuwenstein, M. R., Saija, J. D., Başkent, D., & Hommel, B. (2012). Temporal target integration underlies performance at Lag 1 in the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance* (in press).

Akyürek, E. G., & Hommel, B. (2007). Stimulus and response priming in rapid serial visual presentation: evidence for a dissociation. *Perception and Psychophysics, 69*, 1152–1161.

Akyürek, E. G., Leszczyński, M., & Schubö, A. (2010). The temporal locus of the interaction between working memory consolidation and the attentional blink. *Psychophysiology, 47*, 1134–1141.

Akyürek, E. G., Toffanin, P., & Hommel, B. (2008). Adaptive control of event integration. *Journal of Experimental Psychology: Human Perception and Performance, 34*, 569–577.

Asplund, C. L., Todd, J. J., Snyder, A. P., Gilbert, C. M., & Marois, R. (2010a). Surprise-induced blindness: A stimulus-driven attentional limit to conscious perception. *Journal of Experimental Psychology: Human Perception and Performance*, 36, 1372–1381

Asplund, C. L., Todd, J. J., Snyder, A. P., & Marois, R. (2010b). A central role for the lateral prefrontal cortex in goal-directed and stimulus-driven attention. *Nature Neuroscience*, 13, 507–514

Bacon, W. F., & Egeth, H. E. (1994). Overriding stimulus-driven attentional capture. *Perception and Psychophysics, 55*, 485–496.

Barnard, P. J., Scott, S., Taylor, J., May, J., & Knightley, W. (2004). Paying attention to meaning. *Psychological Science, 15*, 179–186.

Bowman, H., & Wyble, B. (2007). The simultaneous type, serial token model of temporal attention and working memory. *Psychological Review, 114*, 38–70.

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

Chun, M. M. (1997). Temporal binding errors are redistributed by the attentional blink. *Perception and Psychophysics, 59*, 1191–1199.

Chun, M. M., & Potter, M. C. (1995). A two-stage model for multiple target detection in rapid serial visual presentation. *Journal of Experimental Psychology: Human Perception and Performance, 21*, 109–127.

Dalton, P., & Lavie, N. (2006). Temporal attentional capture: effects of irrelevant singletons on rapid serial visual search. *Psychonomic Bulletin and Review, 13*, 881–885.

Di Lollo, V., Kawahara, J.-I., Ghorashi, S. M. S., & Enns, J. T. (2005). The attentional blink: resource depletion or temporary loss of control? *Psychological Research, 69*, 191–200.

Folk, C. L., Leber, A. B., & Egeth, H. E. (2002). Made you blink! Contingent attentional capture produces a spatial blink. *Perception and Psychophysics, 64*, 741–753.

Folk, C. L., Leber, A. B., & Egeth, H. E. (2008). Top-down control settings and the attentional blink: evidence for non-spatial attentional capture. *Visual Cognition, 16*, 616–642.

Folk, C. L., & Remington, R. W. (1998). Selectivity in distraction by irrelevant featural singletons: evidence for two forms of attentional capture. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 847–858.

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance, 18*, 1030–1044.

Folk, C. L., Remington, R. W., & Wright, J. H. (1994). The structure of attentional control: contingent attentional capture by apparent motion, abrupt onset and colour. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 317–329.

Hommel, B., & Akyürek, E. G. (2005). Lag 1 sparing in the attentional blink: benefits and costs of integrating two events into a single episode. *Quarterly Journal of Experimental Psychology, 58A*, 1415–1433.

Jolicœur, P. (1999). Concurrent response-selection demands modulate the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance, 25*, 1097–1113.

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

Jolicœur, P., Sessa, P., Dell'Acqua, R., & Robitaille, N. (2006). On the control of visual spatial attention: evidence from human electrophysiology. *Psychological Research, 70*, 414–424.

Joseph, J. S., Chun, M. M., & Nakayama, K. (1997). Attentional requirements in a 'preattentive' feature search task. *Nature, 387*, 805–807.

Maki, W. S., & Mebane, M. W. (2006). Attentional capture triggers an attentional blink. *Psychonomic Bulletin and Review, 13*, 125–131.

McLaughlin, E. N., Shore, D. I., & Klein, R. M. (2001). The attentional blink is immune to masking-induced data limits. *Quarterly Journal of Experimental Psychology, 54A*, 169–196.

Olivers, C. N. L., & Meeter, M. (2008). A boost and bounce theory of temporal attention. *Psychological Review, 115*, 836–863.

Olivers, C. N. L., & Nieuwenhuis, S. (2006). The beneficial effects of task load, positive affect, and instruction on the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance, 32*, 364–379.

Ouimet, C., & Jolicœur, P. (2007). Beyond Task 1 difficulty: the duration of T1 encoding modulates the attentional blink. *Visual Cognition, 15*, 290–304.

Potter, M. C., Staub, A., & O'Connor, D. H. (2002). The time course of competition for attention: attention is initially labile. *Journal of Experimental Psychology: Human Perception and Performance, 28*, 1149–1162.

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: an attentional blink? *Journal of Experimental Psychology: Human Perception and Performance, 18*, 849–860.

Seiffert, A. E., & Di Lollo, V. (1997). Low-level masking in the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance, 23*, 1061–1073.

Sergent, C., Baillet, S., & Dehaene, S. (2005). Timing of the brain events underlying consciousness during the attentional blink. *Nature Neuroscience, 8*, 1391–1400.

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

Spalek, T. M., Falcon, L. J., & Di Lollo, V. (2006). Attentional blink and attentional capture: endogenous versus exogenous control over paying attention to two important events in close succession. *Perception and Psychophysics, 68*, 674–684.

Theeuwes, J. (1991). Cross-dimensional perceptual selectivity. *Perception and Psychophysics, 50*, 184–193.

Theeuwes, J. (1992). Perceptual selectivity for color and form. *Perception and Psychophysics, 51*, 599–606.

Theeuwes, J. (1994). Stimulus-driven capture and attentional set: selective search for color and visual abrupt onsets. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 799–806.

Theeuwes, J., & Burger, R. (1998). Attentional control during visual search: the effect of irrelevant singletons. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 1342–1353.

Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12*, 97–136.

Visser, T. A. W. (2007). Masking T1 difficulty: processing time and the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance, 33*, 285–297.

Visser, T. A. W., Bischof, W. F., & Di Lollo, V. (1999). Attentional switching in spatial and non-spatial domains: evidence from the attentional blink. *Psychological Bulletin, 125*, 458–469.

Vogel, E. K., Luck, S. J., & Shapiro, K. L. (1998). Electrophysiological evidence for a postperceptual locus of suppression during the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 1656–1674.

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

Ward, R., Duncan, J., & Shapiro, K. L. (1997). Effects of similarity, difficulty, and nontarget presentation on the time course of visual attention. *Perception and Psychophysics, 59*, 593–600.

Wee, S., & Chua, F. K. (2004). Capturing attention when attention "blinks". *Journal of Experimental Psychology: Human Perception and Performance, 30*, 598–612.

Wolfe, J. M. (1998). Visual search. In H. Pashler (Ed.), *Attention* (pp. 13–73). Hove: Psychology Press.

Wyble, B., Bowman, H., & Nieuwenstein, M. (2009). The attentional blink provides episodic distinctiveness: sparing at a cost. *Journal of Experimental Psychology: Human Perception and Performance, 35*, 787–807.