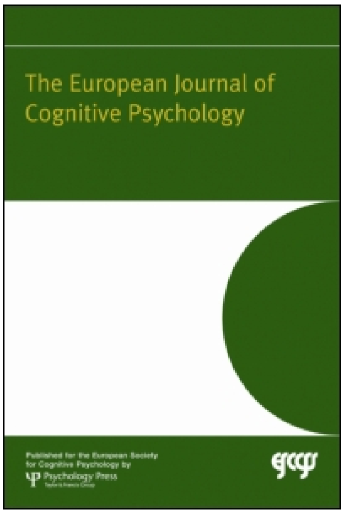

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Rapid allocation of temporal attention in the attentional blink paradigm

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Rapid allocation of temporal attention in the attentional blink paradigm

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How fast can information of a first target (T1) in a rapid serial visual presentation be used for top-down allocation of attention in time? A valid cue about the temporal position of a second target (T2) was integrated into T1. The data show that 100 ms after T1 onset, T2 was identified better than without cue, raising the conditional T2 performance. T1 apparently triggers a facilitative effect of attention, known from other paradigms such as peripheral cueing.

Keywords: Attentional blink; Visual attention; Temporal attention.

The time course of the Attentional Blink (AB) has been studied extensively (e.g., Duncan, Ward, & Shapiro, 1994; Raymond, Shapiro, & Arnell, 1992): If the first target (T1) within a rapid serial visual presentation (RSVP) is correctly reported, the second target (T2) is frequently missed for intertarget lags of 200–300 ms. T2 identification improves progressively as the temporal interval increases up to 700 ms. However, when the second target is presented within 100 ms after the first one, the deficit is usually much reduced. This phenomenon is called lag-1 sparing (e.g., Potter, Chun, Banks, & Muckenhoupt, 1998). The first target thus—with exception of lag 1—interferes for several hundred milliseconds with the accuracy of reporting the second target. The interference is often attributed to a limited capacity for attention to incoming information: While T1 is being processed, it occupies an attentional mechanism. As a consequence, this

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mechanism cannot be used for identification or consolidation of the subsequent T2 (e.g., Chun & Potter, 1995; Martens, Wolters, & van Raamsdonk, 2002; Wyble, Bowman, & Nieuwenstein, 2009; but see Olivers & Meeter, 2008). The exact nature of this apparent limitation is still unknown.

One way to study the deficit is trying to overcome it. This has been accomplished in several ways. For instance, Martens and Johnson (2005) reported a diminished blink if a temporal cue at the beginning of the trial provided information about the target–onset asynchrony (TOA). Potter et al. (2005) showed that when two target words were semantically related, the identification deficit for T2 was reduced. Finally, a distinct visual cue inserted into the RSVP stream also helps to reduce the impairment for T2 (e.g., Nieuwenstein, 2006). These findings indicate that information is rapidly encoded up to the level of semantic and categorical analysis, and that the deficit for T2 can be overcome by top-down information, such as temporal information about T2.

Based on these findings, we ask whether features of T1 are quickly available for top-down allocation of temporal attention. In the experiments of Martens and Johnson (2005), the cue was presented for several hundred milliseconds before the beginning of the RSVP stream. Therefore, observers had sufficient time to process the information. This raises the question of the time course of temporal cueing. From spatial cueing it is known that task-relevant cues can be processed and used for the spatial control of attention rapidly (Ansorge, Kiss, & Eimer, 2009; Scharlau & Ansorge, 2003): Ansorge et al. (2009) presented a cueing display 51 ms prior to the target search array. Facilitation of the subsequent target was contingent on whether the cue shared a feature property that was critical to the performance of the task at hand. According to Scharlau, Ansorge, and Horstmann (2006), facilitation by peripheral cues begins within the first 50 ms after cue onset and peaks at 100–200 ms. If the same attention operates in the AB and peripheral cueing (as for instance assumed by Olivers & Meeter, 2008), we can expect a similar rapid allocation in time as in space.

In order to investigate whether a similarly fast attentional mechanism operates in the temporal domain, we integrated information about the temporal position of T2 into the identity of T1. Both targets were digits, and the digit of T1 validly informed about the TOA. Following Martens and Johnson (2005), we expect better T2 performance if observers were able to strategically use this information for the temporal control of attention. Such a finding would support our idea that a leading target is rapidly processed and can control allocation of attention in time.

EXPERIMENT 1

In Experiment 1, we compared a standard AB paradigm without cues or any other contingencies between the targets to a nearly identical paradigm in which T1 serves as a cue for the temporal position of T2. If T2 performance improves in the cue condition, we can conclude that the relevant features of T1 are quickly available for temporal deployment of attentional resources.

Method

Participants. In all experiments, participants were students from Paderborn University in Germany. All had normal or corrected-to-normal vision. Informed consent was obtained and participants were paid. Forty-two participants took part in Experiment 1 (22 female, mean age: 24).

Apparatus. Participants sat in a dimly lit room. The centre of a 19-inch CRT monitor was at eye level. Viewing distance was 50 cm, set by a chinrest. The resolution was 800×600 pixels at 100 Hz. The experimental program was written in MATLAB 7.7.0 and made use of the PsychToolbox (Brainard, 1997). The observers responded by pressing keys on the keypad.

Stimuli. Stimuli were displayed in black on a medium grey background. The digits 1–9 were used as targets. Distractors were letters from the Roman alphabet except for I, O, B, S, and Z. Stimuli subtended approximately 1° in height in visual angle. Each item was presented for 70 ms and separated from the next by 30 ms. Stimuli were presented at the centre of the screen.

Design. The 42 observers were split into two groups of 21 observers. In the "baseline" group, which saw a standard AB stream, both target digits were selected randomly from the digits 1–9 with the restriction that they were always different. In the "cue" group, the first target digit validly cued the lag T2 was presented in. When T1 was a "1", T2 followed immediately (lag 1), when T1 was a "2", T2 was presented at lag 2, and so on. The second target was again selected randomly with the constraint that it differed from T1. The instruction in the cueing condition emphasised the contingency between the two targets.

We included the lags 1–7 in this experiment (in the cue condition T1 could therefore be one of the digits 1–7). Each lag was repeated 40 times.

Procedure. Participants initiated each trial by pressing a key. After a delay of 800 ms, a fixation cross was presented at the centre of the screen for 200 ms, followed by an RSVP stream consisting of 26 items. Letter distractors were chosen randomly. The first target was the 11th to 15th character, with the exact number being assigned randomly from trial to trial. The second target was followed by 4 to 14 distractors. After each trial, observers identified the two targets in their order of appearance by pressing the corresponding keys on the keypad. In case they had not recognised one or both targets, they were encouraged to guess. The experiment lasted about an hour and was conducted within a single session. Participants were paid for the overall number of trials in which they identified both targets in the correct order, in an attempt to ensure that both groups of participants had the same motivation to perform well.

Results and discussion

Figure 1 (solid lines) shows the identification rate of T2 given that T1 was identified correctly (T2|T1), separately for cue and baseline condition. The conditional accuracy of T2 is commonly reported in AB experiments because the main purpose is to study what effect the correct identification of T1 has on the identification of T2. Therefore, trials on which T1 was not identified

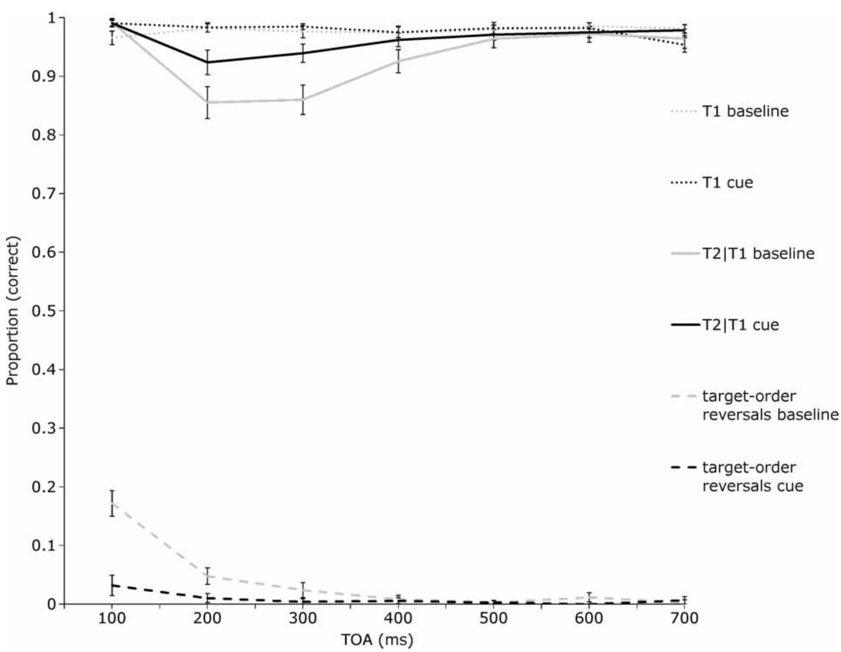

Figure 1. Solid lines: Conditional accuracy of T2|T1 as a function of lag in steps of 100 ms, separately for baseline and cue trials. Order reversals are counted as correct. Dashed lines: Probability of order reversals. Dotted lines: T1 accuracy. Error bars denote standard errors of the mean.

are excluded from data analyses. Responses were counted as correct regardless of the order in which they were made. Since most of the data are between 0.8 and 1.0, these and all later tests were computed with arcsine transformed data to counteract the violation of variance homogeneity.[1]

To test whether T2 performance increased when the temporal position of T2 was cued by T1, we conducted a two-way analysis of variance on T2|T1 with the within-subjects factor lag and the between-subjects factor cueing. Both factors showed significant main effects, $F(6, 280) = 13.75$, $MSE = 0.074$, $p < .01$ for lag, and $F(1, 280) = 9.79$, $MSE = 0.053$, $p < .01$ for cueing. The interaction just failed to reach significance, $F(6, 280) = 2.08$, $MSE = 0.011$, $p = .056$. The increased conditional T2 accuracy did not result from decreased T1 accuracy: The associated two-way ANOVA on T1 showed neither a significant effect of lag, $F(6, 280) = 1.54$, $MSE = 0.002$, $p = .17$, nor of cueing, $F(1, 280) = 0.16$, $MSE = 0.0003$, $p = .69$. The significant interaction, $F(6, 280) = 2.74$, $MSE = 0.005$, $p = .013$, is most likely due to the fact that T1 accuracy in the cueing condition—compared to the baseline condition—is higher at lag 1, but lower at lag 7 (see Figure 1, dotted lines).

An increased T2|T1 accuracy in short lags often comes along with increased target-order reversals (e.g., Hommel & Akyürek, 2005; Wyble, Bowman, & Nieuwenstein, 2009). In the present experiment, however, order reversals were less frequent in the cued condition than in the baseline condition, as can be seen from Figure 1 (dashed lines). Target-order reversals were computed as the proportion of trials in which the two targets are reported in reverse order divided by all trials in with the two targets are reported either in the correct or in reversed order. The two-way ANOVA on order reversals revealed significant main effects for lag, $F(6, 280) = 33.64$, $MSE = 0.07$, $p < .01$, and cueing, $F(1, 280) = 48.3$, $MSE = 0.11$, $p < .01$. Order errors decreased with lag and were less frequent in the cued condition. The interaction between lag and cueing was also significant, possibly due to the fact that in both conditions, order errors decreased almost to zero in the longest lags, $F(6, 280) = 15.4$, $MSE = 0.034$, $p < .01$.

There are two explanations for the decreased order errors in the cue condition. First, the cue might amplify the temporal information. Second, it might help to reconstruct the most likely temporal order. Participants might know if the two targets were presented shortly after each other, or if the TOA was long. Given the interval between the two targets was short and only one of the two digits that the participant identified is small, he or she might decide

[1] Because the number of trials is relatively small we decided to replace a proportion of 1 by (40 – [1/4])/40 = 0.994 and a proportion of 0 by 1/(4*40) = 0.00625, as suggested by Mosteller and Youtz (1961). For the same reason, the arcsine data were computed by the following formula: $y_{transf} = sin^{-1}[\mathrm{SQRT}\{(y + 3/8)/(n + 3/4)\}]$, with y being the raw data, n the number of trials/lag, and y_{transf} the transformed data.

that this digit appeared first. Such a *reconstruction* of temporal order might account for some of the additional correct order reports in the cued condition. This constraint should be kept in mind when interpreting the order errors.

The basic hallmark of the data (i.e., the increased conditional T2 accuracy) supports the supposition that the relevant features of T1 are processed and available for allocation of attention before T2 is presented. If T1 carries information about the temporal position of T2, this information can be used to deploy attentional resources and enhance processing of T2.

Still, Experiment 1 leaves the question unanswered of how fast attentional resources can be allocated in time. As can be seen from Figure 1 (solid lines), the earliest difference between the conditional accuracies in the cued and baseline condition is at lag 2, which is 200 ms after T1 onset. Hence, one could conclude that it takes about 200 ms before the information about T1 identity is implemented into the temporal deployment of attentional resources. Compared to effects of spatial attention, this would be very slow (see Scharlau et al., 2006). But at lag 1, accuracies are at ceiling, so it may be that attentional allocation is faster, but the task was too easy to reveal this (see Figure 1).

There are also some methodological problems in Experiment 1 that need to be fixed in Experiment 2. The T1 set size was smaller in the cueing condition (1–7) than in the baseline condition (1–9). Shapiro, Raymond, and Arnell (1994) showed that the set size of T1 has an effect on the strength of the blink. As a consequence, the improvement in T2 accuracy could be due to this methodological artifact. Furthermore, the different T1 set size could also influence order errors: If participants in the cue group learned that T1 was never an 8 or a 9, they could use this information in their order judgement.

EXPERIMENT 2

Experiment 2 meets the aforementioned methodological objections by a single measure: Participants in the baseline group received the same streams with the same contingency between the two targets as the cue group, but were unaware of it. Additionally, we speeded up the RSVP stream to 20 items/s to preclude ceiling effects for accuracy.

Method

Apparatus, stimuli, design, and procedure were identical to the cueing condition in Experiment 1 except for the following: Characters were presented for only 40 ms and were separated by 10 ms. The second target appeared at lag 1 (TOA of 50 ms), 2, 3, 5, or 6. Each lag was repeated 20 times. The 44 new observers (21 females, mean age: 24) were divided into two groups of 22 observers each.

Different from Experiment 1, both in the baseline group and in the cue group, the first target-digit was a valid cue for the lag T2 was presented in. Therefore, in both conditions T1 could only be "1", "2", "3", "5", or "6". T2 was selected randomly from 1–9, with the constraint that the two targets were always different. In the baseline condition, participants were unaware of the fact that T1 informed about the TOA. In the cue condition, the instruction emphasised the relationship between T1 identity and temporal position of T2. This experiment lasted about half an hour and was conducted in a single session. In this and the following experiment, participants were paid for the time they needed to complete the experiment.

Results and discussion

Figure 2 (solid lines) shows the conditional accuracy of T2 as a function of lag. As expected, the faster presentation rate impaired identification. The

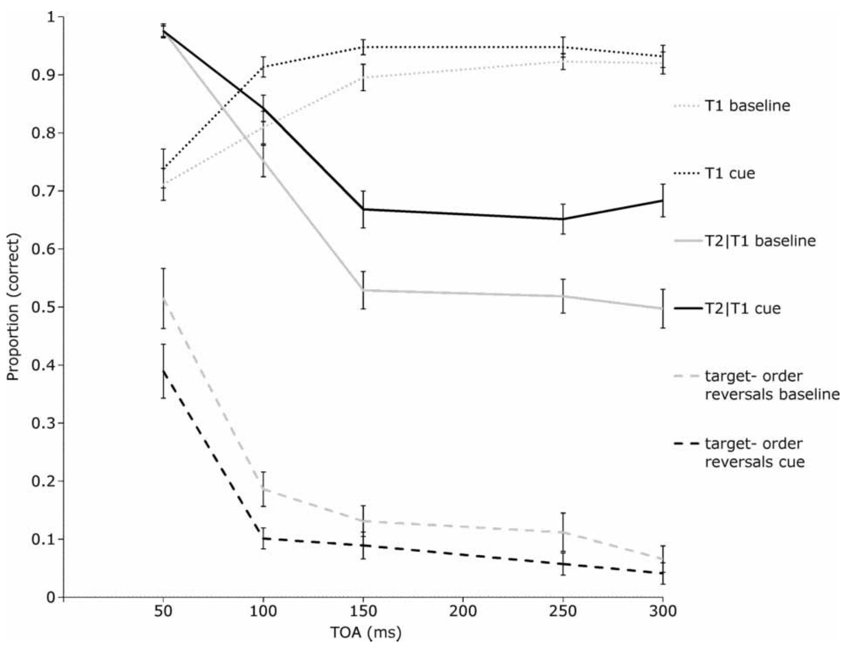

Figure 2. Solid lines: Conditional accuracy of T2|T1 as a function of lag in steps of 50 ms, separately for baseline and cue trials. Order reversals are counted as correct. Dashed lines: Probability of order reversals. Dotted lines: T1 accuracy. Error bars denote standard errors of the mean.

two-way ANOVA on T2|T1 again showed significant main effects for lag, $F(4, 210) = 51.5$, $MSE = 0.79$, $p < .01$, and cueing, $F(1, 210) = 19.5$, $MSE = 0.3$, $p < .01$, and no significant interaction, $F(4, 210) = 1.61$, $MSE = 0.02$, $p < .17$. On average, T2 performance increased by 11% in the cueing condition.

As in Experiment 1, decreased T1 accuracy cannot account for the increased T2|T1 accuracy. T1 was indeed identified better when it served as a cue, as can be seen in Figure 2 (dotted lines) and in the associated two-way ANOVA. Results showed effects of lag, $F(4, 210) = 20.1$, $MSE = 0.22$, $p < .01$, and cueing, $F(1, 210) = 7.7$, $MSE = 0.8$, $p < .01$, and no interaction, $F(4, 210) = 0.8$, $MSE = 0.01$, $p = .51$. A higher T1 accuracy in cued trials compared to uncued ones was also found by Martens and Johnson (2005), Exp. 3). It suggests that participants made more effort to identify T1 in the cue condition, since they knew that this information would facilitate the subsequent identification of T2. The faster presentation rate not only decreased the accuracies, but also led to a higher proportion of target-order reversals (compare Figures 1 and 2). The associated two-way ANOVA was significant for both factors, $F(4, 210) = 33.8$, $MSE = 0.71$, $p < .01$ for lag, and $F(1, 210) = 7.3$, $MSE = 0.15$, $p < .01$ for cueing, and not significant for the interaction, $F(4, 210) = 0.4$, $MSE = 0.01$, $p = .78$. To sum up: In Experiment 2 exactly the same trials were shown in the cued and the baseline condition. Still, we found that cueing increased T2 performance. As can be seen from Figure 2, the higher T2 accuracy was already found 100 ms after T1 onset.

EXPERIMENT 3

Experiments 1 and 2 both showed increased T2 accuracy when the temporal position of T2 was cued by T1. However, one might argue that the cue causes a general boost in performance and not a time-specific attention to T2. It is also possible that it actually is increased motivation caused by the different instruction, not the cue per se that boosts performance. To test these objections, Experiment 3 included invalid trials. If the effect is really due to time-specific attention, T2 performance should be higher in valid trials compared to invalid ones, and a general boost or a boost due to the instruction should be the same for valid and invalid trials.

Method

Apparatus, stimuli, and procedure were identical to Experiment 2, but the design differed in several ways. T2 could either appear at lag 2 (TOA of 100 ms), 3, 8, or 9. Each lag was repeated 60 times. T1 validly cued the temporal position of T2 in 40 trials. In the remaining trials, the cue was invalid: For instance, if T1 was a "2" or "3" (i.e., a short TOA was cued), T2 appeared either at lag 8, or at lag 9 (i.e., at a long TOA). If T1 was a "9" or "8" (i.e., a long TOA was cued), T2 appeared at lag 2 or at lag 3 (a short TOA). The second target was again selected randomly from the target-digits 1–9. The 20 new participants (6 females, mean age: 25) were told that the cue was "almost always" valid and they were encouraged to use it.

Results

The conditional accuracy of T2 is shown in Figure 3, separately for valid trials and for invalid trials. The two-way ANOVA on T2|T1 was significant for both lag, $F(3, 57) = 11.9$, $MSE = 0.25$, $p < .01$, and, more importantly, for validity, $F(1, 57) = 6.4$, $MSE = 0.16$, $p = .02$. The interaction was not significant, $F(3, 57) = 1.2$, $MSE = 0.006$, $p = .32$. T2 was identified better in valid as compared to invalid trials. The average difference was 6.5%. On trials with invalid cues, participants perceived the targets more frequently in

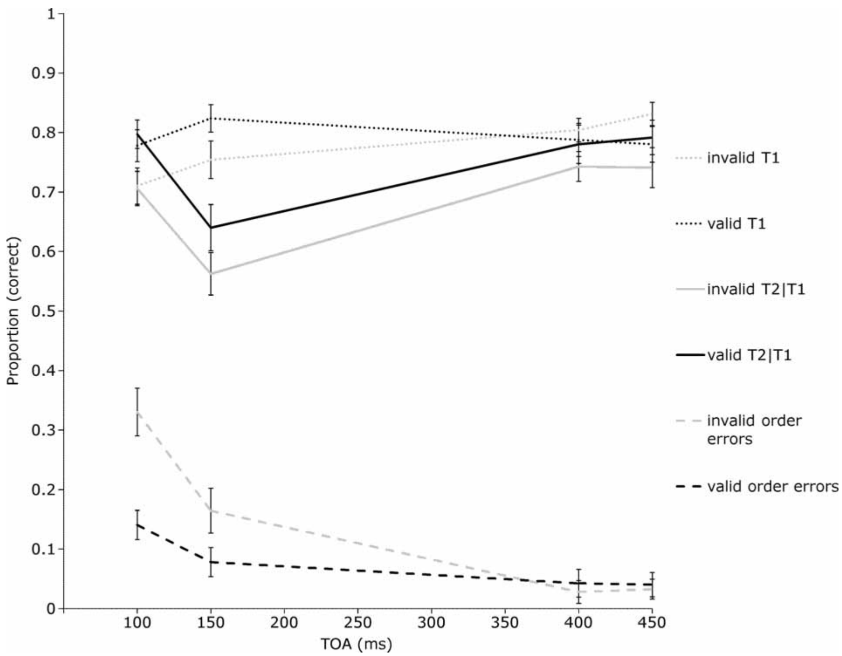

Figure 3. Solid lines: Conditional accuracy of T2|T1 as a function of lag in steps of 50 ms, separately for valid and invalid trials. Order reversals are counted as correct. Dashed lines: Probability of order reversals. Dotted lines: T1 accuracy. Error bars denote standard errors of the mean.

the reversed temporal order, as can be seen from the dashed lines in Figure 3. The corresponding two-way ANOVA on order errors revealed significant effects for the within-subjects factors lag, $F(3, 57) = 34.9$, $MSE = 0.31$, $p < .01$, and validity, $F(1, 57) = 15.3$, $MSE = 0.13$, $p < .01$, and, additionally, a significant interaction, $F(3, 57) = 3.8$, $MSE = 0.04$, $p = .014$.

As in Experiment 2, there was a significant effect on T1 performance. The main effect of validity in the two-way ANOVA on T1 accuracy just failed to reach significance, $F(1, 57) = 3.98$, $MSE = 0.012$, $p = .06$. The main effect of lag and the interaction were significant, $F(3, 57) = 7.3$, $MSE = 0.029$, $p < .01$, and $F(3, 57) = 6.4$, $MSE = 0.03$, $p < .01$, respectively. Different from Experiment 2, since the effect is within subjects, we cannot attribute it to different motivation through a different instruction. It is possibly related to reconstruction of T1 identity. Analogous to the possible reconstruction of temporal order described before, observers might have tried to reconstruct T1 identity based on the perceived temporal distance between the targets. Since the T1 set size was small, this is a promising strategy in trials in which observers detected T1, but could not identify it.

The results of Experiment 3 indicate that the T1-cueing effect is reliable even within subjects. Furthermore, they show that the effect is time-specific: When T1 cued a late T2, but T2 was presented early at lag 2, it was less likely that participants identified it. The same was found if T1 cued a short lag, but T2 appeared at a long one. This suggests that the attentional boost elicited by the cue is time-specific. It facilitates a delimited temporal interval around the anticipated T2 onset.

Admittedly, no baseline-condition without contingencies or unknown contingencies between the targets as in the other experiments was included in Experiment 3. Therefore, we cannot estimate how much of the difference between valid and invalid trials is caused by the cueing benefit and how much is due to cost of allocating attention to the wrong point in time, or because participants stopped searching when an invalid cue indicated a short lag, because they thought they had missed it. Moreover, because of the coarse spacing of lags, the precise time course of the cueing benefit is yet unknown.

GENERAL DISCUSSION

The results of the present study demonstrated that within the time span of 100 ms relevant features of a target are processed and can be used to allocate attentional resources to a point in time: A cue about the lag inherent in T1 helped to identify T2. The comparison between validly and invalidly cued trials further showed that this attentional effect is specific in time and not due to a generic boost in performance. Earlier studies have shown that features of a leading target can facilitate processing of subsequent targets at the same location by spatial allocation of attention (e.g., Wyble, Bowman, & Potter, 2009). Here, we have demonstrated that these features can also be used for an allocation of attention in time, rather than in space. We thus extended previous findings about the temporal deployment of attention (e.g., Coull & Nobre, 1998; Martens & Johnson, 2005). Whereas former studies showed that strategic control over temporal allocation of resources is generally possible, the present experiments indicated that—as in the spatial domain—facilitative effects that require identification of cue features can begin shortly after cue onset (e.g., Ansorge et al., 2009). Although different brain areas seem to be involved in temporal and spatial cueing of attention (Coull & Nobre, 1998), all these findings point to fast and time-restricted effects of attention as an underlying mechanism.

There is a notable difference between the results reported in the three experiments here and those by Martens and Johnson (2005): Whereas Martens and Johnson found a significant increase in T2 identification after 270 ms but not after 720 ms, none of our experiments showed a significant Cueing $\times$ Lag interaction. This indicates that the cueing effect induced in the present experiments raises overall T2 performance, but can be dissociated from the mechanisms that cause the attentional blink deficit.

How can the present results be related to models of the AB? We think that the interference model of Shapiro et al. (1994) could easily account for the presented results. Within this model, the two targets and the distractors immediately following them are buffered in a short-term store. The relative strength of each item in this storage determines whether it wins the competition for resources. According to Martens and Johnson (2005), the temporal cue might function as an extra attribute of a target and therefore influence the allocation of resources in favour of the targets. If this holds true, this can also explain why we did not find that facilitation differed significantly across lags: The additional attribute is added to the target regardless of the lag it is presented in. If this interpretation of the interference model of Shapiro et al. is correct, intrusion errors should also decrease when a temporal cue is available. To test this model further, experimental work in a paradigm that allows this specific kind of error is needed.

However, the present results are also compatible with the more recent Boost and Bounce theory of temporal attention (Olivers & Meeter, 2008). Olivers and Meeter (2008) postulate that the blink is due to a strong inhibitory feedback response after the post-T1 distractor accidentally gets boosted. We would argue that this inhibition of T2 could be counteracted by timely top-down deployment of attention elicited by the temporal cue (also see Wyble, Bowman, & Nieuwenstein, 2009, for a similar mechanism). In sum, the present findings support the idea that temporal and spatial attentional effects are similar in nature and therefore support the conjecture that the same boost of attention may subserve the AB and cueing effects (Olivers & Meeter, 2008).

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