Stimulus localization interferes with stimulus recognition: Evidence from an attentional blink paradigm

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Recognition of a second target (T2) can be impaired if presented within 500 ms after a first target (T1): This interference phenomenon is called the attentional blink (AB; e.g., Raymond, Shapiro, & Arnell, 1992) and can be viewed as emerging from limitations in the allocation of visual attention (VA) over time. AB tasks typically require participants to detect or identify targets based on their visual properties, i.e., pattern recognition. However, no study so far has investigated whether an AB for pattern recognition of T2 can be elicited if T1 implies a second major function of the visual system, i.e., spatial computations. Therefore, we tested in two experiments whether localization of a peripherally presented dot (T1) interferes with the identification of a trailing centrally presented letter T2. For Experiment 1, T2 performance increased with onset asynchrony of both targets in single-task (only report letter) and dual-task conditions. Besides this task-independent T2 deficit, task-dependent interference (difference between single- and dual-task conditions) was observed in Experiment 2, when T1 was followed by location distractors. Overall, our results indicate that limitations in the allocation of VA over time (i.e., an AB) can also be found if T1 requires localization while T2 requires the standard pattern recognition task. The results are interpreted on the basis of a common temporal attentional mechanism for pattern recognition and spatial computations.

Introduction

At a given moment the amount of available visual information exceeds the available processing resources of the brain (Desimone & Duncan, 1995). These processing resources thus need to be allocated both within space and across time. Within the field of visual attention processing limitations in space have theoretically attracted a greater deal of interest. However, limitations in visual processing can also be observed when information is distributed across time (cf. Dux & Marois, 2009).

Using rapid serial visual presentation (RSVP) researchers have tried to shed light on the limits of visual processing across time (Lawrence, 1971, Potter & Levy, 1969).With this technique several temporally separated but spatially overlapping stimuli are displayed at high presentation rates. It could be shown that detecting or even recognizing a single conceptually defined target picture can occur already at a presentation rate of eight pictures per second (Potter, 1975).

A very prominent paradigm employing RSVP is the so-called attentional blink (AB, Raymond, Shapiro, & Arnell, 1992; see also Broadbent & Broadbent, 1987). In the AB paradigm, participants usually have the task to report two targets embedded in a stream of distractors. Stimuli are typically of alphanumeric class and displayed at a rate of 10 Hz at the same spatial position on the screen. The main finding from the AB paradigm is that the identification of the second target

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(T2) is impaired when it follows in close temporal proximity (up to 500 ms) to the first target (T1).

Raymond et al. (1992) were the first to use the term attentional blink. Participants in their study had to identify a white letter (T1) in a stream of otherwise black letters and subsequently detect the presence of a black x (T2). They found the detection accuracy to follow a u-shaped trend across T1-T2 lags (i.e., T2's serial position relative to T1). Furthermore, when the participants were instructed to ignore the white letter, detection of the probe was unimpaired. From this they concluded that the effect was not based purely on sensory interference but rather reflected an attentional limitation. Building upon this, Chun and Potter (1995) were able to show that an AB can also be observed when both targets are defined categorically, e.g., report letters among digits.

A further hallmark of the AB, which was already reported in Raymond et al. (1992), is the so-called lag-1 sparing (Potter, Chun, Banks, & Muckenhoupt, 1998; Visser, Bischof, & Di Lollo, 1999). It refers to the fact that T2 performance is almost unimpaired when it follows T1 immediately, i.e., without intervening distractors. Interestingly, this effect usually cannot be observed when both targets are presented spatially separated, as in the dwell-time paradigm (DT, Duncan, Ward, & Shapiro, 1994; Petersen, Kyllingsbaek, & Bundesen, 2012; Ward, Duncan, & Shapiro, 1997). Duncan et al. (1994) presented one target either below or above fixation and another to the left or right of fixation. Both targets were displayed only briefly and without further distractors but they were subsequently masked. By varying the onset asynchrony between both targets they found an impaired accuracy in reporting the identity of the second target, similar to the AB, lasting several hundred milliseconds. There is evidence that switching between tasks or, as in DT's case, locations accounts for the lack of lag-1 sparing (Visser et al., 1999). Apart from this difference, interference in both AB and DT paradigms is likely to reflect a common limitation of visual processing (cf., MacLean & Arnell, 2012). In the current article we will therefore use both expressions synonymously, referring to the target-onset asynchrony dependent pattern of interference (see also MacLean & Arnell, 2012).

The AB has established itself as the paradigm of choice for studying temporal visual attention (VA). A dominant feature of almost all studies on the AB is that the task requires pattern recognition, i.e., performance is measured in terms of identification or detection of particular visually defined objects. However, this is only one of the main computations the primate visual brain has to do. A second major problem the visual system has to solve is that of spatial computation or localization.

A functional as well as anatomical differentiation between "what" and "where" processing along dorsal and ventral cortical pathways, respectively, was first put forward by Ungerleider and Mishkin (1982) and later taken up by Goodale and Milner (1992; Milner & Goodale, 1995, 2008). The latter studied the now well-known patient D. F., whose visual perception is profoundly affected by brain damage to the ventral stream. They found her ability to differentiate between objects based on visual properties to be impaired, while her spatially based actions on those objects remained somewhat intact. Milner and Goodale (1995, 2008; see also Goodale & Milner, 1992) strongly argued for distinct functions within the two cortical pathways. More specifically, dorsal processing is thought to make spatial computations for guiding actions such as grasping, whereas the ventral stream allows object identification based on visual properties such as color and form.

Even though the strict interpretation of their two visual systems hypothesis has been criticized or reinterpreted (e.g., Franz, Fahle, Bülthoff, & Gegenfurtner, 2001; Rossetti, Pisella, & Vighetto, 2003; Schenk, 2006), the postulation of two main functions of the visual brain, namely spatial computation and pattern recognition, is hardly debated.

A comparable point is made in visual working memory (VWM) research. Within working memory (WM), researchers have distinguished between several domains. Originally Baddeley's influential WM model (Baddeley & Hitch, 1974) sees verbal information to be stored on the basis of subvocal rehearsal processes, while locations and objects are maintained via the so-called visual–spatial sketchpad. However, later research by him and others (Baddeley, 1992, 2012; Klauer & Zhao, 2004; Logie, 1986; Tresch, Sinnamon, & Seamon, 1993) made a point for a further fractionation of visual and spatial WM domains. More specifically, interference within WM follows a double dissociation of visual and spatial WM. For example, Klauer and Zhao (2004, see also Tresch et al., 1993) had participants do a spatial and a visual (object) memory task while concurrently performing either a movement discrimination or color discrimination task. The discrimination tasks caused interference on the memory tasks. However, interference was greater for the matching (i.e., spatial memory–movement discrimination and visual memory–color discrimination) than for the non-matching conditions. Hence, this supports a dissociation of spatial and object processing within the VWM domain.

In summary, there seems to be some evidence suggesting that spatial computations and pattern recognition are treated within functionally different subdomains of the visual system. While there is also evidence for such a distinction within VWM (e.g., Baddeley, 2012), no study has precisely investigated whether and how it might affect the time course of temporal VA as studied in the AB paradigm.

Experiment 1

The current study therefore investigates how far the functional division within the visual system between spatial computations and pattern recognition modulates the allocation of temporal VA. More specifically, we tested whether an AB emerges when T1 and T2 belong to the separate subsystems of pattern recognition and spatial processing, respectively.

The AB might reflect a temporal attentional limitation within the system carrying out pattern recognitions. Hence, interference in the AB could depend on sequential processing of visual pattern information. An AB for pattern recognition that is elicited by a localization task, on the other hand, could indicate that this attentional limitation might be common to both subsystems of visual processing.

To this end, we developed a dual-target paradigm similar to the AB or DT paradigms that requires participants to localize a peripheral dot (T1) and subsequently identify a foveally presented letter (T2). In line with the standard AB procedure, we varied onset asynchrony of both targets. Localization performance was measured in terms of the accuracy of a memory-guided saccade that had to be executed to T1's location. Given the relation between eye movements and VWM (e.g., Herwig, Beisert, & Schneider, 2010; Theeuwes, Belopolsky, & Olivers, 2009), memory-guided saccade accuracy has proven to be an appropriate measure of spatial representations in VWM. Moreover, eye movements convey more detailed spatial information than a match-to-sample task. Letter identification performance served as dependent measure for T2. Hence, Task 1 requires localization, whereas Task 2 requires pattern recognition. If T2 performance remains unimpaired by T1's localization across levels of onset asynchrony, then this result might indicate that spatial computations and pattern recognition rely on separate processing resources or that the AB is specific to the domain of pattern recognition. If, however, T1's localization affects T2 performance similarly as in an AB paradigm with a pattern-recognition task for T1 and T2, then one could assume common processing resources for the domains of pattern recognition and spatial computation.

While half of the participants in the first experiment had to memorize the peripheral dot's location for a later to-be-executed saccade (dual-task condition), the other half was instructed to ignore this stimulus (single-task condition). It is well-known that an onset in the periphery attracts VA in a bottom-up fashion (Yantis & Jonides, 1990). However, this bottom-up driven orienting response might affect temporal VA differently than the processing the visual system has to do when actually localizing and memorizing T1's location (Awh, Jonides, & Reuter-Lorenz, 1998). Therefore, we expect stronger and longer-lasting interference in the dual-task compared to the single-task condition. However, due to the spatial separation between T1 and T2, we do not expect T2 performance to follow a u-shaped trend across lags (Duncan et al., 1994; Visser et al., 1999), i.e., lag-1 sparing.

Methods

Participants

Twenty participants took part in Experiment 1. Their mean age was 26 years. They were randomly assigned to either single- or dual-task conditions. In all the experiments reported here, participants were recruited from either staff or students from Bielefeld University and had normal or corrected-to-normal visual acuity. They received either monetary compensation or course credits.

Apparatus and stimuli

All experiments were programmed with Experiment Builder software (SR Research, Ontario, Canada) and were displayed on a 19-in CRT monitor with a refresh rate of 100 Hz and a resolution of 1,024 by 768 pixels. Eye position was monitored by a video-based eye tracker (Eye Link 1000 tower mount, SR Research, Ontario, Canada). The eye-tracker has a sampling rate of 1 kHz and an average accuracy of 0.25° to 0.5°. Participants' head was fixed by the eye tracker's forehead and chin rest at a viewing distance of 71 cm.

All stimuli were displayed in white on black background. An upper-case letter for the identification task was presented within a 1.5° box (stroke width 0.11°) at the center of the screen. The letter was drawn randomly from all letters of the alphabet except for I, M, O, W, Y, and Z and was approximately 0.4° by 0.4° in size. The mask following the letter was a 0.56° square filled with white scrambled lines. The peripheral dot had a diameter of 0.3° and was displayed at an eccentricity of 5°. The potential positions of this dot corresponded to the 12 full-hour positions of a standard clock face. The unspeeded responses for the letter identification task were made with a standard keyboard.

Design

The between-participants variable was task condition (single- vs. dual-task condition). The within-participants variable was the target-onset asynchrony (TOA, 150 ms, 300 ms, 450 ms, 600 ms, and 900 ms) between the peripheral dot (T1) and the letter (T2). There were 36 repetitions of each TOA, resulting in 180 experimental trials split up into three blocks of 60 trials.

Each participant performed one additional staircase block consisting of 60 trials, in which the TOA was fixed at 900 ms, at the beginning of the experiment. During this staircase block the display duration for T2 was adjusted to match a performance level between 66% and 75% correct identification. The main dependent variable was the percentage of correct letter identification.

Procedure

Participants received written instructions at the start of the experiment, followed by a nine-point calibration procedure of the eye tracker. They began with the staircase block, which only included the single-task condition, i.e., participants were not required to perform any eye movements. The 60 staircase trials were split up into 4 × 15 trials. After each of these sub-blocks participants' performance was checked with respect to the target performance level. Depending on the performance within one sub-block, display duration was either increased or decreased by 20 ms (Sub-blocks 1 and 2) or 10 ms (Sub-blocks 3 and 4). The initial display duration was set to 60 ms. The procedure was set not to fall below 20 ms and not to exceed 100 ms display duration. Participants whose performance in the last two sub-blocks fell below the targeted level were excluded from the experiment. After the staircase block participants were informed that the actual experiment was about to begin. Each trial began with the presentation of a white box at the center of the screen. Participants had to maintain fixation within a quadratic area of 2° at the center of the screen for 500 ms, after which a white dot appeared in the periphery for 100 ms. Depending on condition, participants were either asked to ignore this dot (single-task condition) or to memorize its position as the target for the later to be executed memory-guided saccade (dual-task condition). After a varying amount of time, depending on the TOA condition, a letter appeared at the center of the screen (display duration depended on the outcome of the preceding staircase block), followed by a mask that was presented for 100 ms at the same location. Participants of both conditions were instructed to identify this letter. The fixation box disappeared 800 ms after onset of the letter. This served as a go signal for the memory-guided saccade in the dual-task condition, but was of no relevance to participants of the single-task condition. Participants in the dual-task condition were required to saccade to the memorized location. Saccade accuracy was checked online. That is, if the saccade landed within a 2° radius from the center of the screen or outside an isosceles triangular area (45° angle, 6.5° side length, one corner placed in the center of the screen) an error message appeared, instructing participants to make more accurate saccades, together with a small circle indicating the actual landing position of the saccade as well as T1's location. When no saccade was made within 3000 ms after the go signal, participants received an error message asking them to execute the eye movement faster. Trials on which participants moved their eyes out the central fixation area prior to the go signal were regarded as errors. In all of these cases, trials were repeated over the course of the experiment. At the end of a trial, participants of both conditions were asked to report the letter. Participants were encouraged to guess if they were uncertain of the letter's identity. They did not receive feedback about the accuracy of their response. See Figure 1 for an exemplary trial in Experiment 1.

Results

Display duration for the letter identification task after the staircase block did not differ between the two task conditions, mean display duration 26 ms for the single-task condition and 25 ms in the dual-task condition, $t(18) = 0.32$, $p = 0.75$.

Trials in the dual-task condition were excluded from analysis if the latency (defined as time from fixation-box offset to start of the eye movement) was below 100 ms, i.e., if the saccade was anticipatory. This criterion excluded 10.4% of the trials in the dual-task condition. Because the interval between T2 onset and the fixation-box offset (go signal for memory-guided saccade) was fixed to 800 ms, participants probably anticipated the go signal. This might explain the number of trials with latencies below 100 ms.

For the within-participant analyses of variance (ANOVA) the sphericity assumption was tested by means of Mauchly's test of sphericity and if necessary, Greenhouse–Geisser's ε was used to correct the degrees of freedom. Levene's test of equality of error variances was used for the between-participant factors, and degrees of freedom were accordingly corrected.

T1 performance

First of all we computed T1 performance as the proportion of trials in which the memory-guided saccade landed within a 2° region of interest (ROI) centered on T1. Overall 76% of the memory-guided saccades landed within this ROI. A repeated measures ANOVA (within-participant factor: TOA) revealed that TOA had no significant influence ($p = 0.86$) on the proportion of trials with saccade landing positions within the ROI. Although, this measure might be deemed more comparable to those typically used in AB or DT paradigms (e.g., percent correct identification), the eye-movement data allows more detailed analysis of T1 performance. We computed measures of saccadic

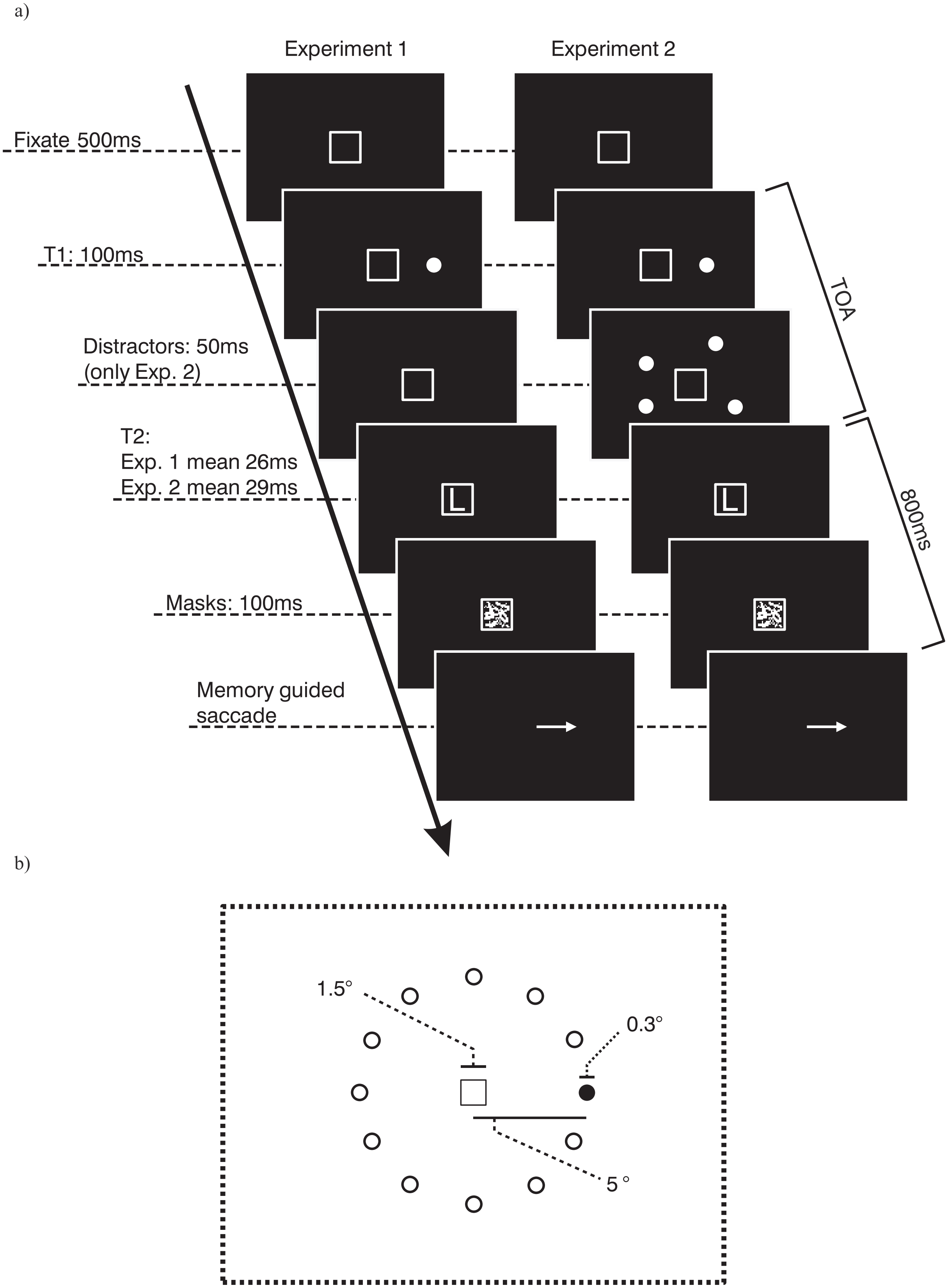

Figure 1. (a) Trial procedure in Experiments 1 and 2. (b) Physical dimensions in the current experiments with potential T1 locations.

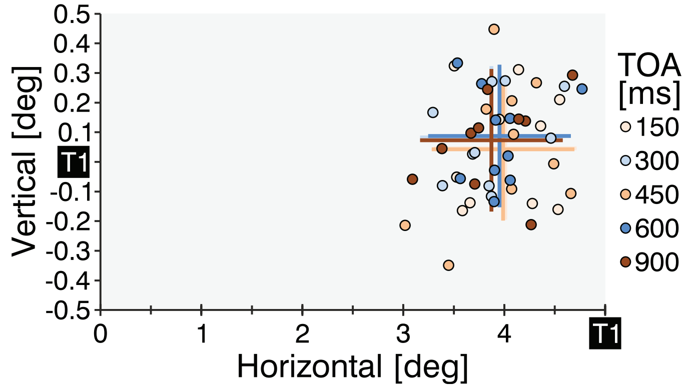

Figure 2. Rotated median landing position as a function of TOA in Experiment 1 per participant (filled circles) and averaged across participants (crosses).

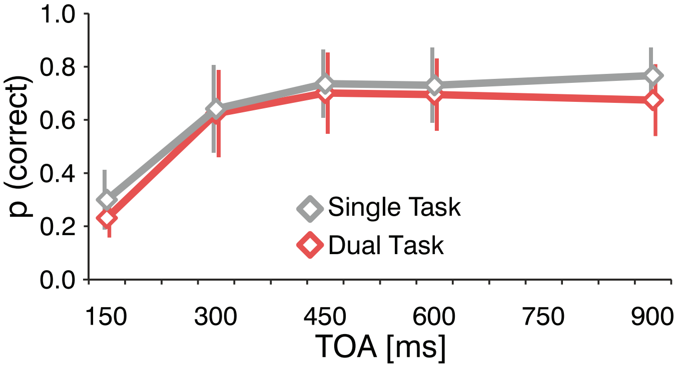

Figure 3. T2 performance as a function of TOA and task condition in Experiment 1. Error bars represent between participant 95% confidence intervals. In the dual-task condition *p*(correct) reflects *p*(T2|T1).

accuracy (i.e., average gain and direction and gain and direction variability) in line with other studies on memory-guided saccades (cf. Herwig et al., 2010; Ploner et al., 2001). None of these revealed significant deviations of memory-guided saccade accuracy as a function of TOA (*p*s > 0.14). The median saccade landed at 3.94° horizontally (towards T1) and 0.04° vertically (perpendicular to T1). The observed undershoot (i.e., saccades fell more than 1° short of T1) of the memory-guided saccade in the direction of T1 reflects a normal finding for this kind of response (cf. Hutton, 2008). Figure 2 depicts the median rotated saccade landing position as a function of TOA. In summary, TOA did not affect T1 processing.

T2 performance

T2 performance was analyzed for T1 correct trials only, $p(T2|T1)$, e.g., Raymond et al. (1992), in the dual-task condition. Figure 3 shows the proportion of correct letter reports as a function of TOA for the two task conditions. A repeated measures ANOVA (within-participant factor: TOA; between-participant factor: task condition) was computed for the data. The within-participant factor TOA reached the level of significance, $F(4, 72) = 85.85$, $p < 0.00001$, however it did not interact with task condition ($p = 0.73$), nor did the main effect of task condition reach the level of significance ($p = 0.58$). Because we generally expected a linear increase of T2 performance (i.e., no lag-1 sparing) with TOA, one-sided pair wise comparisons were performed on the average T2 performance across task conditions. These revealed that at 150 ms TOA T2 performance was significantly different from the average performance at 300 ms TOA, 27% versus 63%, $t(18) = 10.53$, $p < 0.00001$. This comparison was also significant for the performance at 300 ms and 450 ms TOA, 63% versus 72%, $t(18) = 3.88$, $p = 0.0009$. TOAs longer than 300 ms were not significantly different from the next highest TOA (*p*s > 0.37), i.e., performance reached an asymptote of around 72%. Thus, T2 performance was impaired at short TOAs (i.e., 150 ms and 300 ms), but no further modulation of performance occurred for TOAs longer than 300 ms (i.e., 450 ms, 600 ms, and 900 ms).

Discussion

We found strong interference on letter identification performance by a preceding localization stimulus at short TOAs. Interference quickly decreased at longer TOAs. Importantly, performance in the current experiment did not differ between the single- and dual-task conditions.

There are two interesting observations. First, interference quickly decreased. It seems that VA was promptly allocated towards the periphery but could be almost completely withdrawn within 300 ms. Second, localizing and memorizing the peripheral dot did not produce more interference than ignoring it. Thus, interference was not task dependent. This absence of differences in the level of interference between the two task conditions at any of the tested TOAs could be explained in three ways.

First, the equal amount of interference in both task conditions could be due to an automatic task-independent orienting response to the first localization stimulus (Müller & Rabbitt, 1989; Nakayama & Makeben, 1989; Yantis & Jonides, 1990). Subsequently, localizing and memorizing T1 might be computed in a memory domain for spatial information, separate from object WM (Baddeley, 1992, 2012; Klauer & Zhao, 2004; Logie, 1986; Tresch et al., 1993). An interpretation of interference based on low-level visual processes (cf. Breitmeyer & Öğmen, 2006; Whitney & Levi, 2011) seems implausible, given the spatial configuration of stimuli in the current paradigm, that is, spatially widely segregated stimuli for localization and recognition tasks.

Second, it is possible that participants in the single-task condition automatically memorized T1's location into WM much the same as the participants of the dual-task condition. In this case interference would reflect encoding into WM rather than an effect of memory load, as WM capacity would not be exceeded by storage of T1 and T2 (Luck & Vogel, 1997).

Third, within the AB-paradigm masking of T1 is considered a necessary condition for obtaining T2 interference (e.g., Breitmeyer, Ehrenstein, Pritchard, Hiscock, & Crisan, 1999; Chun & Potter, 1995; Moore, Egeth, Berglan, & Luck, 1996; Seiffert & Di Lollo, 1997). Therefore, the lack of task-dependent interference could be due to the absence of a distracting stimulus between T1 and T2. Distractors in the AB act as masks, because they typically overlap in space with the targets. T1 masks are usually pattern masks or generally spatially overlapping distractor items of alphanumeric class. In the current paradigm, masking of T1 or any equivalent are not straight forward to achieve. Simply displaying a spatially confined stimulus at T1's location would merely increase T1's display duration, as it would provide a signal adherent of T1's location. However, displaying additional stimuli at potential target locations as distractors should lead to a situation where T1 is processed under similar conditions as in the standard AB or DT paradigms. In other words, this configuration should create a situation of competition between locations. This could lead to an AB-like pattern of interference for T2 processing.

On the other hand, if the lack of task-dependent T2 interference is based on domain specificity of processing resources or a somewhat automatic memorization of T1's location in the single-task condition, then introducing distractors (masks) should again lead to equivalent performance across TOAs for both task conditions.

Experiment 2

Experiment 2 again investigates how localization interferes with identifying a visually defined T2. However, this time T1 is followed by distractors.

In order to maintain the AB's serial mode of presentation, distractors in Experiment 2 where displayed after offset of T1, i.e., T1 was displayed on its own for the same amount of time as in Experiment 1 (100 ms). Following its offset, four additional dots were displayed at a potential T1 location (50 ms).

Methods

Participants

Twenty participants took part in Experiment 2. Their mean age was 25.6 years. New participants were randomly assigned to either between-participant condition. In order to avoid transfer between single and dual-task conditions, participants who also took part in Experiment 1 were assigned to the same task condition as in Experiment 1. Eight participants from Experiment 1 also participated in Experiment 2 (six in the dual-task condition).

Apparatus and stimuli

The same apparatus and stimuli were used as in Experiment 1. The distractor display consisted of four additional dots that could appear at four randomly selected potential T1 locations other than the one previously occupied by T1. These were displayed at an eccentricity of 5°. The potential positions of these dots corresponded to the 12 full-hour positions of a standard clock face. The distractors were shown for 50 ms immediately after disappearance of T1.

Design

The within-participants variable TOA was altered and consists of durations of 150 ms, 250 ms, 350 ms, 450 ms, and 650 ms. A TOA of 650 ms was used in the staircase block. Apart from this, no changes were made to the design.

Results

Display duration for the letter identification task after the staircase block did not differ between the two task conditions, mean display duration 28 ms for the single-task condition and 30 ms in the dual-task condition, $t(18) = 0.309$, $p = 0.76$. The latency criterion excluded 9.6% of the trials in the dual-task condition.

T1 performance

The same measures of T1 performance were used as in Experiment 1. Again, none of these revealed a significant effect of TOA (within participant ANOVAs: $ps > 0.17$). Thus there was no reliable influence of TOA on T1 performance. Across TOAs 75% of the memory-guided saccades landed within the 2° ROI. The median saccade landed at 3.88° horizontally (towards T1) and 0.003° vertically (perpendicular to T1). Figure 4 depicts the median rotated saccade landing position as a function of TOA in Experiment 2.

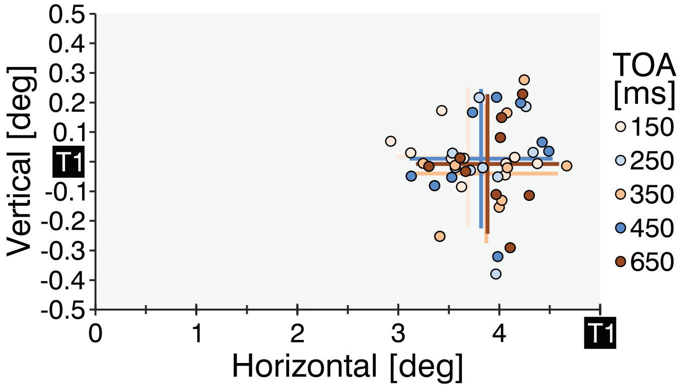

Figure 4. Rotated median landing position as a function of TOA in Experiment 2 per participant (filled circles) and averaged across participants (crosses).

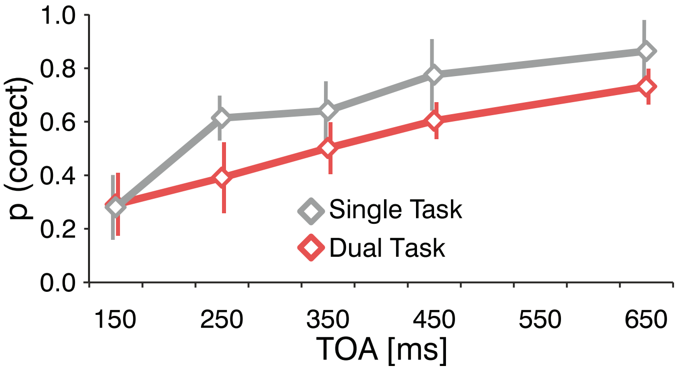

Figure 5. T2 performance as a function of TOA and task condition in Experiment 2. Error bars represent between participant 95% confidence intervals; *p*(correct) in the dual-task condition reflects $p(\mathrm{T2}|\mathrm{T1})$.

T2 performance

Figure 5 shows T2 performance as a function of TOA and task condition in Experiment 2. T2 performance was again analyzed for T1 correct trials only, $p(\mathrm{T2}|\mathrm{T1})$, e.g., Raymond et al. (1992) in the dual-task condition. We conducted a repeated measures analysis of variance (ANOVA) with the within-participant factor TOA (150 ms, 250 ms, 350 ms, 450 ms, and 650 ms) on the percentage of correct letter identification. Task condition (single-task vs. dual-task conditions) went into the analysis as a between-participant factor. This analysis revealed a significant main effect of TOA, $F(4, 72) = 62.28$, $p < 0.0005$, as well as a significant interaction of TOA and task condition, $F(4, 72) = 3.09$, $p = 0.021$. The between-participant factor task condition approached significance, $F(1, 18) = 4.26$, $p = 0.054$.

We compared performance between the two task conditions within the same levels of TOA using independent samples *t* tests. Performance between the two task conditions was not significantly different for 150 ms TOA (single-task condition 28.1% vs. dual-task 29.1%, $p = 0.90$). However, one-sided *t* tests showed significantly higher performance in the single-task condition compared to the dual-task condition at TOAs of 250 ms, 61.3% versus 39.1%, $t(15.263) = 3.13$, $p = 0.007$; 350 ms, 64.2% versus 50.2%, $t(18) = 2.23$, $p = 0.038$; 450 ms, 77.5% versus 60.4%, $t(18) = 2.57$, $p = 0.019$; and 650 ms, 86.4% versus 73.2%, $t(14.417) = 2.31$, $p = 0.037$. We conducted two separate within-subject ANOVAs with the factor TOA for each of the two task conditions. These showed significant main effects of TOA for the single-task condition, $F(4, 36) = 47.97$, $p < 0.0005$, and the dual-task condition, $F(4, 36) = 21.41$, $p < 0.0005$. The relationship between TOA and letter identification performance is characterized by linear trends in both task conditions, single-task condition, $F(1, 9) = 110.23$, $p < 0.0005$, dual-task condition, $F(1, 9) = 57.07$, $p < 0.0005$. Planned comparisons (one-sided *t* tests) revealed that across task conditions, T2 performance at one level of TOA was significantly different from the next level of TOA, 150 and 250 ms, $t(18) = 5.67$, $p < 0.0005$; 250 ms and 350 ms, $t(18) = 2.5$, $p = 0.02$; 350 ms and 450 ms, $t(18) = 4.37$, $p < 0.0005$; 450 ms and 650 ms, $t(18) = 4.0$, $p = 0.0008$. Thus, while in Experiment 1 no increase in T2 performance for TOAs longer than 300 ms was observed, interference in Experiment 2 was effective for a longer duration. To summarize, T2 performance was strongly diminished with the shortest TOA in both task conditions. Also for both task conditions performance increased with TOA, however stronger interference was observed for the dual-task condition than for the single-task condition. Thus, inserting distractors after T1 lead to prolonged and task-modulated interference on T2 performance.[1]

Discussion

T2 performance in both task conditions was again characterized by an increase with TOA. Comparing T2 performance between task conditions across TOAs revealed differences. While at the shortest TOA performance between task conditions is almost equal, already with a TOA of 250 ms performance differs. This difference remains fairly stable for increasing TOAs.

We interpret interference in the single-task condition as reflecting a somewhat automatic allocation of VA towards the peripheral transients. This task-independent interference is effective for a longer amount of time than in Experiment 1, because the additional distractors should attract additional VA resources. Hence, T2 performance in the single task condition might be affected by a bottom-up triggered allocation of attentional resources to T1 and distractor locations.

Interference in the dual-task condition exceeded that of the single-task condition for almost every TOA level. Consequently, this larger interference in the dual-task condition cannot be reduced to a purely bottom-up driven orienting response. This task-dependent interference let us to conclude that an AB for pattern recognition of the second target can emerge from spatial processing requirements of the first target.

General discussion

Temporal constraints on visual perception are typically studied using RSVP. The AB employs this technique in order to investigate temporal VA. However, the AB has so far been only linked to the process of pattern recognition, thus excluding a second major class of inference based on spatial computations. There is some evidence that these two processes are treated in anatomically and functionally distinct subsystems of the visual system (e.g., Goodale & Milner, 1992; Ungerleider & Mishkin, 1982). Therefore the main aim of the current study was to investigate whether temporal VA, as measured in the AB, is affected by this dissociation of visual and spatial processing.

In the first experiment, participants had to localize a target in the periphery and subsequently identify a foveally presented letter. The peripheral onset of the first stimulus interfered with T2 performance irrespective of its task relevance, i.e., there was no significant difference between dual-task and single-task conditions. Interference decreased with increasing onset asynchrony of the two targets. However, task-dependent interference was observed in the second experiment when T1 was followed by additional location distractors. While again T2 performance overall increased with TOA, it was lower in the dual-task condition compared to the single-task condition. Significantly different levels of interference between task conditions were apparent for each level of TOA, except for the shortest (i.e.,150 ms). To summarize, the current study revealed that a task that requires localization of a stimulus in the periphery for subsequent action interferes with a letter identification task.

Interference has two components, a short-lived task independent, and a longer lived task dependent. Both of these may reflect limitations in allocating processing resources over time, i.e., temporal VA. However, we did not find results consistent with a division of visual and spatial processing along dorsal and ventral pathways for the allocation of VA over time. Rather pattern recognition and spatial processing seem to rely on a common attentional mechanism (e.g., Schneider, 1995).

Task and location switching

It might be argued that the interference in the current paradigm is different from that in AB or DT paradigms. More specifically the pattern of interference in the current paradigm differs especially from the standard AB finding, which is typically characterized by a u-shaped trend across TOAs. However, it is well known that this trend is replaced by a monotonic increase across TOAs if targets are presented spatially separated (e.g., Breitmeyer et al., 1999; Duncan et al., 1994; Visser, Zuvic, Bischoff, & Di Lollo, 1999) or when they require different tasks (e.g., Olivers & Meeter, 2008; Visser et al., 1999). More specifically, task- or location-switching has been found to decrease T2 performance at short TOAs (e.g.,Visser et al., 1999). Nonetheless, an increase of T2 performance with TOA can be observed, which is considered an AB proper (e.g., MacLean & Arnell, 2012; Visser, Zuvic, Bischof, & Di Lollo, 1999). It is, however, assumed that switching from one task or location to another produces costs, which may not necessarily reflect the same limitation in temporal VA that cause an AB.

In the current paradigm participants in the dual-task condition had to switch from a localization task to a letter identification task, respectively, from T1's location to T2's location. However, mainly two reasons speak against an explanation merely based on task- or location-switches. First, in Experiment 1 T2 performance increased monotonically up to a TOA of 450 ms and did not differ between single- and dual-task conditions. Hence, if switching would account for the TOA dependent increase of T2 performance one would have to assume that switching occurred irrespective of task instructions. Second, additional task-dependent interference was apparent only in Experiment 2 as a difference in T2 performance between task conditions for TOAs longer than 150 ms. However task- or location switches were necessary in the dual-task conditions of both experiments. Consequently it seems unlikely that the pattern of interference in the current experiments, i.e., the monotonic increase as well as the task-dependent difference in T2 performance, reflect merely switch costs.

In the following we will outline how the pattern of interference may be explained on the basis of a common temporal VA mechanism (e.g., Schneider, 1995) for localization and pattern recognition. Masking of T1 seems to have dissociated task-independent and task-dependent components of interference that might reflect voluntary and involuntary temporal VA.

Task-independent T2 interference

First, we will turn to the task independent component of interference and its relation to temporal VA.

Both experiments revealed an effect of the peripheral onset on T2 identification irrespective of the task requirements. More specifically, T2 performance was low with short TOAs even if participants were instructed to ignore the peripheral stimulus. This task-independent component of interference may reflect an involuntary or automatic allocation of VA to the peripheral onset (Müller & Rabbitt, 1989; Nakayama & Makeben, 1989; Theeuwes, 1991; Yantis & Jonides, 1990). Previous studies using a single target RSVP could show that a salient to be ignored distractor can impair target performance in an AB-like fashion (Maki & Mebane, 2006, Stein, Zwickel, Kitzmantel, Ritter, & Schneider, 2010; Visser, Bischof, & Di Lollo, 2004). Thus, while task relevance is generally deemed important for obtaining an AB, salient stimulus properties that draw on processing resources in an automatic fashion can have comparable effects on the deployment of VA over time. This effect can be further increased when the irrelevant distractor shares features with the target, i.e., when distractor properties are contingent on attentional control settings (Folk, Leber, & Egeth, 2002; Folk, Remington, & Johnston, 1992; Maki & Mebane, 2006; Visser, Bischof, & Di Lollo, 2004). In both experiments of the current study, participants in the single-task condition waited for an onset of a white colored stimulus to occur (T2).The peripheral dot (T1) shared two properties with T2, i.e., the color (white) and the emergence (sudden onset). Thus, the task-independent interference might be explained by assuming a somewhat automatic orienting of attention to the peripheral onset because it matched the attentional control settings required for selecting T2 (see also Nordfang, Dyrholm, & Bundesen, 2013).

Task-dependent T2 interference

The task-dependent component of interference was only apparent in Experiment 2, and only with TOAs longer than 150 ms. Results from Moore et al. (1996) indicate that using a masked instead of an unmasked T1 increases the duration that attention needs to be allocated to T1 (i.e., the dwell time). In line with this finding, the crucial difference between the first and the second experiment (i.e., without and with task-dependent interference, respectively) was the introduction of distractors following T1. Thus, the task-dependent interference has to be related to this manipulation. Most of the theories on the AB stress the role of the first distractor following T1 (i.e., the post-T1 distractor, e.g., Di Lollo, Kawahara, Ghorashi, & Enns, 2005; Olivers & Meeter, 2008). The argument builds on the finding that no AB is observed when this distractor is replaced by a target, i.e., when three consecutive targets are presented without intervening distractors (Di Lollo et al., 2005; Olivers, van der Stigchel, & Hulleman, 2007). Similarly, T2 performance remains unimpaired when T2 follows T1 immediately, i.e., lag-1 sparing (e.g., Raymond et al., 1992). Consequently, whatever causes the AB is not simply a limitation in processing two sequentially presented targets but relates crucially to the selection of successively presented relevant information that is interleaved by irrelevant information. However, such an interruption occurred only in the dual-task condition of Experiment 2 but neither in the dual-task condition of Experiment 1 nor in the single-task conditions of both experiments where only the letter was task relevant. Hence, the dual-task condition in Experiment 2 is the only condition that should show task-dependent interference. Following this line of reasoning, task-dependent interference reflects top-down controlled selection of the peripheral dot. While VA is initially allocated to T1 by a transient attentional mechanism (Experiments 1 and 2), sustained level of VA is required only in Experiment 2 to maintain the relevant spatial signal, thereby resolving the competition introduced by the distractors and performing the localization. This would suggest that localization of an abruptly appearing peripheral target requires involuntary VA. However, voluntary VA is necessary when competitors (distractors) appear in temporal proximity to the target (Moore et al., 1996).

While this would explain why interference is generally increased in the dual-task condition of Experiment 2, it does not explain why interference is not increased at 150 ms TOA in the dual-task condition of Experiment 2. A floor effect for T2 performance at 150 ms TOA can be ruled out as chance performance was 5%, whereas the average T2 performance in both experiments was 28%. However, we might assume that the task-independent interference is stronger, and thus overrides the task-dependent effects at 150 ms TOA. Also, temporal VA might exhibit different time courses for voluntary and involuntary components (e.g., Nakayama & Makeben, 1989; Weichselgartner & Sperling, 1987).

AB models

Several models have been specifically developed to explain the AB with respect to temporal VA. How can our findings be explained by major theories of the AB? First, resource depletion theories (Bowman & Wyble, 2007; Chun & Potter, 1995; Jolicoeur & Dell'Acqua, 1998; Raymond et al., 1992; Shih, 2008) explain the second target deficit by capacity limitations in a processing-stage architecture. For example, Chun and Potter's (1995) two-stage theory proposed that even though items are processed in Stage 1 up to a conceptual representation they need to undergo consolidation in Stage 2 in order to countervail decay or overwriting of the fleeting Stage 1 representation. This second stage, however, is strongly limited in its processing resources. Once processing in Stage 2 started (i.e., for T1), further information (e.g., T2) has to wait until Stage 2 has finished processing. In the same direction interference in the current paradigm could be based on the limited processing capacity when consolidating T1's location in spatial WM. With short TOA T2 would only reach Stage 1 where T2 is replaced by the trailing mask.[2]

Hence, the data in our study are compatible with the assumption that the consolidation process activated in Stage 2 uses resources that are either of central nature (Jolicoeur & Dell'Acqua, 1998; Jolicoeur, Tombu, Oriet, & Stevanovski, 2002; but see Carbone & Schneider, 2010) or that employs common visual–spatial processing recourses. If processing resources where domain specific (i.e., separate resources for spatial computations and pattern recognition) localization should not have led to interference in letter identification, especially not the increased interference observed in the dual-task condition in Experiment 2.

Second, based on Raymond et al.'s (1992) interference theory Olivers and Meeter (2008) proposed their boost and bounce model of temporal attention (B&B). It claims that the AB is a result of inhibitory and excitatory attentional modulation of the visual input. More specifically, based on an attentional set, sensory representations of distractors are inhibited while those of targets are excited in order to deny, respectively, grant access to WM. The time course as well as the spatial specificity of these excitatory and inhibitory responses causes in the standard canonical AB a T1-triggered false excitation of the post-T1 distractor. This excitement of the distractor in turn produces a strong period of suppression that hinders T2 from entering WM. The theory fares well at obviating the notion of limited processing capacity.

For the data of the current study two aspects of B&B seem relevant. First, the theory assumes that switching between attentional sets, sensory domains, tasks, or locations takes time. However, as already mentioned switch costs may only be relevant for the occurrence of lag-1 sparing. Therefore, our data might be more compatible with a second assumption made in B&B, namely that the distractors in the second experiment triggered a strong inhibitory response that prevented T2 from entering WM. However, one aspect of this assumption seems difficult to account for the current findings. B&B seems to rely heavily on the fact that the period of suppression, triggered by the post T1 distractor, occurs because T1, its trailing distractor, and T2 are displayed at the same spatial location. In other words, it relies on excitation to be bound to T1's location and thus spreading to the distractor. In Experiment 2 of this study, the closest a distractor could get to T1 was 2.6° (average minimal distance in a trial was 3.9°). Thus, it is unlikely that such a spatially selective cascade of excitation and inhibition suppresses an even more spatially remote T2, which was presented 5° away from T1 and the distractors. However, the theory might be extended by assuming inhibition and excitation to interact not only via spatial overlap but also in terms of featural overlap between T1, distractors, and T2.

Concluding remarks

Finally, we would like to point out that the difference in T2 performance between task conditions was apparent for longer duration than interference lasts in the standard AB. The maximum TOA in Experiment 2 was 650 ms but nonetheless revealed differences in T2 performance between single- and dual-task conditions. Possibly, this difference would vanish for longer TOAs. However longer lasting interference could also reflect general differences between localization- and pattern-recognition tasks. Awh et al. (Awh & Jonides, 2001; Awh et al., 1998) argued for an active role of attention in spatial WM rehearsal. More specifically, these authors proposed that shifts of VA to a certain location might be equivalent to maintaining that location in spatial WM. Therefore, the interference observed at 650 ms TOA in Experiment 2 might reflect such an active rehearsal process that requires some attentional resources to be maintained at that location. However, we did not observe differences between single- and dual-task conditions in Experiment 1, even though retention of T1 in Experiment 1 should have led to a comparable result. Nonetheless a further experiment at longer TOAs and location distractors would be needed to clarify this point.

A natural extension of the current study is to test the reverse direction of interference, i.e., how pattern recognition affects subsequent spatial computations. Evidence that a similar conclusion can be drawn for this case comes from Carbone and Schneider (2010). Participants in their study had to identify a letter at fixation (T1) and subsequently execute an exogenously triggered speeded saccade to a peripheral target (T2). They found saccadic reaction time to be increased at short as compared to long TOA, thus supporting unitary attentional control within the visual and spatial processing systems (e.g., Schneider, 1995). However, evidence from Carbone and Schneider must be seen as tentative, as it is unclear in how far response selection requirements for the saccade task contributed to the effect. An unspeeded localization task for a location-masked T2 (as in our Experiment 2) instead of a speeded saccade task should be able to generate results that would address this caveat.

In summary, we presented evidence that limitations of temporal VA, as measured in the AB, do also emerge in an experimental paradigm, in which T1 requires spatial processing, while T2 requires the standard pattern recognition task. Our data is compatible with the assumption that temporal VA can have task-independent and task-dependent components. These components seem to follow different time courses and may involve top-down and bottom-up VA to a varying degree. Processing in dorsal and ventral visual streams seems to underlie a common attentional mechanism (cf. Schneider, 1995) in the domain of temporal VA.

Keywords: attentional blink, two visual systems, localization, identification, memory-guided saccade, dual-task, visual attention, working memory

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Footnotes

[1] As suggested by one of the reviewers, we also performed across experiment ANOVAs for T1 and T2 performance (within participant variables: TOA and Experiment) using the six participants of the dual-task condition who participated in both experiments. Because TOAs of both experiments did not match we chose two approaches. One ANOVA were we used five levels of TOA as if they matched up and a second ANOVA with three levels of TOA, averaging performance at 250 ms and 350 ms TOA to get a corresponding 300 ms TOA in Experiment 2 while excluding the longest TOA from both experiments (i.e., 900 ms and 650 ms). These revealed only for T2 performance significant main effects of TOA and Experiment and significant interactions. No significant effects were found for any of the T1 measures. However these results should be treated cautiously due to the dealing with nonmatching TOA levels of both experiments.

[2] It has to be noted that, while Chun and Potter's theory accounts for the TOA dependent increase of performance it does not offer an explanation why interference did not differ between task conditions in Experiment 1 and at 150 ms TOA in Experiment 2.

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