

# Concurrency benefits in the attentional blink: Attentional flexibility and shifts of decision criteria

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**Abstract** Fundamental limitations in performing multiple tasks concurrently are well illustrated by the attentional blink (AB) deficit, which refers to the difficulty in reporting a second target (T2) when it is presented shortly after a first target (T1). Surprisingly, recent studies have shown that the AB, which is often thought of as a manifestation of capacity limitations in central processing, can be reduced when the AB task is performed simultaneously with concurrent distracting activities. In the present study, we sought to investigate whether such concurrency benefits would also be observed when the AB task was performed concurrently with a central demanding timing task. The AB was reduced under concurrent-task conditions, as compared with single-AB-task conditions, even though T1 performance was unaffected by the concurrent task. Moreover, shifts in decision criteria were found to be associated with the concurrency benefit effect.

**Keywords** Attentional blink · Multitasking · Detection sensitivity · Decision criterion · Temporal reproduction

Multitasking is most often highly taxing on human performance. A widely accepted notion is that information processing is constrained by a serial central bottleneck in such a way that there will be little flexibility in the deployment of attention (see Pashler,

1999). There are nevertheless reports, although scarce in the literature, of the beneficial effects of multitasking (see Navon & Gopher, 1979). Such findings were recently obtained in studies combining the attentional blink (AB; Raymond, Shapiro, & Arnell, 1992) procedure with various concurrent mental activities (Arend, Johnston, & Shapiro, 2006; Olivers & Nieuwenhuis, 2005, 2006; Taatgen, Juvina, Schipper, Borst, & Martens, 2009). Such findings are rather surprising, given that the AB phenomenon is often viewed as a manifestation of the central bottleneck, which is thought to be at the root of multitasking deficits. As is detailed below, the present study was conducted to further investigate the nature of concurrency benefits in the AB by measuring response bias and detection sensitivity, in addition to report accuracy, while using a concurrent timing task known to require central resources continuously throughout the task.

The AB refers to the decline in accurate report of a second masked target (T2) when it is presented at short intertarget lags of about 200–500 ms after a first masked target (T1). In most common AB paradigms, the targets are embedded in a rapid serial visual presentation (RSVP) stream of distractors presented at fixation, and responses to both targets are made without speeded pressure, at the end of the RSVP stream. Thus, to be available for report, targets must be consolidated into short-term memory, where the representations must remain active until responses are made. Early bottleneck theories of the AB, such as the two-stage model (Chun & Potter, 1995) and the central interference theory (Jolicœur, 1998, 1999), were based on the notion that central stages of processing have a limited capacity, allowing only a subset of information to proceed at any given time through

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these stages (see Pashler, 1999). Specifically, these theories proposed that when central attention mechanisms are engaged in consolidating a leading target (T1), they are not available to consolidate a subsequent target (T2). Consequently, T1 and T2 perceptual representations cannot be consolidated as efficiently at the same time as when T1 and T2 can be processed independently. While a representation of T1 is being consolidated into short-term memory for later report, consolidation of T2 has to wait (or undergo slower processing; see, e.g., Tombu & Jolicoeur, 2003), during which period the representation of T2 decays and is more susceptible to overwriting by a trailing distractor before being recoded in a more stable format that supports conscious report. It is interesting to note that when T1 and T2 are associated with identical tasks (e.g., identifying letter targets among digit distractors), it is not unusual to observe little or no decline in T2 accuracy when T2 is presented in the first serial position after T1 (i.e., at lag 1), a phenomenon known as *lag 1 sparing* (for a review, see Dell'Acqua, Jolicoeur, Pascali, & Pluchino, 2007; Visser, Bischof, & Di Lollo, 1999). This hallmark effect of the AB is often explained by the slow temporal closing of an attentional gate that governs the passage of perceptual representations to subsequent central stages of processing.

As was detailed in a recent review (Dux & Marois, 2009), the role of central capacity limits in the production of the AB is accepted by the majority of extant theories (but see, e.g., Di Lollo, Kawahara, Shahab Ghorashi, & Enns, 2005; Olivers & Meeters, 2008). However, important doubt has been shed on the nature of these limits and, specifically, on the proposal that the AB is caused by an inflexible structural bottleneck. A result that has significantly contributed to questioning the inflexible bottleneck model is the counterintuitive finding that the AB can be attenuated when performed under conditions of concurrent processing or distraction (Arend et al., 2006; Olivers & Nieuwenhuis, 2005, 2006; Taatgen et al., 2009). Such concurrency benefits in the AB were first reported by Olivers and Nieuwenhuis (2005). They showed that the magnitude of the AB was reduced when participants performed the AB task concurrently with activities such as free association or monitoring a musical sequence for the occurrence of an occasional yell, as compared with when the AB task was performed alone. These concurrency benefits were also observed when participants were instructed to maintain a visual pattern in memory during the AB task or simply were asked to reduce their level of concentration on the AB task (Olivers & Nieuwenhuis, 2006). Other labs have also reported concurrency benefits. Arend et al. showed concurrency benefits when a distracting visual background made of inward-moving, outward-moving, or flickering dots was superimposed on the RSVP

stream. Taatgen et al. also reported a reduced AB when the AB task was performed concurrently with a peripheral red dot detection task.

In order to account for these results, Olivers and Nieuwenhuis (2006) put forward the overinvestment hypothesis, which proposes that the AB may result from an excessive amount of resources devoted to the task of detecting and identifying targets embedded in an RSVP stream of distractors. In a similar way to bottleneck models, the overinvestment hypothesis assumes the existence of a capacity-limited postperceptual stage to which only a few items can gain access in order to be consolidated for further report. For an item to enter the capacity-limited stage, its activation must exceed an internal activation threshold. Inspired by the interference theory (e.g., Isaak, Shapiro, & Martin, 1999; Shapiro & Raymond, 1994), the overinvestment hypothesis assumes that an item's activation is influenced by similarity and temporal proximity to the target. Importantly, overall activation of items in the RSVP stream also increases as more attentional resources are devoted to the AB task. Consequently, allocating an excessive amount of resources to detecting and identifying targets in the RSVP stream could result in a greater number of distractors entering the capacity-limited stage, leading to more competition for encoding and, hence, more interference, which would result in the AB phenomenon, or at least modulate its amplitude. In contrast, if resources are diverted away from the RSVP stream, activation of distractors will be reduced, and therefore, fewer distractors will enter the capacity-limited stage, thus reducing competition/interference and, hence, the magnitude of the AB. This idea is compatible with Lavie's (2005) load theory of selective attention, according to which resources unneeded for targets spill over to distractors, thus creating interference.

The threaded cognition model (Taatgen et al., 2009) also regards the AB as a consequence of an overzealous strategy. According to the threaded cognition model, the AB arises from an overexertion of cognitive control when an intervening distractor is presented. To avoid a potential conflict between target detection and short-term consolidation in these conditions, an inhibitory signal suspends target detection while T1 is being consolidated, which leads to the AB. However, if cognitive control is diverted toward a concurrent task, the inhibitory signal is no longer sent (or is less efficient), which would explain the reduction or elimination of the AB under concurrent conditions. This proposal is compatible with the episodic simultaneous type, serial token model (Wyble, Bowman, & Nieuwenstein, 2009), which proposes that an inhibitory feedback signal is sent during consolidation of a target to facilitate the formation of episodically distinct representations within short-term memory.

Although the reported attenuation of the AB under concurrent conditions has been considered as strong evidence against bottleneck theories, other considerations suggest that such a conclusion may be premature. First, Olivers and Nieuwenhuis (2006) performed a meta-analysis across their experiments (Olivers & Nieuwenhuis, 2005, 2006), which revealed a significant 3.4% improvement of T1 performance in the concurrent conditions, as compared with the single-AB conditions. According to the authors, this pattern of T1 performance is contrary to what bottleneck models would predict. However, if we assume that T1 accuracy reflects the efficiency of T1 processing, as recent electrophysiological evidence has shown (Brisson et al., 2010), bottleneck models would predict that an increase in T1 accuracy should be associated with a reduction of the AB. This is because more efficient processing would create a shorter waiting period in which T2 has to wait before being consolidated, in the same way as when the difficulty of active short-term memory processes in the T1 task (Akyürek, Hommel, & Jollicœur, 2007; Ouimet & Jollicœur, 2007) or the difficulty of online response selection to T1 (see Jollicœur, Dell'Acqua, & Crebolder, 1998, 2001, for reviews) is reduced. Note that even small increases in T1 accuracy, of less than 5%, have been associated with a significant attenuation of the AB magnitude (Brisson, Spalek, & Di Lollo, *in press*).

Second, failures to replicate concurrency benefits by adding music (see Olivers & Nieuwenhuis, 2006, Note 1) or by using a distracting visual background (see Taatgen et al., 2009, p. 12) have been reported, shedding doubt on the reliability of the effect. More important, it can be argued that concurrent activities previously used to elicit concurrency benefits do not require central resources. For example, not only are the instructions to “concentrate less” or to “think about one’s holiday” vague in terms of what kind of resources they involve, but also the compliance of participants in performing the task requirements cannot be measured, or assessed, unless we resort to a circular logic: That is, a concurrency benefit was observed, therefore the participants complied with the instructions; participants complied with the instructions, therefore a concurrency benefit was observed. The same criticism applies when distracting backgrounds were used as the concurrent distraction (Arend et al., 2006). In the case of experiments in which a measurable concurrent task was employed, evidence suggests that they may not involve central capacity. For example, an occasional yell (Olivers & Nieuwenhuis, 2005), as well as a sudden change in color of a peripheral dot (Taatgen et al., 2009), can exogenously capture attention, and therefore detecting the presence of such targets does not necessarily require central attention mechanisms. Moreover, in relation to Olivers and Nieuwenhuis (2006, Experiment 1), in which the

concurrent task required maintenance of a visual pattern in memory, it could be stated that previous research has suggested that maintenance in short-term memory—unlike consolidation—does not require active central resources (e.g., Jollicœur & Dell'Acqua, 1998; Woodman & Vogel, 2005).

Given the importance of concurrency benefits in the modeling of the AB in particular and of multitasking limitations in general, it is important to investigate concurrency effects using a concurrent task known to utilize central resources in a sustained fashion, which would reduce the amount of central capacity that could be devoted to consolidating targets in the AB task. Bottleneck models would predict that performing a central demanding concurrent task should inevitably increase the magnitude of the AB. Therefore, if a beneficial or null effect on the AB is observed in these conditions, it would provide solid evidence in favor of strategic models, such as the overinvestment hypothesis (Olivers & Nieuwenhuis, 2006) and the threaded cognition model (Taatgen et al., 2009), and against the inflexible structural bottleneck model (Chun & Potter, 1995; Jollicœur, 1998, 1999). These results would be even more convincing if concurrency benefits in the AB were observed in the absence of an effect of the concurrent task on T1 performance and if unrelated strategies, such as shifts in decision criteria, were controlled.

The first major goal of the present study was to investigate concurrency benefits in the AB while using a new concurrent task involving interval timing. Timing tasks are known to require attention continuously throughout the stimulus presentation, and they have been investigated extensively under concurrent-processing conditions. The results showed bidirectional interference between timing and numerous perceptual and cognitive tasks: Timing is affected by central demands in concurrent tasks, and performance in concurrent tasks is also perturbed by concurrent timing (see Brown, 1997, 2008, for reviews). The choice of a timing task as the concurrent task enabled us to investigate whether concurrency benefits in the AB would be reproduced using a concurrent timing task, or whether concurrent timing would disturb visual detection in the AB paradigm, as results from timing studies suggest. We also added a single-timing condition, in addition to the single-AB and concurrent AB–timing conditions, in order to evaluate concurrency effects in the timing task, as well as in the AB task.

In the concurrent-task condition, a time interval reproduction task was executed concurrently with the AB task. Participants were asked to estimate the duration of a tone that was presented throughout the RSVP stream used in the AB task and then to reproduce the duration of the tone (or RSVP stream, which was of the same length). Consequently, attention had to be devoted continuously to both the timing and the AB tasks. Numerous studies have shown

that reproducing a time interval (here, the duration of the tone) requires central processing in dual-task paradigms, by demonstrating clear interference effects when time reproduction is performed with other concurrent tasks (Brown, 1995, 1997, 2006; Brown & Merchant, 2007; Casini & Macar, 1997; Champagne & Fortin, 2008; Coull, Vidal, Nazarian, & Macar, 2004; Field & Groeger, 2004; Fortin & Massé, 1999; Rammsayer & Ulrich, 2005). Reproductions are usually more accurate (i.e., closer to the actual time intervals to be reproduced) when time reproduction is performed alone than in concurrent-task conditions. Assuming that attention must be allocated to the time estimation task during the RSVP in the present study, reproductions should be closer to the presented target intervals in the single-timing task than in concurrent-task conditions.

A second important objective of the present study was to evaluate whether concurrency benefits in the AB could be explained by unrelated strategies, such as shifts in decision criteria. To evaluate the role of shifts in decision criteria in concurrency effects, we calculated, in addition to report accuracy,  $A'$  (an index of detection sensitivity) and  $B''$  (an index of response bias, or decision criterion), borrowed from the signal detection theory (Green & Swets, 1966; Wickens, 2002). Indexes of detection sensitivity have been applied previously to short-term memory (Murdock, 1965; Wilken & Ma, 2004) and visual search (Eckstein, Thomas, Palmer, & Shimozaki, 2000). Signal detection theory views detection as a probabilistic decision process about a given signal (the target). Appropriate stimulation builds up evidence for the signal up to a given threshold, which is determined by a decision criterion. Changes in the decision criterion can affect the way information is processed. For instance, a liberal decision criterion means that little evidence is needed to decide that a target was perceived, at the cost of a higher rate of false alarms (deciding that the target is present when it is absent). With a more conservative decision criterion, more evidence is necessary to judge that a target was perceived, which leads to a lower rate of false alarms. A high  $A'$  indicates a high probability of correct detection and a low probability of a false alarm. If concurrency benefits result from better detection sensitivity, the AB as measured with  $A'$  should be reduced in concurrent-processing conditions, relative to the single-AB condition. On the other hand, if adding a concurrent task does not increase detection sensitivity but, rather, produces a shift in decision criteria toward a liberal stance, we should not observe any concurrency benefits when analyzing  $A'$ . With a more liberal criterion, participants need less evidence to decide that a target is present, which may lead to a higher percentage of correct detection (i.e., reduced AB), but also to a higher percentage of false alarms. Detection and identification have been shown to produce

ABs of similar amplitude (e.g., Shapiro, Raymond, & Arnell, 1994). Therefore, to measure detection sensitivity ( $A'$ ) and response bias ( $B''$ ),<sup>1</sup> we presented T1 on half of the trials and T2 on half of the trials, and participants were required to report whether T1 was present or absent and whether T2 was present or absent.

Another means to assess the role of strategy in AB concurrency benefits is to investigate the effect of the order in which the participants performed the single-AB and concurrent conditions. Taatgen et al. (2009) have shown that concurrency benefits were observed only when the single-AB block was performed before the concurrent block. When the order of blocks was reversed, the magnitude of the AB in the single-AB task was reduced, resulting in the absence of a concurrency benefit. If this block order effect is replicated here, and if shifts in decision criteria are also observed, but only when the single-AB block is performed before the concurrent block, it would provide further evidence linking shifts in decision criteria to the concurrency benefit effect. If shifts in decision criteria play no role in concurrency benefits, response bias should not be affected by block order, even though a block order effect is observed on concurrency benefit effects.

In summary, the main issue investigated in the present study was twofold. First, we sought to investigate whether previously reported concurrency benefits in the AB paradigm can also be observed with a concurrent timing task, which has been shown to require central capacity continuously throughout the presentation, or whether the usual interference effect of timing on concurrent tasks and of concurrent tasks on timing would be found. Second, we sought to evaluate whether the observed concurrency benefits resulted from increases in detection sensitivity or

<sup>1</sup>  $A'$  was calculated following the formula by Grier (1971):

$$A' = 0.5 + \{[(H - F) * (1 + H - F)]/[4 * H * (1 - F)]\},$$

where  $H$  is the hit rate (correctly reporting a target as present) and  $F$  is the false alarm rate (reporting a target detection when the target is absent). If the false alarm rate was greater than the hit rate, the following formula was used (Aaronson & Watts, 1987; Snodgrass & Corwin, 1988):

$$A' = 0.5 - \{[(F - H) * (1 + F - H)]/[4 * F * (1 - H)]\}.$$

A measure of response bias,  $B''$ , was also calculated, following the formula by Grier (1971):

$$B'' = [H * (1 - H) - F * (1 - F)]/[H * (1 - H) + F * (1 - F)].$$

If the false alarm rate was greater than the hit rate, the following formula was used (Aaronson & Watts, 1987; Snodgrass & Corwin, 1988):

$$B'' = [F * (1 - F) - H * (1 - H)]/[H * (1 - H) + F * (1 - F)].$$

rather, could be accounted for, at least in part, by changes in decision criterion. Mean time intervals reproduced under concurrent-task conditions and time reproduction single-task conditions were also contrasted. In Experiment 1a, a binary choice visual detection task was associated with T1 and T2, in which the first response involved indicating whether T1 was present or absent and the second response involved indicating whether T2 was present or absent. Experiment 1b was designed to compute identification data in addition to detection data and signal detection theory indicators ( $B''$  and  $A'$ ). Participants had to decide first whether T1 and T2 were present or absent in the RSVP and then had to report the identity of the targets, when present. In Experiment 1b, target identification thus followed target detection. The goal of Experiment 1b was to evaluate whether adding the requirement to identify the targets, in addition to detecting them, could have an impact on the response criterion participants adopted in the detection task. Indeed, it is possible that in these conditions, participants would respond that a target was present only if they were able to identify it and that this would impose a conservative criterion that could differentially impact performance in the single-AB and concurrent conditions. Because previous AB studies that investigated concurrency benefits required identification of both T1 and T2, we felt it was important to investigate the role of response bias in a context where T1 and T2 had to be identified.

## Method

### Participants

Sixty participants from Université Laval volunteered for this study. Half of these participants performed Experiment 1a, and the other half performed Experiment 1b. One participant in Experiment 1a had to be excluded because of exceptionally low performance on the AB task. The remaining 59 participants were between 19 and 32 years of age. All participants reported normal hearing and normal or corrected-to-normal vision. They were paid \$6 for their participation.

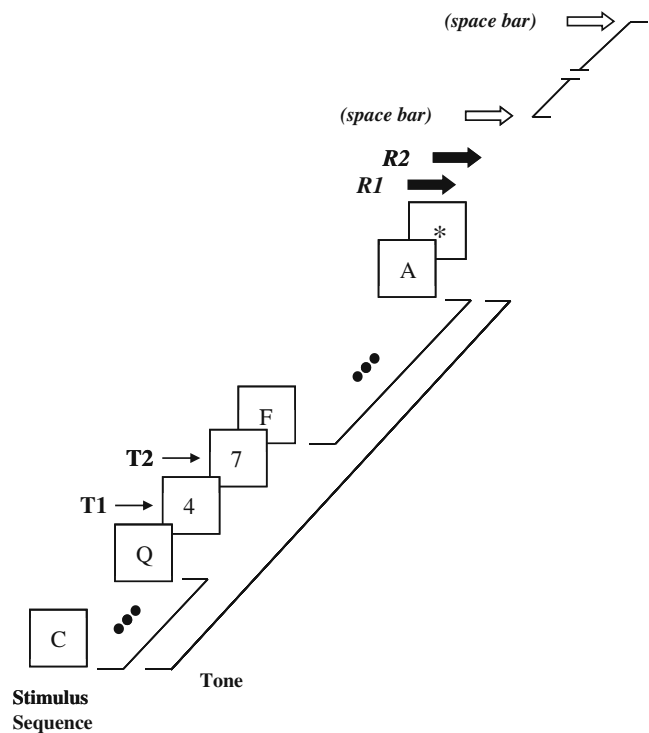
### Stimuli and apparatus

The experiment was run with E-Prime software on a PC computer. All visual stimuli (Arial 50 font) were white on a black background. Distractors were chosen randomly from among the capital letters of the alphabet, excluding A, B, I, O, Q, and Z to minimize target–distractor confusion. Targets were chosen without replacement from among the numbers 2, 3, 4, 7, 8, and 9. The first target, T1, was always the seventh stimulus in the stream. The second target, T2,

was always different from the first target. In the absence of target—T1, T2, or both—the target stimulus was replaced with one distractor.

### Procedure

The experimental session lasted for approximately 70 min. Participants were tested individually, at approximately 50 cm from a computer monitor. When ready, the participants initiated the trial by pressing the space bar on the computer keyboard. At keypress, a fixation cross (+) was displayed for 500 ms at the center of the screen, followed by the presentation of the stimuli. As is illustrated in Fig. 1, there was an RSVP stream of uppercase letters and digits presented on the monitor screen, while an auditory stimulus, a continuous tone (500 Hz), was presented



**Fig. 1** Experiment 1: Example of trial in the concurrent-task condition. Twenty alphanumeric characters were successively presented (C to A in the figure), among which two digits, T1 and T2 (4 and 7 in the figure), had to be reported as being present or absent among letter distractors. When present, T1 was always the 7th stimulus. When present, T2 could be in position 1, 2, 4, or 8 after T1 (it is in position 1 in the figure). R1 and R2 stand for "response to T1" and "response to T2." After executing these two responses, participants were asked, in the concurrent-task condition, to reproduce the duration of the tone by pressing the space bar twice. The tone was synchronized with the visual sequence presentation. In the single-AB-task condition, participants did not have to reproduce the tone duration, and in the single-temporal-task condition, participants did not have to execute R1 and R2. A more detailed description of experimental trials in the concurrent-task, single-AB-task, and single-temporal-task conditions is provided in the text

simultaneously through headphones. The RSVP consisted of 20 letters and digits presented successively at a constant rate of 70, 85, or 100 ms, with no interstimulus interval. The total duration of the visual sequence could therefore be 1,400, 1,700 or 2,000 ms, depending on the rate of presentation. The visual sequence and tone presentation were synchronized so that they started and ended simultaneously; thus, the tone was the same duration as the RSVP. The distractors were uppercase letters, and the targets were digits. When present, the first target (T1: “4” in Fig. 1), was always in the seventh position. The 13 following stimuli could include a second target (T2) or not, which, when present, could be in position 1, 2, 4, or 8 after T1. T2 is the “7” digit in Fig. 1 and is placed in position 1 because it follows T1 immediately. After the last stimulus, an asterisk (\*) appeared, indicating the end of the visual sequence.

In the single-AB task condition of Experiment 1a, participants had to execute two responses, the first (R1) to indicate whether T1 was present or absent, and the second (R2) to indicate whether T2 was present or absent. R1 and R2 were executed by pressing either the “1” (present) or “2” (absent) key on the numerical keyboard of the computer. In Experiment 1b, participants had to report the identity of the targets that were reported as present by pressing the corresponding digit key on the computer keyboard. If a target was reported as absent, no response regarding the target identity was required. In both experiments, a fixation cross appeared after the last response, indicating the beginning of the next trial. Responses were not speeded.

In the concurrent-task condition, immediately after executing the last response in the AB task, participants had to reproduce the tone (or RSVP) duration by pressing the space bar twice, the first keypress indicating the beginning of the tone and the second keypress indicating when, according to the participant, the tone ended. In the single-temporal-task condition, participants were asked to look at the visual sequence but to ignore it and to pay attention to the tone duration only. In this condition, participants were not required to execute R1 and R2, but only to reproduce the time interval with the space bar when the asterisk appeared. Participants were informed that one or two targets could be presented on each trial. Temporal reproductions were measured to the nearest millisecond.

The experimental session was divided into three blocks in which the three experimental conditions were tested separately: a block of single-AB trials on which the AB task was performed alone, a block of single-temporal-task trials on which temporal reproduction was performed alone, and a concurrent-task block in which the visual and temporal tasks were executed concurrently. All the participants were tested in the three blocks, and the order of the blocks was counterbalanced across participants.

The AB task in the single-AB-task condition was practiced in one 12-trial practice block, after which the corresponding 144-trial experimental block was completed. There were 3 trials in each combination of the following factor levels: duration of stimulus presentation (three values: 1,400, 1,700, or 2,000 ms), combination of T1–T2 presence or absence (four values: T1 and T2 present, T1 present and T2 absent, T1 absent and T2 present, and T1 and T2 absent), and intertarget lag, or serial position of T2 relative to T1 (first, second, fourth, or eighth stimulus after T1, which defined positions 1, 2, 4, and 8, respectively). The single-temporal-reproduction task was first practiced on 12 practice trials (6 with feedback on temporal reproduction accuracy, followed by 6 with no feedback), which were followed by 30 experimental trials with no feedback. The three target durations to be reproduced, 1,400, 1,700, and 2,000 ms, were reproduced ten times during the experimental trials. When feedback was provided on temporal reproduction accuracy in practice trials of temporal reproduction, a visual message appeared on the monitor screen, indicating to the participant whether his/her temporal reproduction was too short, too long, or correct. A “correct” temporal reproduction was a reproduction that was within a 10% temporal window centered on the target time interval (e.g., for the 1,400 -ms target interval, a reproduction shorter than 1,470 or longer than 1,330 ms). Concurrent-task parameters were the same as those in the single-AB task, except that there were 16 practice trials on which the AB task and the temporal task were performed concurrently. On the first 8 practice trials, feedback on temporal reproduction accuracy was provided. In each block, values for all the factors were selected randomly on each trial, with the constraint that the number of trials was the same for each combination of factor levels. Feedback on report accuracy in the AB task was never provided, either on practice trials or on experimental trials.

## Results

Separate analyses were conducted to assess performance in the AB task and in the timing task. Presentation rates were collapsed in the AB task analyses, and T1–T2 lag was collapsed in the timing task analyses. The Bonferroni adjustment for multiple comparisons was applied when appropriate. When the Mauchly test for sphericity was significant, the Greenhouse–Geisser correction was applied in all ANOVAs reported in the present study.

### AB task

We assessed performance in the AB task using two measures, percentage of correct detection and detection

sensitivity ( $A'$ ), for both targets. Given that the AB is defined as a decline in accurate report of T2 when T2 is presented shortly after T1 (i.e., at short lags), only typical dual-target RSVP trials were used to calculate T1 detection accuracy, and of these trials, only T1 correct trials were used to calculate T2 detection accuracy. For T2, we also computed  $B''$  as a measure of response bias, on the basis of data from all types of trials (no target, T1 only, T2 only, and T1–T2 trials).

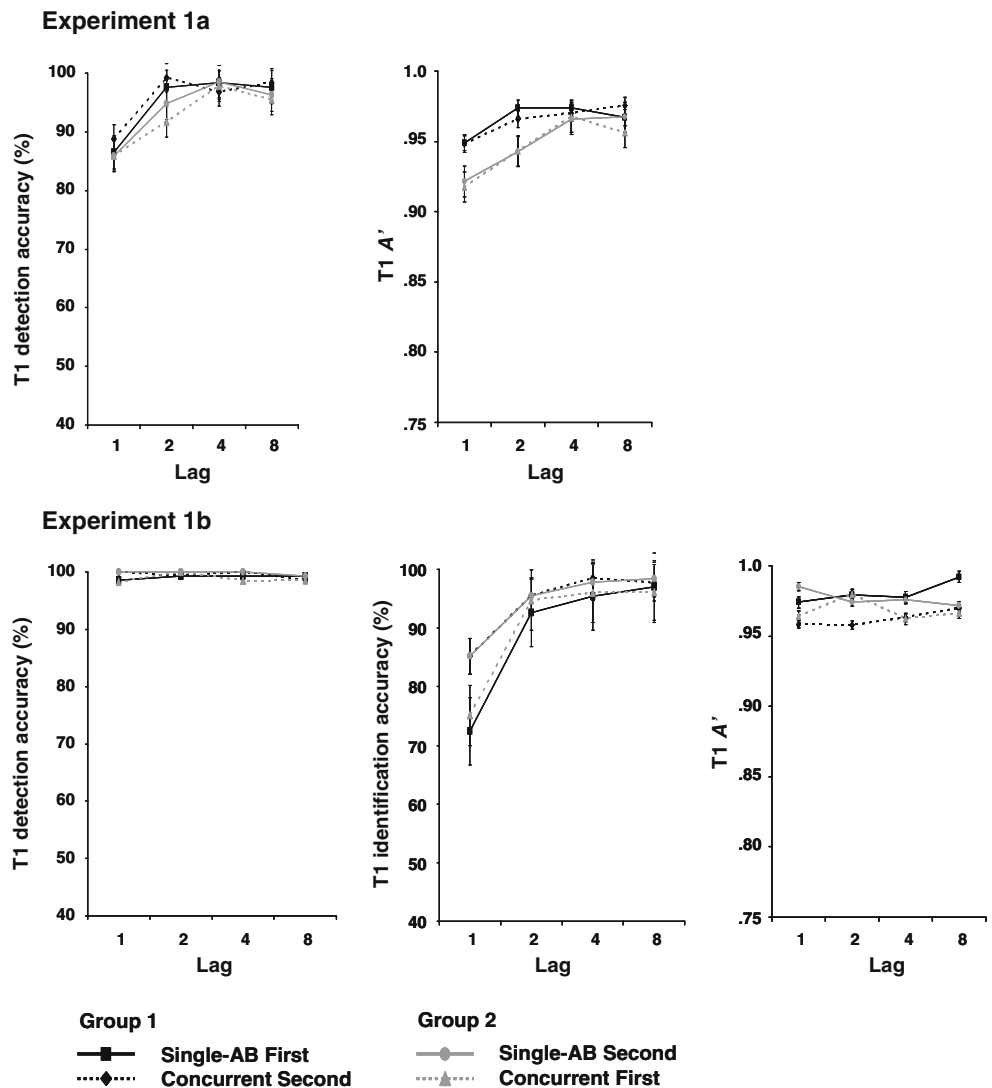
To calculate  $A'$  to T1, correct detection of T1 was defined as detection accuracy of T1 on trials where both T1 and T2 were presented, and false alarms were defined as 1 – T1 detection accuracy on trials where only T2 was presented. To calculate  $A'$  to T2, correct detection of T2 was defined as detection accuracy of T2 on trials where both T1 and T2 were presented, and false alarms were defined as 1 – T2 detection accuracy on trials where only T1 was presented. Trials on which T1 was not correctly detected were rejected from the calculation of both correct

detections and false alarms. Furthermore, on T1-only trials, T1 was always presented in the same position, and there was no lag, since T2 was absent. Consequently, all T1-only trials in a given block type were identical, and thus, lags were collapsed in the calculation of the false alarm rate of T2 detection. Also, false alarm rate was based on the same trials for each lag in a given block type. Contrary to T1-only trials, however, T2-only trials differed between lag conditions, because T2 was not presented at the same position in different lag conditions. Therefore, the false alarm rate of T1 detection was based on different trials for each lag  $\times$  block type cell.

The identification task was required only in Experiment 1b, and therefore, identification data were obtained only in this experiment.

*T1 performance* T1 performance on dual-task trials is plotted as a function of block type, block order, and T1–T2 lag in Fig. 2. Data from Experiment 1a are presented in

**Fig. 2** T1 performance in Experiments 1a and 1b. Upper panels: Mean percentages of correct detection (left) and detection sensitivity (right:  $A'$ ) in Experiment 1a as a function of block order, block type, and lag. Lower panels: Mean percentages of correct detection (left), correct identification (center), and detection sensitivity (right:  $A'$ ) in Experiment 1b as a function of block order, block type, and lag. Error bars represent the standard errors of the means



the upper panels, and data from Experiment 1b are presented in the lower panels.

**T1 detection accuracy** T1 detection accuracy (see Fig. 2, upper left and lower left panels) was analyzed in a 2 (experiment: Experiment 1a, Experiment 1b)  $\times$  2 (block order: single AB before concurrent, concurrent before single AB)  $\times$  2 (block type: single-AB task, concurrent task)  $\times$  4 (T1–T2 lag: 1, 2, 4, 8) repeated measures analysis of variance (ANOVA), with block type and T1–T2 lag as within-subjects factors and experiment and block order as between-subjects factors. T1 detection accuracy was generally higher in Experiment 1b than in Experiment 1a, leading to a main effect of experiment,  $F(1, 55) = 25.25$ ,  $p < .001$ . As has often been observed in AB studies, T1 accuracy was lower when T2 was presented at lag 1 than at other lags, leading to a main effect of lag,  $F(3, 165) = 15.78$ ,  $p < .001$ . However, the lag effect was absent in Experiment 1b, which explained the lag  $\times$  experiment interaction,  $F(3, 165) = 15.21$ ,  $p < .001$  (and also the main effect of experiment). No other main effect or interaction was observed, all  $F$ s  $< 1.42$ .

**T1 identification accuracy** T1 identification accuracy was lower when T2 was presented at lag 1 than at other lags (see Fig. 2, lower center panels), leading to a main effect of lag,  $F(3, 84) = 44.11$ ,  $p < .001$ . No main effect of block type or block order was observed, both  $F$ s  $< 1$ . However, both the block type  $\times$  block order interaction,  $F(1, 28) = 13.04$ ,  $p = .001$ , and the block type  $\times$  lag  $\times$  block order interaction,  $F(3, 84) = 4.84$ ,  $p = .015$ , were significant, reflecting better performance at lag 1 in the second block than in the first block, independently of block type.

**T1 detection sensitivity** ( $A'$ ) T1 detection sensitivity was also impaired at lag 1, as compared with the other lags, but only in Experiment 1a (see Fig. 2, upper left and lower left panels). This was evidenced by a main effect of lag,  $F(3, 165) = 5.27$ ,  $p = .004$ , and a lag  $\times$  experiment interaction,  $F(3, 165) = 4.33$ ,  $p = .011$ . The main effect of experiment was also marginally significant,  $F(1, 55) = 3.62$ ,  $p > .06$ . No other main effect or interaction was observed, all  $F$ s  $< 1.98$ , except for the main effect of block type,  $F(1, 55) = 3.09$ ,  $p > .08$ .

**T2 performance** T2 performance on dual-task trials is plotted as a function of block type, block order, and T1–T2 lag in Fig. 3. Data from Experiment 1a are presented in the upper panels, and data from Experiment 1b are presented in the lower panels.

**T2|T1 detection accuracy** T2|T1 detection accuracy is presented in the upper left and lower left panels for

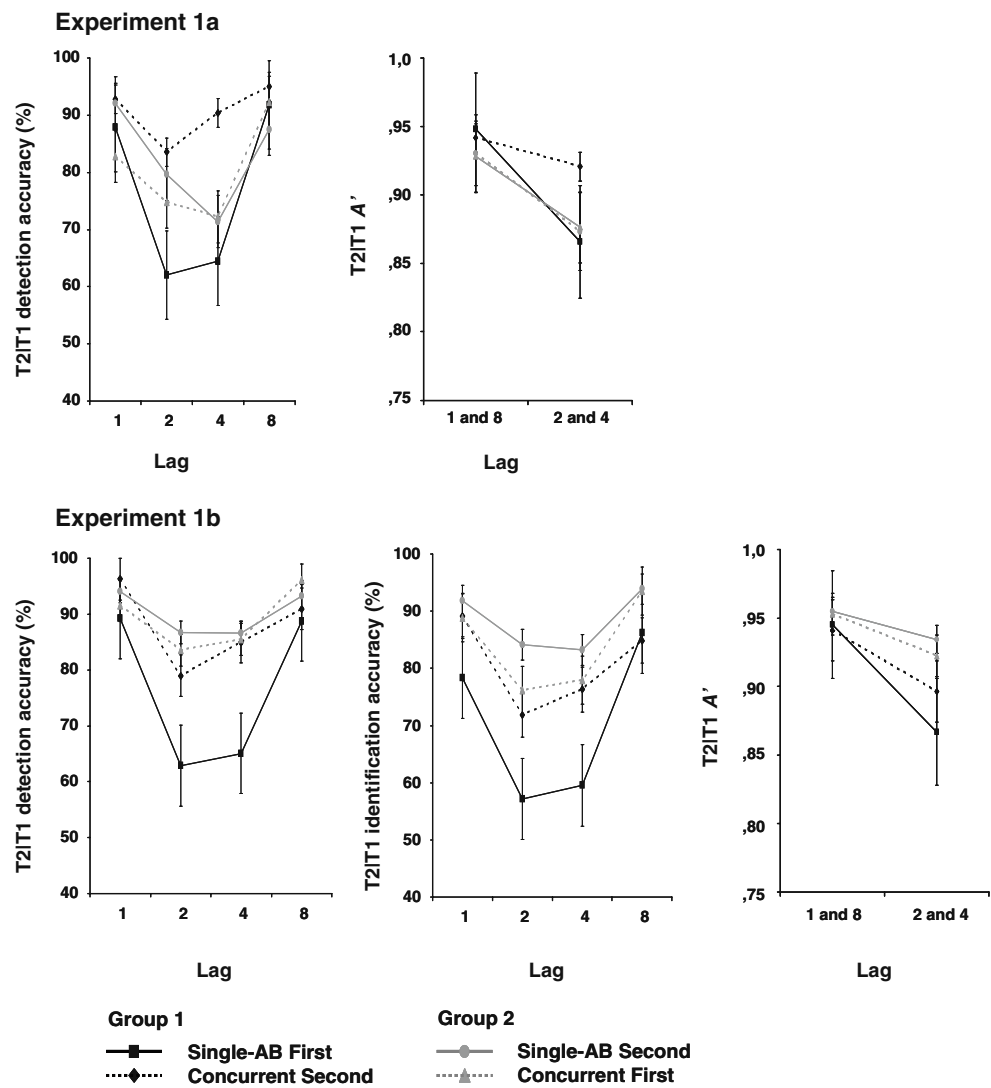
Experiment 1a and Experiment 1b, respectively. The four-way interaction was not significant,  $F(3, 159) = 1.83$ ,  $p > .15$ . On the other hand, a block order  $\times$  block type  $\times$  lag interaction was significant,  $F(3, 159) = 3.38$ ,  $p = .027$ , which led us to perform separate ANOVAs for participants who performed the single-AB task before the concurrent task and participants who performed the single-AB task after the concurrent task. When the single-AB task was performed first, a main effect of lag was observed,  $F(3, 78) = 7.53$ ,  $p = .001$ . Pairwise comparisons confirmed that T2|T1 accuracy was lower at lags 2 and 4 than at lag 8, both  $p$ s  $< .001$ . This drop in T2|T1 accuracy at short lags is the signature of the AB deficit. Note that performance at lag 1 was similar to performance at lag 8,  $t(28) = 0.89$ ,  $p > .37$ . This phenomenon is known as *lag 1 sparing* and is a hallmark of the AB phenomenon. A main effect of block was also observed,  $F(1, 26) = 6.34$ ,  $p = .018$ , and the block  $\times$  lag interaction was also significant,  $F(3, 78) = 3.56$ ,  $p = .033$ . Paired sample  $t$  tests confirmed that the average of the T2|T1 detection accuracy at lags 1 and 8 was significantly higher in the concurrent condition than in the single-AB-task condition,  $t(28) = 2.81$ ,  $p = .009$ , as was the average of the T2|T1 detection accuracy at lags 2 and 4,  $t(28) = 5.71$ ,  $p < .001$ . Importantly, the size of the effect of block type was greater at lags 2 and 4 (20.7%) than at lags 1 and 8 (4.5%),  $t(28) = 4.37$ ,  $p < .001$ , revealing the presence of a concurrency benefit effect in the magnitude of the AB in this group of participants.

When the single-AB task was performed after the concurrent block, a main effect of lag was again observed,  $F(3, 87) = 8.70$ ,  $p < .001$ . Pairwise comparisons showed that T2|T1 accuracy was lower at lags 2 and 4 than at lag 8, both  $p$ s  $\leq .01$ . Performance at lag 1 was again similar to performance at lag 8,  $t(29) = 0.89$ ,  $p > .37$ . Contrary to what was observed when the single-AB task was performed before the concurrent task, for participants who performed the single-AB task after the concurrent task, we observed no main effect of block,  $F(1, 29) = 1.97$ ,  $p > .17$ , and no block  $\times$  lag interaction,  $F(3, 87) = 1.25$ ,  $p > .29$ . The absence of concurrency benefits in the AB was confirmed by subsequent paired-sample  $t$  tests, which showed that the average of the T2|T1 detection accuracy at lags 2 and 4 was not significantly different between block type conditions,  $t(29) = 1.11$ ,  $p > .27$ , nor was the average of the T2|T1 detection accuracy at lags 1 and 8,  $t(29) = 0.33$ ,  $p > .74$ .

**T2|T1 identification accuracy** T2|T1 identification accuracy in Experiment 1b is presented in the lower center panel of Fig. 3. As for detection accuracy, a significant triple interaction was observed when T2|T1 identification accuracy was analyzed,  $F(3, 84) = 3.14$ ,  $p = .04$ . When the single-AB task was performed before the concurrent task, a main effect of lag was observed,  $F(3, 42) = 6.97$ ,  $p = .001$ .



**Fig. 3** T2 performance in Experiments 1a and 1b. Upper panels: Mean percentages of correct detection (left) and detection sensitivity (right:  $A'$ ) in Experiment 1a as a function of block order, block type, and lag. Lower panels: Mean percentages of correct detection (left), correct identification (center), and detection sensitivity (right:  $A'$ ) in Experiment 1b as a function of block order, block type, and lag. Error bars represent the standard errors of the means



Pairwise comparisons confirmed that T2|T1 accuracy was lower at lags 2 and 4 than at lag 8, both  $ps < .04$ , and performance at lag 1 was similar to performance at lag 8,  $p = 1$ . A main effect of block was also observed,  $F(1, 14) = 8.16$ ,  $p = .013$ , and the block  $\times$  lag interaction was marginally significant,  $F(3, 42) = 2.83$ ,  $p = .066$ . Paired-sample  $t$  tests showed that the average of the T2|T1 identification accuracy at lags 1 and 8 was statistically equivalent in the concurrent condition to that in the single-AB-task condition,  $t(14) = 1.33$ ,  $p > .20$ , whereas the average of the T2|T1 identification accuracy at lags 2 and 4 was higher in the former than in the latter block type condition,  $t(14) = 2.85$ ,  $p = .013$ .

When the single-AB task was performed after the concurrent block, a main effect of lag was again observed,  $F(3, 42) = 6.98$ ,  $p = .003$ , and pairwise comparisons confirmed that T2|T1 accuracy was lower at lags 2 and 4 than at lag 8, both  $ps < .05$ , whereas performance at lag 1 was similar to performance at lag 8,  $p = 1$ . Contrary to what

was observed when the single-AB task was performed before the concurrent task, here we observed no main effect of block,  $F(1, 14) = 2.60$ ,  $p > .12$ , and no block  $\times$  lag interaction,  $F < 1$ . The absence of concurrency benefits in the AB was confirmed by subsequent paired-sample  $t$  tests, which showed that the average of the T2|T1 identification accuracy at lags 1 and 8 was not significantly different between block type conditions,  $t(14) = 0.054$ ,  $p > .60$ , nor was the average of the T2|T1 identification accuracy at lags 2 and 4,  $t(14) = 1.84$ ,  $p = .088$ .

**T2|T1 detection sensitivity ( $A'$ )** In relation to T2 performance, the result of main interest was the magnitude of the AB (i.e., the difference in T2 performance during the AB period, as compared with outside the AB period) in the single-AB and concurrent conditions. In order to increase the stability of our measures of  $A'$  to T2, we collapsed hit rate data from lag 1 and lag 8 trials to assess performance outside the AB and collapsed hit rate data from lag 2 and

lag 4 trials to assess performance during the AB (for similar methods, see Colzato, Spapé, Pannebakker, & Hommel, 2007; Taatgen et al., 2009). As was mentioned above, the false alarm rate was calculated by collapsing all lags in a given block type. Therefore, for each participant, the hit rate was calculated on the basis of 18 trials for each experimental cell, and the false alarm rate was based on 36 trials. The  $A'$  values measured in Experiments 1a and 1b are presented in the upper right and lower right panels of Fig. 3. They were analyzed in a 2 (experiment: Experiment 1a, Experiment 1b)  $\times$  2 (block order: single AB before concurrent, concurrent before single AB)  $\times$  2 (block type: single-AB task, concurrent-task)  $\times$  2 (T1–T2 lag: 1 and 8, 2 and 4) repeated measures ANOVA, with block type and T1–T2 lag as within-subjects factors and block order as a between-subjects factor. As for T2 detection accuracy, no main effect of experiment and no any interaction with this factor were observed, and therefore, the data from both experiments were collapsed in subsequent analyses. A significant triple interaction between block order, block type, and lag was observed for T2 detection sensitivity,  $F(1, 57) = 9.35, p = .003$ . For participants who performed the single-AB task before the concurrent task, a main effect of lag was observed,  $F(1, 28) = 36.35, p < .001$ , showing that the AB phenomenon was still present when both misses and false alarms were taken into account. The main effect of block type was also significant,  $F(1, 28) = 4.66, p = .04$ , as well as the block type  $\times$  lag interaction,  $F(1, 28) = 16.56, p < .001$ . Paired-sample  $t$  tests revealed a pattern of concurrency benefit in the AB, in that the average of  $A'$  to T2 at lags 1 and 8 was not significantly different between block type conditions,  $t(28) = 0.65, p > .52$ , but the average of  $A'$  to T2 at lags 2 and 4 was significantly higher in the concurrent condition than in the single-AB-task condition,  $t(28) = 3.50, p = .002$ .

For participants who performed the single-AB task after the concurrent task, a main effect of lag on T2 detection sensitivity was again observed,  $F(1, 29) = 18.04, p < .001$ . No main effect of block type and no block  $\times$  lag interaction were observed, both  $F$ s  $< 1$ . The absence of concurrency benefits in the AB in this group of participants was confirmed by subsequent paired-sample  $t$  tests, which showed that the average of  $A'$  to T2 at lags 1 and 8 was not significantly different between block type conditions,  $t(29) = 0.27, p > .78$ , nor was the average of  $A'$  to T2 at lags 2 and 4,  $t(29) = 0.47, p > .64$ .

**Decision criteria ( $B''$ )**  $B''$  values were submitted to a 2 (experiment: Experiment 1a, Experiment 1b)  $\times$  2 (block order: single AB before concurrent, concurrent before single AB)  $\times$  2 (block type: single-AB task, concurrent task) repeated measures ANOVA, with block type as a within-subjects factor and experiment and block order as

between-subjects factors. There was no main effect of experiment,  $F(1, 55) = 1.59, p > .21$ , and no interaction (experiment  $\times$  block order,  $F < 1$ ; experiment  $\times$  block type,  $F(1, 55) = 3.43, p = .07$ ; experiment  $\times$  block order  $\times$  block type,  $F(1, 55) = 2.99, p > .08$ ). Therefore, the data from both experiments were collapsed in subsequent analyses. The main effect of block order was not significant,  $F < 1$ . However, a main effect of block type was observed,  $F(1, 57) = 12.26, p = .001$ , as well as a block order  $\times$  block type interaction,  $F(1, 57) = 11.43, p = .001$ . Paired-sample  $t$  tests confirmed that a shift in decision criterion was present for participants who performed the single-AB task before the concurrent task, participants being more liberal in the concurrent-task block than in the single-AB-task block ( $B'' = -.02$  and  $.42$  in the concurrent-task and single-AB-task blocks, respectively),  $t(28) = 3.93, p = .001$ . However, such a shift was absent for participants who performed the single AB task after the concurrent task ( $B'' = .17$  and  $.17$  in the concurrent-task and single-AB-task blocks, respectively),  $t(29) = 0.12, p > .90$ .

#### Timing task

As is shown in Table 1 (left part), mean reproductions lengthened with increasing value of target durations to be reproduced in the single-temporal-task and concurrent-task conditions,  $F(2, 114) = 817.58, p < .001$ , confirming that the timing task was performed correctly in both conditions. Although this was true in both experiments, the lengthening of reproductions was slightly more pronounced in Experiment 1b than in Experiment 1a, which led to an experiment  $\times$  target duration interaction,  $F(2, 114) = 3.54, p = .043$ . The lengthening of reproductions with increasing target duration was more pronounced in the single-temporal-task than in the concurrent-task block, as shown by the significant interaction between block type and target duration,  $F(2, 114) = 28.61, p < .001$ . Indeed, when participants reproduced temporal intervals in single-temporal-task conditions, their temporal reproductions were closer to the actual presented durations than when the time reproduction task was performed in concurrent-task conditions. Finally, reproductions were generally longer in the concurrent-task block than in the single-temporal-task block,  $F(1, 57) = 25.18, p < .001$ , and this effect was larger in Experiment 1a than in Experiment 1b (experiment  $\times$  block type interaction,  $F(1, 57) = 6.86, p = .011$ ).

When block order (single AB first, concurrent first) was included as a between-subjects factor, there was no significant interaction with this factor, all  $F$ s  $< 1.37$ , except for a block type  $\times$  experiment  $\times$  block order triple interaction,  $F(1, 55) = 4.94, p = .03$ . The main effect of block order was also marginally significant,  $F(1, 55) =$

**Table 1** Means and standard deviations for reproduced intervals in Experiment 1a and Experiment 1b (in milliseconds), in each condition of block type (single temporal task, concurrent task) and at each value of target duration, for the group that performed the Single-AB task before the concurrent task (Group 1) and for the group that performed the Single-AB task after the Concurrent task (Group 2)

Condition	Group 1		Group 2	
	Single temporal <i>M (SD)</i>	Concurrent	Single temporal	Concurrent
Target duration	Experiment 1a			
1,400 ms	1,507 (90)	1,698 (157)	1,503 (141)	1,830 (203)
1,700 ms	1,788 (92)	1,888 (144)	1,752 (96)	2,005 (180)
2,000 ms	1,964 (105)	2,045 (157)	1,961 (110)	2,148 (219)
Target duration	Experiment 1b			
1,400 ms	1,530 (141)	1,678 (79)	1,613 (126)	1,740 (129)
1,700 ms	1,788 (150)	1,921 (114)	1,879 (115)	1,944 (159)
2,000 ms	2,060 (140)	2,100 (135)	2,118 (114)	2,081 (180)

3.86,  $p = .055$ , indicating that responses tended to be slower in the group of participants that performed the concurrent block first. In sum, these results indicate that the effect of block order on concurrency benefits in the AB is not caused by a trade-off between the temporal task and the AB task and, more generally, further support the absence of concurrency benefits when the concurrent task was performed first.

## Discussion

A first objective of the present study was to verify whether concurrency benefits in the AB, previously observed when the AB task was performed simultaneously with concurrent distracting activities (e.g., Olivers & Nieuwenhuis, 2005, 2006), would be observed with a concurrent timing task that required central demands throughout the RSVP presentation. To provide a better description of the impact of adding a concurrent task, performance in the AB task was analyzed with multiple indicators, such as percentage of correct detection and percentage of correct identification, but also measures of detection sensitivity ( $A'$ ) and decision criteria ( $B''$ ) borrowed from signal detection theory.

The pattern of results was very similar in conditions where the AB task required only detecting the targets (Experiment 1a) or required reporting the identity of the targets when they were reported as present (Experiment 1b), despite the fact that  $B''$  values were generally (but not statistically) higher in Experiment 1b than in Experiment 1a. Higher  $B''$  values in Experiment 1b would suggest that the requirement of identifying targets in the AB task resulted in participants' adopting a more conservative response criterion, which could reflect a tendency to report that T2 was present only if the target was identified. This hypothesis is supported by the observation that, when a correct detection was reported, participants almost always correctly identified T2 (mean T2 identification accuracy given T2 correct detection was 96.3%).

As was expected, the analyses of T2 performance on dual-target trials revealed an AB independently of whether correct detection, correct identification, or  $A'$  was used as the independent variable. Moreover, the amplitude of the AB in detection and identification was equivalent, replicating previous studies (e.g., Shapiro et al., 1994).

For participants who performed the single-AB block before the concurrent block, the AB was attenuated when the AB task was performed concurrently with the timing task, as compared with when it was performed alone. These results replicate concurrency benefits observed in previous studies (Arend et al., 2006; Olivers & Nieuwenhuis, 2005, 2006; Taagen et al., 2009) using a measurable concurrent task known to require central resources. Results from the timing task demonstrated that participants performed this task adequately and that central attention mechanisms were drawn to the task as required. These concurrency benefits on T2 performance were obtained even though T1 performance was not modulated by the concurrent task. This is an important result because any concurrency benefit in the AB accompanied by an increase in T1 performance could be accounted for by bottleneck models, as explained in the Introduction. Moreover, any concurrency benefit in the AB accompanied by a decline in T1 performance could be accounted for by a trade-off between T1 and T2, which could also be explained by traditional capacity-based models.

Interestingly, for participants who performed the single-AB condition before the concurrent condition, the  $B''$  indicator suggests that these participants who performed the single-AB task before the concurrent task became more liberal in their decision to report the presence of T2 under concurrent-task conditions, resulting in higher rates of false alarms in T1-only trials, when T2 was not presented. Although shifts in response criterion cannot explain the whole of the effect, because concurrency benefits were also observed when both correct detection and false alarms were taken into account using the  $A'$  measure (and with the

identification data of Experiment 1b), it nevertheless seems to play a significant role. The importance of the decision criteria in understanding concurrency benefit effects is highlighted by the fact that participants who performed the concurrent task before the single-AB task did not exhibit any shifts in decision criteria or any concurrency benefit.

The observation that concurrency effects were present for participants who performed the single-AB condition before the concurrent condition, but not for participants who performed the conditions in reverse order, replicates the block order effect reported in Taatgen et al. (2009). In addition, the present results suggest that the differences in shifts of response criteria, depending on which of the single-AB or concurrent task was performed first, participate in the block order effect. This suggests that participants are somewhat constrained to adopt a liberal bias in the concurrent condition. When the concurrent task is performed first, the bias is carried over to the next block. It may also be argued that practice increases detection sensitivity and/or temporal identification, but only in conditions where the single-AB task is performed alone first and then incorporated into a concurrent condition. In the present study, it is difficult to dissociate practice effects from the concurrency benefit effect. However, previous studies have failed to show practice effects in the AB within 400 trials when T2 was in the same color as all other items in the RSVP stream (e.g., Choi & Watanabe, 2009, 2010), as in the present study, suggesting that practice effects cannot explain the reported block order effect (but see Taatgen et al., 2009).

Interestingly, temporal reproduction was not subject to a block order effect, suggesting that concurrency benefits are not caused by a trade-off between the temporal task and the AB task. Moreover, temporal reproduction lengthened with increases in the duration of the target intervals to be reproduced in the single-temporal-task condition, as well as in the concurrent-task condition. This is a key result in the analysis of timing performance, because it shows that the temporal task was performed correctly in both conditions, ensuring that attentional resources were allocated to the temporal task. Indeed, the objective of Experiment 1 being to test whether the AB task is performed better in concurrent central-processing conditions, it was essential to demonstrate that central resources were allocated to the concurrent task. The fact that participants discriminated well the three target durations, reproducing them in an orderly fashion in the single-temporal-task condition, as well as in the concurrent-task condition, confirms that during the simultaneous visual and auditory stimulus presentations, they were indeed processing information in order to reproduce their durations. The lengthening of temporal reproductions with increases in the target duration

to be reproduced was more pronounced in the single-temporal-task than in the concurrent-task conditions. In fact, reproductions were closer to the presented interval in the single-temporal-task condition than in the concurrent-task condition. This result may be expected, given that timing is usually more accurate when performed alone than when performed under concurrent-processing conditions (e.g., Brown, 1995).

Reproduced intervals were also generally longer in the concurrent-task condition than in the single-temporal-task condition. This result may be taken to suggest that the participants based their temporal judgments on the visual presentation and that, in addition to its duration, the number of perceived changes in the visual presentation influenced temporal estimates (see, e.g., Brown, 1995). A similar observation was made in comparable conditions, in which participants were asked to reproduce target intervals of about 5 s (Macar & Ivry, 2002). In Macar and Ivry's study, changes in visual stimuli had to be detected during 5-s intervals. Reproductions of this 5-s target interval lengthened as the number of changes increased during the interval, an effect that was specifically observed under conditions of higher load in the visual task. The authors interpreted this result as suggesting that participants used the number of perceived changes in visual presentation to estimate time when the number of changes to process in the visual task was high. When this mode of time estimation is used, nontemporal information, such as the perceived number of the events taking place during the target interval, is assumed to serve as the basis for inferring the passage of time (Brown, 1995; Hicks, Miller, & Kinsbourne, 1976; Macar & Ivry, 2002; McClain, 1983; Ornstein, 1969; Zakay & Block, 2004; Zakay, Tsal, Moses, & Shahar, 1994). Therefore, the number of perceived changes contributed to temporal judgments under these conditions, like the target interval itself, to which the temporal judgment was clearly related. In the present study, the number of perceived events during the target interval to be reproduced was likely to be greater in the concurrent-task than in the single-task condition: Participants had to process the visual stimuli in concurrent-task conditions, whereas they were instructed to ignore the RSVP in the single-temporal-reproduction task. This should have led to a higher number of perceived events during the interval to be reproduced in the concurrent-task condition than in the single-temporal-task condition, resulting in longer interval reproductions. In the concurrent condition, the number of visual stimuli, in addition to their duration, would therefore have contributed to determining the value of temporal estimates.

Although the difference in reproduced duration between the single-temporal-task and the concurrent-task conditions yields insightful (yet speculative) information regarding processes involved in the timing task in Experiment 1, the

most important result in timing data with regard to our research endeavor is that temporal reproductions are clearly related to the target intervals to be reproduced in the concurrent-task condition. This demonstrates that while participants are performing the AB task, they also devote resources to the timing task, which is likely to reduce the amount of attention that participants can devote to the AB task. Despite this decrease in resources allocated to the AB task, the AB was attenuated in the concurrent condition, replicating the concurrency benefits reported in previous studies (Olivers & Nieuwenhuis, 2005, 2006; see also Arend et al., 2006; Taatgen et al., 2009).

Importantly, the finding that a central demanding concurrent task does not increase the magnitude of the AB and tends to result in an opposite, beneficial effect, even when shifts in decisional processes are controlled, does not fit well with the idea that attentional resources are limited and deployed in a serial manner, strictly constrained by an inflexible structural bottleneck (Chun & Potter, 1995; Jolicoeur, 1998, 1999). Indeed, structural bottleneck models would predict that diverting central attention toward the central demanding timing task would negatively affect consolidation in short-term memory of both T1 and T2, resulting in a larger AB, but also likely in poorer T1 performance. Interestingly, T1 performance (independently of whether it was assessed using detection accuracy, identification accuracy, or  $A'$ ) was unaffected by the additional requirement of performing the concurrent timing task. This is an important result, because it rules out the possibility that participants mobilized additional resources to adequately perform the requirements of the more demanding concurrent-task condition. According to bottleneck models, mobilizing additional central resources could increase the efficiency of T1 processing, which not only would increase T1 performance, but also consequently would reduce the period T2 would have to wait before being consolidated itself and, thus, would result in attenuation of the AB. On the other hand, a decrease in T1 performance would have provided evidence of a trade-off between T1 and T2, which could be viewed as a consequence of capacity sharing (e.g., Shapiro, Schmitz, Martens, Hommel, & Schnitzler, 2006; Tombu & Jolicoeur, 2003). The hypothesis that the concurrent task leads to a trade-off between T1 and T2 performance in the AB task is further denied by the observation that T1 performance was equivalent for participants who performed the single-AB condition before the concurrent condition and for participants who performed the conditions in reverse order. Despite equivalent T1 performance, only the former group exhibited a concurrency benefit effect. Capacity sharing could also assume that concurrency benefits could be the consequence of allocating more capacity to the AB task and less to the timing task, leading to better performance in the

former task and poorer performance in the latter. However, block order (i.e., whether the single-AB task was performed before or after the concurrent task) had no effect on performance in the timing task and a strong effect on concurrency benefits, which is hard to reconcile with the capacity-sharing account. Moreover, the capacity-sharing account would predict that both T1 and T2 performance should improve in the concurrent task, which was not the case.

Instead, the fact that the AB was facilitated to some extent when performed with a time reproduction task supports models that assume that the AB is a consequence of an overinvestment of resources in the AB task (Olivers & Nieuwenhuis, 2006) or an overexertion of cognitive control (Taatgen et al., 2009). For example, the overinvestment hypothesis suggested by Olivers and Nieuwenhuis (2006) proposed that when performed alone, with no concurrent task, a suboptimal mode of stimulus processing would be used in the AB paradigm, characterized by an unnecessary and excessive amount of attentional resources devoted to the RSVP. The excessive amount of attentional resources allocated to the RSVP stream promotes the entry of task-irrelevant items (i.e., distractors) into short-term memory, increasing processing interference in this second stage. Drawing away some resources from the RSVP by various manipulations promoting divided attention improves performance by reducing the number of task-irrelevant items that enter short-term memory. Previous manipulations include viewing a visual background unrelated to the AB task or pictures of positive affective content, asking participants to perform an additional memory task or a dot task or simply asking them to focus less on the AB task (Arend et al., 2006; Olivers & Nieuwenhuis, 2005, 2006; Taatgen et al., 2009). The present study extends these conclusions to a time reproduction task, which is known to require central attention, but improved, or did not disturb, performance on the AB task, depending on which of the single AB or concurrent tasks was performed first. The temporal reproduction task may have diverted central attention away from the AB task, thus reducing the amount of task-irrelevant information entering short-term memory that could interfere with second-stage processing of task-relevant target information, as postulated by the overinvestment hypothesis. The present study further suggests that a more liberal criterion in the AB task may interact with this relatively diffuse mental state, contributing to the more efficient mode of processing. These conclusions rely on the notion that participants performed the timing task in both experiments. Results show that the reproduced intervals varied with presented target durations and were obviously related to the real presented durations to be reproduced, confirming that resources were allocated to the timing task. This is a key result because it ensures that the participants were allocat-

ing resources to the temporal task while they were performing the AB task.

Evidence of concurrency benefits reported here and in previous studies (Arend et al., 2006; Olivers & Nieuwenhuis, 2005, 2006; Taatgen et al., 2009) provide support for models that advocate flexibility in attention limitations, such as Olivers and Nieuwenhuis (2006) overinvestment hypothesis and the threaded cognition model (Taatgen et al., 2009). The overinvestment hypothesis postulates that if an excessive amount of attentional resources are allocated to the RSVP stream, increased interference in the second stage of processing may result in the AB phenomenon. However, if resources are diverted away from the RSVP, distractors are processed to a lesser extent, which reduces the magnitude of the AB phenomenon. This idea is compatible with Lavie's (2005) load theory of selective attention, according to which resources not needed for targets spill over to distractors, thus creating interference. On the other hand the threaded cognition model assumes that the AB is caused by an overzealous mechanism that sends an inhibition signal when a distractor is presented during the consolidation of T1, in order to protect T1. Increasing the load of the procedural module that controls the inhibition signals, by adding a concurrent task, will decrease the probability that the signal will be sent, thus reducing the AB. Whether it is through the overinvestment of attentional resources (Olivers & Nieuwenhuis, 2006) or through an overexertion of cognitive control (Taatgen et al., 2009), attentional limitations seem to be flexible, rather than structural.

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