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The Beneficial Effects of Additional Task Load, Positive Affect, and Instruction on the Attentional Blink

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The attentional blink reflects the impaired ability to identify the 2nd of 2 targets presented in close succession—a phenomenon that is generally thought to reflect a fundamental cognitive limitation. However, the fundamental nature of this impairment has recently been called into question by the counterintuitive finding that task-irrelevant mental activity improves attentional blink performance (C. N. L. Olivers & S. Nieuwenhuis, 2005). The present study found a reduced attentional blink when participants concurrently performed an additional memory task, viewed pictures of positive affective content, or were instructed to focus less on the task. These findings support the hypothesis that the attentional blink is due to an overinvestment of attentional resources in stimulus processing, a suboptimal processing mode that can be counteracted by manipulations promoting divided attention.

Keywords: visual attention, attentional blink, emotion, dual task performance, working memory

The human visual system is limited in the amount of information it can process across time, as has become apparent from research exploring the temporal dynamics of visual attention. Using the rapid serial visual presentation (RSVP) paradigm, this research has found that the detection of the second of two targets (T2) within a stream of distractors is impaired when T2 is presented within about 500 ms of the first target (T1; e.g., Chun & Potter, 1995; Raymond, Shapiro, & Arnell, 1992; see also Kahneman, Beatty, & Pollack, 1967). To characterize this phenomenon, Raymond et al. (1992) coined the term *attentional blink.* It is as if attention is temporarily unavailable for new input when earlier relevant visual information is being processed. Converging evidence from several studies has indicated that the attentional blink occurs quite late in the information-processing stream. For example, participants can pick up on the semantic identity of a "blinked" item, even though they cannot report on it (e.g., Luck, Vogel, & Shapiro, 1996; Martens, Wolters, & Van Raamsdonk, 2002). Furthermore, studies using cross-modal stimulus presentation have shown that processing of visual information can suffer from an attentional blink induced by an auditory target and vice versa, a finding that suggests a central processing limit (Arnell & Jolicoeur, 1999; Dell'Acqua, Turatto, & Jolicoeur, 2001). The relatively late locus of the blink is also suggested by masking studies. Masking of the targets is crucial for the occurrence of an attentional blink, but the findings indicate that simultaneous integration masks, which corrupt the visual input at a lower level, are less successful than subsequent interruption masks, which appear to substitute for the target at a higher level of processing (Brehaut, Enns, & Di Lollo, 1999; Dell'Acqua, Pascali, Jolicoeur, & Sessa, 2003; Giesbrecht & Di Lollo, 1998; Grandison, Ghirardelli, & Egeth, 1997; Seiffert & Di Lollo, 1997; but see Giesbrecht, Bischof, & Kingstone, 2003).

Various explanations of the attentional blink have been proposed (Chun & Potter, 1995; Duncan, Ward, & Shapiro, 1994; Giesbrecht & Di Lollo, 1998; Jolicoeur & Dell'Acqua, 1998; Nieuwenhuis, Gilzenrat, Holmes, & Cohen, 2005; Raymond et al., 1992; Seiffert & Di Lollo, 1997; Shapiro & Raymond, 1994; Vogel, Luck, & Shapiro, 1998), but they all stress the limited-capacity nature of attentional processing as the main determinant. For example, Chun and Potter (1995) proposed a two-stage theory. In the first stage, items are processed up to a relatively high-level short-term representation (including conceptual or semantic activation, and hence often referred to as *conceptual short-term memory*; Potter, 1993). This initial representation is vulnerable to interference, and a second stage is required to transform (or consolidate) it into the more durable form of memory required for the generation of a response. However, this second stage is limited in capacity, and when it is occupied by T1, T2 suffers. Similarly, Raymond, Shapiro, and Arnell (1995) and Shapiro and Raymond (1994) proposed that multiple items from the RSVP stream may enter a *visual short-term memory* buffer. Within visual short-term memory, the items compete for subsequent retrieval, causing T2 to suffer from interference. This competition is biased by limited-capacity attentional weighting, with the items being assigned different weights depending on their temporal position and similarity to the targets. When T1 takes up too many of these resources (i.e., is assigned too strong a weight), T2 may easily be overridden by one of the distractors or may not even be represented at all in visual short-term memory.

The Beneficial Effects of Concurrent Task-Irrelevant Mental Activity on the Attentional Blink

An important (implicit) assumption underlying previous theoretical accounts is that the attentional blink reflects a fundamental,

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unavoidable processing limitation that is exposed when the system is faced with the computational challenges posed by the RSVP paradigm. However, we have recently reported evidence that challenges this assumption by indicating that the size of the attentional blink is modulated by the general mental state of the observer (Olivers & Nieuwenhuis, 2005). The evidence suggests that in the context of the RSVP paradigm, concentrating hard is a suboptimal processing mode that promotes rather than prevents the occurrence of the processing limitations reflected in the attentional blink.

In one experimental condition, we instructed participants to actively think about their holidays or the shopping requirements for a meal with friends while performing an attentional blink task involving the identification of two digits within a stream of letters (Olivers & Nieuwenhuis, 2005). The importance of the attentional blink task was not mentioned. Surprisingly, T2 identification improved significantly (by 10%–15%) relative to a control condition in which participants received the standard instruction to concentrate on the task at hand. In another experimental condition, participants were required to listen to a rhythmic tune while performing the attentional blink task. In one version, they had the additional task of detecting a yell occasionally present in the tune. Again, T2 performance improved considerably, to the extent that the attentional blink almost disappeared.[1]

At first sight, limited-capacity theories may seem able to explain these results by assuming that fewer resources were allocated to T1 in the free association and music conditions. Various studies have shown that the fewer the processing resources required for (or assigned to) T1, the weaker the attentional blink for T2 (see Chun & Potter, 1995, Table 1; Seiffert & Di Lollo, 1997; Shore, McLaughlin, & Klein, 2001; see also Hommel, Schmitz, Shapiro, & Schnitzler, 2003). However, we found that detection of T1 did not deteriorate (if anything it improved slightly). This is difficult to explain in terms of a simple redistribution of resources. In another condition, we also ruled out the hypothesis that the observed improvements in performance were due to participants being overall more motivated in the critical experimental conditions: We rewarded participants for each correct (and punished them for each incorrect) T1 and T2 detection according to a scheme that could potentially double their earnings. It was assumed that this would make the observers more motivated. Nevertheless, T2 identification was no better than in the standard control condition and was again worse than in the free association and music conditions. This suggests that overall motivation contributed little.

To explain these findings, we hypothesized that the beneficial effects of task-irrelevant mental activity on the attentional blink might occur because observers are in a more diffuse mental state (Olivers & Nieuwenhuis, 2005). To deal with the multiple requirements of the two tasks (e.g., watch, listen, think), participants need to adopt a more distributed mode of attention. This broader, more flexible operating mode temporally widens attention and, therefore, benefits the processing of targets that are closely separated in time. However, although perhaps intuitively appealing, this hypothesis is not entirely satisfactory. First, the adoption of a diffuse mental state implies that, as a whole, fewer attentional resources are allocated to the RSVP task. Although a more distributed state of attention may be relatively beneficial to T2, in its current form, the hypothesis fails to explain why T1 detection does not suffer. A second and perhaps more fundamental concern is that the concept of a diffuse mental state is theoretically underspecified and therefore open to multiple interpretations.

The Present Study

In the present study, we tested two new hypotheses regarding the mechanisms by which distracting task circumstances result in a reduced attentional blink for T2 in combination with no deterioration—or even an improvement—in performance for T1. The first hypothesis, the *overinvestment hypothesis,* is rooted in existing explanations of the attentional blink, but offers a novel perspective on them. The second hypothesis, the *positive-affect hypothesis,* is derived from existing behavioral and neurobiological work demonstrating the beneficial effects of positive affect on task performance. Although more explicit, both hypotheses are consistent with our previous and more general suggestion that the effects of distraction on the attentional blink are mediated through variations in general mental state.

The Overinvestment Hypothesis

The overinvestment hypothesis is illustrated in Figure 1. Following earlier theories (Chun & Potter, 1995; Jolicoeur & Dell'Acqua, 1998; Shapiro, Arnell, & Raymond, 1997), we assume that initially all RSVP items receive a considerable amount of processing, leading to transient representations of these items at a conceptual level. The amount of processing for a particular item may be biased by factors such as similarity to the target or temporal position in the stream (e.g., Isaak, Shapiro, & Martin, 1999; Shapiro & Raymond, 1994). Also following earlier theories, we assume that these vulnerable representations compete for a limited-capacity processing stage, to which only one (Chun & Potter, 1995; Jolicoeur & Dell'Acqua, 1998) or at most a few (Shapiro et al., 1997) items can gain access. Access to this second stage is necessary for an item to be consolidated for later report, and here we assume that an item enters this stage when its activation exceeds an internal activation threshold. However, if items other than T1 and T2 enter this limited-capacity stage, these may interfere with the consolidation process through competition or substitution masking.

The critical claim of the overinvestment hypothesis is that processing interference in the second stage is a direct consequence of allocating too many attentional resources to the RSVP stream, which leads to the entry of too many task-irrelevant items. Conversely, a reduction in attentional focus limits the number of items that can access the second stage, which alleviates the amount of interference and reduces the probability of an attentional blink.

[1] It deserves mentioning that a recent attempt to replicate this result has failed. T. Spalek and V. Di Lollo (personal communication, May–August 2005) used the same displays and the same musical tune as Olivers and Nieuwenhuis (2005), but did not ask participants to perform the additional task of detecting a yell in the tune. (Note though that Olivers & Nieuwenhuis, 2005, did not find a difference between conditions with and without a yell-detection task.) We therefore decided to rerun the original experiment (including some design improvements). We again found a significant improvement in the music condition relative to the standard condition, but this improvement was substantially smaller than the original effect, and the attentional blink did not disappear. The data from both labs are available on request, and we plan to fully report on them elsewhere.

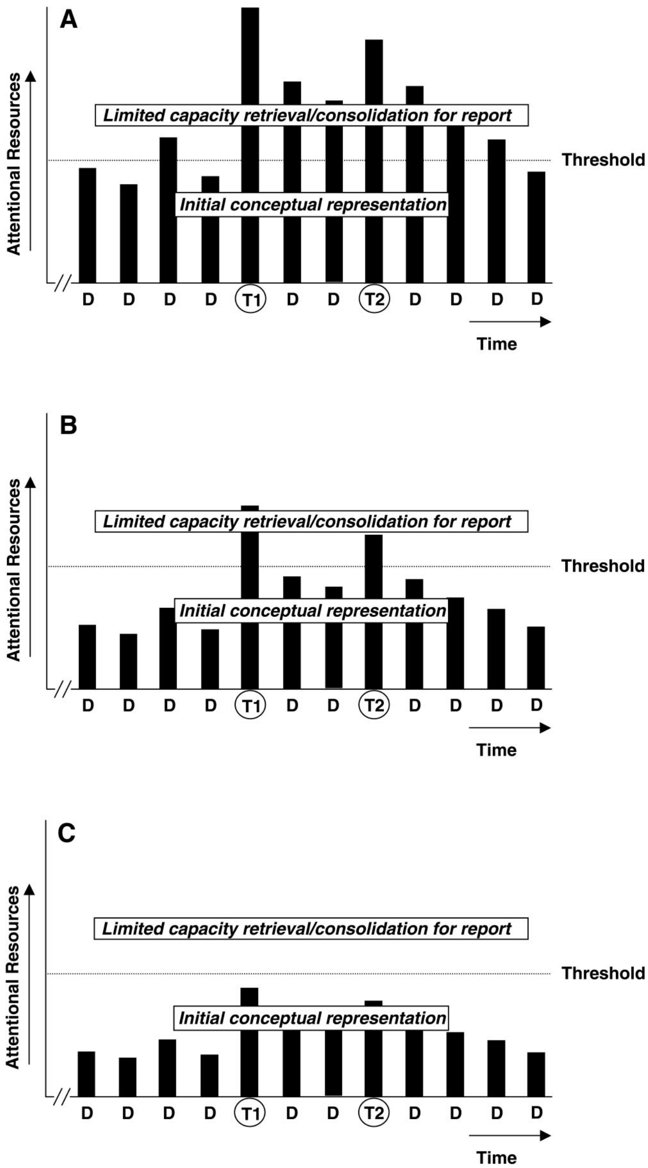

Figure 1. Schematic illustration of the overinvestment hypothesis. The *x*-axis represents the items in the rapid serial visual presentation stream. The *y*-axis represents the amount of attention invested in the items. In Panel A, too many resources are invested, resulting in multiple items competing for consolidation, including several distractors. In Panel B, the diminished resources lead to the targets, but not the distractors, reaching the consolidation stage. When too few resources are spent, as in Panel C, no items reach the consolidation stage. D = distractor; T1 = Target 1; T2 = Target 2.

Figure 1A represents the standard case of an attentional blink experiment. Perhaps ushered by the experimenter, the participant is determined to do well and strongly focuses his or her attention on the RSVP task. Normally, this degree of focused attention is advantageous, because in the real world, target objects are relatively stationary or at least unlikely to be quickly replaced by an irrelevant object. However, in the more artificial case of the RSVP stream, in which items rapidly succeed one another, the high amount of attention paid to each of the items results in the selection not only of T1 and T2, but also of several task-irrelevant items. As noted above, this increases the amount of competition or the probability of substitution in the second, limited-capacity stage, thereby reducing T2 accuracy and, to a lesser degree, T1 accuracy.

Compare this with the case when the observer performs an additional task, as is represented in Figure 1B. Because the additional task draws away attentional resources from the RSVP stream, fewer distractors will reach threshold, resulting in reduced interference in the second stage. Provided that both targets still reach threshold (on the basis of their match with internal templates of the targets), detection of T2 will actually benefit from this reduction in resources and, to a lesser extent, so may T1, because the system is less likely to spuriously respond to earlier distractors. Finally, Figure 1C represents the case in which too few resources are allocated to the RSVP task. When observers are too distracted or disengaged, none of the items are likely to reach threshold, and no targets will be detected.

Thus, whereas observers may believe that being fully dedicated to the task will result in optimal performance, the overinvestment hypothesis suggests that an intermediate level of attention is actually more beneficial. Having observers perform an additional task is one way of reducing the amount of attention to this intermediate level. Note that existing theories of the attentional blink stress the fundamental lack of attentional resources caused by the processing of T1 as the main source of interference in T2 processing. The overinvestment hypothesis offers a radically different perspective by proposing that it is, in fact, the *overinvestment of attention* in the RSVP stream that results in the limited-capacity stage being overwhelmed with items and hence results in interference in T2 processing.

The Positive-Affect Hypothesis

As discussed earlier, we observed improved attentional blink performance when we asked participants to concurrently think about their holidays or an imaginary dinner or asked them to concurrently listen (and respond) to music (Olivers & Nieuwenhuis, 2005). As we suggested above, the overinvestment hypothesis can explain these findings by referring to the resources needed by the additional task that had to be fulfilled. However, the improved performance may also have been due to a more positive affective state as evoked by, for example, the frivolous contents of the thoughts or the upbeat nature of the tune. Recent studies by Fenske and Eastwood (2003) and Dreisbach and Goschke (2004) have shown that positive affect can modulate selective attention. Using an adaptation of Eriksen and Eriksen's (1974) flanker task, Fenske and Eastwood (2003) found compatibility effects of flanking distractors on a central target when the target was a schematic happy face, but not when it was a schematic sad face, suggesting that the spatial scope of attention was affected by the emotion conveyed by the face. In Dreisbach and Goschke's study, participants were required to detect a target of a certain color, while they had to ignore a distractor presented in what had previously been the target color. Normally this leads to *perseveration costs* on the first few trials, because the old target color is initially difficult to ignore. However, Dreisbach and Goschke found that perseveration costs were reduced when the trials were preceded by positively laden pictures relative to neutral and negative pictures. They concluded that positive affect induces cognitive flexibility, biasing attentional orienting toward the new color. Indeed, it has been assumed for a long time that cognitive performance is influenced by the motivational and emotional states of the organism (Easterbrook, 1959; Wachtel, 1967; for reviews, see Ashby, Isen, & Turken, 1999; Derryberry & Tucker, 1994; Isen, 1999). Specifically, negative stimuli, negative feelings, and feelings of stress tend to lead to a narrowing of the mind, whereas positive affect is known to enhance cognitive flexibility in a wide variety of tasks, including verbal fluency, free association, categorization, problem-solving, and selective attention tasks. According to Ashby et al. (1999), such effects of positive affect on cognition are mediated by increased dopamine levels (see also Beatty, 1995). The dopamine system has also been implicated in increased performance on short-term memory tasks (Braver & Cohen, 2000; Fuster, 1997; Goldman-Rakic, 1995; Gray, 2001). This is directly relevant to attentional blink theories, which almost invariably assign an important role to short-term memory processes.

We believe that the concept of cognitive flexibility lies close to what we have referred to as a diffuse mental state, a state characterized by the exploration rather than exploitation of information-processing strategies, by scanning and flexible responding rather than selective and focused attention, and by observers being receptive to an increased variety of input. Thus, positive affect may contribute to improved attentional blink performance by rendering the system less temporally focused, making it more sensitive to multiple targets, and/or increasing the capacity to store or retrieve those targets.

In our earlier work (Olivers & Nieuwenhuis, 2005), the effects of an additional task and positive affect on the attentional blink were potentially confounded. For example, thinking about one's holiday may be regarded as an additional task but may also be regarded as an activity inducing positive affect. In the present study, we tested the possible effects of these variables in separate experiments. We first tested the overinvestment hypothesis in Experiment 1, in which each RSVP trial was presented during the retention interval of a short-term memory task. According to the overinvestment hypothesis, the additional memory task should have led to a reduced attentional blink compared with when no such additional task was present. The positive-affect hypothesis was tested in Experiment 2, in which the RSVP streams were preceded by briefly presented pictures of positive, negative, or neutral content. If positive affect reduces the magnitude of the attentional blink, then we should have seen a performance improvement with positive pictures.

We assumed that the additional-task and positive-affect manipulations indirectly induced a more diffuse attentional state, without the observer necessarily being aware of this. This left open the question of whether, in the absence of additional task requirements or other exogenous influences, observers themselves can induce a more beneficial attentional state. Experiment 3 explored the possibility of an endogenously generated diffuse attentional state by directly instructing participants to focus less on the RSVP task. According to the overinvestment hypothesis, this should have improved performance.

Finally, although the overinvestment hypothesis and positive-affect hypothesis have been presented here as reflecting separate variables (one more cognitive, the other more affective), the two may be fundamentally related. We discuss this further in the General Discussion section, but for now we stress that any evidence for one hypothesis should not be seen as evidence against the other.

Experiment 1: An Additional Task Improves Attentional Blink Performance

In this and subsequent experiments, participants completed a standard attentional blink task in which both T1 and T2 were digits in an RSVP stream consisting of letters, all black on a gray background (Chun & Potter, 1995; the same task was used by Olivers & Nieuwenhuis, 2005). In the critical condition of Experiment 1, each attentional blink trial was presented during the retention interval of a simple short-term memory task. The RSVP stream was preceded by a pattern consisting of three randomly drawn line segments, as is illustrated in Figure 2A. In the additional-task condition, participants were required to remember the pattern while viewing and responding to the RSVP stream and to compare the memorized pattern with the pattern presented on the subsequent trial. They indicated a match by pressing the space bar. Performance for T1 and T2 in this condition was compared with performance in a no-additional-task condition, in which the same random line patterns preceded each RSVP trial, but participants were not required to remember and respond to them. We assumed that the requirements of the additional memory task would draw away attentional resources from the RSVP stream. If the attentional blink is indeed due to an overinvestment of attentional resources, this additional-task manipulation should have reduced the attentional blink.

Method

Participants. Twenty-eight students of the Vrije Universiteit Amsterdam were randomly assigned to either of two conditions. Fourteen (8 male, 2 left-handed, ages 16–22 years, average age = 19 years) were assigned to the additional-task condition. The other 14 (7 male, 1 left-handed, ages 17–22 years, average age = 20 years) were assigned to the no-additional-task condition. All participants were paid 4 euro. They were naive to the purpose of the experiment, and none of them had participated in any of the experiments of Olivers and Nieuwenhuis (2005).

Stimuli, procedure, and design. Stimulus generation and response recording were done with E-Prime (2003). The stimuli were the same in the additional-task and no-additional-task conditions. A trial started with a line pattern presented for 2,000 ms. The pattern consisted of three white (70 cd/m^2) line segments on a gray (16 cd/m^2) background. The endpoints of the line segments were randomly chosen from within a circular area (radius: 1.6° visual angle) around the center of the screen, with the restriction that each line segment would be at least 1.2° long. After a 1,000-ms blank period, a 0.5° × 0.5° fixation cross was presented for 1,000 ms in the center of the display and was subsequently replaced by a rapid serial presentation of 13 to 21 letters, each measuring approximately 0.8 × 0.8°. Each letter was randomly drawn (without replacement) from the alphabet and presented for 75 ms, followed by a 25-ms blank. *I, O, Q,* and *S* were left out because they resemble digits. On each trial, 2 of the letters were replaced with digits, randomly drawn (without replacement) from the digits 2 through 9. The second digit (T2) was presented 3 to 6 temporal positions from the end of the stream. The temporal distance between the first digit (T1) and the second (T2) was systematically varied from 1 to 5 items, corresponding to lags of 100, 200, 300, 400, and 500 ms (Lags 1–5, respectively). The entire RSVP series was presented in black on a gray (40 cd/m^2) background. After 1,000 ms, a new trial started.

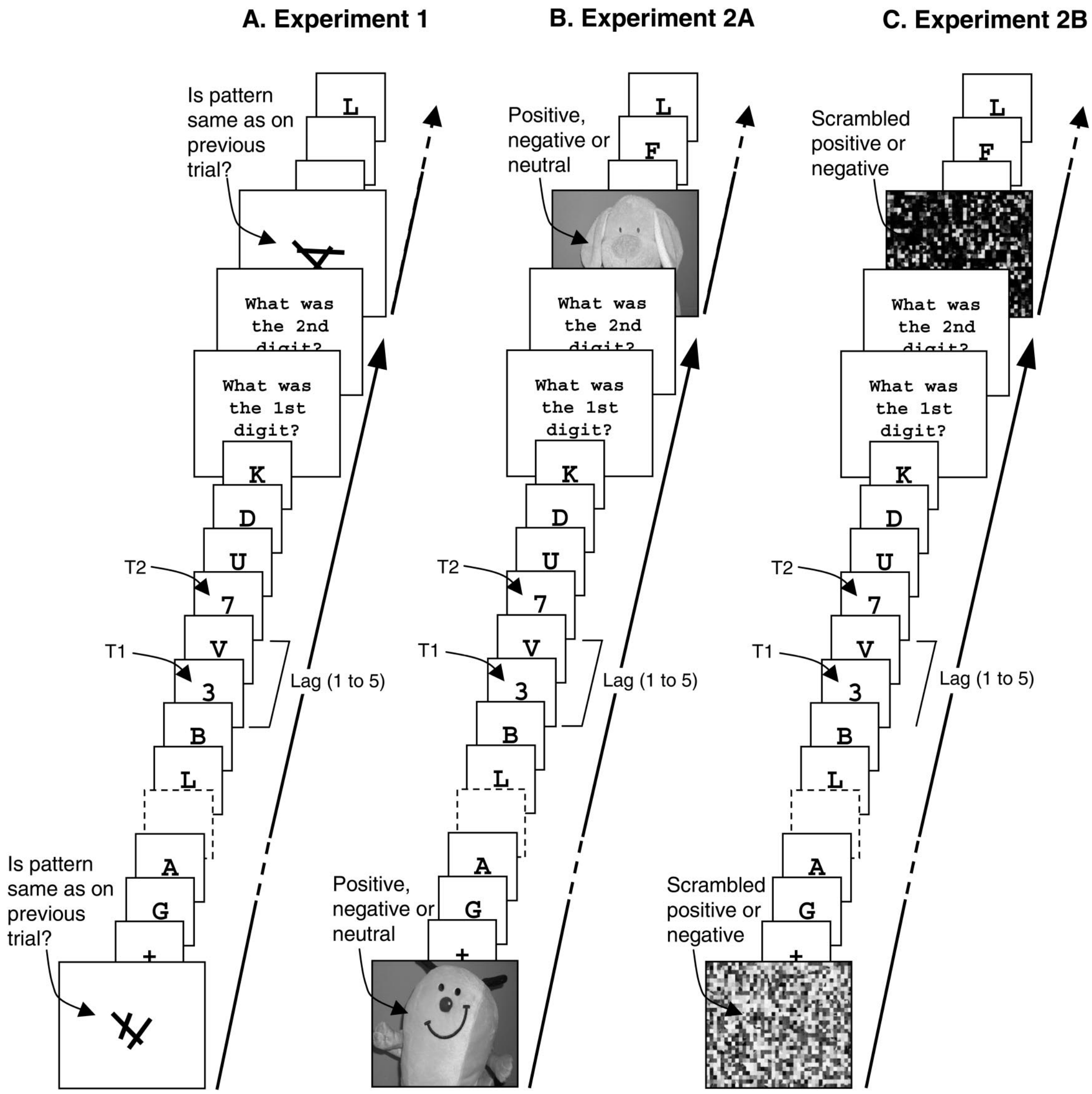

Figure 2. Schematic illustration of the procedures of (A) Experiment 1, (B) Experiment 2A, and (C) Experiment 2B. T1 = Target 1; T2 = Target 2. The photos printed here are for example only; to maintain the research value of the images in the *International Affective Picture System (IAPS),* we have not included actual *IAPS* photos.

Participants' primary task was to identify both T1 and T2. An unspeeded response was made at the end of each trial by typing the digits in order on a standard keyboard. In the additional-task condition, participants were instructed to remember the random line patterns presented before the RSVP stream. Whenever the pattern was the same as that on the previous trial (25% of trials), the space bar was to be pressed within 2,000 ms. When it was different (75% of trials), no response was required. Misses and false alarms were followed by feedback stating that the pattern was either the same or different, respectively. Consecutive patterns, if different, differed only in one of the three line segments. In the no-additional-task condition, the same patterns were presented, but the participants were simply asked to watch them. The experiment started with 10 practice trials, followed by two blocks of 100 trials each, resulting in a total of 40 trials per lag, which were randomly mixed. The experiment lasted approximately 25 min. During the practice stage, digit identification errors were followed by negative feedback in red stating, *No, it was #*, with # being the correct digit. During the main experiment, no feedback was provided on the RSVP task. Participants were instructed to guess whenever they could not identify a digit. In all conditions, all instructions were automated and presented on screen. Apart from initial set up and final payments, participants did not interact with the experimenter, who was a lab assistant naive to the main purpose of the experiments.

Results

In the additional-task condition, the average overall accuracy was 89% on the memory task. Accuracy data were submitted to an analysis of variance (ANOVA) with pattern type (same, different) and lag (1, 2, 3, 4, and 5) as variables. Overall, accuracy was higher on different-pattern trials (92%) than on same-pattern trials (83%), $F(1, 13) = 9.64$, $MSE = 0.030$, $p < .01$. There was no main effect of or interaction with lag (Fs < 1.2, *ns*). Pattern type and memory accuracy had no significant effects on RSVP task performance; therefore, we collapsed the data across these variables.

To assess performance on the RSVP task, average T1 and T2 identification accuracy data were submitted to an ANOVA with condition (additional task, no additional task) and lag as variables. Trials on which T1 and T2 were accurately identified but in the wrong order were treated as correct. Figure 3A shows the results for T1. Accuracy increased slightly but significantly with lag, $F(4, 104) = 8.00$, $MSE = 0.003$, $p < .001$. There was a weak trend toward overall better performance in the additional-task condition, $F(1, 26) = 2.27$, $MSE = 0.094$, $p < .15$ (this was significant for Lags 3–5, $p < .001$). There was no Condition $\times$ Lag interaction ($F < 1$, *ns*).

Figure 3B shows the results for T2 when T1 was identified correctly. However, the same pattern of results held when T2 performance was analyzed independent of T1 accuracy. There was a main effect of lag, $F(4, 104) = 13.74$, $MSE = 0.008$, $p < .001$. Accuracy dropped after the first lag and then gradually increased again. There was a trend toward overall better performance in the additional-task condition, $F(1, 26) = 2.59$, $MSE = 0.058$, $p = .12$. More important is the significant Lag $\times$ Condition interaction, $F(4, 104) = 2.63$, $MSE = 0.008$, $p < .05$. The drop in accuracy after the first lag was shallower in the additional-task condition than in the no-additional-task condition.

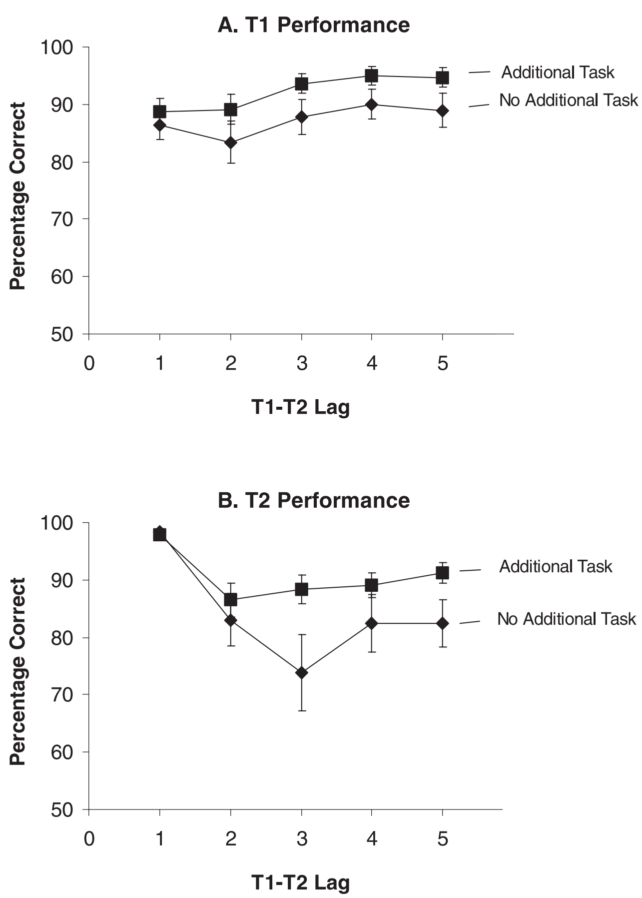

Figure 3. Average identification accuracy (% correct) for (A) the first target (T1) and (B) the second target (T2) in the RSVP task of Experiment 1 as a function of Lags 1–5 (100–500 ms) between the targets and the presence of an additional task involving the remembering of a random line pattern. Error bars denote one standard error of the mean.

Discussion

Overall, the results show the classic attentional blink pattern: Processing of the second of two targets in an RSVP stream was impaired when it closely followed the first target (cf. Chun & Potter, 1995; Raymond et al., 1992). Further corroborating previous studies, the attentional blink was reduced for Lag 1, a phenomenon that has been referred to as *Lag 1 sparing* (Potter, Chun, Banks, & Muckenhoupt, 1998). The important new result is that the attentional blink was substantially reduced (here by an average of about 9% for Lags 2–5) by giving participants the additional task of having to remember a random line pattern. This result is difficult to explain under a simple limited-capacity account, according to which T2 suffers because T1 uses up the available resources. If so, then the reduction of resources available for the RSVP task should have led to a more profound rather than an ameliorated blink. We also note that the additional task did not lead to a mere shifting of resources from T1 to T2. If anything, performance for T1 also improved, though not significantly, in the additional-task condition.

The results provide direct support for the overinvestment hypothesis. To fulfill the additional task requirements, observers needed to shift resources away from the RSVP task. As a result, fewer distractors in the stream could gain access to the limited-capacity stage and interfere with the targets for control over responding. The improvement in performance is especially remarkable given that the additional task involved remembering a visual pattern across trials. As we noted earlier, limitations in short-term memory are thought to play an important role in the attentional blink. Assuming that the additional task put an increased load on short-term memory, one might expect T2 performance to be worse rather than better, compared with the no-additional-task condition. Nevertheless, short-term memory accounts could accommodate the current findings by referring to the different types of stimulus materials used by the two tasks; it is not implausible that random line patterns and alphanumeric characters are processed and stored in short-term memory systems that do not interfere with each other (Baddeley & Hitch, 1974; Jonides et al., 1996; Logie, 1995; E. E. Smith et al., 1995; Tresch, Sinnamon, & Seamon, 1993).

Experiment 2: Positive Affect Reduces the Attentional Blink

In Experiment 2A, we investigated the effects of positive affect on the attentional blink. We used the same RSVP task as in Experiment 1, except that, instead of random line patterns, the trials were now preceded by briefly presented photographs from the International Affective Picture System (IAPS, Lang, Bradley, & Cuthbert, 2005, see Figure 2B for an illustration of the experimental procedure). There was no additional task involved. The neutral-affect condition contained pictures of everyday objects, such as a towel, a basket, and a cup. It served as a baseline for the positive-affect condition, which contained pictures of a more pleasant content, such as babies, puppies, and smiling children. This condition was designed to induce at least a temporary positive affective state in the observers, but it may also have increased their arousal levels relative to the neutral conditions. To control for the latter possibility, the negative-affect condition contained pictures of a more negative content, such as a snake, a crying child, and a skin-puncturing syringe. The negative pictures were matched to the positive pictures with respect to arousal value, according to the IAPS ratings. The same pictures were used in a visual attention task by Dreisbach and Goschke (2004; see *The Positive-Affect Hypothesis* section of this article). According to the positive-affect hypothesis, we should observe a reduced attentional blink in the positive-affect condition relative to the neutral condition. If, however, the improved performance is due to increased arousal levels, then we should also see an improvement in the negative-affect condition.

The positive, negative, and neutral pictures we used in Experiment 2A may have differed not only in affective content, but also in terms of lower level visual properties. For example, the positive pictures were lighter overall (average 10.2 cd/m^2) than the neutral and negative pictures (average 1.2 and 2.6 cd/m^2, respectively). This is perhaps not surprising given the gloomy content of the last category, but it may have led to differential effects of luminance adaptation on the attentional blink (Giesbrecht, Bischof, & Kingstone, 2004). Similarly, overall variations in color could also have contributed to performance differences (Plack & Shick, 1974; Smets, 1969). Experiment 2B was conducted to rule out the possibility that the effects observed in Experiment 2A were due to such low-level differences. It replicated the positive- and negative-affect conditions of Experiment 2A (i.e., the conditions that differed the most in performance), but presented scrambled versions of the pictures. The scrambling resulted in the pictures becoming unrecognizable, while low-level visual aspects, such as overall luminance and color, were preserved (see Figure 2C for an example). If the improved performance in the positive-affect condition of Experiment 2A was due to these low-level differences, then we should see an improvement for the scrambled positive pictures too. In contrast, if performance in Experiment 2A improved because of the differences in content, then there should be no difference in performance between the positive and negative scrambled pictures.

Method

Participants. In Experiment 2A, 42 students of the Vrije Universiteit Amsterdam were randomly assigned to one of three conditions. Fourteen (9 male, 3 left-handed, ages 16–31 years, average age = 21 years) were assigned to the neutral-affect condition. Another 14 (7 male, 2 left-handed, ages 19–25 years, average age = 21 years) were assigned to the positive-affect condition. The final 14 (8 male, 2 left-handed, ages 18–35 years, average age = 23 years) were assigned to the negative-affect condition. All participants were paid 4 euro. None of the participants had participated in Experiment 1 or in Olivers and Nieuwenhuis's (2005) study. In Experiment 2B, 26 new participants were randomly assigned to one of two conditions. Thirteen (4 male, 1 left-handed, ages 19–35 years, average age = 26.5 years) were assigned to the negative scrambled condition. Another 13 (2 male, 2 left-handed, ages 18–37 years, average age = 27.1 years) were assigned to the positive scrambled condition. None of the participants had participated in Experiment 1 or 2A or in Olivers and Nieuwenhuis's (2005) study.

Stimuli, procedure, and design. The experimental setup was largely the same as in Experiment 1, with the following changes: There were no random line patterns and there was no additional task. Instead, each RSVP stream was preceded by a picture from the IAPS database (Lang et al., 2005), which was presented displaywide for 250 ms, followed by a 100-ms blank display and a 150-ms fixation cross. In Experiment 2A, participants saw 10 neutral pictures, 10 positive pictures, and 10 negative pictures. According to IAPS norms, the mean pleasantness ratings ($\pm SE$) for these sets are 4.90 (0.95), 7.68 (1.52), and 2.89 (1.66), respectively. According to the same norms, the arousal ratings ($\pm SE$) are 2.56 (1.85), 4.71 (2.38), and 5.25 (2.23), respectively. Participants were instructed to simply look at the pictures. It was made clear that they would not be asked to remember them later. To control for possible mood differences prior to the experiment, participants rated their mood on three 7-point rating scales (*excited–relaxed*, *awake–tired*, *happy–sad*). Furthermore, at the end of the experiment, they were asked how interesting (or boring) they found the experiments, how interesting (or boring) they found the pictures,[2] how positive or sad they felt after the experiment, and how positive or sad they found the pictures (all on 7-point rating scales). Finally, they were shown all 10 pictures and asked to choose the three that "induced the strongest feelings" to see if some pictures might induce a stronger blink than others. This was not clearly the case, and we do not report on this further. The experiment ended with a debriefing about the aim of the experiment and the opportunity to talk about the pictures in case participants found them too upsetting, especially in the negative condition. None did.

Experiment 2B was identical to Experiment 2A except for the following changes: We dropped the neutral condition and instead directly compared the conditions containing positive and negative pictures. However, these pictures were now scrambled. The scrambling process divided each picture into small 0.7° × 0.7° squares, which were then randomly rearranged, making sure that no square was lost. This way the pictures became unrecognizable, but preserved their overall luminance and color.

Results

Experiment 2A. Average T1 and T2 accuracy data were submitted to an ANOVA with affect condition (neutral, positive, negative) and lag (1–5) as variables. Trials on which T1 and T2 were accurately identified but in the wrong order were treated as correct. Figure 4A shows the results for T1. There was a trend toward overall better performance in the positive-affect condition, relative to the neutral and negative conditions, $F(2, 39) = 2.47$, $MSE = 0.045$, $p < .10$. The effect was significant when comparing only the positive and negative conditions, $F(1, 26) = 5.75$, $MSE = 0.038$, $p < .05$. There were no effects involving lag (all Fs < 1, *ns*).

Figure 4B shows the results for T2 contingent on correct T1 identification, but the same pattern of results also held when T2 was analyzed regardless of T1 accuracy. There was a main effect of lag, $F(4, 156) = 42.96$, $MSE = 0.011$, $p < .001$. Accuracy dropped after Lag 1 and then gradually increased again. There was also an effect of affect type. Performance was better overall in the positive-affect condition than in the neutral and negative-affect conditions, $F(2, 39) = 4.00$, $MSE = 0.084$, $p < .05$. Furthermore, the Lag × Affect Condition interaction was significant, $F(8, 156) = 2.23$, $MSE = 0.011$, $p < .05$. The drop in accuracy after

[2] Note that there is no straightforward Dutch translation for *arousal* without also invoking a sexual connotation. Therefore, rather than asking participants how aroused they were, we asked them how excited/relaxed they were beforehand and afterward asked them how bored they were by the experiment and pictures.

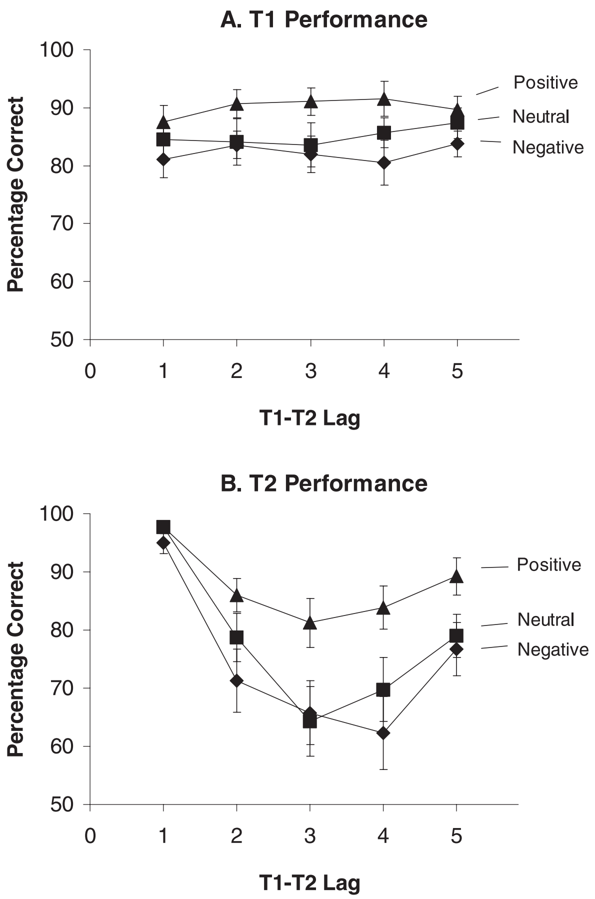

Figure 4. Average identification accuracy (% correct) for (A) the first target (T1) and (B) the second target (T2) in the RSVP task of Experiment 2A as a function of Lags 1–5 (100–500 ms) between the targets and the affective content of the preceding pictures (positive, neutral, and negative). Error bars denote one standard error of the mean.

Lag 1 was shallower in the positive-affect condition than in the neutral and negative-affect conditions. Separate pairwise comparisons revealed that performance in the positive-affect condition was better than in the neutral condition. There was a main effect of affect condition, $F(1, 26) = 4.90$, $MSE = 0.067$, $p < .05$, and a significant Lag × Affect Condition interaction, $F(4, 104) = 3.20$, $MSE = 0.009$, $p < .02$. The positive-affect condition was also better than the negative-affect condition: affect condition, $F(1, 26) = 7.64$, $MSE = 0.082$, $p = .01$; Lag × Affect Condition interaction, $F(4, 104) = 3.18$, $MSE = 0.010$, $p < .02$. In contrast, the neutral and negative-affect conditions did not differ significantly (all *F*s < 1, *ns*). We also performed a correlation analysis in which we related the average T2 performance on Lags 2, 3, and 4 (i.e., the lags on which the strongest attentional blink effects occurred) to the emotional valence and arousal ratings of the individual pictures (as provided by the IAPS database; Lang et al., 2005) within each affect condition. The only correlation that reached significance was a trend for worse performance in the positive-affect condition for pictures rated as more arousing ($r = -.68$, $p < .05$).

To control for possible a priori mood differences between the three groups, we asked participants to rate how excited, positive, and awake they were beforehand. Table 1 shows the average ratings. None of the differences could consistently explain the results, except that the positive-affect group felt overall slightly more excited beforehand. Although this was not significant ($p = .190$), we decided to run a control analysis in which we compared the most excited group of participants (excitement ratings 1–4, $N = 11$) with the least excited group (excitement ratings 6–7, $N = 15$) on T2 performance. The analysis revealed no differences between these groups (all *F*s < 0.1, *ns*). In fact, across the entire sample of participants ($N = 42$), there was no correlation between the a priori level of excitement and performance ($r = .08$, *ns*). Together, this makes the level of arousal beforehand an unlikely candidate for explaining the results.

Table 1 also shows the ratings of various aspects after the experiment. Somewhat surprising is that the experiment was considered least boring in the neutral condition (although this finding was not significant), especially given that the pictures were rated most boring in this condition (approaching significance). In fact, across conditions, how boring the participants rated the overall experiment and their attentional blink performance were significantly correlated, to the extent that the more boring they found the experiment, the better they performed ($r = .36$, $p < .05$). Note further that the negative pictures were at least as exciting as (or less boring than) the positive pictures. This is important because it confirms our assumption that the negative and positive pictures were equally arousing relative to the neutral pictures. Finally, a strong difference in ratings—and the only one that corresponds directly with the differences in attentional blink performance—

Table 1
Average Mood and Arousal Ratings Before and After Experiment 2A for the Neutral, Positive-Affect, and Negative-Affect Conditions

Question and anchors for rating scales	Affect condition: Neutral	Positive	Negative	p[a]
Before the experiment				
How excited do you feel? (*excited–relaxed*)	5.2	4.4	5.1	.190
How tired do you feel? (*awake–tired*)	4.1	3.9	3.5	.535
How positive do you feel? (*happy–sad*)	3.4	3.0	2.6	.323
After the experiment				
How boring was the experiment? (*not boring–boring*)	3.6	4.7	4.5	.209
How boring were the pictures? (*not boring–boring*)	5.2	4.0	3.8	.057
How positive do you feel? (*happy–sad*)	4.0	3.7	3.1	.140
How positive were the pictures? (*happy–sad*)	4.6	3.1	5.1	<.001

Note. Ratings were given on a scale from 1 to 7.
[a] This column shows p values for an analysis of variance testing the differences among affect conditions.

was found for the emotional content of the pictures. The positive pictures were rated more positively than the neutral and negative pictures.

Experiment 2B. Average T1 and T2 accuracy data were submitted to an ANOVA with affect type (positive scrambled, negative scrambled) and lag (1–5) as variables. Trials on which T1 and T2 were accurately identified but in the wrong order were treated as correct. Figure 5A shows the results for T1. There was a main effect of lag, $F(4, 96) = 5.96$, $MSE = 0.004$, $p < .001$. There were no effects involving affect type (all Fs < 1, *ns*). Figure 5B shows the results for T2 contingent on T1 accuracy, but the same pattern of results held when T2 was analyzed independent of T1 accuracy. There was a main effect of lag, $F(4, 96) = 24.12$, $MSE = 0.011$, $p < .001$. Accuracy dropped after the first lag and then gradually increased again. There were no effects involving affect type (all Fs ≤ 1, *ns*).

As in Experiment 2A, we asked participants to rate how excited, positive, and awake they felt beforehand. Table 2 shows the average ratings. There were no significant differences, although there was a slight trend toward the positive scrambled group feeling somewhat happier beforehand. Table 2 also shows the ratings collected after the experiment. Of most importance is that, in contrast to Experiment 2A, the scrambled positive and negative pictures were now rated equally with regard to affective content. This confirmed that our scrambling manipulation was successful at obscuring differences in affective value between the groups of pictures.

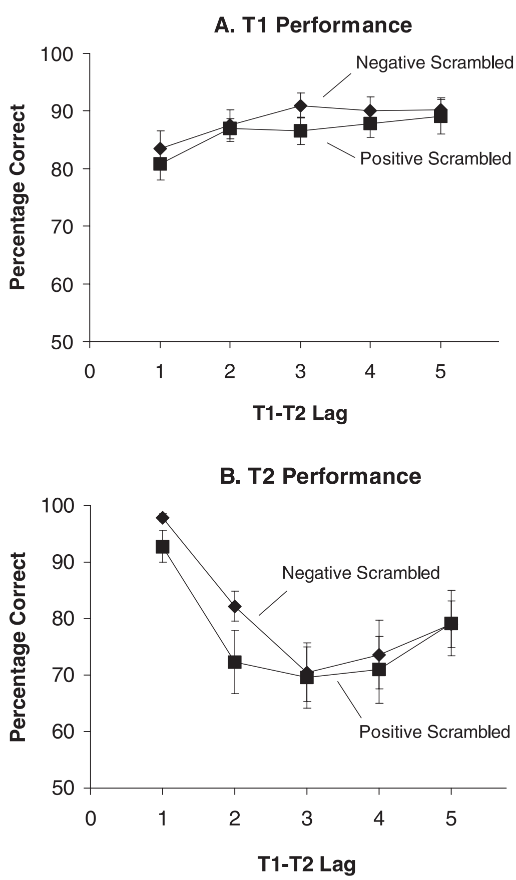

Figure 5. Average identification accuracy (% correct) for (A) the first target (T1) and (B) the second target (T2) in the rapid serial visual presentation (RSVP) task of Experiment 2B as a function of Lags 1–5 (100–500 ms) between the targets and the type of picture preceding the RSVP stream (positive or negative scrambled pictures). Error bars denote one standard error of the mean.

Table 2
Average Mood and Arousal Ratings Before and After Experiment 2B for the Positive Scrambled and Negative Scrambled Conditions

Question and anchors for rating scales	Affect condition: Positive scrambled	Affect condition: Negative scrambled	p^a
Before the experiment			
How excited do you feel? (*excited–relaxed*)	4.6	5.3	.365
How tired do you feel? (*awake–tired*)	4.9	3.9	.270
How positive do you feel? (*happy–sad*)	2.7	3.4	.101
After the experiment			
How boring was the experiment? (*not boring–boring*)	3.7	3.0	.336
How boring were the pictures? (*not boring–boring*)	4.7	4.0	.499
How positive do you feel? (*happy–sad*)	3.8	3.2	.372
How positive were the pictures? (*happy–sad*)	3.5	3.5	.868

Note. Ratings were given on a scale from 1 to 7.
[a] This column shows *p* values for a *t* test of the differences between affect conditions.

Discussion

Taken together, the results of Experiments 2A and 2B provide clear evidence for the positive-affect hypothesis. Briefly presenting positive affective pictures before the RSVP stream improved T2 identification by about 12% relative to neutral pictures and by about 16% relative to negative pictures (averaged across Lags 2–5). Again, this improvement was not at the expense of T1. There was also a trend toward an improvement for T1 identification with more positively laden pictures. Experiment 2B demonstrated that the improvement was also not due to low-level visual differences between the groups of pictures. Furthermore, the results cannot be explained by the fact that the positive pictures were more arousing than the neutral pictures. The negative pictures were as arousing as the positive pictures according to the IAPS ratings and according to our participants' own boringness ratings. Yet, the negative pictures, if anything, led to slightly worse T1 and T2 detection accuracy relative to the neutral pictures and certainly led to worse detection accuracy relative to the positive pictures. Also, within the positive condition, there was a tendency for worse performance with more arousing pictures, as indicated by a negative correlation between arousal values and T2 performance.

Furthermore, across conditions, the participants who found the experiment boring tended to perform better. Taken together, this might suggest that performance is especially aided under positively affective and slightly underarousing conditions.

Our findings corroborate those of Dreisbach and Goschke (2004) and Fenske and Eastwood (2003), who found a greater influence of distracting information under positive-affect conditions. In their studies, this influence occurred across different feature dimensions or different spatial locations. The present results suggest that positive affect also influences selection across time, allowing for improved target detection in RSVP tasks.

An alternative, but related, explanation of the findings may lie in the fact that negative stimuli appear to capture attention more than positive stimuli (Eastwood, Smilek, & Merikle, 2001, 2003).[3] This would mean that attention is summoned better on negative trials, which, according to the overinvestment hypothesis, is detrimental to performance. This way, the affective value of the pictures does not affect performance directly, but through recruiting more or less attention to the task. In the General Discussion section, we return to the possible link between the positive-affect hypothesis and the overinvestment hypothesis.

Note further that we do not wish to suggest that the differences in performance in Experiment 2A were due to long-term mood changes caused by the affect-laden pictures. Indeed, the little difference between the different conditions with regard to participants' self-assessed mood ratings before and after the experiment suggests that no such long-term mood changes occurred. However, several studies have shown that IAPS pictures induce at least temporary changes in emotion-related brain activation (measured as differences between blocks of trials or even on a trial-by-trial basis; Hariri, Tessitore, Mattay, Fera, & Weinberger, 2002; Lang, Bradley, & Cuthbert, 1998; Liberzon et al., 2000; Northoff et al., 2002; J. C. Smith, Bradley, & Lang, 2005). Our results suggest that the pictures also induced such short-lived emotional changes in Experiment 2A. Of course, this is not to say that the attentional blink may not be affected by long-term mood changes. On the contrary, a study by Rokke, Arnell, Koch, and Andrews (2002) has shown that moderately to severely dysphoric students suffered from a longer and more profound attentional blink than mildly dysphoric and nondysphoric students. This fits with the idea that a more positive state of mind may benefit performance in the attentional blink task.

Experiment 3: Instruction to Concentrate Less Reduces the Attentional Blink

So far we have tried to induce a more distributed attentional state by imposing on the observer additional task requirements (the current Experiment 1 and the free association and music conditions of Olivers & Nieuwenhuis, 2005) or different stimuli (the current Experiment 2 and the music condition of Olivers & Nieuwenhuis, 2005). In this sense, the more diffuse mental state was forced by external circumstances, possibly without the participant's awareness. In Experiment 3, we investigated whether observers could actively adopt the more beneficial attentional state themselves if we simply instructed them to do so. For this purpose, we compared two groups of participants. At the start of the first half of the experiment, both groups received exactly the same instruction, namely to concentrate maximally on the RSVP stream. After this first block, for one of the groups (the standard group), the instruction to concentrate was then simply repeated. For the other group (the unfocused group), the instruction changed: They were now asked to try and concentrate a little less and adopt a more diffuse state of attention. On the basis of the overinvestment hypothesis, we predicted that for this group, performance in the second half of the experiment would improve relatively more than for the standard group.

Furthermore, Experiment 3 served to exclude another explanation of the data so far. Up to now, the crucial manipulations have been between groups of participants. There may therefore have been a risk that the effects were due to a priori differences between groups (despite random allocation of participants). Because in Experiment 3 both groups initially received exactly the same instruction, the first half of the experiment allowed for a baseline comparison of the two groups.

Method

Participants. Twenty-four students of the Vrije Universiteit Amsterdam were randomly assigned to either of two conditions. Twelve (6 male, 12 right-handed, ages 18–21 years, average age = 21 years) were assigned to the standard instruction condition. The other 12 (5 male, 1 left-handed, ages 18–35 years, average age = 21 years) were assigned to the unfocused condition. All participants were paid 4 euro. They were naive as to the purpose of the experiment, and none of them had participated in the previous experiments.

Stimuli, procedure, and design. The stimuli and experimental procedure were the same as in the previous two experiments, except for the following changes. Only the RSVP stimuli and task were included (no additional tasks or stimuli). All participants first received a standard explanation of the task, which they then practiced for 15 trials. Then, at the start of the real experiment, all participants received the same instruction, namely to "try to concentrate as much as possible and correctly identify as many digits as possible" (translated from Dutch). All participants then performed the first block of 100 trials (20 for each lag). Then, in the standard-instruction condition, the instruction was essentially repeated: "In the next block you will receive exactly the same task. Try again to maximally concentrate. It turns out that the task often becomes easier the second time around." In the unfocused condition, however, the instruction changed:

> In the next block you will receive exactly the same task. However, we would like to ask you to concentrate a little less. In other words, keep on looking at the stream, but try to pay a little less attention to the digits. Try to adopt a slightly more "diffuse," "absent-minded," "passive" attitude, and let the digits "come at you" in a way. This may appear strange, but it turns out that the task often becomes easier.

Both groups then completed the second block of 100 trials. We decided to end both instructions by mentioning that "the task often becomes easier" (even if this may not have been the case for the standard group), to prevent any effects due to positive expectations. All instructions were presented on the screen, and the experiment was run by a lab assistant naive as to which participant received which condition.

Results

Trials on which T1 and T2 were accurately identified but in the wrong order were treated as correct. Figures 6A and 6C show the

[3] We thank a reviewer for raising this possibility.

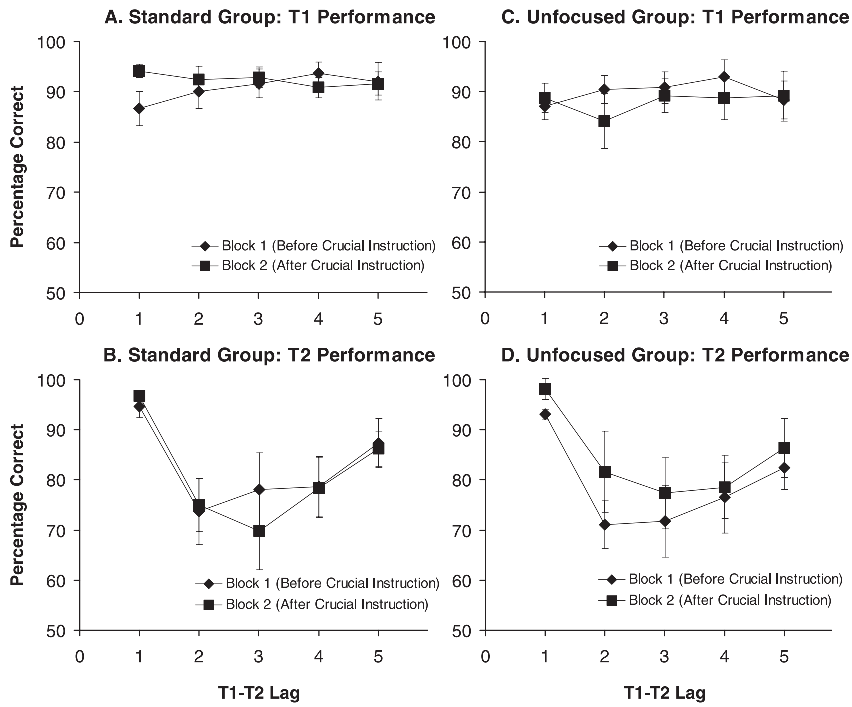

Figure 6. Average identification accuracy (% correct) for (Panels A and C) the first target (T1), and (Panels B and D) the second target (T2) of two targets in the rapid serial visual presentation task of Experiment 3, as a function of Lags 1–5 (100–500 ms) between the targets and the specific block of trials (either before or after the crucial instruction). Panels A and B show performance for the standard instruction group, and Panels C and D show performance for the unfocused group. Error bars denote one standard error of the mean. Note that these error bars reflect between-subjects variability and therefore do not reveal much about the differences between blocks in this graph. They serve to compare the unfocused group with the standard group.

results for T1 for the two blocks, separated for the standard instruction group and the unfocused group. Block 1 was run before the crucial instruction, and performance in this block served as a baseline; Block 2 was run after the crucial instruction. Accuracy data were entered in an ANOVA with block and lag as within-subject variables and with instruction type as a between-subjects variable. The only significant effect was a Block × Lag interaction, $F(4, 88) = 3.44$, $MSE = 0.003$, $p < .02$. In Block 1, accuracy appeared to increase slightly with lag, whereas in Block 2, accuracy, if anything, dropped slightly with lag.

Figures 6B and 6D show the results for T2 when T1 was identified correctly for the two blocks and the results separated for the standard and unfocused groups. There was a main effect of lag, $F(4, 88) = 12.51$, $MSE = 0.036$, $p < .001$, because accuracy dropped after the first lag and then gradually increased again. Moreover, there was a significant Instruction Type × Block interaction, $F(1, 22) = 6.32$, $MSE = 0.011$, $p < .02$. Performance in Block 2 (i.e., after the crucial instruction), when compared with that in Block 1 (before the crucial instruction), improved more for the unfocused group than for the standard instruction group. Separate comparisons within the two groups revealed a significant improvement in Block 2 in the unfocused group, $F(1, 11) = 9.43$, $MSE = 0.009$, $p < .02$, but not in the standard group ($F < 1$, *ns*). In the unfocused group, 10 out of 12 participants showed an improvement; in the standard group, only 5 out of 12 showed improvement. It should be noted, however, that these effects were weaker when T2 performance was analyzed independent of T1 accuracy, although there was still a trend toward an Instruction Type × Block interaction, $F(1, 22) = 2.78$, $MSE = 0.014$, $p = .11$.

Discussion

The results indicate that observers can, on the basis of instructions, actively adopt the more distributed attentional state that appears so beneficial to RSVP performance. The group that, halfway through the experiment, received the instruction to change strategy and try to concentrate a little less improved their overall accuracy, whereas the group that was reminded to keep on concentrating did not. Moreover, the roughly equal performance in the first block (if anything the unfocused group was a little worse) showed that a priori differences between groups cannot account for this effect.

Unlike in the previous experiments, there was no tendency for T1 performance to improve too in the distributed attention condition. If anything, T1 performance in the second block appeared to suffer a little for the unfocused group. Although this was not significant ($p = .27$), one may argue that under the present instruction manipulations, the improvement on T2 occurred at the expense of T1. However, the fact that the improvements were stronger when T2 performance was analyzed contingent on T1 correct trials (as compared with all T1 trials) goes against this argument: If T2 detection improves at the expense of T1 detection, then one would expect stronger improvements when T1 was not detected. Future research will have to further examine the effects of attention manipulations on the relationship between T1 and T2.

General Discussion

In a previous study (Olivers & Nieuwenhuis, 2005), we found that task-irrelevant mental activity had a beneficial effect on performance in the attentional blink task. The present article sought to investigate the mechanisms responsible for these counterintuitive results. In the current experiments, we found that detection accuracy of T2, and to a lesser extent also T1, improved when participants concurrently performed an additional task or viewed pictures of positive content. These results replicate the pattern of results found in our previous study and provide initial evidence for two specific hypotheses: the overinvestment hypothesis and the positive-affect hypothesis.

According to the former hypothesis, the probability of an attentional blink is substantially increased by an overinvestment of attentional resources in the RSVP stream. This causes task-irrelevant RSVP items to spuriously gain entry to a limited-capacity processing stage, where they interfere with processing of the targets, thus threatening the consolidation of these targets for subsequent report. The overinvestment hypothesis predicts that drawing away attentional resources from the RSVP stream should lead to improvements in attentional blink performance. This prediction was tested in Experiment 1 by having participants perform a short-term memory task concurrently with the attentional blink task. We found that under these circumstances, the attentional blink was less profound than in a control condition without an additional memory task. The hypothesis was further confirmed in Experiment 3, where we found that explicit instructions to concentrate less on the task led to stronger improvements than instructions to concentrate.

According to our second hypothesis, a reduced attentional blink may be the result of increased cognitive flexibility as induced by positive affect. Previous research has shown that, when presented with stimuli of positive affective valence, observers are less focused on a single source of information and more flexibly orient to multiple and/or novel stimuli (Ashby et al., 1999; Dreisbach & Goschke, 2004; Derryberry & Tucker, 1994; Fenske & Eastwood, 2003). In addition to widening the window of attention, positive affect has also been associated with increases in short-term memory capacity. Both variables may be beneficial to target detection in an RSVP stream. The positive-affect hypothesis was tested and confirmed in Experiment 2: When RSVP streams were preceded by briefly presented positively laden pictures, the attentional blink was less profound than when they were preceded by neutral pictures. This effect was not due to increased arousal, because equally arousing negative pictures did not result in any improvements. The effect was also not due to low-level perceptual differences between the pictures. Taken together, the results indicate that both cognitive (in terms of an additional task and instructions) and affective (in terms of positive valence) variables may contribute to an ameliorated attentional blink.

Relation to Existing Theories

The present as well as our earlier results (Olivers & Nieuwenhuis, 2005) are difficult to explain in terms of traditional thinking about the attentional blink. All prevalent theories of the attentional blink rely on the assumption that T2 suffers because T1 occupies valuable resources. Under certain circumstances, improvements may be expected for T2, but only at the expense of T1. In this sense, we could regard T1 and T2 as two communicating vessels; the more resources required for the one, the fewer are left for the other. Indeed, various studies have confirmed a negative correlation between behavioral indices or neural correlates of T1 and T2 processing (Chun & Potter, 1995, Table 1; Hommel et al., 2003; Seiffert & Di Lollo, 1997; Shore et al., 2001; see also Kahneman, 1973, p. 151). However, note that in most of our experiments, if anything, T1 detection improved when observers were associating freely (Olivers & Nieuwenhuis, 2005), listening to music (Olivers & Nieuwenhuis, 2005), doing another task (Experiment 1), or being presented with positive stimuli (Experiment 2). Most of these improvements were relatively small and only approached significance, and in one experiment (the current Experiment 3), there was even a small decrement. However, in a meta-analysis across the experiments of Olivers and Nieuwenhuis (2005) and those presented here, we pooled all experimental conditions (involving free association, music, additional tasks, positive affect, and instruction to be unfocused) and compared them with the control conditions (i.e., the standard instruction and neutral-affect conditions involving no additional tasks). The analysis revealed a small (3.4%) but significant improvement for the experimental conditions, $F(1, 144) = 4.01$, $MSE = 0.053$, $p < .05$ (no interaction with lag, $F < 1$, *ns*). Taken together the picture is clear: T1 detection does not suffer and may even benefit from the more diffuse state induced by irrelevant mental activity and positive affect.

However, our results are easy to reconcile with existing theories if these theories let go of the notion that the attentional blink reflects a fundamental limitation of the cognitive system. This is not to say that information processing in the attentional blink task is not limited in capacity; ultimately, a selection of incoming information has to be made to enable coherent action (e.g., Allport, 1987). However, the current results suggest that the limited-capacity processing stage may be overwhelmed by an influx of rapidly succeeding items if too much rather than too little attention is paid to the RSVP stream. Reducing the amount of resources devoted to the RSVP stream will reduce the likelihood of distractors reaching the limited-capacity stage. This is especially beneficial to processing of T2, but to a lesser extent is also beneficial to the processing of T1, which too may suffer from interference from spuriously selected distractors. Note that the overinvestment hypothesis is also consistent with findings that it is substitution masking that is particularly effective in eliciting an attentional blink (e.g., Giesbrecht & Di Lollo, 1998), that observers often make substitution errors in their reports (e.g., Isaak et al., 1999), and that the attentional blink appears time locked to the first post-T1 distractor rather than to T1 itself (Di Lollo, Kawahara, Ghorashi, & Enns, 2005; Olivers, van der Stigchel, & Hulleman, in press): Overinvestment in the RSVP stream promotes the selection of the T1 and T2 masks.

Relation Between the Overinvestment Hypothesis and the Positive-Affect Hypothesis

So far we have presented the overinvestment hypothesis and the positive-affect hypothesis as describing independent cognitive and affective mechanisms. However, it is feasible that positive affect has an influence on the balance between focused and divided attention similar to that of adding another task or providing other sources of distraction. As we have discussed, positive affect is assumed to increase cognitive flexibility, which is characterized by an increased receptivity to a variety of input (Ashby, Isen, & Turken, 1999). It is not hard to conceive of this explorative state as involving the taking away of resources from any specific task or stimulus and assigning them more evenly across the environment. This way, the positive-affect hypothesis may invoke the same mechanisms as proposed by the overinvestment hypothesis: Instead of an additional task, it is the positive affective state that pulls away resources from the central RSVP task, resulting in reduced interference. Tentatively then, we propose that the attentional blink is reduced through a more diffuse mental state characterized by a more even distribution of attentional resources. This diffuse state may be reached in multiple ways, including the concurrent performance of an additional task and positive affect.

As mentioned earlier, the effect of positive affect on cognition may be mediated in part by the dopamine system, a system that has been associated with both affective and cognitive functioning (Ashby et al., 1999; Beatty, 1995; Braver & Cohen, 2000; Fuster, 1997; Goldman-Rakic, 1995; Gray, 2001). In this respect, it is interesting that the dopamine system projects more strongly to the left than to the right hemisphere (see Tucker & Williamson, 1984, for a review). This seems consistent with the finding that positive affect more strongly benefits performance on typical left hemisphere tasks, whereas negative affect appears to improve performance on right hemisphere tasks (Davidson, 1995; Gray, 2001; Heller & Nitschke, 1997; Heller, Nitschke, & Miller, 1998; Sutton & Davidson, 1997). Furthermore, the left hemisphere has been associated with the temporal orienting, sequencing, and switching of attention, whereas the right hemisphere appears to be more involved in spatial and sustained aspects of attention (e.g., Banich, 1997; Cabeza & Nyberg, 2000; Coull & Nobre, 1998; Pardo, Fox, & Raichle, 1991). This raises the possibility that performance in attentional blink tasks is determined by the balance between attentional processing in the two hemispheres: (a) a right-lateralized attention system that serves to induce a focused state in the observer, concentrating attention on a limited amount of information (something that, according to the overinvestment hypothesis, is detrimental in RSVP tasks), and (b) a left-lateralized system for the effective distribution of attention in time, which benefits performance in RSVP tasks and is promoted by increased positive affect.

Some support for this conjecture may be found in a recent case study by Giesbrecht and Kingstone (2004) involving an individual with a split brain. This person showed a strong attentional blink when T2 was presented to the right hemisphere, but no blink when T2 was presented to the left hemisphere. Similarly, Hillstrom, Husain, Shapiro, and Rorden (2004) reported the case of a person with severe and relatively widespread right-side cortical damage. This individual showed an attentional blink for targets presented to the right hemisphere but, in contrast with control participants, showed no blink for targets presented to the left hemisphere. The same group also found that more specific damage to the temporo–parietal junction, whether left or right, led to a more profound blink, whereas damage to the superior parietal lobule did not (Shapiro, Hillstrom, & Husain, 2002). Cooper, Humphreys, Hulleman, and Praamstra (2004) reported that the attentional blink was reduced when transcranial magnetic stimulation was applied to the right posterior parietal cortex of healthy participants. Together, these results may suggest that the attentional blink is a right-hemisphere-related deficit. The intriguing implication is that by shifting the balance toward the left hemisphere, the attentional blink is reduced. It remains to be seen how this balance relates to attentional blink performance in other clinical and nonclinical populations. For instance, it has been found that both adults and children with attention-deficit/hyperactivity disorder—believed to be a dopamine-related impairment—show a deeper and/or more protracted attentional blink (Hollingsworth, McAuliffe, & Knowlton, 2001; Mason, Humphreys, & Kent, 2005).

Relation to Other Findings

In a recent study, Akyürek and Hommel (2005) investigated the effects of short-term memory load on the attentional blink in a design very similar to the design we used in Experiment 1. The rationale of their experiments was that if attentional blink performance depends on short-term memory processes (as is held by some existing theories), then memory load should affect the magnitude of the attentional blink. Akyürek and Hommel indeed found that both T1 and T2 accuracy decreased with increasing memory load. At first sight, this may appear inconsistent with our finding that task-irrelevant mental activity is beneficial to attentional blink performance, especially in Experiment 1, where we used a short-term memory task. However, Akyürek and Hommel found effects of load only when the memory content was related to the items in the stream (i.e., digits, letters, or science fiction characters). In a condition in which memory content was unrelated to the contents of the stream, T2 accuracy was overall highest at almost 90%, and it was not affected by memory load. Note that in our Experiment 1, the to-be-remembered patterns were also unrelated to the RSVP items. Moreover, Akyürek and Hommel did not include a baseline condition without an additional memory task, as this fell beyond the purpose of their experiments. Together, these considerations leave open the possibility that the presence of an additional task may have had an overall beneficial effect on attentional blink performance.

Our results are further corroborated by Arend, Johnston, and Shapiro (in press), who found that the attentional blink was attenuated when the RSVP stream was embedded in a display containing distracting computer-simulated starfield motion. This suggests that distraction within the same modality as the RSVP stream (i.e., the visual modality) also leads to improvements. Our findings also shed new light on a report by Kristjánsson and Nakayama (2002). These authors conducted an attentional blink experiment in which the distance between T1 and T2 was varied not only in time (i.e., lag), but also in space, because the two targets could appear at different locations within multiple RSVP streams. The interesting finding was that the attentional blink was more attenuated (by as much as 16%) with increasing spatial distance between the targets. Performance for T2 was worst when it appeared in the same location (i.e., the same stream) as T1. Kristjánsson and Nakayama (2002) interpreted these results as reflecting an inhibitory annulus surrounding T1, such that streams close to T1 were suppressed. The overinvestment hypothesis offers an alternative explanation: The attentional blink may be the result of a localized overinvestment of resources, resulting in T2 being overwritten by spuriously active distractors. This investment is likely to be highest for the streams that contain or are close to T1. The more distant streams may benefit from a more moderate amount of attention. Thus, both Kristjánsson and Nakayama's results and Arend et al.'s results are consistent with the idea that attentional blink performance may improve when attention is more spatially distributed.

The finding that a mild degree of distraction may sometimes improve cognitive performance is not new. For example, Thompson, Schellenberg, and Husain (2001) found that listening to Mozart improved performance on a spatial task, a finding that they attributed to the effects of positive affect and increased arousal. Furthermore, professional golfers have been shown to improve their putting performance when simultaneously performing an auditory discrimination task as compared with when they are fully concentrating on playing golf (Beilock, Carr, MacMahon, & Starkes, 2002). Kuhl and Kazén (1999) found reduced interference in a Stroop task under positive-affect conditions (as induced by emotionally laden prime words), but only when the participants had to perform another task in addition.

The overinvestment hypothesis also bears some relationship to the perceptual load theory of Lavie (1995). Lavie found that an easy perceptual task suffers relatively more than a difficult perceptual task from distracting information. According to Lavie, this is because observers, in principle, invest all attentional resources available in the task. In the easy task, not all these resources are necessary, and some attention will spill over to the distractors. The distractors are then processed up to a relatively high level where they interfere with the task. It would be interesting to see if interference can be reduced, and performance improved, by forcing observers to divert attention away from the central task—just as we have done in the RSVP paradigm.

Of further relevance to the present investigation is a visual search study by Smilek, Enns, Eastwood, and Merikle (in press). They found that a relatively difficult search improved (in terms of search function slopes as well as overall response times) when observers adopted a passive search mode, in which they were instructed "to be as receptive as possible" and let the target just "pop into their minds" (Smilek et al., in press). Notably, Smilek et al. also found improvements in search efficiency (as indicated by slopes but not by overall response times in this case) when the search task was accompanied by an additional short-term memory task. They concluded that search benefits from a shifting of cognitive strategy from a reliance on slow executive control processes to a reliance on rapid automatic attentional orienting processes. Once more, we believe this interpretation is consistent with what we have referred to as a more diffuse mental state, in which observers are more explorative and more susceptible to multiple inputs.

Finally, and perhaps closest to our own study, we mention an early observation by Kahneman (1973), whose participants were presented with a rapid series of words to each ear, from which they were required to detect several target words: "The phenomenology of the situation is suggestive: subjects report that they deliberately refrain from paying particular attention to any word, because they realize that doing so involves 'missing' several other words" (p. 149).

Together, the above findings suggest an intriguing influence of general mental state on simple cognitive processes. It will be a difficult but exciting challenge to try to develop new concepts and theories aimed at capturing this influence. In this article, we have made a beginning at characterizing the effects of general mental state on the temporal dynamics of attention.

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