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Blinks of the Mind: Memory Effects of Attentional Processes

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If 2 words are presented successively within 500 ms, subjects often miss the 2nd word. This attentional blink reflects a limited capacity to attend to incoming information. Memory effects were studied for words that fell within an attentional blink. Unrelated words were presented in a modified rapid serial visual presentation task at varying stimulus-onset asynchronies, and attention was systematically manipulated. Subsequently, recognition, repetition priming, and semantic priming were measured separately in 3 experiments. Unidentified words showed no recognition and no repetition priming. However, blinked (i.e., unidentified) words did produce semantic priming in related words. When, for instance, *ring* was blinked, it was easier to subsequently identify *wedding* than *apple*. In contrast, when the blinked word itself was presented again, it was not easier to identify than an unrelated word. Possible interpretations of this paradoxical finding are discussed.

The visual system is limited in the number of items it can process at any given time. This limited capacity is clearly reflected by the phenomenon of the attentional blink (AB; Raymond, Shapiro, & Arnell, 1992). An AB occurs when two target stimuli (e.g., two words, letters, digits, or simple features) appear in close temporal proximity to each other amidst a rapid stream of nontarget stimuli. Although the first target can be identified correctly, subjects show a remarkable deficit in identifying the second target, the period of interference lasting for several hundred milliseconds. No AB effect occurs when subjects are instructed to ignore the first target (e.g., Duncan, Martens, & Ward, 1997), which implies that the AB is truly an attentional effect and not some sort of masking. Apparently, an attentional mechanism somehow suppresses, or interferes with, the processing of the second target while the first target is still being processed for identification (see, e.g., Chun, 1997; Potter, Chun, Banks, & Muckenhoupt, 1998; Raymond et al., 1992).

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An interesting question is to what extent words that fall within an AB are still processed. There are several indications that the attentional mechanism responsible for the AB is more complicated than a simple early gating device and that the problem probably occurs much later in the course of visual information processing (e.g., Chun & Potter, 1995; Maki, Frigen, & Paulson, 1997; Shapiro & Raymond, 1994). This question is addressed in this article by investigating the effect of words appearing in a rapid serial visual presentation (RSVP) task in posttrial tests of implicit and explicit memory. More specifically, our question is whether recognition, and repetition or semantic priming, can be found for words that fall within an AB, outside the subject's awareness.

Several studies have addressed the problem of identifying at what stages the processing deficit of the AB occurs. Vogel, Luck, and Shapiro (1998; see also Luck, Vogel, & Shapiro, 1996) used evoked response potentials (ERPs) to pinpoint processing stage deficits. No suppression was observed for ERP components of blinked words corresponding to sensory and semantic processing (P1 and N1), whereas complete suppression occurred for components corresponding to conscious identification, or working memory update (P300). Importantly, however, the N400 component, indicating a mismatch with a previously presented prime, was unaffected by whether the word was blinked. Similar results were reported recently by Rolke, Heil, Streb, and Hennighausen (2001). When an AB effect was induced in an RSVP task, missed words did not elicit a P300, indicating that they were not explicitly recognized. However, a normal N400 mismatch effect was observed, indicating that the blinked words had been processed up to a semantic level of analysis. Moreover, Shapiro, Caldwell, and Sorensen (1997) observed that a subject's own name tends not to suffer from an AB. All these results clearly correspond with earlier suggestions that both perceptual and semantic information of blinked words is processed but that an impairment occurs in a postperceptual processing stage in which perceptual information is somehow overwritten or erased in working memory (Chun & Potter, 1995; Shapiro & Raymond, 1994; Shapiro, Raymond, & Arnell, 1994).

With regard to the behavioral effects of the processing of blinked words, the results are less clear. Studies addressing this question have used some form of semantic priming paradigm, and both positive and negative results have been reported. Broadbent and Broadbent (1987) failed to find a priming effect of a first target (T1) on the recall of an associatively related second target (T2). Maki, Frigen, and Paulson (1997), however, using a larger set of more strongly associated items, did find semantic priming effects during an AB. They showed that when two target words are semantically related, T1 can prime T2 even though T2 was blinked and could not be reported. They even reported priming effects by a semantically related nontarget word occurring in the blink interval of T1. Although this semantic priming only lasted for approximately 100 ms, it is consistent with the view that word meaning is extracted from blinked words.

In a study by Shapiro, Driver, Ward, and Sorensen (1997), the subjects' task was to report the identities of three specified targets in an RSVP stream of nontarget digits. In the first experiment, T1 (a white digit) was to produce an AB for T2 (an uppercase letter), which in turn would enable possible priming for the third target (T3, a lowercase letter). Even when the T2 letter could not be reported, identification accuracy for T3 was enhanced if the letters had the same identity. In a second experiment, subjects had to identify three colored target words in an RSVP stream of black nontargets. It was found that both correct and incorrect identification of T2 enhanced performance on identifying a semantically related T3.

Rolke et al. (2001) used a modification of the procedure of Shapiro et al. (1997). They presented three colored target words among black nontarget words in an RSVP task. Association strength was varied between T2 and T3. When T2 was correctly identified, the percentage of correct T3 responses increased with increasing association strength. In case of blinked T2 primes, no facilitation effect on correct identification of T3 items was found, and actually an effect in the opposite direction was observed.

It should be noted, however, that the methodology used in the studies of Shapiro et al. (1997) and Rolke et al. (2001) probably has not been optimal in showing actual priming effects. In Experiment 2 reported by Shapiro et al., only 13 word pairs were used repeatedly, and they were practiced several times before being used in the experimental trials. In the study reported by Rolke et al., 24 sets of target words were used, and subjects had to indicate identification of the three target words by successively recognizing each one among all 24 possible words at that position in the RSVP task. Thus, a possible priming effect of one word on another in the RSVP task was measured by exposing subjects to all possible words (the ones shown as targets in other trials and the critical one shown in the present trial). In both studies, the possibility of learning and bias effects obscuring the actual priming that was looked for cannot be excluded.

In sum, whereas neurophysiological measures clearly show results indicating processing of blinked items to a high level, studies using behavioral measures have produced mixed results and the methodology used can be criticized. Moreover, the behavioral studies only looked at semantic priming by measuring priming effects of T1 on T2, or of T2 on T3. A paradigm that may be more suited to show behavioral effects of processing during an AB is a repetition priming task. To our knowledge no studies have been reported that looked at possible repetition priming effects of words presented within an AB. In the studies reported here, we used words presented once as stimuli and a perceptual identification task to study long-term repetition and semantic priming effects of items presented within and outside an AB.

We hypothesized that blinked words would be fully processed and that the AB effect would be caused by an impairment in a postperceptual stage of processing (e.g., Chun & Potter, 1995; Shapiro & Raymond, 1994). The question raised in the present study is whether we can find any effects of the initial processing of items presented during the AB in implicit and explicit memory tests over time intervals much larger than the intervals used by Maki, Frigen, & Paulson (1997). Contrary to the previously discussed studies, in which only a small set of words was used repeatedly, we used a large set of words, with each word being presented only once. The stimulus presentation procedure used to generate an AB (i.e., two RSVP streams) also allowed us to study the effects of dividing attention between two equivalent target stimuli. In Experiment 1 we studied the effect of different attention conditions, and of ABs, on recognition and repetition priming performance. In Experiment 2, repetition priming was measured with a shorter time interval between study and test. Finally, in Experiment 3, we looked at semantic priming, that is, priming of words semantically related to words presented in an AB task.

Experiment 1

In Experiment 1 we systematically varied the amount of attention while subjects tried to identify words presented in an AB-inducing paradigm. Attention was manipulated by having subjects either attend to one of two streams of stimuli (creating a full-attention and a no-attention condition) or attend to both streams of stimuli (a divided-attention condition). Induction of ABs was manipulated by presenting a second target word either 143 or 715 ms after the first target. Effects of attention manipulations, and of ABs, on performance in an explicit memory test (recognition) and an implicit memory test (perceptual identification threshold) were determined. It was hypothesized that manipulation of attention would affect performance in an explicit memory test but not in an implicit memory test (see, e.g., MacDonald & MacLeod, 1998; Mulligan, 1997; Parkin, Reid, & Russo, 1990; Parkin & Russo, 1990; Wolters & Prinsen, 1997).

Method

Design and subjects. Three independent variables were combined in a $2 \times 2 \times 3$ factorial within-subjects design. Factors were stimulus-onset asynchrony (SOA; 143 or 715 ms), starting order (horizontal or vertical stream starting first), and attention (full, divided, or no attention). Dependent variables were performance in a recognition and a repetition priming (i.e., perceptual identification) test. Twenty-four undergraduate students at Leiden University, Leiden, the Netherlands, participated in the experiment.

Materials. Three hundred eighty-four Dutch words were selected from the CELEX lexical database (Baayen, Piepenbrock, & van Rijn, 1993) to create two lists of words. Half of the subjects were presented List 1 during the study task, the other half List 2. Half of the presented words were tested in a subsequent implicit memory task, the other half in an explicit memory task. Words from the list that was not presented to the subject were used as control words in either the implicit or the explicit memory task. All items were commonly used four-letter words (i.e., highly frequent and infrequent words were avoided) that could be nouns, verbs, or adjectives. Care was taken to avoid semantic relations between any of these words. In addition, 72 four-letter words (commonly used first names) were selected for practice trials.

Procedure. The experiment consisted of three tasks: a study task, a threshold identification task, and a recognition task. For the study task, we adapted the AB paradigm, as used by Duncan et al. (1997). We refer to the study task as the AB task. Throughout each AB task trial, a display was shown containing a central fixation dot and four four-dot markers indicating two horizontal and two vertical stimulus locations (see Figure 1). Overall display dimensions were approximately 3.47° × 3.47°. Streams of stimuli were presented in left–right stimulus positions (referred to as the horizontal stream) and upper–lower positions (referred to as the vertical stream). Within a substream, stimuli were presented for 156 ms, separated by 130 ms from the next stimulus in that position. Stimuli in the left and the right position of the horizontal stream appeared simultaneously, and the same was true for stimuli in the upper and the lower position of the vertical stream. There was a delay of 143 ms between the horizontal and the vertical stream, with either the horizontal or the vertical stream starting first. In each trial, one position in the horizontal stream (either the left or the right position) and one position in the vertical stream (either the upper or the lower position) contained one four-letter target word among nine nontargets. Nontargets consisted of a row of four *x*s, approximately 1.15° in length. Thus, within the streams of stimuli, one target word appeared in either the left or the right position, and one target appeared in either the upper or the lower position. Targets were always preceded by at least five nontargets. The second target was presented either 143 or 715 ms after the onset of the first target. Each target word presented in the AB task was used only once. All combinations of starting order (horizontal or vertical stream starting first) and SOA of the two target words (143 or 715 ms) were randomly determined and equally distributed within each experimental block.

The presentation of trials in the AB task was divided into three blocks, each with a different instruction. The order of these blocks was counterbalanced between subjects. A block consisted of 12 practice trials, followed by 32 experimental trials. Throughout each trial, subjects were to keep their eyes fixated on the central cross in the middle of the screen. The instruction given before each block was (a) to focus on the horizontal positions, identify the target word, and ignore the vertical stream; (b) to focus on the vertical positions, identify the target, and ignore the horizontal

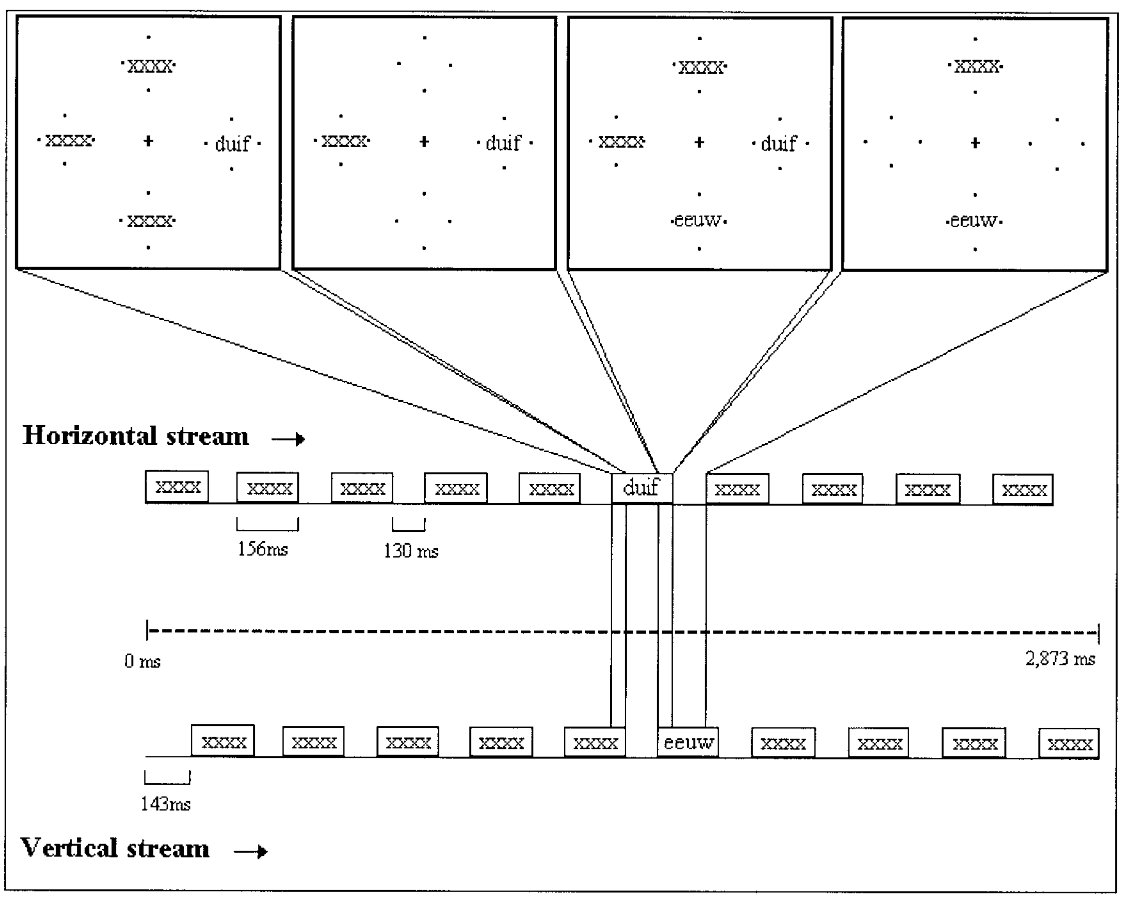

Figure 1. A schematic representation of a trial in Experiment 1. Part of the trial is highlighted by four screen shots showing the actual screen display during that time interval. Stimuli in the horizontal stream are presented at left and right positions, and stimuli in the vertical stream are presented in upper and lower positions of the display. Only one position in the horizontal and one position in the vertical stream contain a target word. In this particular trial, the horizontal stream starts first, with the first target appearing in the right position, followed by a second target in the lower position of the vertical stream, at a stimulus-onset asynchrony (SOA) of 143 ms. In a trial with an SOA of 715 ms, the second target would appear two items later.

stream; or (c) to divide attention over both streams and to identify both target words. In this way, attention to target stimuli was systematically manipulated. In the first two conditions, words in the attended stream received full attention, and words in the ignored stream received no attention. In the third condition, attention was equally divided over both the horizontal and vertical streams, reducing the possibility of task-switching, which is often the case in dual-task experiments. By varying the SOA between the first and the second target, we expected to induce an AB in the divided-attention condition at an SOA of 143 ms, but not at an SOA of 715 ms (on the basis of the literature and previous experiments).

Eye movements were not recorded in this experiment (nor in the other experiments reported here). Given the continuous stream of nontarget items, the unpredictability of target locations, the short stimulus durations, the time it takes to make an eye movement, and the requirement to fixate the eyes on the fixation point, it is unlikely that eye movements could play an important role here. Moreover, decreasing the distance between target locations and the fixation point has been shown not to have any effect on dual-task performance (Vecera & Farah, 1994).

Subjects were to withhold their responses until stimulus presentation in both streams had stopped. Responses were unspeeded and given vocally. The experimenter watched a second monitor that displayed the correct target words and scored each subject's responses by pressing the appropriate buttons on a keyboard. After the experimenter gave feedback on whether the responses were correct or incorrect, the next trial was initiated, with streams starting 250 ms later. Each block was followed by a short break.

After the AB task (the study phase), a perceptual identification task was given as an implicit memory test. Subjects were told that they were now going to perform a visual word processing task, and no reference was made to the preceding task. One hundred ninety-two words were presented in random order, one by one in the middle of the screen, and had to be identified. Half of these words were words from the previous AB task, and the other half were new words. Preceded by an exclamation mark with a duration of 1 s, each word was presented for 39 ms, followed by a mask consisting of four *x*s for 250 ms. The presentation duration was chosen because it resulted in about 60% correct responses in a pilot experiment, which was a suitable baseline performance for our purposes. The experimenter saw the correct word on the second monitor, scored each subject's vocal response, and provided feedback regarding whether it was correct or incorrect.

Finally, a recognition test was given to measure explicit memory performance. One by one, in random order, 192 words were presented in the middle of the screen. Half of these words had previously been presented during the AB task and had not been part of the implicit memory test, whereas the other half were new words. The task was self-paced, and subjects were instructed to say whether they had seen the word during the AB task. Vocal responses were scored by the experimenter using the keyboard and a second monitor that provided the correct answer. Subjects were given no feedback during this task. In total, the experiment took approximately 1.5 hr.

Results and Discussion

For all tasks, the proportions of correct word identifications were determined. To correct for the use of proportions in the analyses described below, we stabilized the variances by applying an arcsine transformation on mean proportions correct per subject and condition (Winer, 1962, p. 221).

Identification in the AB task. Mean accuracy (percentage correct word identification) in the AB task is shown in Figure 2. Negative SOAs refer to the first target word in each trial; positive SOAs refer to the second target. The values shown are means across the horizontal and vertical streams, which were scored independently. The focused-attention condition showed stable accuracy overall that was not time-locked to target word onsets. Of primary interest is the time course of interference between one target word and another in the divided-attention condition. Whereas performance was accurate for words presented at an SOA of 715 ms, accuracy was substantially reduced when a first target word was followed 143 ms later by a second target in the other stream. This pattern of interference clearly reflects an AB. A repeated measures analysis of variance (ANOVA) confirmed a significant effect of attention, $F(1, 23) = 37.05$, $MSE = 0.09$, $p < .001$, and SOA, $F(3, 69) = 56.92$, $MSE = 0.07$, $p < .001$, and a significant Attention $\times$ SOA interaction, $F(3, 69) = 44.10$, $MSE = 0.05$, $p < .001$. Separate analyses of divided and focused attention showed a significant effect of SOA on divided attention, $F(3, 69) = 84.16$, $MSE = 0.07$, $p < .001$, but not on focused attention. Pairwise comparisons of differences between means confirmed that in the divided-attention condition, only accuracy at an SOA of $+143$ significantly differed from the other SOAs ($p < .001$). Divided- and focused-attention performance did not differ except at an SOA of 143 ms, $t(23) = 12.55$, $SD = 0.35$, $p < .001$.

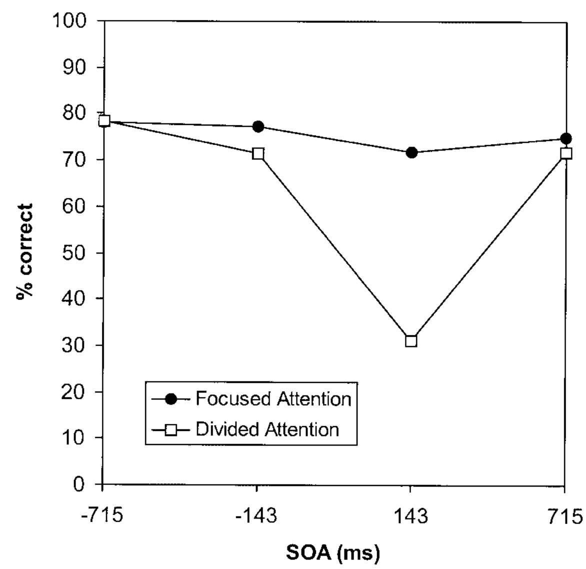

Figure 2. Mean accuracy (percentage correct for word identification) as a function of stimulus-onset asynchrony (SOA) in the attentional blink task of Experiment 1. Negative SOAs refer to the first target in each trial; positive SOAs refer to the second target.

Recognition results. The results of the recognition task are shown in Figure 3. Recognition of unidentified and no-attention words did not differ significantly from control words (percentage of false alarms was 13.2). A repeated measures ANOVA on correct recognition scores showed a significant effect of attention, $F(2, 46) = 122.65$, $MSE = 0.54$, $p < .001$, but no effect of SOA and no interaction. Mean pairwise comparisons showed that performance in the no-attention condition was significantly different from that in the focused-attention ($p < .001$) and divided-attention ($p < .001$) conditions. Performance on identified words in the focused-attention condition was significantly better than that in the divided-attention condition ($p < .05$).

Perceptual threshold results. Identification of attended target words in the AB task was either successful or unsuccessful. Re-

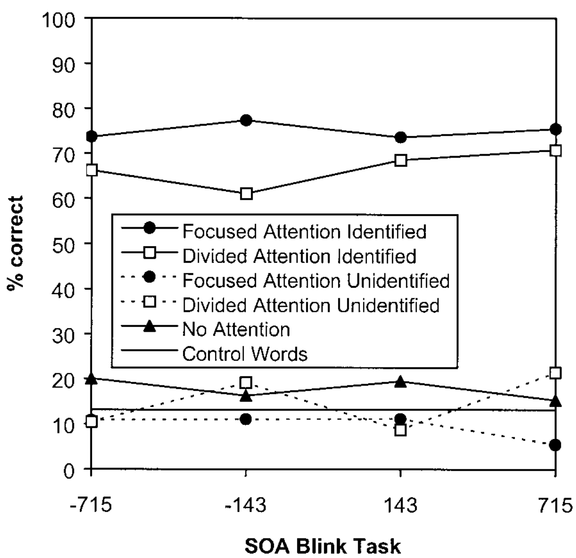

Figure 3. Mean accuracy (percentage correct for word recognition) as a function of stimulus-onset asynchrony (SOA) in the recognition test of Experiment 1. Negative SOAs refer to target words that were presented first in the attentional blink (AB) task, and positive SOAs refer to target words presented second. Solid lines show recognition performance for identified words in the AB task and words presented in the no-attention condition. Dotted lines reflect words that were not successfully identified in the previous AB task. The straight line reflects mean percentage of false alarms (recognizing a control word as a target word). Scores that are higher indicate explicit recall of (identified) words presented in the prior AB task.

sults in the subsequent perceptual identification test were analyzed accordingly. We first present results in the threshold task for words that were successfully identified and reported in the preceding AB task ("AB identified words") and then turn to the AB nonidentified data. It should be noted that there are two kinds of baseline data, namely, identification of control words (words not presented in the AB task) and identification of words presented in the nonattended condition of the AB task. The first was used to determine whether, and in which conditions, priming occurred. Because there was only a single value for identification of control words, these comparisons were done with *t* tests. The second baseline was used in ANOVAs as a base rate for comparison with the performance on identifying attended words. Because in the AB task no responses were collected for nonattended items, the data for these items were used both in the analysis of words identified and of words not identified in the AB task. In all three studies reported, we first present *t*-test analyses indicating in which conditions priming occurred, followed by ANOVAs showing the main and interaction effects of attention and SOA manipulations.

Perceptual threshold results for words identified in the AB task. First, it was determined whether the ability to identify a target word in the threshold identification test was better than for control words. Better performance indicates repetition priming. The results of the perceptual identification task are shown in Figure 4. Paired sampled *t* tests confirmed repetition priming effects at all SOA levels in the focused-attention condition, $ts(23) \geq 2.86$, $SDs = 0.56$ to 0.73, $ps < .01$. Words in the divided-attention condition were also significantly primed at all SOA levels, $ts(23) \geq 3.46$, $SDs = 0.45$ to 0.70, $ps < .01$. No priming occurred for unattended words (the no-attention condition), except at an SOA of 715 ms, $t(23) = 2.87$, $SD = 0.42$, $p < .01$.

A repeated measures analysis on the number of correct target identifications showed significant effects of attention, $F(2, 46) = 13.60$, $MSE = 0.35$, $p < .001$, but no significant effect of SOA and no interaction. Mean pairwise comparisons showed that performance in the no-attention condition was significantly different from performance in the focused-attention ($p < .001$) and divided-attention ($p < .001$) conditions. Divided- and focused-attention performance did not differ at any SOA, which is in line with the implicit memory literature (e.g., MacDonald & MacLeod, 1998; Parkin et al., 1990; Parkin & Russo, 1990).

Perceptual threshold results for words not identified in the AB task. The results of words that were not correctly identified in the AB task are also shown in Figure 4 (dotted lines). Paired sampled *t* tests showed no repetition priming effects for focused-attention and divided-attention conditions compared with control words. A repeated measures analysis on the number of correct target identifications in the focused-, divided-, and no-attention conditions showed a significant effect of attention, $F(2, 46) = 4.87$, $MSE = 0.73$, $p < .05$, but no effect of SOA and no interaction. Although inspection of Figure 4 suggests that performance on unidentified items in the focused- and divided-attention conditions was lower than on control words, this difference was not significant.

The main question addressed in this experiment is whether repetition priming occurs for words that fall within an AB. The

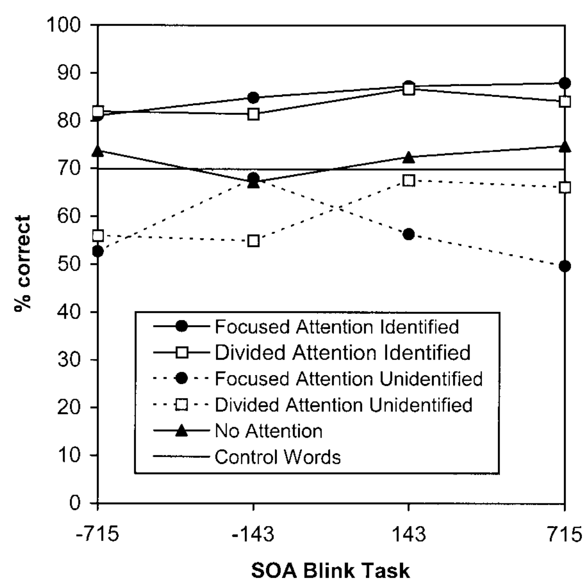

Figure 4. Mean accuracy (percentage correct for word identification) as a function of stimulus-onset asynchrony (SOA) in the perceptual identification task of Experiment 1. Negative SOAs refer to target words that were presented first in the attentional blink (AB) task, and positive SOAs refer to target words presented second. Solid lines show threshold performance for identified words in the AB task and words presented in the no-attention condition. Dotted lines reflect words that were not successfully identified in the previous AB task. The straight line reflects baseline identification performance for unstudied control words. Scores that are higher indicate perceptual priming effects by the prior AB task.

occurrence of such a blink is reflected in the AB task when the first word is successfully identified and the second word, presented at an SOA of 143 ms, is not correctly identified. Therefore, we selected words from these typical AB trials ("true blinks"; i.e., Target 1 identified and Target 2 not identified), and we looked at implicit and explicit performance of these truly blinked words. No significant repetition priming (65.8%) or recognition (7.3%) was observed for such blinked words, compared with control words (69.8% in the repetition priming task and 13.2% false alarms in the recognition task, respectively) or nonattended words (72.4% and 19.5%, respectively).

Experiment 2

In Experiment 1, no repetition priming was found for unidentified words, including words that fell within an AB. However, approximately 20 min passed between presentation of a word during the AB task (the study phase) and its presentation in the implicit memory test. It might be possible that blinked words are primed but that this priming wears off or is interfered with in a period of 20 min in which many other words are processed. Therefore, in Experiment 2 a shorter interval between study and test was used to test whether repetition priming does occur. To accomplish this, each trial within the AB task was immediately followed by a threshold identification task, to measure repetition priming effects over a shorter interval and without intermediate presentation of other words.

Method

Design and subjects. Thirty-six undergraduate students at Leiden University participated in this experiment; they had not participated in Experiment 1. The same factorial design was used as in Experiment 1, but explicit memory performance was no longer measured.

Materials. From the CELEX database (Baayen et al., 1993), a list of 336 words was created. All items were commonly used four-letter words that could be nouns, verbs, or adjectives. Care was taken to avoid semantic relations between any of these words. In addition, 112 four-letter words (commonly used first names) were selected for the practice trials.

Procedure. The experiment contained two blocks, consisting of 72 experimental trials and 24 practice trials. Before each block, subjects were given instructions to either divide or focus their attention. The order of these instructions and blocks, as well as the nature of the focused-attention instructions (focus on vertical or horizontal stream), was counterbalanced across subjects. The computer randomly assigned words as T1, T2, or control throughout the experiment. In this way, words were randomly presented in all conditions.

Each trial was subdivided in two subsequent tasks: a study task and a test task. For the study task, the same AB task was used as in Experiment 1, with target words appearing at horizontal and vertical locations. Depending on instruction, one or two of these targets had to be identified. Verbal responses were scored by the experimenter by pressing appropriate buttons on the keyboard.

Each trial was immediately followed by a perceptual identification task. A four-letter word was flashed on the screen for 39 ms, followed by a 500-ms backward mask consisting of a row of four *x*s. One third of these words was the first target word from the preceding AB task trial, one third was the second target, and the other third consisted of unstudied words (control words). As in Experiment 1, subjects were instructed to try to identify the word and to name it aloud. When the experimenter had scored the response, the next AB task trial was initiated. In both tasks, no feedback on performance was given to the subject.

With this new procedure, approximately 7 s elapsed between presenting a target word in the AB task trial and testing it in the subsequent perceptual identification task. The duration of the experiment was approximately 1 hr.

Results and Discussion

For all tasks, the proportions of correct word identifications were determined. Variances were stabilized using the transformation described in Experiment 1.

Identification in the AB task. For the AB task, divided-attention performance was compared with performance in the focused-attention condition (control). Figure 5 shows that the results were similar to the results for the AB task in Experiment 1. The divided-attention data showed a strong decrement in the ability to report T2 when it was presented 143 ms after the onset of T1. This AB effect was confirmed with a repeated measures ANOVA. A significant effect of both attention, $F(1, 35) = 22.77$, $MSE = 0.20$, $p < .001$, and SOA, $F(3, 105) = 84.01$, $MSE = 0.06$, $p < .001$, and a significant interaction, $F(3, 105) = 27.55$, $MSE = 0.05$, $p < .001$ were found. Separate analyses of divided and focused attention showed a significant effect of SOA on divided attention, $F(3, 105) = 109.32$, $MSE = 0.05$, $p < .001$, but also, in contrast to Experiment 1, on focused attention, $F(3, 105) = 8.63$, $MSE = 0.06$, $p < .001$. We further address the decrement in focused-attention performance in the General Discussion section. Pairwise comparisons of differences between means showed that divided- and focused-attention performance did not differ except at an SOA of +143, $t(35) = 12.03$, $SD = 0.33$, $p < .001$.

Perceptual threshold results. As described earlier, each AB task trial was followed by a perceptual identification task to measure repetition priming of the stimuli that had just been presented. A target word could have received divided attention, full attention, or no attention (the ignored word in the focused-attention

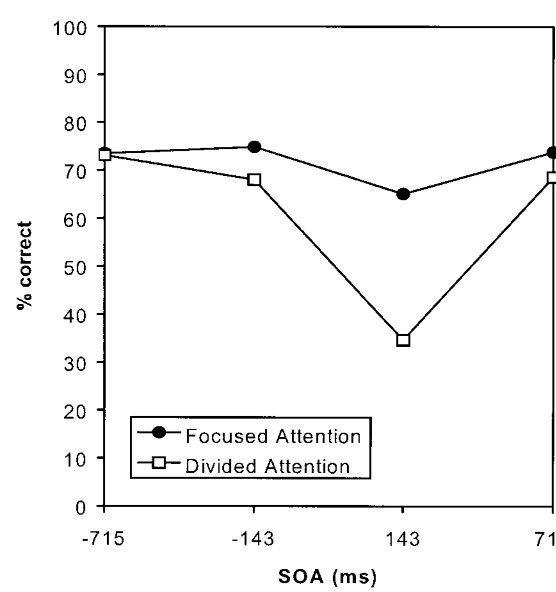

Figure 5. Mean accuracy (percentage correct for word identification) as a function of stimulus-onset asynchrony (SOA) in the attentional blink task of Experiment 2. Negative SOAs refer to the first target in each trial; positive SOAs refer to the second target.

condition). Separate analyses were carried out for words that had or had not been successfully identified in the prior AB task. As in Experiment 1, we first present comparisons with control words (words not presented in the AB task) in the form of *t* tests, followed by ANOVAs for analyzing the effects of attention and SOA manipulations in the AB task. For optimal comparability, perceptual identification performance of target words was compared with control words that were tested in the same (divided- or focused-attention) block.

Perceptual threshold results for words identified in the AB task. For the threshold identification task, percentages correct for identification of target words presented in the various conditions are shown in Figure 6. Priming effects were tested relative to performance on control words. For AB identified words, *t* tests showed significant priming for words that had received full (focused) attention, at all SOA levels, $ts(35) \geq 5.89$, $SDs = 0.78$ to 0.85, $ps < .001$. Words that had received divided attention were also significantly primed at all SOA levels, $ts(35) \geq 7.97$, $SDs = 0.61$ to 0.75, $ps < .001$. Compared with control words, no significant priming was observed for words that had been presented in the AB task under conditions of no attention (the ignored word in the focused-attention condition), at any of the SOAs.

A repeated measures analysis on the number of correct target identifications in the threshold identification task showed significant effects of attention, $F(2, 70) = 43.13$, $MSE = 0.71$, $p < .001$, no significant effect of SOA, and no interaction. Interestingly, the absence of SOA effects in all of the experimental conditions indicates that words presented at short SOAs showed as much priming as words presented at longer SOAs.

Mean pairwise comparisons showed that performance in the no-attention condition was significantly different from that in the focused-attention ($p < .001$) and divided-attention ($p < .001$) conditions. Performance in the divided- and focused-attention conditions did not differ, which is in line with the implicit memory literature.

Perceptual threshold results for words not identified in the AB task. The results for words that were not identified in the AB task are also shown in Figure 6 (dotted lines). Words that had received no attention in the AB task did not differ from control words. Significant differences were found, however, comparing control words with both focused-attention, $ts(35) \geq 3.16$, $SDs = 0.88$ to 1.1, $ps < .01$, and divided-attention, $ts(35) \geq 2.74$, $SDs = 0.17$ to 0.88, $ps < .01$, conditions for all SOAs, except 143 ms. However, as can be seen in Figure 6, these differences were quite unlike what might be expected. Performance for unidentified target words presented in these conditions was actually lower instead of higher than for control words.

As in Experiment 1, we again selected the typical AB trials (identification of the first target followed by no identification of the second target word in the divided-attention condition). Threshold identification performance for these words was 35.6%, which also is significantly lower than the 46.5% performance for the control words, $t(35) = 5.13$, $SD = 0.34$, $p < .001$. So it seems that words that are not identified in the AB task, whether blinked or otherwise, are harder to identify when encountered again than are completely new words.

This observation is surprising, because one would expect performance to be either the same (indicating a lack of repetition priming) or higher (indicating priming). The finding seems to indicate that blinked words not only are wiped out of working memory but also are somehow actively inhibited, comparable to the negative priming effect (Tipper, 1985). It should be noted, however, that by selecting words that were not successfully identified in the prior AB task one runs the risk of selecting a subset of trials containing words that, for whatever reasons, are somewhat more difficult to identify than other words. If priming effects are subsequently compared with performance for control words, the results could be confounded because the control words consist of both difficult and easy-to-identify words. In that case, the reduced performance is an artifact instead of an indication of suppression.

To check this explanation, we selected only words that had appeared in the experiment both as a control word and as a blinked word (across different subjects). We obtained an accuracy score of 36.6% for blinked words (based on 175 observations) and of 42.2% (instead of 46.5%) for control words (based on 346 observations). Fisher's z scores showed no significant difference between these scores ($z = 1.24$, $p = .107$). So it appears that indeed in this case the suppression effect is an artifact caused by a comparison of different sets of words.

The observation of unidentified items being below baseline in the perceptual threshold task might also be explained in terms of intrusion errors. If subjects made intrusion errors when attempting to report T2, particularly reporting words that share orthography with the actual T2, there might be a tendency to misidentify that T2 again when it is presented in the perceptual threshold task and to report it as the intrusion item. Unfortunately, we could not inspect

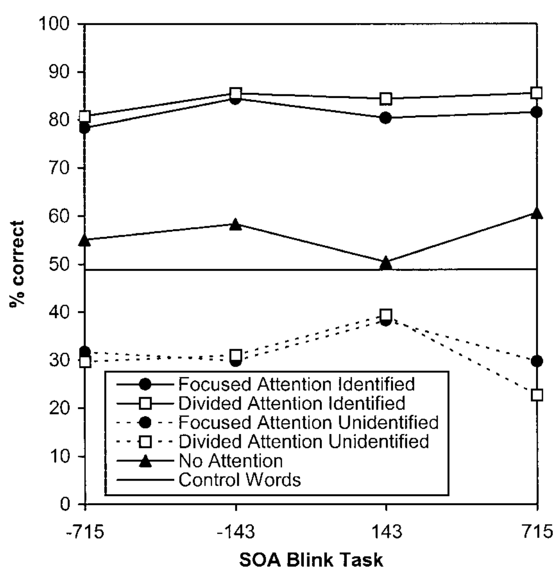

Figure 6. Mean accuracy (percentage correct for word identification) as a function of stimulus-onset asynchrony (SOA) in the perceptual identification task of Experiment 2. Negative SOAs refer to target words that were presented first in the attentional blink (AB) task, and positive SOAs refer to target words presented second. Solid lines show threshold performance for identified words in the AB task and words presented in the no-attention condition. Dotted lines reflect words that were not successfully identified in the previous AB task. Mean correct control words used in the focused- and divided-attention blocks were 51.3% and 46.5%, respectively. Scores that are higher indicate repetition priming effects by the prior AB task.

our data for such intrusion errors, as these were not recorded in the experiment. Although the observation of an apparent suppression effect is intriguing and deserves to be followed up in subsequent studies, at this point we cannot say whether it is a real effect or whether it reflects intrusion errors or a selection artifact.

The main conclusion from the study reported here is that no repetition priming occurs for blinked words. This leaves two possibilities. Either blinked words are processed but do not leave any lasting traces in memory or they do leave some trace that does not show up in a perceptual identification test. The purpose of Experiment 3 was to test this latter possibility.

Experiment 3

Experiments 1 and 2 showed that words falling within an AB do not lead to repetition priming in a data-driven test, that is, they are not perceptually primed. In Experiment 3, we wanted to determine whether these blinked words do not leave a trace at all or whether some form of processing is taking place that does not show up in a perceptual priming test but might show up in a semantic priming task. If we would find priming of semantically related words, this would suggest that although perceptual information from the blinked word is suppressed or overwritten in working memory, semantic processing has taken place and leaves an observable trace.

Method

Design and subjects. Thirty-six undergraduate students at Leiden University participated in this experiment; they had not participated in Experiment 1 or 2. The same factorial design was used as in Experiment 2.

Materials. The materials were the same as in Experiment 2, with the following modification. For each of the 336 target words, another word was selected that was strongly associated with it, for instance, *lady–gentleman*, *jazz–music*, or *weak–strong*. The associated words were based as much as possible on normative association lists (de Groot, 1980; de Groot & de Bil, 1987). The same criterion for intermediate frequency was used, but the word-length criterion had to be relaxed by allowing words consisting of 3 to 13 letters. Where associations were missing, they were supplied by two colleagues who were asked to give a strong semantic association to each of the 336 original target words. A pilot experiment showed effective semantic priming for all selected words.

Procedure. The procedure was the same as in Experiment 2, except for the stimuli used in the perceptual identification task. Instead of presenting a word that was a target in the previous AB task trial, a semantically associated word was briefly presented. Presentation duration of the associated word was 39 ms, and presentation was followed by a 500-ms mask of 14 *x*s. Subjects were asked to try to identify and report the associated word. No feedback on the subjects' performance was provided. Practice words were presented in the same way as in Experiment 2.

Results and Discussion

For both the AB task and the threshold identification task, the proportions of correct word identifications were determined. For all analyses, proportions were corrected as in Experiments 1 and 2.

Identification in the AB task. The AB task was exactly the same as in Experiment 2, and identification and blink results were practically the same as well (see Figure 7). A repeated measures ANOVA showed a significant effect of both attention, $F(1, 35) = 40.65$, $MSE = 0.16$, $p < .001$, and SOA, $F(3, 105) = 108.94$, $MSE = 0.07$, $p < .001$, and a significant Attention × SOA interaction, $F(3, 105) = 23.39$, $MSE = 0.05$, $p < .001$, was found. Separate repeated measures analyses showed a significant effect of SOA on divided attention, $F(3, 105) = 180.55$, $MSE = 0.04$, $p < .001$, and focused attention, $F(3, 105) = 15.96$, $MSE = 0.08$, $p < .001$. Pairwise comparisons of differences between means confirmed that only accuracy at an SOA of +143 was significantly different from the other SOAs ($p < .001$).

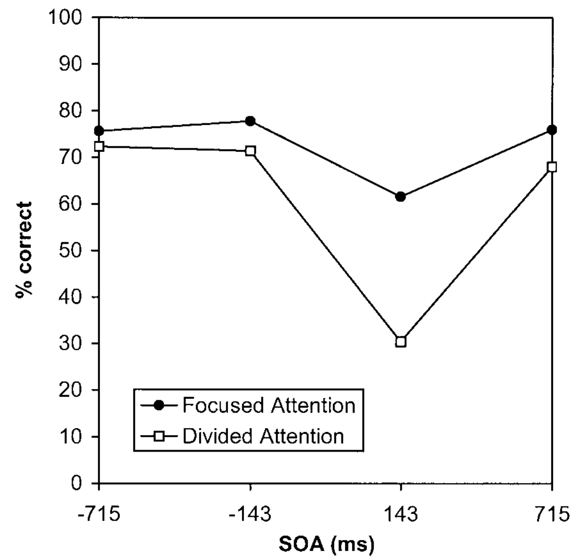

Figure 7. Mean accuracy (percentage correct for word identification) as a function of stimulus-onset asynchrony (SOA) in the attentional blink task of Experiment 3. Negative SOAs refer to the first target in each trial; positive SOAs refer to the second target.

Threshold results for words semantically related to identified words in the AB task. Figure 8 shows the results from the threshold identification task for words that were semantically related to words previously presented in the AB task. First, it was determined whether the ability to identify words semantically related to words identified in the AB task was better than for control words (unrelated words that had not been presented in the previous AB task). For AB identified words, *t* tests showed significant priming for the words semantically related to words that had received full (focused) attention, at all SOA levels, $ts(35) \geq 3.35$, $SDs = 0.66$ to 0.74, $ps < .01$. Words related to identified words in the divided-attention condition were also significantly primed at all SOA levels, $ts(35) \geq 2.94$, $SDs = 0.44$ to 0.57, $ps < .01$, except an SOA of +143, which did show a trend, $t(35) = 1.99$, $SD = 1.07$, $p = .054$. No significant priming was observed for words related to items from the no-attention condition (ignored words in the AB task), at any of the SOAs. Although these results show a consistent pattern, it should be noted that these analyses were based on relatively small numbers of observations (i.e., about four and eight observations per subject at each SOA in the focused- and divided-attention conditions, respectively).

A repeated measures analysis on the number of correct target identifications in the perceptual identification task for words presented in the focused-, divided-, and no-attention conditions confirmed the *t* test results. This analysis showed a significant effect

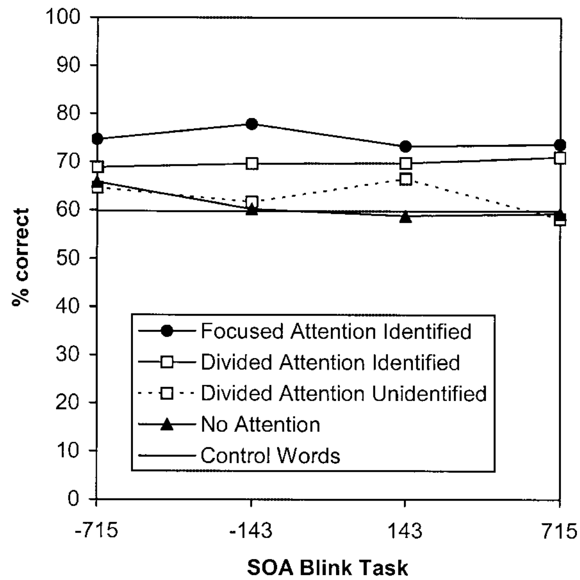

Figure 8. Mean accuracy (percentage correct for word identification) as a function of stimulus-onset asynchrony (SOA) in the perceptual identification task of Experiment 3. Shown values are for words that are semantically related to words presented in the prior attentional blink (AB) task, at different levels of attention and SOA. Negative SOAs refer to target words that were presented first in the AB task, and positive SOAs refer to target words presented second. Solid lines show threshold performance for words semantically related to identified targets in the AB task and for words presented in the no-attention condition. The dotted line shows threshold performance on words semantically related to unidentified words in the previous AB task. Only the divided-attention condition is shown. The number of relevant observations per SOA in the focused-attention condition was too small to be included in this figure. Mean correct control words used in the divided-attention condition was 59.8%. Scores that are higher indicate semantic priming effects by the prior AB task.

of attention, $F(2, 70) = 12.44$, $MSE = 0.52$, $p < .001$, no significant effect of SOA, and no interaction. The absence of SOA effects in all of the experimental conditions shows that the amount of priming was not affected when targets were presented at a short SOA. Mean pairwise comparisons showed that performance in the no-attention condition was significantly different from that in the focused-attention ($p < .001$) and divided-attention ($p < .05$) conditions. Also, the divided- and focused-attention conditions differed significantly ($p < .05$).

Threshold results for words semantically related to nonidentified words in the AB task. Figure 8 also shows the results from the threshold identification task for words that were semantically related to nonidentified words in the AB task (dotted lines). Compared with control words, no differences in performance were found for words related to words that had received focused, divided, or no attention, with one exception. There was a significant semantic priming effect, $t(35) = 3.22$, $SD = 0.35$, $p < .01$, in the divided-attention condition at an SOA of +143 (i.e., the AB condition). This effect was still present when only true blink data (see Experiment 2 for selection procedure) were analyzed, $t(35) = 3.08$, $SD = 0.46$, $p = .004$. Threshold performance for words related to blinked words was 67.4% correct (based on 218 observations), whereas performance for control words was 59.8%.

Note that there is no longer a risk of a confounding by selection effect in this analysis. Previously, we argued that the subset of blinked words that subjects failed to identify might generally be words that are somehow more difficult to process than other words. When compared with control words that include a random selection of both easy and difficult words, any difference that is observed might be an artifact instead of a real difference. In Experiment 3, however, we tested semantically associated words instead of the target words themselves. Even though blinked words might generally be more difficult words to identify, there is no reason to assume that an association of this target word is also perceptually more difficult to identify. Moreover, if item selection effects were operating, they would mitigate against scoring above baseline. The above-baseline performance itself is inconsistent with item selection effects. Therefore, we are confident that the observed effect is not an artifact. We conclude that even words that subjects were unaware of, that is, when they were presented during an AB, cause a priming effect in semantically related words.

Given that we observed a reliable semantic priming effect for blinked words (i.e., unidentified words presented in the divided-attention condition of the AB task at an SOA of 143 ms), why did we not find semantic priming effects for unidentified words in the other conditions (at other SOAs, and with focused attention)? We believe there is a theoretical explanation for these findings, which we elaborate in the General Discussion section. However, there is one other possible explanation that has to be mentioned. It has to be realized that all conditions in which no semantic priming was found were based on relatively few trials, so those results are not very stable. In the AB condition with an SOA of 143 ms, approximately 70% of the T2 words were blinked (i.e., not identified). In contrast, in all other conditions only 20%–30% of the words were not successfully identified. Only a third of all the nonidentified items was subsequently tested. Therefore, the semantic priming found in the typical blink condition (divided attention and an SOA of 143 ms) is based on over twice as many observations (on average about nine per subject) than the other conditions (on average about four per subject), making this result much more reliable. At the same time, however, this indicates that we cannot be very sure about the absence of semantic priming in the other conditions.

To summarize, significant semantic priming occurred for words that were related to attended and successfully identified words in the prior AB task. Words that were not attended produced no such priming. Remarkably, however, blinked words that were not identified in the AB task did produce significant semantic priming. Threshold identification performance for words semantically associated to blinked words was not significantly different from the mean performance of words associated to identified words. This suggests that amount of priming was the same and that the occurrence of an AB had no adverse effect on priming of semantically related words.

General Discussion

Empirical Findings

The main question of interest in this article was whether long-term repetition and semantic priming effects can be observed for words that fall within an AB. In the experiments, the AB paradigm as used by Duncan et al. (1997) was adapted to systematically manipulate attention while presenting T1 and T2 at varying SOAs. In all three studies reported, the paradigm induced an AB when two target words that were presented at a short SOA (143 ms) had to be reported (the divided-attention condition). In this case, subjects failed to identify T2 in about 70% of the trials, reflecting the occurrence of an AB. A result in the AB task reported in this study that is somewhat incongruent with previous results is a small but significant SOA-dependent decrement of target identification performance in the focused-attention condition (Experiments 2 and 3). Other studies (e.g., Duncan et al., 1997) have shown that subjects are quite capable of ignoring a first target, and these studies have not reported an effect of SOA in conditions of focused attention. Although many studies have shown a small, insignificant decrease in performance, the lack of a significant effect is commonly taken as evidence that the decrement in divided-attention performance is truly an effect of attention instead of some visual masking effect. We do not think, however, that the present finding is problematic because it did not have an effect on the priming data, which is the central topic of this article.

Results of Experiment 1 showed that relative to unstudied control words, recognition and repetition priming performance increased for identified target words in full- and divided-attention conditions. However, when subjects did not attend to a target word, or failed to identify the target word in the AB task, no significant recognition or repetition priming occurred. More specifically, no recognition or repetition priming was observed for blinked words (unidentified target words that followed an identified target word at an SOA of 143 ms in the divided-attention condition). These results were replicated in Experiment 2, in which repetition priming was measured within a much shorter time interval, immediately after each trial of the AB task. Experiment 3 showed semantic priming for words related to identified words in the AB task. No such semantic priming was found for words related to unattended or unidentified target words, with one important exception however. Priming did occur for words semantically related to blinked words. If, for example, the word *ring* is blinked, it is subsequently easier to identify the briefly presented word *wedding* than an unrelated word such as *apple*. In discussing the possible implications of the findings reported here, we make a distinction between the priming effects of items falling outside and within an AB.

Priming effects of words falling outside an AB. Experiments 1–3 showed significant priming for words presented in full- or divided-attention conditions that were identified. No significant priming effects were found for words that had received no attention or words that were not identified. Apparently, to produce repetition or semantic priming over intervals of at least a few seconds, stimuli must be attended (cf. MacDonald & MacLeod, 1998; Maki, Frigen, & Paulson, 1997) or at least receive an amount of processing necessary for long-term changes in memory traces to occur (Wolters & Prinsen, 1997).

No differences were found in the repetition priming effects of identified items in focused- and divided-attention conditions in Experiments 1 and 2. However, this manipulation did affect recognition performance (Experiment 1) and the semantic priming effect in Experiment 3. This latter finding seems to contradict some reports in the literature indicating that manipulations of attention do not affect performance in implicit memory tests (e.g., MacDonald & MacLeod, 1998; Parkin et al., 1990; Parkin & Russo, 1990). However, findings of attentional effects on implicit memory performance are not uncommon (see Hawley & Johnston, 1991; Pickering, Mayes, & Shoquirat, 1988), and it has been suggested that such effects may be expected in impoverished (i.e., very brief or very weak) presentation conditions (Hawley & Johnston, 1991; Wolters & Prinsen, 1997) and in conceptually driven implicit memory tests in particular (Mulligan, 1997).

Priming effects of words falling within an AB. Of primary interest in the studies reported here are possible priming effects of words falling within an AB that cannot be identified. As was noted in the introduction, several studies using ERP measures showed that such blinked words are fully processed and that an AB occurs at some postperceptual stage. In the studies reported here, words falling within an AB that were identified showed recognition and priming effects comparable to identified words falling outside an AB. Words falling within an AB that were not identified showed no repetition priming for blinked words in a perceptual threshold task. In contrast, however, a semantic priming effect for words related to target words in the AB task was observed. This finding was upheld when the analysis was restricted to true blinks only (i.e., correct identification of the first and no identification of the second target word in the divided-attention condition). Although it has to be acknowledged that the effect size was rather small and based on a relatively limited number of observations, this finding seems rather robust. It may be noted, for example, that no significant differences were found in the amount of priming for blinked words and for identified words within and outside the AB.

The semantic priming effect caused by unidentified target words presented in the AB task clearly suggests that blinked words are processed up to a conceptual representation level and that suppression occurs at a later stage. However, this priming effect is paradoxical in two respects. First, why is this priming effect found only for unidentified words at an SOA of 143 ms and not at other SOAs? Second, how can it be that priming occurs for a semantically related word but not when the target word itself is repeated?

With regard to the first paradox, we suggest that if a word is not identified in conditions that, in principle, would allow identification, this indicates a reduction of normal processing due, for example, to temporary distraction. In contrast, if a word is not identified in an AB situation, this probably indicates normal processing to a high level in a first stage but interference in a postperceptual processing stage required for reaching conscious awareness. This situation seems similar to a paradoxical result reported by Marcel (1983) showing that as SOA between a word and a mask was reduced, subjects reached chance performance earlier on the detection of the presence of a word than on a semantic decision about that word. Thus, when information necessary for detecting the presence of a given target was already lost, the meaning of that target was still accessible.

The second paradoxical finding may be explained by following up on the explanation of the first paradox. We suggest that the second processing stage, required for becoming aware of the presence and identity of a stimulus, may consist of a binding process in which high-level representations feed back on the perceptual representations. This binding process for the first target probably interferes with the binding process of the second target, for instance, by corrupting its perceptual representation. So the first stage of processing of the second target stimulus may proceed normally, causing activation of related semantic representations (and later semantic priming), whereas the second stage of processing is interfered with, causing a suppression of its perceptual and semantic representations and an inability to report this target (and absence of priming). We return to this explanation in the next section discussing models of the AB.

The priming effect of words semantically related to target words found in Experiment 3 stands in sharp contrast with the generally observed difficulty in showing semantic priming effects lasting longer than a few hundred milliseconds. Semantic priming effects can be based on automatic (i.e., spreading activation) and controlled (i.e., expectancy-induced) processes (see Neely, 1991). Automatic semantic priming often seems extremely short-lived. A number of studies have shown that it is strongly reduced or even completely eliminated if one or more unrelated words intervene between presentation of the prime and the target (e.g., Joordens & Besner, 1992; Masson, 1995). Recently, however, evidence for semantic priming surviving up to eight intervening items was obtained by Joordens and Becker (1997) in a lexical decision task. Long-term semantic priming was also reported by McDermott (1997). In that study, subjects studied series of words strongly associated to nonpresented critical words. Semantic priming of these critical words was observed in word-stem and word-fragment completion tasks (for a discussion of these effects, see Zeelenberg & Pecher, 2002). These findings suggest that an automatic semantic priming effect, showing up in our study after about 7 s and after subjects gave one or two verbal responses, is not inconceivable.

Models of the AB

There are currently three leading models of the AB: the two-stage model (Chun, 1997; Chun & Potter, 1995), the interference model (e.g., Isaak, Shapiro, & Martin, 1999), and a hybrid model suggested by Vogel et al. (1998). These models share a high degree of convergence in that they assume that all items presented in a stream of information are fully processed up to the point of conceptual or semantic representations, and that the AB is described as a deficit in processing the second target arising from a capacity-limited second stage of processing.

The two-stage model conceptualizes second target processing difficulty to be a difficulty in the process of binding semantic (type) information to perceptual (token) information. The AB is seen as a failure of a second target to reach Stage 2, because this stage is still occupied with binding and consolidating a previous target. According to the interference model, both targets are fully processed and enter working memory. However, because of the limited capacity of working memory, both targets have to compete for the available resources. The AB reflects this interference, which causes the second target to be lost from working memory. The hybrid model assumes both the two stages and an interference process. After information is fully identified at all levels of analyses, it is stored in a conceptual short-term memory buffer. At this stage, items are not yet available for overt report and conscious awareness, and their representations are highly susceptible to interference and decay. Subsequently, attention consolidates relevant items by transferring them into a more durable and reportable form in visual working memory. The phenomenon of an AB is explained by assuming that while attentional processes are engaged in transferring T1, they are temporarily unavailable for T2, resulting in loss of information and errors in reporting T2.

We suggest the following alternative model to explain the phenomenon of AB and the pattern of results reported in this article. This alternative is similar to the models discussed, in that it also assumes that a second target item is fully processed in a first stage and that the AB is due to a deficit occurring in a second processing stage. It differs, however, in the nature of the assumed deficit. There is converging evidence that awareness of the presence and identity of a visual stimulus depends on an attentional process consisting of a feedback mechanism from high-level representations to preceding lower level representations (e.g., Chelazzi, Miller, Duncan, & Desimone, 1993; Lamme, 2001; Mehta, Ulbert, & Schroeder, 2000; Van der Velde & De Kamps, 2001). This feedback process follows a feedforward processing cycle that activates representations in subsequent processing levels, up to representations corresponding with the meaning of a stimulus, and even possible relevant responses. This feedforward cycle occurs in the absence of awareness of the presence of the stimulus. Visual awareness is critically dependent on a feedback cycle reactivating early representations in primary visual cortex. Such feedback can be interpreted as a process of binding high-level representations to the lower level representations that caused their activation. This idea suggests a mechanism for the hypothesis that object perception is mediated by linking semantic type information to spatiotemporal token information in the form of object files (Chun, 1997; Kahneman & Treisman, 1984; Kanwisher, 1991).

We suggest that the phenomenon of the AB results from interference with this feedback-binding process of T2. The feedback-binding process of T1 suppresses or corrupts the perceptual representation of T2. This interferes with the feedback-binding cycle of T2, causing the AB phenomenon. The corruption of the perceptual representation of T2 explains why the subject is unable to report the word and why no repetition priming is found for blinked T2 items. In turn, the corruption of the perceptual representation may also weaken the semantic representation, thereby further reducing the chances of finding repetition priming. Intact semantic priming is still possible because the feedforward processing cycle of T2 activates semantically related representations, which enhances subsequent identification of items corresponding with these representations. The assumption of an intact feedforward processing cycle of T2 also allows an explanation of the fact that erroneous T2 responses often are not random guesses. Instead, responses tend to be other nontarget items from the stream of information (Isaak et al., 1999; Maki, Couture, Frigen, & Lien, 1997). Although these items can be ignored, they probably are fully processed. Occasionally, therefore, they may be identified and influence response probabilities.

The model suggested here is also consistent with the finding that the size of an AB depends on the discriminability between targets and distractors in an RSVP task (e.g., Chun, 1997). Less discriminability probably results in greater interference between multiple competing feedback-binding processes. Moreover, it is consistent with the finding that the AB effect is enhanced when target items are physically similar (Raymond, Shapiro, & Arnell, 1995; Shapiro & Raymond, 1994; Shapiro et al., 1994), because in that case more interference in the feedback-binding process of T2 is to be expected.

A phenomenon related to AB is the repetition blindness (RB) effect (e.g., Kanwisher, 1991). Here the same target is repeated, and subjects have to decide whether one or two targets were seen. In comparison with AB, RB presents an additional difficulty in individuating the second occurrence of a repeated item as a distinct event. RB typically decreases as a function of increasing SOAs and is especially prominent at very brief SOAs (e.g., Chun, 1997). This may indicate a gradient of two identical feedback-binding processes merging into a single conscious percept. Interestingly, the AB effect typically shows a U-shaped function of SOA. The AB deficit is small when T2 occurs within 100 ms after T1; it is largest at SOAs of about 200 ms and decreases again, asymptoting at about 500 ms. This temporal pattern of AB might be expected if the time course of the feedback cycle takes about 200 ms and if the peak interfering effect on processing T2 occurs when feedback of T1 and feedforward activation of T2 at the level of perceptual spatiotemporal representations coincide. Because the feedforward sweep reaches higher visual representation areas in about 80 to 120 ms, and the P300 component of ERP measures (corresponding to conscious identification and probably successfully completed binding) occurs about 300 ms after stimulus onset, this does not seem an unlikely, albeit a highly speculative, estimate.

To summarize, the model presented here suggests that the AB reflects the time that is needed to bind semantic and perceptual information. Under the conditions in which AB effects typically occur, the dominant activation of one target will temporarily prevent interactive enhancement and binding of semantic and perceptual activations of other relevant targets. The model described is speculative and needs further working out. Although the model is broadly similar to alternative models, and all of them are closely related to ideas expressed in an early article by Duncan (1980), the binding model suggested here provides a more neurological view of the processes that may cause the AB effect.

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