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Priming in the attentional blink: Perception without awareness?

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The attentional blink refers to a reduction in accuracy that occurs when observers are required to identify the second of two rapidly sequential targets. Even when the second target cannot be reported, however, it is still capable of priming the response to a subsequent related item. At issue in the present work was whether this priming is attributable mainly to conscious or unconscious processes. To answer this question, we used an exclusion procedure that permitted an assessment of the relative dominance of conscious and unconscious processes. The results showed that second targets that are identified incorrectly are nonetheless processed extensively outside of awareness. Moreover, this processing is sufficient to prime a subsequent response for at least 1 s after the onset of the prime.

From watching the evening news, to talking on the telephone, to feeling the keys beneath our fingers as we type, our experience consists of a rapid stream of inputs across our sensory modalities. Although this wealth of environmental information is a boon to us, it is also a constant threat to overwhelm our limited processing capabilities. To prevent such sensory overload, the brain has evolved specialized mechanisms for selecting

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certain information from the environment, while filtering out extraneous or unimportant input.

Selective attention in vision has been studied using a paradigm known as *rapid serial visual presentation* (RSVP). A representative example comes from Chun and Potter (1995; Experiment 1). In that experiment, observers were presented with an RSVP stream of digits displayed at the center of the screen at a rate of 10 items/s. Embedded within the digit stream were two letter targets, separated by a variable temporal interval. Chun and Potter (1995) found that identification of the first target (T1) was uniformly high. In contrast, identification of the second target (T2) varied as a function of the temporal interval (lag) between the targets. At shorter lags (e.g., 200-300 ms), T2 identification was poor. As lag increased to about 700 ms, however, T2 identification returned to a level equivalent to that of T1. The deficit in T2 accuracy at short lags has been named *attentional blink* (AB).

Theoretical accounts have focused on high-level processing of T1 as the prime determinant of the AB deficit (see Raymond, Shapiro, & Arnell, 1992 for a refutation of explanations based on low-level vision). On these accounts (e.g., Raymond, Shapiro, & Arnell, 1995; Chun & Potter, 1995), the requirement to attend to the first target delays allocation of attentional resources to the second target for a period of several hundred ms. As a result, if the second target is presented soon after the first, it cannot be processed immediately, and is thus vulnerable to decay or overwriting by subsequent stimuli (e.g., Giesbrecht and Di Lollo, 1998). As inter-target interval increases, however, processing of the first target is more likely to be completed by the time the second target is presented, thus allowing ready access to attentional resources.

Although a delay in the allocation of attention to T2 clearly impairs identification, there is abundant evidence to suggest that at least some processing of T2 can occur in the absence of attention. This has been shown by Shapiro, Caldwell, and Sorensen (1997a) who demonstrated that an observer's name can escape the blink more easily than other people's names or common nouns. Indeed, processing of an unattended T2 can occur up to a semantic level, as has been shown by Luck, Vogel and Shapiro (1996; see also Vogel, Luck, & Shapiro, 1998; Rolke, Heil, Streb, & Hennighausen, 2001) who recorded event-related brain activity during the AB. They found that the amplitude of the N400 wave varied as a function of the semantic mismatch between T2 and a context word, even when the identity of T2 could not be reported.

In addition, recent evidence suggests that processing of an unattended T2 is sufficient to prime subsequent items in the RSVP stream. For example, Shapiro, Driver, Ward, and Sorensen (1997b) presented an RSVP stream of words that were coloured black. Embedded within this stream were three non-black target words. The three targets were separated from one another by intervals of 270 ms. This temporal separation was sufficient to yield maximum impairment for T2, and eliminate any harmful effects of T1 on T3. As in previous studies, T2 identification was severely impaired by the requirement to attend to T1. However, even when T2 failed to be identified, identification of T3 was better when it was semantically related to T2 than when it was unrelated. This suggests that processing of an unattended T2 is sufficient to prime a subsequent semantically-related item.

At issue in the present work is whether the priming demonstrated by Shapiro et al. (1997b) was due to unconscious—as distinct from conscious—processing of the unattended T2. It is commonly assumed in AB studies that at least some aspect of T2-processing occurs outside of awareness. For example, Shapiro et al. (1997b) state ‘‘Awareness of events during the blink can be prevented, but type activation can apparently continue unconsciously…’’ (p. 99). Similarly, Rolke et al. (2001) propose that the AB may be ‘‘an attentional manipulation that prevents conscious priming mechanisms … allowing automatic spread of activation to occur.’’ (p. 167). These arguments, however, are predicated on a dissociation between two measures of T2 processing: identification and priming. In the study of Shapiro et al. (1997b), for example, the identification measure showed that T2 could not be identified correctly on ‘‘blinked’’ trials, whereas the priming measure indicated that the unreported T2 facilitated perception of a related T3. The fact that priming occurred indicated that T2 had been processed at least to some degree. By the same token, the fact that T2 could not be reported accurately suggested that T2 had not been processed up to a conscious level. Taken together, these two considerations led to the conclusion that some form of unconscious processing of T2 had taken place.

Although finding such a dissociation is indeed suggestive, it does not provide conclusive evidence that unconscious perception has occurred. As noted by Merikle (1992; Merikle, Joordens, & Stolz, 1995), it is first necessary to show that there is no conscious component in the processing of the prime. That is, the display conditions must be such that the observer cannot identify the prime (T2, in the study of Shapiro et al., 1997b) at a level higher than chance (i.e., d’ should be equal to zero). Unless this ‘‘null-sensitivity’’ criterion can be met, the possibility remains that priming is mediated, at least in part, by conscious processing of the prime.

In the studies of Shapiro et al. (1997b) and Rolke et al. (2001), it is clear that the null-sensitivity criterion proposed by Merikle (1992) had not been met. In the study by Shapiro et al (1997b), identification accuracy for T2, which was used as a prime, was approximately 46% (chance = 7.7%); in the study of Rolke et al. (2001), T2 accuracy was approximately 49% (chance = 4.2%). Clearly, the display conditions in these studies allowed T2 to be identified at a level beyond what would be expected by mere guessing if T2 had not been presented. This, in turn, raises the possibility that conscious processing of T2 occurred on at least some trials. To the extent that this happened, priming in the studies of Shapiro et al. (1997b) and Rolke et al. (2001) may have been mediated by conscious, rather than unconscious, perception of T2.

As an alternative to the null sensitivity criterion, Merikle et al. (1995) suggested using a single measure that indexes the relative dominance of conscious and unconscious processes. Such a measure places conscious and unconscious influences in opposition to one another, with each yielding different experimental outcomes. On this option, it is not necessary to demonstrate that conscious influences are completely absent in order to conclude that unconscious processing has occurred. Instead, what must be demonstrated is merely that unconscious influences are predominant in determining the response.

One way of assessing the relative dominance of conscious and unconscious perception is to use an exclusion procedure in which observers are asked *not* to use perceived information to complete a task. For example, in the experiment of Debner and Jacoby (1994), a prime word (e.g., spear) was presented, followed by a word-stem consisting of the first three letters of the prime (e.g., spe__). Observers were required to complete the stem without using the word that had just been presented. Debner and Jacoby (1994) found that when the prime word was presented under full-attention conditions, it was used to complete the stem significantly less often than a baseline level established under comparable conditions. In contrast, when the prime was presented under divided-attention conditions, it was used to complete the stem significantly more often than baseline level.

Such deviations from baseline can be used to assess the magnitude of subliminal priming on two assumptions. The first is that conscious perception of the prime will always allow successful exclusion performance. For example, a consciously-perceived prime will never be used to complete a word-stem. The second assumption is that observers will follow exclusion instructions whenever the prime is perceived consciously. Given these assumptions, primes that are perceived consciously should be used *less often* than baseline. Conversely, primes that are perceived subliminally will be used *more often* than baseline, in violation of exclusion instructions. Given this logic, Debner and Jacoby (1994) concluded that attended primes were perceived consciously because they were used less often than baseline. By the same token, they concluded that unattended primes were perceived subliminally because they were used more often than baseline.

In the present work, we employed an exclusion procedure similar to that used by Debner and Jacoby (1994; see also Merikle et al., 1995) in order to investigate two questions. The first was whether an unattended T2 was perceived without awareness. Second, given that T2 was perceived without awareness, we wished to find out whether this was sufficient to prime a subsequent word-stem completion task. We addressed these questions using a methodology that combined the procedures of Shapiro et al. (1997b) and Debner and Jacoby (1994). A conventional AB sequence was presented in which T2 acted as a prime for a subsequent word-stem completion task. Attention to T2 was manipulated by varying the temporal interval between T1 and T2, with T2 always backward masked.

In brief, the principal objective of the present experiment was to determine whether an unattended T2 in the RSVP paradigm was processed without awareness, and to determine whether this processing was sufficient to prime performance on a subsequent task. On each trial, the display consisted of an RSVP stream containing two targets amongst distractors. The first target was always a string of identical digits. The second target was either an English word or a pronounceable non-word, with equal probability. The stream ended with a three-letter word-stem which, when the second target was a word, consisted of the first three letters of that word.

Observers were instructed to complete the stem using a word other than the second target. Performance on word trials was used to estimate an exclusion score that represented the proportion of trials on which observers used the second target to complete the word stem in violation of exclusion instructions. Performance on non-word trials was used to estimate a baseline score that represented the proportion of trials on which a stem would be completed with a target word by chance alone. Based on the logic of the exclusion procedure, we expected primes that were perceived consciously to yield exclusion scores lower than baseline. Conversely, we expected primes that were perceived subliminally to yield exclusion scores that were higher than baseline.

Method

Participants. Thirty-five undergraduate psychology students at the University of British Columbia participated for course credit. All participants were either native speakers of English or had learned the English language by the age of four. All reported normal or corrected-to-normal vision.

Apparatus and Stimuli. All stimuli were displayed on a Tektronix 608 oscilloscope, equipped with P15 phosphor. At a viewing distance of 57 cm, set by a headrest, all stimuli subtended approximately 4.5° of visual angle horizontally, and 1.0° vertically. The background and surrounding visual field were dark, except for dim illumination of the keyboard.

Distractors consisted of strings of seven identical, lowercase letters (e.g., yyyyyyy) presented at a luminance of 26 cd/m^2. The first target was a string of seven identical digits between 1 and 9 (e.g., 8888888). The second target was a string of between 5 and 7 letters that formed either an English word (e.g., cloth) or a pronounceable non-word (e.g., flixard). Both targets were presented at a luminance of 52 cd/m^2. The luminance of the targets was higher in order to make them more distinguishable from the distractors. Two pools of items were constructed to serve as second targets, consisting of 180 words and 90 non-words, respectively. Words ranged in frequency from 1 to 2724 occurrences per million (Kucera & Francis, 1967), and satisfied two criteria. First, that the initial three letters could be completed with between two and four additional letters to make at least two other English words. Second, that at least one of the alternative completions for the initial three letters had a greater word frequency than the selected word. Non-words were formed by selecting a 5 to 7-letter word not already in the target pool, and changing between 1 and 3 of its letters. As a result of these changes, non-words remained pronounceable, but did not have the same initial three letters as any of the target words.

Procedure. The experiment consisted of a total of 132 trials comprising 12 practice trials, followed by 120 experimental trials. Stimulus presentation followed a sequence similar to that of Luck et al. (1996), with all items displayed for 33 ms, and followed by a 50-ms inter-stimulus interval (ISI) during which the screen remained blank.

Observers pressed the space bar to begin a trial. Five-hundred milliseconds later, the RSVP stream began in the centre of the screen with the presentation of either 7 or 10 distractors. The sequence of distractors varied randomly, with the constraint that identical letter strings never appeared sequentially. Next, the two targets were presented, separated by one of three SOAs—either 83, 249, or 581 ms (henceforth referred to as Lags 1, 3, and 7 respectively). At the shortest lag, the second target came directly after the first, while at Lags 3, and 7, the inter-target interval was filled by the presentation of further distractor strings. Finally, a single distractor string was presented as a backward mask after the second target.

The second target consisted of either a word or a non-word selected at random from the target pools without replacement. Word and non-word targets were presented equally often. On trials in which the second target was a non-word, it was paired randomly with a word from the target pool. On these occasions, the non-word was presented during the RSVP sequence, but observers completed a word-stem corresponding to the paired word. For example, if the non-word ''flixard'' was paired with the word ''special'', ''flixard'' would be presented as the second target, followed by the word-stem ''spe____''. On trials in which the second target was a word, it was presented during the RSVP sequence, and was followed by a stem consisting of its initial three letters.

At the end of the RSVP sequence, the screen was left blank for 500 ms, and then observers completed three tasks. First, a question mark and the word ''number'' prompted observers to indicate whether the first target consisted of a string of odd or even digits. Observers responded by pressing one of two appropriately-marked keys on the keyboard. Next, a question mark and the word ''word'' appeared on the display as a prompt to observers to indicate whether the second target was a word or a non-word. This response was also made by pressing one of two appropriately-marked keys on the keyboard. Finally, a three-letter word-stem appeared on the screen. Observers were instructed at the beginning of the experiment to complete these stems so as to spell any word other than the second target. The stem-completion response was made by typing two to four letters on the keyboard, and then pressing the ''Enter'' key. Responses of less than two or more than four letters were not allowed. Entries that were not recognized as valid English words by the computer were flagged with an onscreen message that read ''unknown word''. This message remained on the screen for 1000 ms, and was replaced by the word-stem. This sequence was repeated until a valid completion was made, at which point the computer recorded the responses, and the next trial began.

Results

Only trials on which the response to T1 was correct were used in computing lexical decision and exclusion scores. This amounted to 97.6% of the trials. The exclusion of trials on which T1 is incorrect is a common practice when analyzing performance in the AB, and is designed to ensure that the first target in the RSVP stream has been attended.

Lexical decision. Mean accuracy scores in the lexical decision task were 72%, 79%, and 84% at Lags 1, 3, and 7 respectively. Separate one-sample *t*-tests performed at each lag showed that mean lexical-decision accuracy exceeded chance level (i.e., 50%) at all lags ($p < .001$ in every case). A one-way ANOVA revealed a significant improvement in performance over lags, $F(2, 68) = 25.64$, $MSe = 0.005$, $p < .001$. Such improvement over lags is the hallmark of the AB, and has generally been ascribed to increased availability of attentional resources for processing the second target (e.g., Chun & Potter, 1995; Raymond et al., 1992).

Exclusion performance. Following Shapiro et al. (1997) and Rolke et al. (2001), separate analyses were carried out on the stem-completion data, according to whether the corresponding lexical decision was correct or incorrect. It was assumed that on the majority of trials on which the lexical decision was made correctly the second target had been attended. These trials were expected to yield evidence of conscious processing of the prime. In contrast, it was assumed that on the majority of trials on which the lexical decision was incorrect, the second target had not been attended. These trials were expected to yield evidence of unconscious processing of the prime.

For trials on which the second target was a word, mean exclusion scores were calculated by determining the proportion of trials on which the word was used to complete its corresponding stem. Separate means were calculated for trials on which the lexical decision was correct or incorrect, at each of the three lags. This yielded a total of six exclusion scores. Comparable mean baseline scores were calculated on trials in which the second target was a non-word by determining the proportion of trials on which the paired word was used to complete the word-stem. Because the paired word on these trials was not actually shown to observers, its use to complete the stem was by chance alone. Separate mean baseline scores were calculated for trials on which the lexical decision was correct or incorrect, at each of the three lags. This yielded a total of six baseline scores.

To determine whether primes were perceived consciously or subliminally, difference scores were computed by subtracting baseline scores from their corresponding exclusion scores. This yielded two difference scores at each lag: one for trials on which the lexical decision was made correctly, and one for trials on which the lexical decision was made incorrectly. These difference scores are shown in Figure 1.

Positive scores in Figure 1 indicate that primes were perceived subliminally; negative scores indicate that primes were perceived consciously. For example, if the mean baseline score was 0.20, and the mean exclusion score in the same condition was 0.30, the difference score would be 0.10. This would indicate that when a word was displayed as T2, it was used to complete its corresponding stem 10% more often than it would have by chance alone. Given that observers were instructed not to use the word, this positive score would be indicative of the dominance of unconscious perception. In contrast, if the baseline score was 0.20, and the corresponding exclusion score was 0.15, the difference score would be -0.05. This would indicate that when a word was displayed as T2, it was used to complete its corresponding stem 5% less often than it would have by chance alone. Performance that is below chance level indicates that observers were able to perceive the word consciously, and thus exclude it from their responses.

On trials in which the lexical decision was incorrect (Figure 1, filled circles), an ANOVA revealed that the exclusion scores did not vary significantly across lags, $F(2, 68) = 0.30$, $MSe = 0.10$, $p = .74$. Moreover, planned comparisons indicated that exclusion scores were significantly greater than baseline scores (i.e., chance) at Lag 1, $t(34) = 2.45$, $p = .019$, Lag 3, $t(34) = 2.26$, $p = .031$, and Lag 7, $t(34) = 2.62$, $p = .013$. This pattern of results suggests that there was a relative dominance of unconscious perception whenever the second target was unattended (as indexed by lexical decision scores), regardless of lag.

On trials in which the lexical decision was correct (Figure 1, open circles), an ANOVA indicated that exclusion scores declined as lag increased, $F(4, 31) = 3.89$, $MSe = 0.01$, $p = .025$. Planned comparisons conducted separately at each lag revealed that exclusion scores were marginally below baseline at Lag 1, $t(34) = 1.59$, $p = .12$, and were significantly below baseline at Lag 3, $t(34) = 3.71$, $p = .001$, and Lag 7, $t(34) = 6.62$, $p < .001$. On the assumption that the prime was attended on the majority of trials on which the lexical decision was made correctly, these results indicate that observers complied with the exclusion instructions. Namely, the fact that performance was below baseline suggests that, as a rule, when primes were attended, they were perceived consciously, and thus were not used to complete the word-stems.

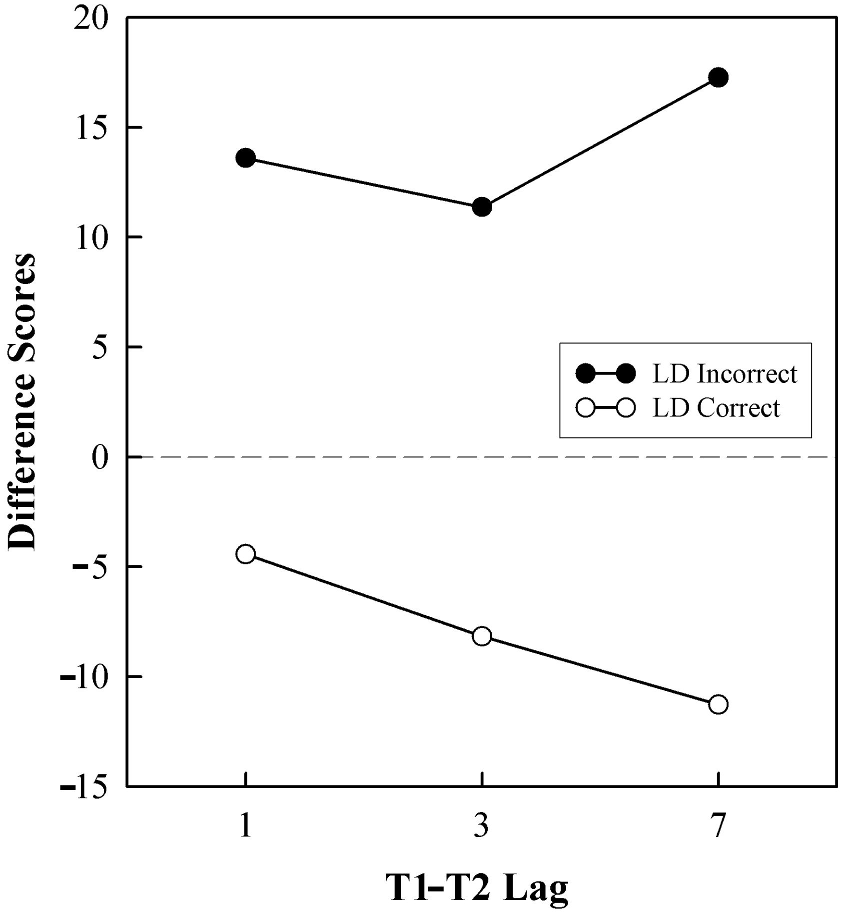

Figure 1. Exclusion performance as a function of the temporal lag between the first and the second target. Symbols represent difference scores between the condition in which the second target was a word (exclusion scores) and the condition in which it was a non-word (baseline scores). Filled circles: trials on which the lexical decision (LD) about the second target was incorrect. Open circles: trials on which the lexical decision about the second target was correct.

DISCUSSION

Answered in the present work are two key questions about the nature of processing of unattended targets in the AB. First, it is clear that unattended items can be processed outside awareness. This is indicated by the finding that exclusion scores were consistently above baseline when observers made an incorrect lexical decision about T2. Second, it is clear that the processing of unattended targets is sufficient to prime future responses. This conclusion is warranted by the finding that performance on the stem-completion task was influenced by the identity of T2, regardless of whether observers could determine whether T2 was a word or a non-word.

The present findings provide evidence for a link between perception without awareness and the AB deficit. Observers who were unable to determine whether T2 was a word or not, thus showing an AB deficit, were also unable to exclude T2-words in a subsequent word-stem completion task. Such exclusion failures are consistent with earlier results indicating that extensive processing occurs for unattended items. Moreover, this pattern of results eliminates any ambiguity as to whether priming obtained in earlier studies (e.g., Shapiro et al., 1997b) was mediated by conscious or unconscious processes. The outcome of the present work is consistent with earlier claims that the AB interferes with conscious processing but leaves the unconscious processing of target items unaffected.

As well as providing unambiguous evidence for subliminal priming in the AB, the present findings provide new information about the time-course of priming. We found that priming extended for at least one second from the onset of the prime to the onset of the word-stem. This interval is substantially longer than had been reported in earlier studies. For example, Shapiro et al. (1997b) reported priming over a period of 300 ms (the only interval tested). Similarly, Maki, Frigen, & Paulson (1997) found that unattended distractors in an RSVP stream primed a subsequent target, but only when it was presented directly after the distractor (i.e., within about 100 ms).

One possible reason for the longer period of priming seen in the present work may lie in methodological differences between the present and earlier experiments. The measure of priming in earlier studies consisted of identification accuracy for the primed item. In contrast, in the present study, priming was measured by means of an exclusion task. It is possible that exclusion tasks may be more sensitive to unconscious influences than identification tasks, thus yielding higher levels of priming. Starting from a higher level, priming evidenced in exclusion tasks would be expected to last over a longer period than the initially weaker priming seen in identification tasks.

Concluding comments

It is clear from the present work that substantial processing of T2 occurs outside of awareness for ''blinked'' items in the AB paradigm. This indicates that items that are not selected for attentive processing can nonetheless influence behaviour. It remains for further work to investigate the timecourse of priming as well as the conditions under which inattention to a prime leads to subliminal priming.

REFERENCES

Chun, M. M., & Potter, M. C. (1995). A two-stage model for multiple target detection in rapid serial visual presentation. *Journal of Experimental Psychology: Human Perception and Performance*, *21*, 109–127.

Debner, J. A., & Jacoby, L. L. (1994). Unconscious perception: Attention, awareness, and control. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *20*, 304–317.

Giesbrecht, B. L., & Di Lollo, V. (1998). Beyond the attentional blink: Visual masking by object substitution. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 1454–1466.

Kucera, H. & Francis, W. (1967). *Computational analysis of present-day American English.* Brown University Press: Providence, RI.

Luck, S. J., Vogel, E. K., & Shapiro, K. L. (1996). Word meanings can be accessed but not reported during the attentional blink. *Nature*, *383*, 616–618.

Maki, W. S., Frigen, K., & Paulson, K. (1997). Associative priming by targets and distractors during rapid serial visual presentation: Does word meaning survive the attentional blink? *Journal of Experimental Psychology: Human Perception and Performance*, *23*, 1014–1034.

Merikle, P. M. (1992). Perception without awareness: Critical issues. *American Psychologist*, *47*, 792–795.

Merikle, P. M., Joordens, S., & Stolz, J. A. (1995). Measuring the relative magnitude of unconscious influences. *Consciousness and Cognition*, *4*, 422–439.

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 849–860.

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1995). Similarity determines the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance*, *21*, 653–662.

Rolke, B., Heil, M., Streb, J., & Hennighausen, E. (2001). Missed prime words within the attentional blink evoke an N400 semantic priming effect. *Psychophysiology*, *38*, 165–174.

Shapiro, K., Caldwell, J., & Sorensen, R. E. (1997a). Personal names and the attentional blink: A visual ''cocktail party'' effect. *Journal of Experimental Psychology: Human Perception and Performance*, *23*, 504–514.

Shapiro, K., Driver, J., Ward, R., & Sorensen, R. E. (1997b). Priming from the attentional blink: A failure to extract visual tokens but not visual types. *Psychological Science*, *8*, 95–100.

Vogel, E. K., Luck, S. J., & Shapiro, K. L. (1998). Electrophysiological evidence for a postperceptual locus of suppression during the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 1656–1674.

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